Aviation Mechanic
HANDBOOK

EIGHTH EDITION

Based on original text by **Dale Crane**
Edited by **Keith Anderson**

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AVIATION SUPPLIES & ACADEMICS, INC.
NEWCASTLE, WASHINGTON

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First edition published 1992. Eighth edition published 2022.

None of the material in this book supersedes any operational documents or procedures issued by the Federal Aviation Administration, aircraft and avionics manufacturers, flight schools, or the operators of aircraft.

ASA-MHB-8-PD
ISBN 978-1-64425-228-4

Additional format available:
Print Book ISBN 978-1-64425-227-7

Acknowledgments: Snap-on Tools, cover photo; Greg Mellema/Abaris, Section 17; Champion Aviation Products, Appendix 2; Concorde Battery, Appendix 3; Michelin Aircraft Tire, Appendix 4.

Library of Congress Cataloging-in-Publication Data:
Names: Crane, Dale, author. | Anderson, Keith, 1960- editor. |
Aviation Supplies & Academics, Inc., publisher.
Title: Aviation mechanic handbook / based on the original text by Dale Crane;
edited by Keith Anderson.
Description: Eighth edition. | Newcastle, Washington : Aviation Supplies & Academics, Inc., 2022. |
Includes index.
Identifiers: LCCN 2022001466 (print) | LCCN 2022001467 (ebook) | ISBN 9781644252277
(spiral bound) | ISBN 9781644252284 (pdf)
Subjects: LCSH: Airplanes—Maintenance and repair—Handbooks, manuals, etc. |
LCGFT: Handbooks and manuals.
Classification: LCC TL671.9 .C6648 2022 (print) | LCC TL671.9 (ebook) |
DDC 629.134/6—dc23/eng/20220201
LC record available at https://lccn.loc.gov/2022001466
LC ebook record available at https://lccn.loc.gov/2022001467

Introduction

Even though ways to look up mechanics reference information via the internet are widely available today, there is still significant benefit to keeping a printed "quick reference" guide handy in a toolbox or workbench drawer. Your time as an aviation mechanic is too valuable to be spent looking through stacks and pages of reference books to find a particular chart, formula or diagram you need on a particular job. The editorial staff at ASA has done this job for you and compiled this *Aviation Mechanic Handbook* to be a handy toolbox source of useful information.

For your convenience, this handbook is arranged in 18 sections with a table of contents at the beginning of each section, as well as complete contents at the front of the book and index at the back.

This information has been compiled from a large number of industry and government publications, and every effort has been made to ensure its applicability and accuracy.

The *ASA Aviation Mechanic Handbook* is a companion volume to the *ASA Dictionary of Aeronautical Terms*. The two books are the core of ASA's training materials for aircraft mechanics.

ASA is dedicated to providing quality training materials for the aviation industry. Your feedback regarding our books will help us to continue to produce the materials you need. Visit the ASA website often (**asa2fly.com**) to find updates to operations and procedures due to FAA changes that may affect this publication.

ASA and the author wish to thank Greg Mellema of Abaris Training for his contribution of the material for Section 17, "Composites" for the Third Edition of the *Aviation Mechanic Handbook*.

Contents

Section 1: General Information

1.1 Fraction, Decimal, and Metric Equivalents

Fraction	Decimal	MM	Fraction	Decimal	MM
1/64	0.0156	0.397	33/64	0.5156	13.097
1/32	0.0313	0.794	17/32	0.5313	13.494
3/64	0.0469	1.191	35/64	0.5469	13.891
1/16	0.0625	1.588	9/16	0.5625	14.287
5/64	0.0781	1.984	37/64	0.5781	14.684
3/32	0.0938	2.381	19/32	0.5938	15.081
7/64	0.1094	2.778	39/64	0.6094	15.478
1/8	**0.1250**	**3.175**	**5/8**	**0.6250**	**15.875**
9/64	0.1406	3.572	41/64	0.6406	16.272
5/32	0.1563	3.969	21/32	0.6563	16.669
11/64	0.1719	4.366	43/64	0.6719	17.066
3/16	0.1875	4.762	11/16	0.6875	17.463
13/64	0.2031	5.159	45/64	0.7031	17.860
7/32	0.2188	5.556	23/32	0.7188	18.256
15/64	0.2344	5.953	47/64	0.7344	18.653
1/4	**0.2500**	**6.350**	**3/4**	**0.7500**	**19.049**
17/64	0.2656	6.747	49/64	0.7656	19.447
9/32	0.2813	7.144	25/32	0.7813	19.844
19/64	0.2969	7.541	51/64	0.7968	20.239
5/16	0.3125	7.937	13/16	0.8125	20.638
21/64	0.3281	8.334	53/64	0.8281	21.034
11/32	0.3438	8.731	27/32	0.8438	21.431
23/64	0.3594	9.128	55/64	0.8594	21.828
3/8	**0.3750**	**9.525**	**7/8**	**0.8750**	**22.225**
25/64	0.3906	9.922	57/64	0.8906	22.622
13/32	0.4063	10.319	29/32	0.9063	23.018
27/64	0.4219	10.716	59/64	0.9219	23.416
7/16	0.4375	11.112	15/16	0.9375	23.812
29/64	0.4531	11.509	61/64	0.9531	24.209
15/32	0.4688	11.906	31/32	0.9688	24.606
31/64	0.4844	12.303	63/64	0.9844	25.003
1/2	**0.5000**	**12.700**	**1**	**1.0000**	**25.400**

1.2 Conversions

Multiply	**By**	**To Get**
acres	43,560	square feet
acres	4,047	square meters
acre feet	3.259 x 10^5	gallons
amperes / sq. cm.	6.452	amperes / sq. inch
amperes / sq. inch	0.1550	amperes / sq. cm.
ampere hours	3,600	coulombs
ampere hours	0.03731	faradays
ampere turns	1.257	gilberts
ampere turns / cm	2.540	ampere turns / inch
ampere turns / cm	1.257	gilberts / cm.
ampere turns / inch	0.4950	gilberts / centimeter
ampere turns / meter	0.01257	gilberts / centimeter
atmospheres	76.0	centimeters of mercury
atmospheres	33.9	feet of water
atmospheres	29.92	inches of mercury
atmospheres	10,332	kilograms / sq. meter
atmospheres	14.69	pounds / sq. inch
barrels of oil	42	gallons
bars	0.9869	atmospheres
bars	106	dynes / sq. centimeter
bars	14.50	pounds / sq. inch
Btu	1.0550 x 10^{10}	ergs
Btu	778.3	foot-pounds
Btu	252.0	gram-calories
Btu	1,054.8	joules
Btu	107.5	kilogram-meters
Btu	2.928 x 10^{-4}	kilowatt-hours
Btu / hour	0.2162	foot-pounds / second
Btu / hour	3.929 x 10^{-4}	horsepower-hours
Btu / hour	0.2931	watts
Btu / minute	12.96	foot-pounds / second
Btu / minute	0.02356	horsepower
Btu / minute	17.57	watts
bushels	1.2445	cubic feet
bushels	2,150.4	cubic inches
bushels	35.24	liters
bushels	4	pecks
bushels	64	pints (dry)

Multiply	By	To Get
centimeters	3.281×10^{-2}	feet
centimeters	0.3937	inches
centimeter-dynes	1.020×10^{-3}	centimeter-grams
centimeter-dynes	7.376×10^{-8}	pound-feet
centimeter-grams	980.7	centimeter-dynes
centimeter-grams	7.233×10^{-5}	pound-feet
cm of mercury	0.01316	atmospheres
cm of mercury	0.4461	feet of water
cm of mercury	136.0	kilograms / sq. meter
cm of mercury	27.85	pounds / sq. foot
cm of mercury	0.1934	pounds / sq. inch
cm / second	1.9685	feet / minute
cm / second	0.03281	feet / second
cm / second	0.036	kilometers / hour
cm / second	0.0194	knots
cm / second / second	0.03281	feet / second / second
cm / second / second	0.02237	miles / hour / second
circular mils	5.067×10^{-6}	square centimeters
circular mils	0.7854	square mils
circular mils	7.854×10^{-7}	square inches
coulombs	1.036×10^{-5}	faradays
cubic centimeters	3.531×10^{-5}	cubic feet
cubic centimeters	0.06102	cubic inches
cubic centimeters	10^{-6}	cubic meters
cubic centimeters	1.308×10^{-6}	cubic yards
cubic centimeters	2.642×10^{-4}	gallons (U.S.)
cubic centimeters	0.001	liters
cubic centimeters	2.113×10^{-3}	pints (U.S.)
cubic feet	0.8036	bushels
cubic feet	28,320	cubic centimeters
cubic feet	1,728	cubic inches
cubic feet	0.02832	cubic meters
cubic feet	7.48052	gallons (U.S.)
cubic feet	28.32	liters
cubic feet / minute	0.1247	gallons / second
cubic feet / minute	0.4720	liters / second
cubic feet / second	448.831	gallons / minute
cubic inches	16.39	cubic centimeters
cubic inches	5.787×10^{-4}	cubic feet
cubic inches	1.639×10^{-5}	cubic meters
cubic inches	2.143×10^{-5}	cubic yards
cubic inches	4.329×10^{-3}	gallons (U.S.)

Multiply	By	To Get
cubic inches	0.01639	liters
cubic meters	28.38	bushels
cubic meters	35.31	cubic feet
cubic meters	61,023	cubic inches
cubic meters	1.308	cubic yards
cubic meters	264.2	gallons (U.S.)
cubic yards	27	cubic feet
cubic yards	46,656	cubic inches
cubic yards	0.7646	cubic meters
cubic yards	202	gallons (U.S.)
cubic yards	764.6	liters
cubic yards / minute	3.367	gallons / second
cubic yards / minute	12.74	liters / second
days	24	hours
days	1,440	minutes
days	86,400	seconds
degrees (angular)	60	minutes
degrees (angular)	0.01111	quadrants
degrees (angular)	0.01745	radians
degrees (angular)	3,600	seconds
degrees / second	0.01745	radians / second
degrees / second	0.1667	revolutions / minute
degrees / second	2.778 x 10^{-3}	revolutions / second
drams	1.7718	grams
drams	0.0625	ounces
dynes	1.020 x 10^{-3}	grams
dynes	10^{-7}	joules / centimeter
dynes	10^{-5}	joules / meter (newtons)
dynes	7.233 x 10^{-5}	poundals
dynes	2.248 x 10^{-6}	pounds
dynes / sq. centimeter	10^{-6}	bars
ergs	9.480 x 10^{-11}	Btu
ergs	1.0	dyne-centimeters
ergs	7.367 x 10^{-8}	foot-pounds
ergs	0.2389 x 10^{-7}	gram-calories
ergs	3.7250 x 10^{-14}	horsepower-hours
ergs	10^{-7}	joules
ergs	0.2778 x 10^{-13}	kilowatt-hours
ergs / second	5.688 x 10^{-9}	Btu / minute

Multiply	By	To Get
ergs / second	1.341×10^{-10}	horsepower
ergs / second	10^{-10}	kilowatts
faradays	26.8	ampere-hours
faradays	9.649×10^{4}	coulombs
fathoms	6	feet
feet	30.48	centimeters
feet	0.3048	meters
feet	1.645×10^{-4}	miles (nautical)
feet	1.894×10^{-4}	miles (statute)
feet of water	0.02950	atmospheres
feet of water	0.8826	inches of mercury
feet of water	62.43	pounds / square foot
feet / minute	0.5080	centimeters / second
feet / minute	0.01667	feet / second
feet / second	1.097	kilometers / hour
feet / second	0.5921	knots
feet / second	0.6818	miles / hour
feet / second / second	0.6818	miles / hour / second
foot-pounds	1.286×10^{-3}	Btu
foot-pounds	1.356	joules
foot-pounds	3.24×10^{-4}	kilogram-calories
foot-pounds	0.1383	kilogram-meters
foot-pounds / minute	3.030×10^{-5}	horsepower
foot-pounds / minute	2.260×10^{-5}	kilowatts
furlongs	660	feet
gallons	3,785	cubic centimeters
gallons	0.1337	cubic feet
gallons	231	cubic inches
gallons	3.785	liters
gallons (Imperial)	1.20095	gallons (U.S.)
gallons (U.S.)	0.83267	gallons (Imperial)
gallons / minute	2.228×10^{-3}	cubic feet / second
gausses	6.452	lines of flux / sq. inch
gausses	10^{-8}	webers / sq. centimeter
gilberts	0.7958	ampere-turns
gilberts / centimeter	2.021	ampere-turns / inch
gills	0.1183	liters
grains (troy)	0.06480	grams
grains (troy)	2.0833×10^{-3}	ounces (avoir.)
grams	980.7	dynes

Multiply	By	To Get
grams	9.807×10^{-5}	joules / centimeter
grams	0.03527	ounces (avoir.)
grams	0.07093	poundals
grams	2.205×10^{-3}	pounds
grams / cubic cm.	62.43	pounds / cubic foot
grams / square cm.	2.0481	pounds / square foot
gram-calories	3.9683×10^{-3}	Btu
gram-calories	4.1868×10^{7}	ergs
gram-calories	3.0880	foot-pounds
gram-calories	1.1630×10^{-6}	kilowatt-hours
gram-centimeters	9.297×10^{-8}	Btu
gram-centimeters	980.7	ergs
gram-centimeters	9.807×10^{-5}	joules
hectares	2.471	acres
horsepower	42.44	Btu / minute
horsepower	33,000	foot-pounds / minute
horsepower	550	foot-pounds / second
horsepower (metric)	542.5	foot-pounds / second
horsepower (metric)	0.9863	horsepower
horsepower	10.68	kilogram-calories / min.
horsepower	745.7	watts
hours	3,600	seconds
inches	2.540	centimeters
inches	8.333×10^{-2}	feet
inches	2.540×10^{-2}	meters
inches	25.40	millimeters
inches	1,000	mils
inches of mercury	3.342×10^{-2}	atmospheres
inches of mercury	1.133	feet of water
inches of mercury	345.3	kilograms / sq. meter
inches of mercury	0.4912	pounds / sq. inch
inches of mercury	33.864	millibars
inches of water	7.355×10^{-2}	inches of mercury
inches of water	3.613×10^{-2}	pounds / sq. inch
joules	9.480×10^{-4}	Btu
joules	10^{7}	ergs
joules	0.7376	foot-pounds
joules	2.389×10^{-4}	kilogram-calories
joules	0.1020	kilogram-meters

Multiply	By	To Get
joules	2.778×10^{-4}	watt-hours
joules / centimeter	10^{7}	dynes
joules / centimeter	723.3	poundals
joules / centimeter	22.48	pounds
kilograms	980,665	dynes
kilograms	9.807	joules / meter (newtons)
kilograms	70.93	poundals
kilograms	2.205	pounds
kilograms	9.842×10^{-4}	tons (long)
kilograms	1.102×10^{-3}	tons (short)
kilograms / cubic meter	0.06243	pounds / cubic foot
kilograms / sq. meter	9.687×10^{-5}	atmospheres
kilograms / sq. meter	0.2048	pounds / square foot
kilogram-calories	3.968	Btu
kilogram-calories	3,088	foot-pounds
kilogram-calories	4,186	joules
kilogram-meters	9.294×10^{-3}	Btu
kilogram-meters	7.233	foot-pounds
kilometers	3,281	feet
kilometers	0.6214	miles
kilometers / hour	0.9113	feet / second
kilometers / hour	0.5396	knots
kilometers / hour	0.6214	miles / hour
kilowatts	56.92	Btu / minute
kilowatts	4.426×10^{4}	foot-pounds / minute
kilowatts	1.341	horsepower
kilowatt-hours	3,413	Btu
kilowatt-hours	2.655×10^{6}	foot-pounds
kilowatt-hours	3.6×10^{6}	joules
knots	6,080	feet / hour
knots	1.8532	kilometers / hour
knots	1.151	miles (statute) / hour
knots	1.689	feet / second
leagues	3.0	miles
lines of flux / sq. cm.	1.0	gausses
lines of flux / sq. inch	0.1550	gausses
lines of flux / sq. inch	1.550×10^{-9}	webers / sq. centimeter
liters	1,000	cubic centimeters
liters	61.02	cubic inches
liters	0.2642	gallons (U.S.)
liters / minute	5.886×10^{-4}	cubic feet / second

Multiply	By	To Get
lumens / sq. foot	1.0	foot-candles
lux	0.0929	foot-candles
maxwells	10^{-8}	webers
meters	3.281	feet
meters	39.37	inches
meters	5.396×10^{-4}	miles (nautical)
meters	6.214×10^{-4}	miles (statute)
meters	1.094	yards
meters / second	3.6	kilometers / hour
meters / second	2.237	miles / hour
meter-kilograms	9.807×10^{7}	centimeter-dynes
meter-kilograms	7.233	pound-feet
miles (nautical)	6,076.103	feet
miles (nautical)	1.852	kilometers
miles (nautical)	1.1508	miles (statute)
miles (statute)	5,280	feet
miles (statute)	1.609	kilometers
miles (statute)	0.8689	miles (nautical)
miles (statute)	1,760	yards
miles / hour	1.467	feet / second
miles / hour	1.609	kilometers / hour
miles / hour	0.8684	knots
millimeters	3.281×10^{-3}	feet
millimeters	0.03937	inches
mils	2.54×10^{-3}	centimeters
mils	0.001	inches
minutes (angular)	0.01667	degrees
minutes (angular)	1.852×10^{-4}	quadrants
minutes (angular)	2.909×10^{-4}	radians
ounces	16.0	drams
ounces	437.5	grains
ounces	28.3495	grams
ounces	0.0625	pounds
ounces (fluid)	1.805	cubic inches
ounces (fluid)	0.02957	liters
ounces (troy)	1.09714	ounces (avoir.)
pint (dry)	33.60	cubic inches
pint (liquid)	0.4732	liters
poundals	13,826	dynes
poundals	14.10	grams

Multiply	By	To Get
poundals	0.1383	joules / meter (newtons)
poundals	0.01410	kilograms
poundals	0.03108	pounds
pounds	453.5924	grams
pounds	4.448	joules / meter (newtons)
pounds	0.4536	kilograms
pounds	16	ounces
pounds	32.17	poundals
pounds	0.0005	tons (short)
pounds of water	0.1198	gallons
pounds / cubic foot	16.02	kilograms / cubic meter
pounds / cubic inch	27.68	grams / cubic centimeter
pounds / square inch	0.06804	atmospheres
pounds / square inch	2.307	feet of water
pounds / square inch	2.036	inches of mercury
quadrants (angular)	90	degrees
quadrants (angular)	5,400	minutes
quadrants (angular)	1.571	radians
quarts (liquid)	57.75	cubic inches
quarts (liquid)	0.9463	liters
radians	57.30	degrees
radians	3,438	minutes
radians	0.6366	quadrants
radians / second	9.549	revolutions / minute
revolutions / minute	6.0	degrees / second
revolutions / minute	0.1047	radians / second
rods	16.5	feet
square centimeters	1.973×10^5	circular mils
square centimeters	0.1550	square inches
square inches	1.273×10^6	circular mils
square inches	6.452	square centimeters
square meters	10.76	square feet
square meters	1.196	square yards
square miles	640	acres
square millimeters	1,973	circular mils
square mils	1.273	circular mils
tons (long)	1,016	kilograms
tons (long)	2,240	pounds
tons (metric)	1,000	kilograms
tons (metric)	2,205	pounds

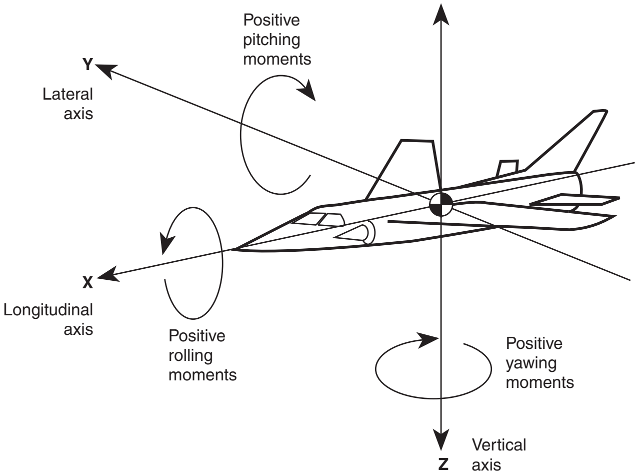
Multiply	By	To Get
tons (short)	907.185	kilograms
tons (short)	2,000	pounds
watts	3.413	Btu / hour
watts	10^7	ergs / second
watts	44.27	foot-pounds / minute
watts	1.341×10^{-3}	horsepower
watt-hours	3.413	Btu
watt-hours	2,656	foot-pounds
watt-hours	367.2	kilogram-meters
webers	10^8	maxwells
webers / sq. inch	1.55×10^7	gausses
yards	36	inches
yards	0.9144	meters

Notes

1.3 Aircraft Nomenclature

Axes of an Airplane

An airplane in flight is free to rotate about three axes: horizontal, longitudinal and vertical. Each axis is perpendicular to the others and each passes through the center of gravity.

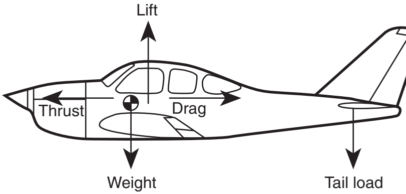


The three axes of an aircraft are mutually perpendicular, and all pass through the center of gravity of the aircraft.

Forces Acting on an Aircraft in Flight

In straight-and-level, unaccelerated flight the forces about the aircraft center of gravity are balanced. Lift acts upward and is opposed by weight and the aerodynamic tail load which act downward. Thrust acting forward is opposed by drag which acts rearward.

In straight-and-level, unaccelerated flight the forces about the center of gravity are balanced.



In straight-and-level, unaccelerated flight, the forces about the center of gravity are balanced.

Types of Aircraft Structure

Truss

A type of structure made up of longitudinal beams and cross braces. Compression loads between the main beams are carried by rigid cross braces called compression struts. Tension loads are carried by stays, or wires, that go from one main beam to the other and cross between the compression struts.

Most fabric-covered wings are constructed with a Pratt truss. The spars are the main beams and the cross braces are the compression struts or compression ribs. The stays are the drag and antidrag wires. The drag wires run from the front spar inboard to the rear spar outboard, and oppose the drag forces that try to move the wing tips backward. The antidrag wires run from the rear spar inboard to the front spar outboard. They oppose the aerodynamic forces that try to move the wing tips forward.

The Warren truss is used for the fuselage of most steel tube and fabric aircraft. The main beams are the longerons and the cross braces are steel tube diagonals which carry both compression and tension loads.

Monocoque

A single-shell that carries all of the flight loads in its outer surface. A chicken egg is a perfect example of a natural monocoque structure.

Metal monocoque aircraft fuselages have a minimum of internal structure, usually with just formers to provide the shape. Thin sheets of metal (called skins) riveted to the formers provide a rigid, strong, streamlined structure. Dents in the skins destroy the integrity of a monocoque structure.

Wooden monocoque aircraft structures are similar to those of metal. Thin sheets of aircraft plywood are glued to the formers to provide a strong, lightweight structure.

Modern composite structures are made of resins reinforced with special fabrics and formed in molds or over patterns; these provide a shell sufficiently strong to carry all the flight loads.

Semimonocoque

Most larger metal aircraft have a semimonocoque structure. This differs from the monocoque by having a series of longerons and stringers between the formers to support the skins and provide additional strength.

1.4 Joint Aircraft System/Component (JASC) Code

Based on ATA-100 and ATA-2200 Systems of Identification

The Joint Aircraft System/Component (JASC) Code table is a modified version of the Air Transport Association of America (ATA) Specification 100 code, developed by the FAA's Regulatory Support Division (AFS-600). Over the years, the JASC Code format of the ATA-100 Specifications has gained widespread industry acceptance. In a harmonized effort, the FAA's counterparts in Australia and Canada have adopted the JASC Code with only a few exceptions. Some Canadian aircraft manufacturers have also adopted this new standard.

This table can be used as a quick reference chart, to assist in the coding and review of aircraft structures or systems data. It uses the new JASC code four (4) digit format, in which the first two digits represent the code "chapter" title. The titles have been modified in some cases to clarify the intended use of the accompanying code.

Note: The JASC Code divides the engine-related codes into two groups to separate turbine and reciprocating engines. The codes for the turbine engines are in JASC Code Chapter 72, Turbine/Turboprop Engine. The codes for the reciprocating engines are now exclusively found in Chapter 85, Reciprocating Engine.

11	**Placards And Markings**
1100	Placards And Markings

12	**Servicing**
1210	Fuel Servicing
1220	Oil Servicing
1230	Hydraulic Fluid Servicing
1240	Coolant Servicing

14	**Hardware**
1400	Miscellaneous Hardware
1410	Hoses And Tubes
1420	Electrical Connectors
1430	Fasteners
1497	Miscellaneous Wiring

18	**Helicopter Vibration**
1800	Helicopter Vib/Noise Analysis
1810	Helicopter Vibration Analysis
1820	Helicopter Noise Analysis
1897	Helicopter Vibration System Wiring

21	**Air Conditioning**
2100	Air Conditioning System
2110	Cabin Compressor System
2120	Air Distribution System
2121	Air Distribution Fan
2130	Cabin Pressure Control System

2131	Cabin Pressure Controller
2132	Cabin Pressure Indicator
2133	Pressure Regul/Outflow Valve
2134	Cabin Pressure Sensor
2140	Heating System
2150	Cabin Cooling System
2160	Cabin Temperature Control System
2161	Cabin Temperature Controller
2162	Cabin Temperature Indicator
2163	Cabin Temperature Sensor
2170	Humidity Control System
2197	Air Conditioning System Wiring

22 Auto Flight

2200	Auto Flight System
2210	Autopilot System
2211	Autopilot Computer
2212	Altitude Controller
2213	Flight Controller
2214	Autopilot Trim Indicator
2215	Autopilot Main Servo
2216	Autopilot Trim Servo
2220	Speed-Attitude Correction System
2230	Auto Throttle System
2250	Aerodynamic Load Alleviating
2297	Autoflight System Wiring

23 Communications

2300	Communications System
2310	HF Communication System
2311	UHF Communication System
2312	VHF Communication System
2320	Data Transmission Auto Call
2330	Entertainment System
2340	Interphone/Passenger Pa System
2350	Audio Integrating System
2360	Static Discharge System
2370	Audio/Video Monitoring
2397	Communication System Wiring

24 Electrical Power

2400	Electrical Power System
2410	Alternator-Generator Drive
2420	AC Generation System
2421	AC Generator-Alternator
2422	AC Inverter
2423	Phase Adapter
2424	AC Regulator
2425	AC Indicating System
2430	DC Generating System
2431	Battery Overheat Warning System
2432	Battery/Charger System
2433	DC Rectifier/Converter
2434	DC Generator-Alternator
2435	Starter-Generator
2436	DC Regulator
2437	DC Indicating System
2440	External Power System
2450	AC Power Distribution System
2460	DC Power/Distribution System
2497	Electrical Power System Wiring

25	Equipment/Furnishings
2500	Cabin Equipment/ Furnishings
2510	Flight Compartment Equipment
2520	Passenger Compartment Equipment
2530	Buffet/Galleys
2540	Lavatories
2550	Cargo Compartments
2551	Agricultural Spray System
2560	Emergency Equipment
2561	Life Jacket
2562	Emergency Locator Beacon
2563	Parachute
2564	Life Raft
2565	Escape Slide
2570	Accessory Compartment
2571	Battery Box Structure
2572	Electronic Shelf Section
2597	Equip/Furnishing System Wiring

26 Fire Protection

2600	Fire Protection System
2610	Detection System
2611	Smoke Detection
2612	Fire Detection
2613	Overheat Detection
2620	Extinguishing System
2621	Fire Bottle, Fixed
2622	Fire Bottle, Portable
2697	Fire Protection System Wiring

27 Flight Controls

2700	Flight Control System
2701	Control Column Section
2710	Aileron Control System
2711	Aileron Tab Control System
2720	Rudder Control System
2721	Rudder Tab Control System
2722	Rudder Actuator
2730	Elevator Control System
2731	Elevator Tab Control System
2740	Stabilizer Control System
2741	Stabilizer Position Indicating
2742	Stabilizer Actuator
2750	TE Flap Control System
2751	TE Flap Position Ind. System
2752	TE Flap Actuator
2760	Drag Control System
2761	Drag Control Actuator
2770	Gust Lock/Damper System
2780	LE Slat Control System
2781	LE Slat Position Ind. System
2782	LE Slat Actuator
2797	Flight Control System Wiring

28 Fuel

2800	Aircraft Fuel System
2810	Fuel Storage
2820	Aircraft Fuel Distrib. System
2821	Aircraft Fuel Filter/Strainer
2822	Fuel Boost Pump
2823	Fuel Selector/Shut-Off Valve
2824	Fuel Transfer Valve
2830	Fuel Dump System

2840	Aircraft Fuel Indicating System
2841	Fuel Quantity Indicator
2842	Fuel Quantity Sensor
2843	Fuel Temperature Indicator
2844	Fuel Pressure Indicator
2897	Fuel System Wiring

29 Hydraulic Power

2900	Hydraulic Power System
2910	Hydraulic System, Main
2911	Hydraulic Power Accumulator, Main
2912	Hydraulic Filter, Main
2913	Hydraulic Pump, (Electric/Engine, Main
2914	Hydraulic Handpump, Main
2915	Hydraulic Pressure Relief Valve, Main
2916	Hydraulic Reservoir, Main
2917	Hydraulic Pressure Regulator, Main
2920	Hydraulic System, Auxiliary
2921	Hydraulic Accumulator, Auxiliary
2922	Hydraulic Filter, Auxiliary
2923	Hydraulic Pump, Auxiliary
2925	Hydraulic Pressure Relief, Auxiliary
2926	Hydraulic Reservoir, Auxiliary
2927	Hydraulic Pressure Regulator, Auxillary
2930	Hydraulic Indicating System
2931	Hydraulic Pressure Indicator
2932	Hydraulic Pressure Sensor
2933	Hydraulic Quantity Indicator
2934	Hydraulic Quantity Sensor
2997	Hydraulic Power System Wiring

30 Ice And Rain Protection

3000	Ice/Rain Protection System
3010	Airfoil Anti/De-Ice System
3020	Air Intake Anti/De-Ice System
3030	Pitot/Static Anti-Ice System
3040	Windshield/Door Rain/Ice Removal
3050	Antenna/Radome Anti-Ice/De-Ice System
3060	Prop/Rotor Anti-Ice/De-Ice System
3070	Water Line Anti-Ice System
3080	Ice Detection
3097	Ice/Rain Protection System Wiring

31 Instruments

3100	Indicating/Recording System
3110	Instrument Panel
3120	Independent Instruments (Clock, etc.)
3130	Data Recorders (Flt/Maint)
3140	Central Computers (EICAS)
3150	Central Warning
3160	Central Display
3170	Automatic Data
3197	Instrument System Wiring

32 Landing Gear

3200	Landing Gear System
3201	Landing Gear/Wheel Fairing
3210	Main Landing Gear
3211	Main Landing Gear Attach Section
3212	Emergency Flotation Section
3213	Main Landing Gear Strut/ Axle/Truck
3220	Nose/Tail Landing Gear
3221	Nose/Tail Landing Gear AttachSection
3222	Nose/Tail Landing Gear Strut/Axle
3230	Landing Gear Retract/ Extend System
3231	Landing Gear Door Retract Section
3232	Landing Gear Door Actuator
3233	Landing Gear Actuator
3234	Landing Gear Selector
3240	Landing Gear Brake System
3241	Brake Anti-Skid Section
3242	Brake
3243	Master Cylinder/Brake Valve
3244	Tire
3245	Tire Tube
3246	Wheel/Ski/Float
3250	Landing Gear Steering System
3251	Steering Unit
3252	Shimmy Damper
3260	Landing Gear Position And Warning
3270	Auxiliary Gear (Tail Skid)
3297	Landing Gear System Wiring

33 Lights

3300	Lighting System
3310	Flight Compartment Lighting
3320	Passenger Compartment Lighting
3330	Cargo Compartment Lighting
3340	Exterior Lighting
3350	Emergency Lighting
3397	Light System Wiring

34 Navigation

3400	Navigation System
3410	Flight Environment Data
3411	Pitot/Static System
3412	Outside Air Temperature Indicator Sensor
3413	Rate of Climb Indicator
3414	Airspeed/Mach Indicator
3415	High Speed Warning
3416	Altimeter, Barometric/ Encoder
3417	Air Data Computer
3418	Stall Warning System
3420	Attitude and Direction Data System
3421	Attitude Gyro and Indicator System
3422	Directional Gyro and Indicator System
3423	Magnetic Compass
3424	Turn and Bank/Rate of Turn Indicator
3425	Integrated Flight Director System
3430	Landing and Taxi Aids

3431	Localizer/VOR System
3432	Glide Slope System
3433	Microwave Landing System
3434	Marker Beacon System
3435	Heads Up Display System
3436	Wind Shear Detection System
3440	Independent Position Determining System
3441	Inertial Guidance System
3442	Weather Radar System
3443	Doppler System
3444	Ground Proximity System
3445	Air Collision Avoidance System (TCAS)
3446	Non Radar Weather System
3450	Dependent Position Determining System
3451	DME/TACAN System
3452	ATC Transponder System
3453	LORAN System
3454	VOR System
3455	ADF System
3456	Omega Navigation System
3457	Global Positioning System
3460	Flt Management Computing Hardware System
3461	Flight Manage. Computing Software System
3497	Navigation System Wiring

35 Oxygen

3500	Oxygen System
3510	Crew Oxygen System
3520	Passenger Oxygen System
3530	Portable Oxygen System
3597	Oxygen System Wiring

36 Pneumatic

3600	Pneumatic System
3610	Pneumatic Distribution System
3620	Pneumatic Indicating System
3697	Pneumatic System Wiring

37 Vacuum

3700	Vacuum System
3710	Vacuum Distribution System
3720	Vacuum Indicating System
3797	Vacuum System Wiring

38 Water/Waste

3800	Water And Waste System
3810	Potable Water System
3820	Wash Water System
3830	Waste Disposal System
3840	Air Supply (Water Press. System)
3897	Water/Waste System Wiring

45 Central Maint. System

4500	Central Maint. Computer
4597	Central Maint. System Wiring

49 Airborne Auxiliary Power

4900	Airborne APU System
4910	APU Cowling/Containment
4920	APU Core Engine

4930	APU Engine Fuel and Control
4940	APU Start/Ignition System
4950	APU Bleed Air System
4960	APU Controls
4970	APU Indicating System
4980	APU Exhaust System
4990	APU Oil System
4997	APU System Wiring

51 Standard Practices/Structures

5100	Standard Practices/Structures
5101	Aircraft Structures
5102	Balloon Reports

52 Doors

5200	Doors
5210	Passenger/Crew Doors
5220	Emergency Exits
5230	Cargo/Baggage Doors
5240	Service Doors
5241	Galley Doors
5242	E/E Compartment Doors
5243	Hydraulic Compartment Doors
5244	Accessory Compartment Doors
5245	Air Conditioning Compart. Doors
5246	Fluid Service Doors
5247	APU Doors
5248	Tail Cone Doors
5250	Fixed Inner Doors
5260	Entrance Stairs
5270	Door Warning System
5280	Landing Gear Doors
5297	Door System Wiring

53 Fuselage

5300	Fuselage Structure (General)
5301	Aerial Tow Equipment
5302	Rotorcraft Tail Boom
5310	Fuselage Main, Structure
5311	Fuselage Main, Frame
5312	Fuselage Main, Bulkhead
5313	Fuselage Main, Longeron/Stringer
5314	Fuselage Main, Keel
5315	Fuselage Main, Floor Beam
5320	Fuselage Miscellaneous Structure
5321	Fuselage Floor Panel
5322	Fuselage Internal Mount Structure
5323	Fuselage Internal Stairs
5324	Fuselage Fixed Partitions
5330	Fuselage Main, Plate/Skin
5340	Fuselage Main, Attach Fittings
5341	Fuselage, Wing Attach Fittings
5342	Fuselage, Stabilizer Attach Fittings
5343	Landing Gear Attach Fittings
5344	Fuselage Door Hinges
5345	Fuselage Equipment Attach Fittings
5346	Powerplant Attach Fittings
5347	Seat/Cargo Attach Fittings
5350	Aerodynamic Fairings
5397	Fuselage Wiring

54 Nacelles/Pylons

5400	Nacelle/Pylon Structure

5410	Nacelle/Pylon, Main Frame
5411	Nacelle/Pylon, Frame/Spar/Rib
5412	Nacelle/Pylon, Bulkhead/Firewall
5413	Nacelle/Pylon, Longeron/Stringer
5414	Nacelle/Pylon, Plate Skin
5415	Nacelle/Pylon, Attach Fittings
5420	Nacelle/Pylon Miscellaneous Structure
5497	Nacelle/Pylon System Wiring

55 Stabilizers

5500	Empennage Structure
5510	Horizontal Stabilizer Structure
5511	Horizontal Stabilizer, Spar/Rib
5512	Horizontal Stabilizer, Plate/Skin
5513	Horizontal Stabilizer, Tab Structure
5514	Horiz Stab Miscellaneous Structure
5520	Elevator Structure
5521	Elevator, Spar/Rib Structure
5522	Elevator, Plates/Skin Structure
5523	Elevator, Tab Structure
5524	Elevator Miscellaneous Structure
5530	Vertical Stabilizer Structure
5531	Vertical Stabilizer, Spar/Rib Structure
5532	Vertical Stabilizer, Plates/Skin
5533	Ventral Structure
5534	Vertical Stabilizer Miscellaneous Structure
5540	Rudder Structure
5541	Rudder, Spar/Rib
5542	Rudder, Plate/Skin
5543	Rudder, Tab Structure
5544	Rudder Miscellaneous Structure
5550	Empennage Flight Control Attach Fitting
5551	Horizontal Stabilizer, Attach Fitting
5552	Elevator/Tab, Attach Fittings
5553	Vertical Stabilizer Attach Fittings
5554	Rudder/Tab, Attach Fittings
5597	Stabilizer System Wiring

56 Windows

5600	Window/Windshield System
5610	Flight Compartment Windows
5620	Passenger Compartment Windows
5630	Door Windows
5640	Inspection Windows
5697	Window System Wiring

57 Wings

5700	Wing Structure
5710	Wing, Main Frame Structure
5711	Wing Spar
5712	Wing, Rib/Bulkhead

5713	Wing, Longeron/Stringer
5714	Wing, Center Box
5720	Wing Miscellaneous Structure
5730	Wing, Plates/Skins
5740	Wing, Attach Fittings
5741	Wing, Fuselage Attach Fittings
5742	Wing, Nac/Pylon Attach Fittings
5743	Wing, Landing Gear Attach Fittings
5744	Wing, Cont. Surface Attach Fittings
5750	Wing, Control Surfaces
5751	Ailerons
5752	Aileron Tab Structure
5753	Trailing Edge Flaps
5754	Leading Edge Devices
5755	Spoilers
5797	Wing System Wiring

61 Propellers/Propulsors

6100	Propeller System
6110	Propeller Assembly
6111	Propeller Blade Section
6112	Propeller De-Ice Boot Section
6113	Propeller Spinner Section
6114	Propeller Hub Section
6120	Propeller Controlling System
6121	Propeller Synchronizer Section
6122	Propeller Governor
6123	Propeller Feathering/ Reversing
6130	Propeller Braking
6140	Propeller Indicating System
6197	Propeller/Propulsors System Wiring

62 Main Rotor

6200	Main Rotor System
6210	Main Rotor Blades
6220	Main Rotor Head
6230	Main Rotor Mast/ Swashplate
6240	Main Rotor Indicating System
6297	Main Rotor System Wiring

63 Main Rotor Drive

6300	Main Rotor Drive System
6310	Engine/Transmission Coupling
6320	Main Rotor Gearbox
6321	Main Rotor Brake
6322	Rotorcraft Cooling Fan System
6330	Main Rotor Transmission Mount
6340	Rotor Drive Indicating System
6397	Main Rotor Drive System Wiring

64 Tail Rotor

6400	Tail Rotor System
6410	Tail Rotor Blades
6420	Tail Rotor Head
6440	Tail Rotor Indicating System
6497	Tail Rotor System Wiring

65 Tail Rotor Drive

6500	Tail Rotor Drive System
6510	Tail Rotor Drive Shaft

6520	Tail Rotor Gearbox
6540	Tail Rotor Drive Indicating System
6597	Tail Rotor Drive System Wiring

67 Rotors Flight Control

6700	Rotorcraft Flight Control
6710	Main Rotor Control
6711	Tilt Rotor Flight Control
6720	Tail Rotor Control System
6730	Rotorcraft Servo System
6797	Rotors Flight Control System Wiring

71 Powerplant

7100	Powerplant System
7110	Engine Cowling System
7111	Engine Cowl Flaps
7112	Engine Air Baffle Section
7120	Engine Mount Section
7130	Engine Fireseals
7160	Engine Air Intake System
7170	Engine Drains
7197	Powerplant System Wiring

72 Turbine/Turboprop Engine

7200	Engine (Turbine/Turboprop)
7210	Turbine Engine Reduction Gear
7220	Turbine Engine Air Inlet Section
7230	Turbine Engine Compressor Section
7240	Turbine Engine Combustion Section
7250	Turbine Engine Accessory Drive
7261	Turbine Engine Oil System
7270	Turbine Engine Bypass Section
7297	Turbine Engine System Wiring

73 Engine Fuel And Control

7300	Engine Fuel And Control
7310	Engine Fuel Distribution
7311	Engine Fuel/Oil Cooler
7312	Fuel Heater
7313	Fuel Injector Nozzle
7314	Engine Fuel Pump
7320	Fuel Controlling System
7321	Fuel Control/Turbine Engines
7322	Fuel Control/Reciprocating Engines
7323	Turbine Governor
7324	Fuel Divider
7330	Engine Fuel Indicating System
7331	Fuel Flow Indicating
7332	Fuel Pressure Indicating
7333	Fuel Flow Sensor
7334	Fuel Pressure Sensor
7397	Engine Fuel System Wiring

74 Ignition

7400	Ignition System
7410	Ignition Power Supply
7411	Low Tension Coil
7412	Exciter
7413	Induction Vibrator
7414	Magneto/Distributor
7420	Ignition Harness (Distribution)
7421	Spark Plug/Igniter

7430	Ignition/Starter Switching
7497	Ignition System Wiring

75 Air

7500	Engine Bleed Air System
7510	Engine Anti-Icing System
7520	Engine Cooling System
7530	Compressor Bleed Control
7531	Compressor Bleed Governor
7532	Compressor Bleed Valve
7540	Bleed Air Indicating System
7597	Engine Bleed Air System Wiring

76 Engine Controls

7600	Engine Controls
7601	Engine Synchronizing
7602	Mixture Control
7603	Power Lever
7620	Engine Emergency Shutdown System
7697	Engine Control System Wiring

77 Engine Indicating

7700	Engine Indicating System
7710	Power Indicating System
7711	Engine Pressure Ratio (EPR)
7712	Engine BMEP/Torque Indicating
7713	Manifold Pressure (MP) Indicating
7714	Engine RPM Indicating System
7720	Engine Temperature Indicating System
7721	Cylinder Head Temp (CHT) Indicating
7722	Eng. EGT/TIT Indicating System
7730	Engine Ignition Analyzer System
7731	Engine Ignition Analyzer
7732	Engine Vibration Analyzer
7740	Engine Integrated Instrument System
7797	Engine Indicating System Wiring

78 Engine Exhaust

7800	Engine Exhaust System
7810	Engine Collector/Tailpipe/Nozzle
7820	Engine Noise Suppressor
7830	Thrust Reverser
7897	Engine Exhaust System Wiring

79 Engine Oil

7900	Engine Oil System (Airframe)
7910	Engine Oil Storage (Airframe)
7920	Engine Oil Distribution (Airframe)
7921	Engine Oil Cooler
7922	Engine Oil Temp. Regulator
7923	Engine Oil Shutoff Valve
7930	Engine Oil Indicating System
7931	Engine Oil Pressure
7932	Engine Oil Quantity
7933	Engine Oil Temperature
7997	Engine Oil System Wiring

80 Starting

8000	Engine Starting System
8010	Engine Cranking
8011	Engine Starter
8012	Engine Start Valves/ Controls
8097	Engine Starting System Wiring

81 Turbocharging

8100	Exhaust Turbine System (Recip)
8110	Power Recovery Turbine (Recip)
8120	Exhaust Turbocharger
8197	Turbocharging System Wiring

82 Water Injection

8200	Water Injection System
8297	Water Injection System Wiring

83	Accessory Gearboxes
8300	Accessory Gearboxes
8397	Accessory Gearbox System Wiring

85 Reciprocating Engine

8500	Engine (Reciprocating)
8510	Reciprocating Engine Front Section
8520	Reciprocating Engine Power Section
8530	Reciprocating Engine Cylinder Section
8540	Reciprocating Engine Rear Section
8550	Reciprocating Engine Oil System
8560	Reciprocating Engine Supercharger
8570	Reciprocating Engine Liquid Cooling
8597	Reciprocating Engine System Wiring

1.5 Aircraft Nationality Identification

The following aircraft nationality marks are referenced in FAA Order JO 7340.2L, Contractions, effective December 2, 2021, as notified to the International Civil Aviation Organization (ICAO), in accordance with ICAO Annex 7, Aircraft Nationality and Registration Marks.

Registration	**Country**
AP	Pakistan
A2	Botswana
A3	Tonga
A40	Oman
A5	Bhutan
A6	United Arab Emirates
A7	Qatar
A8	Liberia
A9C	Bahrain
B	China (including Hong Kong SAR and Macao SAR)
C, CF	Canada
CC	Chile
CN	Morocco
CP	Bolivia (Plurinational State of)
CR, CS	Portugal
CU	Cuba
CX	Uruguay
C2	Nauru
C5	Gambia
C6	Bahamas
C9	Mozambique
D	Germany
DQ	Fiji
D2	Angola
D4	Cape Verde
D6	Comoros
EC	Spain
EI, EJ	Ireland
EK	Armenia
EP	Iran (Islamic Republic of)
ER	Republic of Moldova
ES	Estonia
ET	Ethiopia
EW	Belarus
EX	Kyrgyzstan
EY	Tajikistan
EZ	Turkmenistan
E3	Eritrea
E5	Cook Islands
E7	Bosnia and Herzegovina
F	France
G	United Kingdom
HA	Hungary
HB	(plus national emblem) Liechtenstein
HB	(plus national emblem) Switzerland
HC	Ecuador
HH	Haiti
HI	Dominican Republic
HJ, HK	Colombia
HL	Republic of Korea
HP	Panama
HR	Honduras
HS	Thailand
HZ	Saudi Arabia
H4	Solomon Islands
I	Italy
JA	Japan
JU	Mongolia
JY	Jordan
J2	Djibouti

Registration	Country
J3	Grenada
J5	Guinea–Bissau
J6	Saint Lucia
J7	Dominica
J8	Saint Vincent and the Grenadines
LN	Norway
LQ, LV	Argentina
LX	Luxembourg
LY	Lithuania
LZ	Bulgaria
M	Isle of Man
N	United States
OB	Peru
OD	Lebanon
OE	Austria
OH	Finland
OK	Czech Republic
OM	Slovakia
OO	Belgium
OY	Denmark
P	Democratic People's Republic of Korea*
PH	Netherlands
PJ	Netherlands Antilles (Netherlands)
PK	Indonesia
PP, PR, PT, PU	Brazil
PZ	Suriname
P2	Papua New Guinea
P4	Aruba (Netherlands)
RA	Russian Federation
RDPL	Lao People's Democratic Republic*
RP	Philippines*
SE	Sweden
SP	Poland
ST	Sudan
SU	Egypt
SX	Greece
S2	Bangladesh
S5	Slovenia
S7	Seychelles
S9	Sao Tome and Principe
TC	Turkey
TF	Iceland
TG	Guatemala
TI	Costa Rica
TJ	Cameroon
TL	Central African Republic
TN	Congo
TR	Gabon
TS	Tunisia
TT	Chad
TU	Ivory Coast
TY	Benin
TZ	Mali
T7	San Marino
T8	Palau
UK	Uzbekistan
UN	Kazakhstan
UR	Ukraine
VH	Australia
VP–A	Anguilla (United Kingdom)
VP–B, VQ–B	Bermuda (United Kingdom)
VP–C	Cayman Islands (United Kingdom)
VP–F	Falkland Islands (Malvinas) (United Kingdom)
VP–G	Gilbraltar (United Kingdom)
VP–L	Virgin Islands (United Kingdom)
VP–M	Montserrat (United Kingdom)
VQ–H	St. Helena/Ascension (United Kingdom)
VQ–B, VP–B	Bermuda (United Kingdom)
VQ–T	Turks and Caicos (United Kingdom)
VT	India

Registration	Country
V2	Antigua and Barbuda
V3	Belize
V4	Saint Kitts and Nevis
V5	Namibia
V6	Micronesia (Federated States of)
V7	Marshall Islands
V8	Brunei Darussalam
XA, XB, XC	Mexico (plus national emblem)
XT	Burkina Faso
XU	Cambodia
XV	Viet Nam
XY, XZ	Myanmar
YA	Afghanistan
YI	Iraq
YJ	Vanuatu
YK	Syrian Arab Republic
YL	Latvia
YN	Nicaragua
YR	Romania
YS	El Salvador
YU	Serbia
YV	Venezuela (Bolivarian Republic of)
Z	Zimbabwe*
ZK, ZL, ZM	New Zealand
ZP	Paraguay
ZS, ZT, ZU	South Africa
Z3	The former Yugoslav Republic of Macedonia
2	Bailiwick of Guernsey (United Kingdom)
3A	Monaco
3B	Mauritius
3C	Equatorial Guinea
3D	Swaziland
3X	Guinea
4K	Azerbaijan
4L	Georgia
4O	Montenegro

Registration	Country
4R	Sri Lanka
4W	Yemen
4X	Israel
4YB	Arab Air Cargo (Jordan)
5A	Libya
5B	Cyprus
5H	United Republic of Tanzania
5N	Nigeria
5R	Madagascar
5T	Mauritania
5U	Niger
5V	Togo
5W	Samoa
5X	Uganda
5Y	Kenya
6O	Somalia
6V, 6W	Senegal
6Y	Jamaica
7O	Yemen
7P	Lesotho
7QY	Malawi
7T	Algeria
8P	Barbados
8Q	Maldives
8R	Guyana
9A	Croatia
9G	Ghana
9H	Malta
9J	Zambia
9K	Kuwait
9L	Sierra Leone
9M	Malaysia
9N	Nepal
9Q	Democratic Republic of the Congo
9U	Burundi
9V	Singapore
9XR	Rwanda
9Y	Trinidad and Tobago

** This mark differs from the provision in paragraph 2.3 of Annex 7, Aircraft Nationality and Registration Marks.*

1.6 Title 14 of the Code of Federal Regulations

The following is a list of all current regulations in Title 14, “Aeronautics and Space.” For the complete list of all 14 CFR Parts (including those reserved for later use), visit **faa.gov**.

Part	**Title**
Subchapter A—Definitions and General Requirements	
1	Definitions and abbreviations
3	General requirements
5	Safety Management Systems
Subchapter B—Procedural Rules	
11	General rulemaking procedures
13	Investigative and enforcement procedures
14	Rules implementing the Equal Access to Justice Act of 1980
15	Administrative claims under Federal Tort Claims Act
16	Rules of practice for Federally-assisted airport enforcement proceedings
17	Procedures for protests and contract disputes
Subchapter C—Aircraft	
21	Certification procedures for products and articles
23	Airworthiness standards: normal, utility, acrobatic, and commuter category airplanes
25	Airworthiness standards: transport category airplanes
26	Continued airworthiness and safety improvements for transport category airplanes
27	Airworthiness standards: normal category rotorcraft
29	Airworthiness standards: transport category rotorcraft
31	Airworthiness standards: manned free balloons
33	Airworthiness standards: aircraft engines
34	Fuel venting and exhaust emission requirements for turbine engine powered airplanes
35	Airworthiness standards: propellers
36	Noise standards: aircraft type and airworthiness certification
39	Airworthiness directives
43	Maintenance, preventive maintenance, rebuilding, and alteration
45	Identification and registration marking
47	Aircraft registration

48	Registration and Marking Requirements for Small Unmanned Aircraft
49	Recording of aircraft titles and security documents

Subchapter D—Airmen

60	Flight simulation training device initial and continuing qualification and use
61	Certification: Pilots, flight instructors, and ground instructors
63	Certification: Flight crewmembers other than pilots
65	Certification: Airmen other than flight crewmembers
67	Medical standards and certification
68	Requirements for Operating Certain Small Aircraft Without a Medical Certificate

Subchapter E—Airspace

71	Designation of Class A, Class B, Class C, Class D, and E airspace areas; air traffic service routes; and reporting points
73	Special use airspace
77	Safe, efficient use, and preservation of the navigable airspace

Subchapter F—Air Traffic and General Operating Rules

91	General operating and flight rules
93	Special air traffic rules
95	IFR altitudes
97	Standard instrument approach procedures
99	Security control of air traffic
101	Moored balloons, kites, amateur rockets, unmanned free balloons, and certain model aircraft
103	Ultralight vehicles
105	Parachute operations
107	Small Unmanned Aircraft Systems

Subchapter G—Air Carriers and Operators for Compensation or Hire: Certification and Operations

110	General requirements
117	Flight and Duty Limitations and Rest Requirements: Flightcrew Members
119	Certification: Air carriers and commercial operators
120	Drug and alcohol testing program
121	Operating requirements: Domestic, flag, and supplemental operations
125	Certification and operations: Airplanes having a seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 pounds or more; and rules governing persons on board such aircraft

129	Operations: Foreign air carriers and foreign operators of U.S.-registered aircraft engaged in common carriage
133	Rotorcraft external-load operations
135	Operating requirements: Commuter and on-demand operations and rules governing persons on board such aircraft
136	Commercial air tours and national parks air tour management
137	Agricultural aircraft operations
139	Certification of airports

Subchapter H—Schools and Other Certificated Agencies

141	Pilot schools
142	Training centers
145	Repair stations
147	Aviation maintenance technician schools

Subchapter I—Airports

150	Airport noise compatibility planning
151	Federal aid to airports
152	Airport aid program
153	Airport operations
155	Release of airport property from surplus property disposal restrictions
156	State block grant pilot program
157	Notice of construction, alteration, activation, and deactivation of airports
158	Passenger facility charges (PFCs)
161	Notice and approval of airport noise and access restrictions
169	Expenditure of Federal funds for nonmilitary airports or air navigation facilities thereon

Subchapter J—Navigational Facilities

170	Establishment and discontinuance criteria for air traffic control services and navigational facilities
171	Non-Federal navigation facilities

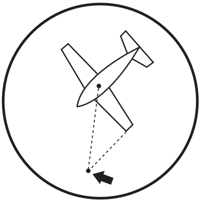
Subchapter K—Administrative Regulations

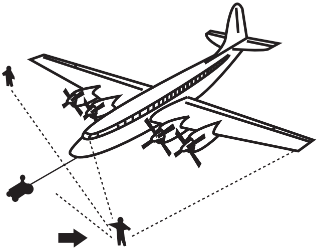
183	Representatives of the Administrator
185	Testimony by employees and production of records in legal proceedings, and service of legal process and pleadings
187	Fees
189	Use of Federal Aviation Administration communications system
193	Protection of voluntarily submitted information

Subchapter N—War Risk Insurance

198	Aviation insurance

1.7 Standard Taxi Signals

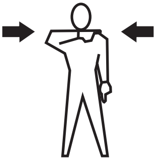

Signalman's position


Signalman directs towing

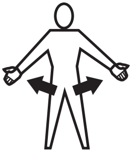

Flagman directs pilot

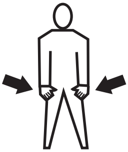

Proceed straight ahead

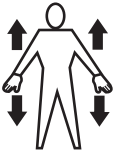

Stop

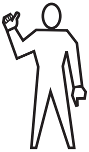

Cut engines

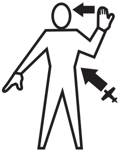

Start engines

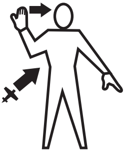

Pull chocks

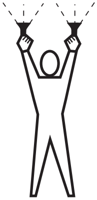

Insert chocks


Slow down


All clear (O.K.)


Left turn


Right turn


Night operation

1.8 Troubleshooting

Troubleshooting is one of the most important skills an AMT must develop. Systematic troubleshooting can save hours of time and prevent components being needlessly replaced. It can be learned if you apply a few simple rules:

1. *Know how the system should operate*. Sounds absurdly simple, but it is the secret of successful troubleshooting. You must know the way the components work separately and the way they work together.
2. *Observe how the system is operating.* Any difference between the way a system is operating and the way it should operate is an indication of trouble, and you can concentrate your efforts on these differences to find the problem.
3. *Divide the system to find the trouble.* AMT time is valuable so you must find the trouble in the shortest length of time. To do this, you must operate with a minimum of lost motion. Isolate the malfunctioning system, then find which subsystem or component is not working as it should.
4. *Look for the obvious problem first.* Popped circuit breakers, switches or valves in the wrong position have been the cause of wasted troubleshooting time.

Section 2: Physical and Chemical

Periodic Table of Elements

Periods	Light Metals		Heavy Metals										Nonmetals					Inert Gases
	I A	II A	III B	IV B	V B	VI B	VII B	VIII			I B	II B	III A	IV A	V A	VI A	VII A	
1	1 **H** 1.00797				4 **Be** 9.0122	Atomic number Symbol Atomic weight												2 **He** 4.0026
2	3 **Li** 6.941	4 **Be** 9.0122				Transition Elements							5 **B** 10.811	6 **C** 12.01115	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984	10 **Ne** 20.179
3	11 **Na** 22.9898	12 **Mg** 24.305							Group VIII				13 **Al** 26.9815	14 **Si** 28.086	15 **P** 30.9736	16 **S** 32.064	17 **Cl** 35.453	18 **Ar** 39.948
4	19 **K** 39.0983	20 **Ca** 40.08	21 **Sc** 44.956	22 **Ti** 47.90	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.94	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.70	29 **Cu** 63.54	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.905	40 **Zr** 91.22	41 **Nb** 92.906	42 **Mo** 95.94	43 **Tc** (97)	44 **Ru** 101.07	45 **Rh** 102.905	46 **Pd** 106.4	47 **Ag** 107.868	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.69	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.9045	54 **Xe** 131.30
6	55 **Cs** 132.905	56 **Ba** 137.34	57* **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.948	74 **W** 183.85	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.09	79 **Au** 196.967	80 **Hg** 200.59	81 **Tl** 204.37	82 **Pb** 207.19	83 **Bi** 208.980	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** 226.02	89** **Ac** (227)															

Atomic weights in ( ) are mass numbers of most stable isotope of that element.

Rare Earth Elements	* Lathanide Series	58 **Ce** 140.12	59 **Pr** 140.907	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.35	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.925	66 **Dy** 162.50	67 **Ho** 164.930	68 **Er** 167.26	69 **Tm** 168.934	70 **Yb** 173.04	71 **Lu** 174.97
	** Actinide Series	90 **Th** 232.038	91 **Pa** 231.0359	92 **U** 238.03	93 **Np** 237.0482	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (254)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

2.1 Temperature Conversion

To convert between the temperature scales, use these formulas:

Fahrenheit to Celsius:

$$°F = 1.8 \times °C + 32$$

or

$$°F = \frac{(9 \times °C)}{5} + 32$$

Celsius to Fahrenheit:

$$°C = \frac{°F - 32}{1.8}$$

or

$$°C = \frac{5(°F - 32)}{9}$$

For interpolation, 1°C = 1.8°F

°C	**← °F | °C →**	**°F**
-73.3	-100	-148.0
-70.6	-95	-139.0
-67.8	-90	-130.0
-65.0	-85	-121.0
-62.2	-80	-112.0
-59.4	-75	-103.0
-56.7	-70	-94.0
-53.9	-65	-85.0
-51.1	-60	-76.0
-48.3	-55	-67.0
-45.6	-50	-58.0
-42.8	-45	-49.0
-40.0	-40	-40.0
-37.2	-35	-31.0
-34.4	-30	-22.0
-31.7	-25	-13.0
-28.9	-20	-4.0
-26.1	-15	5.0
-23.3	-10	14.0
-20.6	-5	23.0
-18.3	-1	30.2
-17.8	0	32.0
-17.2	1	33.8
-16.7	2	35.6
-16.1	3	37.4
-15.6	4	39.2
-15.0	5	41.0
-14.4	6	42.8
-13.9	7	44.6
-13.3	8	46.4
-12.8	9	48.2
-12.2	10	50.0
-11.7	11	51.8
-11.1	12	53.6
-10.6	13	55.4
-10.0	14	57.2

°C	← °F | °C →	°F
-9.4	15	59.0
-8.9	16	60.8
-8.3	17	62.6
-7.8	18	64.4
-7.2	19	66.2
-6.7	20	68.0
-6.1	21	69.8
-5.6	22	71.6
-5.0	23	73.4
-4.4	24	75.2
-3.9	25	77.0
-3.3	26	78.8
-2.8	27	80.6
-2.2	28	82.4
-1.7	29	84.2
-1.1	30	86.0
-0.6	31	87.8
0.0	32	89.6
0.6	33	91.4
1.1	34	93.2
1.7	35	95.0
2.2	36	96.8
2.8	37	98.6
3.3	38	100.4
3.9	39	102.2
4.4	40	104.0
5.0	41	105.8
5.6	42	107.6
6.1	43	109.4
6.7	44	111.2
7.2	45	113.0
7.8	46	114.8
8.3	47	116.6
8.9	48	118.4
9.4	49	120.2
10.0	50	122.0
10.6	51	123.8
11.1	52	125.6
11.7	53	127.4
12.2	54	129.2
12.8	55	131.0
13.3	56	132.8
13.9	57	134.6
14.4	58	136.4
15.0	59	138.2
15.6	60	140.0
16.1	61	141.8
16.7	62	143.6
17.2	63	145.4
17.8	64	147.2
18.3	65	149.0
18.9	66	150.8
19.4	67	152.6
20.0	68	154.4
20.6	69	156.2
21.1	70	158.0
21.7	71	159.8
22.2	72	161.6
22.8	73	163.4
23.3	74	165.2
23.9	75	167.0
24.4	76	168.8
25.0	77	170.6
25.6	78	172.4
26.1	79	174.2
26.7	80	176.0
27.2	81	177.8
27.8	82	179.6
28.3	83	181.4
28.9	84	183.2
29.4	85	185.0
30.0	86	186.8
30.6	87	188.6
31.1	88	190.4
31.7	89	192.2
32.2	90	194.0
32.8	91	195.8
33.3	92	197.6
33.9	93	199.4
34.4	94	201.2
35.0	95	203.0
35.6	96	204.8
36.1	97	206.6
36.7	98	208.4

°C	← °F | °C →	°F
37.2	99	210.2
37.8	100	212.0
38.3	101	213.8
38.9	102	215.6
39.4	103	217.4
40.0	104	219.2
40.6	105	221.0
41.1	106	222.8
41.7	107	224.6
42.2	108	226.4
42.8	109	228.2
43.3	110	230.0
43.9	111	231.8
44.4	112	233.6
45.0	113	235.4
45.6	114	237.2
46.1	115	239.0
46.7	116	240.8
47.2	117	242.6
47.8	118	244.4
48.3	119	246.2
48.9	120	248.0
49.4	121	249.8
50.0	122	251.6
50.6	123	253.4
51.1	124	255.2
51.7	125	257.0
52.2	126	258.8
52.8	127	260.6
53.3	128	262.4
53.9	129	264.2
54.4	130	266.0
55.0	131	267.8
55.6	132	269.6
56.1	133	271.4
56.7	134	273.2
57.2	135	275.0
57.8	136	276.8
58.3	137	278.6
58.9	138	280.4
59.4	139	282.2
60.0	140	284.0
60.6	141	285.8
61.1	142	287.6
61.7	143	289.4
62.2	144	291.2
62.8	145	293.0
63.3	146	294.8
63.9	147	296.6
64.4	148	298.4
65.0	149	300.2
65.6	150	302.0
66.1	151	303.8
66.7	152	305.6
67.2	153	307.4
67.8	154	309.2
68.3	155	311.0
68.9	156	312.8
69.4	157	314.6
70.0	158	316.4
70.6	159	318.2
71.1	160	320.0
71.7	161	321.8
72.2	162	323.6
72.8	163	325.4
73.3	164	327.2
73.9	165	329.0
74.4	166	330.8
75.0	167	332.6
75.6	168	334.4
76.1	169	336.2
76.7	170	338.0
77.2	171	339.8
77.8	172	341.6
78.3	173	343.4
78.9	174	345.2
79.4	175	347.0
80.0	176	348.8
80.6	177	350.6
81.1	178	352.4
81.7	179	354.2
82.2	180	356.0
82.8	181	357.8
83.3	182	359.6

°C	← °F | °C →	°F
83.9	183	361.4
84.4	184	363.2
85.0	185	365.0
85.6	186	366.8
86.1	187	368.6
86.7	188	370.4
87.2	189	372.2
87.8	190	374.0
88.3	191	375.8
88.9	192	377.6
89.4	193	379.4
90.0	194	381.2
90.6	195	383.0
91.1	196	384.8
91.7	197	386.6
92.2	198	388.4
92.8	199	390.2
93.3	200	392.0
93.9	201	393.8
94.4	202	395.6
95.0	203	397.4
95.6	204	399.2
96.1	205	401.0
96.7	206	402.8
97.2	207	404.6
97.8	208	406.4
98.3	209	408.2
98.9	210	410.0
99.4	211	411.8
100.0	212	413.6
100.6	213	415.4
101.1	214	417.2
101.7	215	419.0
102.2	216	420.8
102.8	217	422.6
103.3	218	424.4
103.9	219	426.2
104.4	220	428.0
107.2	225	437.0
110.0	230	446.0
112.8	235	455.0
115.6	240	464.0
118.3	245	473.0
121.1	250	482.0
123.9	255	491.0
126.7	260	500.0
129.4	265	509.0
132.2	270	518.0
135.0	275	527.0
137.8	280	536.0
140.6	285	545.0
143.3	290	554.0
146.1	295	563.0
148.9	300	572.0
154.4	310	590.0
160.0	320	608.0
165.6	330	626.0
171.1	340	644.0
176.7	350	662.0
182.2	360	680.0
187.8	370	698.0
193.3	380	716.0
198.9	390	734.0
204.4	400	752.0
210.0	410	770.0
215.6	420	788.0
221.1	430	806.0
226.7	440	824.0
232.2	450	842.0
237.8	460	860.0
243.3	470	878.0
248.9	480	896.0
254.4	490	914.0
260.0	500	932.0
265.6	510	950.0
271.1	520	968.0
276.7	530	986.0
282.2	540	1004.0
287.8	550	1022.0
293.3	560	1040.0
298.9	570	1058.0
304.4	580	1076.0
310.0	590	1094.0
315.6	600	1112.0

°C	← °F | °C →	°F
321.1	610	1130.0
326.7	620	1148.0
332.2	630	1166.0
337.8	640	1184.0
343.3	650	1202.0
348.9	660	1220.0
354.4	670	1238.0
360.0	680	1256.0
365.6	690	1274.0
371.1	700	1292.0
376.7	710	1310.0
382.2	720	1328.0
387.8	730	1346.0
393.3	740	1364.0
398.9	750	1382.0
404.4	760	1400.0
410.0	770	1418.0
415.6	780	1436.0
421.1	790	1454.0
426.7	800	1472.0
432.2	810	1490.0
437.8	820	1508.0
443.3	830	1526.0
448.9	840	1544.0
454.4	850	1562.0
460.0	860	1580.0
465.6	870	1598.0
471.1	880	1616.0
476.7	890	1634.0
482.2	900	1652.0
487.8	910	1670.0
493.3	920	1688.0
498.9	930	1706.0
504.4	940	1724.0
510.0	950	1742.0
515.6	960	1760.0
521.1	970	1778.0
526.7	980	1796.0
532.2	990	1814.0
537.8	1000	1832.0
548.9	1020	1868.0
560.0	1040	1904.0
571.1	1060	1940.0
582.2	1080	1976.0
593.3	1100	2012.0
604.4	1120	2048.0
615.6	1140	2084.0
626.7	1160	2120.0
637.8	1180	2156.0
648.9	1200	2192.0
660.0	1220	2228.0
671.1	1240	2264.0
682.2	1260	2300.0
693.3	1280	2336.0
704.4	1300	2372.0
715.6	1320	2408.0
726.7	1340	2444.0
737.8	1360	2480.0
748.9	1380	2516.0
760.0	1400	2552.0
771.1	1420	2588.0
782.2	1440	2624.0
793.3	1460	2660.0
804.4	1480	2696.0
815.6	1500	2732.0
826.7	1520	2768.0
837.8	1540	2804.0
848.9	1560	2840.0
860.0	1580	2876.0
871.1	1600	2912.0
882.2	1620	2948.0
893.3	1640	2984.0
904.4	1660	3020.0
915.6	1680	3056.0
926.7	1700	3092.0
937.8	1720	3128.0
948.9	1740	3164.0
960.0	1760	3200.0
971.1	1780	3236.0
982.2	1800	3272.0
993.3	1820	3308.0
1004.4	1840	3344.0
1015.6	1860	3380.0
1026.7	1880	3416.0

°C	← °F | °C →	°F
1037.8	1900	3452.0
1048.9	1920	3488.0
1060.0	1940	3524.0
1071.1	1960	3560.0
1082.2	1980	3596.0
1093.3	2000	3632.0
1104.4	2020	3668.0
1115.6	2040	3704.0
1126.7	2060	3740.0
1137.8	2080	3776.0
1148.9	2100	3812.0
1160.0	2120	3848.0
1171.1	2140	3884.0
1182.2	2160	3920.0
1193.3	2180	3956.0
1204.4	2200	3992.0
1215.6	2220	4028.0
1226.7	2240	4064.0
1237.8	2260	4100.0
1248.9	2280	4136.0
1260.0	2300	4172.0
1271.1	2320	4208.0
1282.2	2340	4244.0
1293.3	2360	4280.0
1304.4	2380	4316.0
1315.6	2400	4352.0
1326.7	2420	4388.0
1337.8	2440	4424.0
1348.9	2460	4460.0
1360.0	2480	4496.0
1371.1	2500	4532.0
1382.2	2520	4568.0
1393.3	2540	4604.0
1404.4	2560	4640.0
1415.6	2580	4676.0
1426.7	2600	4712.0
1437.8	2620	4748.0
1448.9	2640	4784.0
1460.0	2660	4820.0
1471.1	2680	4856.0
1482.2	2700	4892.0
1493.3	2720	4928.0
1504.4	2740	4964.0
1515.6	2760	5000.0
1526.7	2780	5036.0
1537.8	2800	5072.0
1565.6	2850	5162.0
1593.3	2900	5252.0
1621.1	2950	5342.0
1648.9	3000	5432.0

Absolute Temperature

The Kelvin temperature scale uses the same graduations as are used in the Celsius scale. Zero degrees Kelvin (0°K) is absolute zero, and is equal to -273°C.

$$°K = °C + 273$$

and

$$°C = °K – 273$$

The Rankine temperature scale uses the same graduations as are used in the Fahrenheit scale. Zero degrees Rankine (0°R) is absolute zero, and is equal to -460°F.

$$°R = °F + 460$$

and

$$°F = °R – 460$$

2.2 ICAO Standard Atmosphere

Altitude	**Temperature**		**Pressure**	**Speed of Sound**
Feet	***°F***	***°C***	***In. Hg***	***Knots***
–2,000	66.10	19.0	32.15	666.0
–1,000	62.50	17.0	31.01	663.7
0	59.00	15.0	29.92	661.7
1,000	55.43	13.0	28.86	659.5
2,000	51.87	11.0	27.82	657.2
3,000	48.30	9.1	26.82	654.9
4,000	44.74	7.1	25.84	652.6
5,000	41.17	5.1	24.90	650.3
6,000	37.60	3.1	23.98	647.9
7,000	34.04	1.1	23.09	645.6
8,000	30.47	-0.8	22.23	643.3
9,000	26.90	-2.8	21.39	640.9
10,000	23.34	-4.8	20.58	638.6
15,000	5.51	-14.7	16.89	626.7
20,000	-12.32	-24.6	13.75	614.6
25,000	-30.15	-34.5	11.12	602.2
30,000	-47.90	-44.4	8.885	589.5
35,000	-65.82	-54.2	7.041	576.6
*36,089	-69.70	-56.5	6.683	573.8
40,000	-69.70	-56.5	5.558	573.8
45,000	-69.70	-56.5	4.355	573.8
50,000	-69.70	-56.5	3.425	573.8
55,000	-69.70	-56.5	2.693	573.8
60,000	-69.70	-56.5	2.118	573.8
65,000	-69.70	-56.5	1.665	573.8
70,000	-69.70	-56.5	1.310	573.8
75,000	-69.70	-56.5	1.030	573.8
80,000	-69.70	-56.5	0.810	573.8
85,000	-64.80	-53.8	0.637	577.4
90,000	-56.57	-49.2	0.504	583.4
95,000	-48.34	-44.6	0.400	589.3
100,000	-40.11	-40.1	0.320	595.2

*Geopotential of the tropopause

2.3 Density of Various Solids and Liquids

Substance	Specific Gravity	Pounds/ Cubic Foot	Pounds/ Gallon
Cork	0.22	13.7	
Gasoline	0.72	44.9	6.02
JP-4	0.79	49.0	6.60
Alcohol (methyl)	0.81	50.5	6.76
JP-5	0.82	51.2	6.84
Kerosine	0.82	51.2	6.84
Oil (Petroleum)	0.89	55.5	7.43
Ice	0.92	57.4	
Oil (Synthetic)	0.93	58.0	7.76
Water (fresh)	1.00	62.4	8.35
Water (sea)	1.03	64.3	8.60
Ethylene Glycol	1.12	69.9	9.35
Sugar	1.59	99.2	
Carbon Tetrachloride	1.60	99.8	13.36
Magnesium	1.74	108.6	
Salt	2.18	136.0	
Aluminum	2.70	168.5	
Zinc	7.10	443.0	
Steel	7.83	488.6	
Iron	7.90	493.0	
Brass	8.65	539.8	
Copper	8.95	558.5	
Lead	11.37	709.5	
Mercury	13.55	845.6	113.14
Gold	19.31	1,204.9	

Density of Various Gases

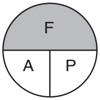
Gas	Specific Gravity	Pounds/ Cubic Foot
Hydrogen	0.073	0.00561
Helium	0.146	0.01114
Air	1.000	0.07651
Nitrogen	1.020	0.07807
Oxygen	1.166	0.08921
Carbon Dioxide	1.613	0.12341

2.4 Hydraulic Relationships

Relationships exist between pressure, area, and volume in a hydraulic actuator that allow us to find the value of any one of them when the other two are known. Circle graphs make it easy for us to visualize the way to find the desired value.

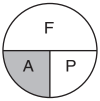
To find the value of the shaded area, multiply the other two if they are both below the horizontal line. Divide if they are separated by the horizontal line.

The amount of force produced by a hydraulic actuator can be found by multiplying the pressure in pounds per square inch (psi), by the area of the piston in square inches.



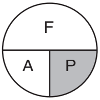
$$F = P \times A$$

The area of a piston needed to produce a given amount of force can be found by dividing the force, in pounds, by the pressure of the hydraulic fluid in psi.



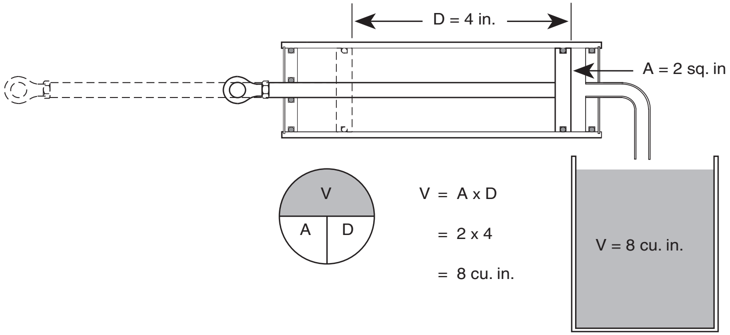
$$A = \frac{F}{P}$$

The amount of pressure needed for a piston having a given area (in square inches) to produce a known force may be found by dividing the amount of force by the area of the piston.



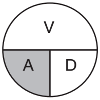
$$P = \frac{F}{A}$$

Relationships exist between the volume of fluid moved by a piston in a cylinder, the area of the piston, and the distance the piston moves. Circle graphs make it easy for us to visualize the way to find the desired value.



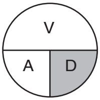
$$V = A \times D$$
$$= 2 \times 4$$
$$= 8 \text{ cu. in.}$$

The volume of fluid, in cubic inches, moved by a piston is found by multiplying the area of the piston in square inches, by the distance the piston has moved in inches.



$$A = \frac{V}{D}$$
$$= \frac{8}{4}$$
$$= 2 \text{ sq. in.}$$

The area of a piston needed to move a given quantity of fluid is found by dividing the volume of the fluid by the distance the piston moves.



$$A = \frac{V}{A}$$
$$= \frac{8}{2}$$
$$= 4 \text{ inches}$$

The distance that a piston with a given area must move to displace a given volume of fluid is found by dividing the volume of the fluid by the area of the piston.

2.5 Quantity of Liquid in a Drum

Estimating Quantity of Liquid in a Standard 55-Gallon Drum

Drum Upright

Depth of Liquid (inches)	Gallons (approx.)
31	54.0
30	52.0
29	50.0
28	48.5
27	47.0
26	45.0
25	43.5
24	41.5
23	40.0
22	38.0
21	36.5
20	34.5
19	33.0
18	31.5
17	29.5
16	27.5
15	26.0
14	24.5
13	22.5
12	21.0
11	19.0
10	17.5
9	15.5
8	14.0
7	12.0
6	10.5
5	8.5
4	7.0
3	5.0
2	3.5
1	2.0

Drum On Its Side

Depth of Liquid (inches)	Gallons (approx.)
20	55.0
19	52.5
18	50.0
17	47.5
16	44.5
15	41.5
14	38.5
13	35.0
12	32.0
11	28.5
10	25.0
9	22.0
8	18.5
7	15.5
6	12.5
5	9.5
4	7.0
3	4.5
2	2.5
1	0.8

Section 3: Mathematics

3.1 Measurement Systems

There are two systems of measurement used in the United States: the U.S. Customary system (U.S.), and the metric system.

The U.S. Customary system was mainly derived from the British Imperial system in which there is no correlation between the units, and the basis of many are arbitrary. However, they have been used for so long that most of us are familiar with them. The metric system, on the other hand, is based upon absolute and repeatable physical factors. The sizes of the units change in multiples of 10.

The metric system had its start in France late in the eighteenth century when the unit of length, the meter, was accepted as being equal to one ten-millionth of the length of the arc from the equator to the North Pole. The unit of mass was the kilogram which was equal to the mass of water contained in a cube whose length, width, and height are one tenth of a meter.

The metric system spread slowly from France to other European countries. In the United States, in July of 1866, legislation was signed into law authorizing, but not mandating the use of the metric system. More than one hundred years later, in 1968, Congress authorized an intensive study to determine the advantages and disadvantages of increased use in the U.S. of the metric system. In 1975 the U.S. Metric Board was established to coordinate the voluntary conversion to the metric system.

The Omnibus Trade Bill passed in 1988 required most federal agencies to convert to metric units in their activities by 1992.

Enthusiastic adoption of the metric system in the U.S. has been slow because of the tremendous amount of machinery and equipment in use that was built to U.S. dimensions. However, the increase in international trade has caused many U.S. manufacturers to include both U.S. and metric dimensions in their service literature. The popularity of foreign automobiles in the U.S. has increased the familiarity of most Americans with metric dimensions. Most professional mechanics and technicians now have two sets of hand tools, one U.S. and the other metric.

The International System of Units (SI)

The International System of Units is founded on seven base units:

length	meter
mass	kilogram
time	second
electrical current	ampere
temperature	°Kelvin
amount of substance	mole
luminous intensity	candela

These units make up a complete set from which all other units of measurement can be derived.

The Metric System

The metric system is based upon dividing and multiplying the standard units by the powers of 10 and giving each a name indicating its value.

Prefix	Symbol	Power
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
UNIT		
deci	d	10^{-1}
centi	c	10^{-2}
mili	m	10^{-3}
micro	m	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

U.S. – Metric Conversion

The basis of many units in the U.S. system are arbitrary and are not reproducible. But by relating them to one of the units in the SI system, they are traceable back to a reproducible basic unit.

Length

1 inch		2.54 centimeters
1 foot	12 inches	30.48 centimeters
1 yard	3 feet	0.9144 meter
1 statute mile	5,280 feet	1.609 kilometers
1 nautical mile	6,076 feet	1.852 kilometers

Weight

1 ounce		28.3495 gram
1 pound	16 ounces	0.4536 kilogram
1 ton	2,000 pounds	907.2 kilograms

Volume

1 cubic inch		16.39 cubic centimeters
1 cubic inch		0.01639 liter
1 U.S. gallon	231 cubic inches	3.785 liters
1 Imperial gallon	1.2 U.S. gallons	4.542 liters

3.2 Mathematical Constants

$\pi = 3.1416$

$\pi^2 = 9.8696$

$\pi^3 = 31.0063$

$\frac{1}{\pi} = 0.3183$

$\frac{1}{\pi^2} = 0.1013$

$\sqrt{\pi} = 1.7725$

$\frac{1}{\sqrt{\pi}} = 0.5642$

$\frac{1}{2\pi} = 0.1592$

$\left[\frac{1}{2\pi}\right]^2 = 0.0253$

$2\pi = 6.2832$

$2\pi^2 = 39.4784$

$4\pi = 12.5664$

$\frac{\pi}{2} = 1.5708$

$\sqrt{\frac{\pi}{2}} = 1.253$

$\sqrt{2} = 1.4142$

$\sqrt{3} = 1.7321$

$\frac{1}{\sqrt{2}} = 0.7071$

$\frac{1}{\sqrt{3}} = 0.5773$

$\log \pi = 0.4971$

$\log \pi^2 = 0.9943$

$\log \sqrt{\pi} = 0.2486$

$\log \frac{\pi}{2} = 1.5708$

3.3 Mathematical Symbols

$+$	Plus, or positive
$-$	Minus, or negative
$\times$ or $\cdot$	Multiplied by
$\div$	Divided by
$=$	Equal to
$\neq$	Not equal to
$\cong$	Approximately equal to
$\geq$	Greater than or equal to
$\leq$	Less than or equal to
$\equiv$	Identical with
$>$	Greater than
$<$	Less than
$\parallel$	Parallel with
$\perp$	Perpendicular to
$\pm$	Plus or minus
∞	Infinity
$\triangle$	Increment
$\sqrt{a}$	Square root of a
$\sqrt[3]{a}$	Cube root of a
$\lvert a \rvert$	Absolute value of a
$\angle$	Angle
$\therefore$	Therefore
$\exists$	There exists
$:$	Ratio

3.4 Squares, Square Roots, Cubes, Cube Roots of Numbers

Number	Square	Square Root	Cube	Cube Root
1	1	1.0000	1	1.0000
2	4	1.4142	8	1.2599
3	9	1.7321	27	1.4423
4	16	2.0000	64	1.5874
5	25	2.2361	125	1.7110
6	36	2.4495	216	1.8171
7	49	2.6458	343	1.9129
8	64	2.8284	512	2.0000
9	81	3.0000	729	2.0801
10	100	3.1623	1,000	2.1544
11	121	3.3166	1,331	2.2240
12	144	3.4641	1,728	2.2894
13	169	3.6056	2,197	2.3513
14	196	3.7417	2,744	2.4101
15	225	3.8730	3,375	2.4662
16	256	4.0000	4,096	2.5198
17	289	4.1232	4,913	2.5713
18	324	4.2426	5,832	2.6207
19	361	4.3589	6,859	2.6684
20	400	4.4721	8,000	2.7144
21	441	4.5826	9,261	2.7589
22	484	4.6904	10,648	2.8020
23	529	4.7958	12,167	2.8439
24	576	4.8990	13,824	2.8845
25	625	5.0000	15,625	2.9240
26	676	5.0990	17,576	2.9625
27	729	5.1962	19,683	3.0000
28	784	5.2915	21,952	3.0366
29	841	5.3852	24,389	3.0723
30	900	5.4772	27,000	3.1072
31	961	5.5678	29,791	3.1414
32	1,024	5.6569	32,768	3.1748
33	1,089	5.7446	35,937	3.2075
34	1,156	5.8310	39,304	3.2396
35	1,225	5.9161	42,875	3.2711

Number	Square	Square Root	Cube	Cube Root
36	1,296	6.0000	46,656	3.3019
37	1,369	6.0828	50,653	3.3322
38	1,444	6.1644	54,872	3.3620
39	1,521	6.2450	59,319	3.3912
40	1,600	6.3246	64,000	3.4200
41	1,681	6.4031	68,921	3.4482
42	1,764	6.4807	74,088	3.4760
43	1,849	6.5574	79,507	3.5034
44	1,936	6.6333	85,184	3.5303
45	2,025	6.7082	91,125	3.5569
46	2,116	6.7823	97,336	3.5830
47	2,206	6.8557	103,823	3.6088
48	2,304	6.9282	110,592	3.6342
49	2,401	7.0000	117,649	3.6593
50	2,500	7.0711	125,000	3.6840
51	2,601	7.1414	132,651	3.7084
52	2,704	7.2111	140,608	3.7325
53	2,809	7.2801	148,877	3.7563
54	2,916	7.3485	157,464	3.7798
55	3,025	7.4162	166,375	3.8030
56	3,136	7.4833	175,616	3.8259
57	3,249	7.5498	185,193	3.8485
58	3,364	7.6158	195,112	3.8709
59	3,481	7.6811	205,379	3.8930
60	3,600	7.7460	216,000	3.9149
61	3,721	7.8103	226,981	3.9365
62	3,844	7.8740	238,328	3.9579
63	3,969	7.9373	250,047	3.9791
64	4,096	8.0000	262,144	4.0000
65	4,225	8.0623	274,625	4.0207
66	4,356	8.1240	287,496	4.0412
67	4,489	8.1854	300,763	4.0615
68	4,624	8.2462	314,432	4.0817
69	4,761	8.3066	328,509	4.1016
70	4,900	8.3666	343,000	4.1213
71	5,041	8.4262	357,911	4.1408
72	5,184	8.4853	373,248	4.1602
73	5,329	8.5440	389,017	4.1793
74	5,476	8.6023	405,224	4.1983

Number	Square	Square Root	Cube	Cube Root
75	5,625	8.6603	421,875	4.2172
76	5,776	8.7178	438,976	4.2358
77	5,929	8.7750	456,533	4.2543
78	6,084	8.8318	474,552	4.2727
79	6,241	8.8882	493,039	4.2908
80	6,400	8.9443	512,000	4.3089
81	6,561	9.0000	531,441	4.3267
82	6,724	9.0554	551,368	4.3445
83	6,889	9.1104	571,787	4.3621
84	7,056	9.1652	592,704	4.3795
85	7,225	9.2195	614,125	4.3968
86	7,396	9.2736	636,056	4.4140
87	7,569	9.3274	658,503	4.4310
88	7,744	9.3808	681,472	4.4480
89	7,921	9.4340	704,969	4.4647
90	8,100	9.4868	729,000	4.4814
91	8,281	9.5394	753,571	4.4979
92	8,464	9.5917	778,688	4.5144
93	8,649	9.6437	804,357	4.5307
94	8,836	9.6954	830,584	4.5468
95	9,025	9.7468	857,375	4.5629
96	9,216	9.7980	884,736	4.5789
97	9,409	9.8489	912,673	4.5947
98	9,604	9.8995	941,192	4.6104
99	9,801	9.9499	970,299	4.6261
100	10,000	10.0000	1,000,000	4.6416

3.5 Diameter, Circumference and Area of a Circle

Diameter *Units*	**Circumference** *Units*	**Area** *Square Units*
1	3.1416	0.7854
2	6.2832	3.1416
3	9.4248	7.0686
4	12.5664	12.566
5	15.7080	19.635
6	18.8496	28.274
7	21.9911	38.485
8	25.1327	50.265
9	28.2743	63.617
10	31.4159	78.540
11	34.5575	95.033
12	37.6991	113.10
13	40.8407	132.73
14	43.9823	153.94
15	47.1239	176.71
16	50.2655	201.06
17	53.4071	226.98
18	56.5487	254.47
19	59.6903	283.53
20	62.8319	314.16
21	65.9735	346.36
22	69.1150	380.13
23	72.2566	415.48
24	75.3982	452.39
25	78.5398	490.87
26	81.6814	530.93
27	84.8230	572.56
28	87.9646	615.75
29	91.1062	660.52
30	94.2478	706.86
31	97.3894	754.77
32	100.5310	804.25
33	103.6726	855.30
34	106.8142	907.92
35	109.9557	962.11

Diameter ***Units***	**Circumference** ***Units***	**Area** ***Square Units***
36	113.0973	1,017.88
37	116.2389	1,075.21
38	119.3805	1,134.12
39	122.5221	1,194.59
40	125.6637	1,256.64
41	128.8053	1,320.25
42	131.9469	1,385.44
43	135.0885	1,452.20
44	138.2301	1,520.53
45	141.3717	1,590.43
46	144.5133	1,661.90
47	147.6549	1,734.95
48	150.7964	1,809.56
49	153.9380	1,885.74
50	157.0796	1,963.50
51	160.2212	2,042.82
52	163.3628	2,123.72
53	166.5044	2,206.18
54	169.6460	2,290.22
55	172.7876	2,375.83
56	175.9292	2,463.01
57	179.0708	2,551.76
58	182.2124	2,642.08
59	185.3540	2,733.97
60	188.4956	2,827.43
61	191.6372	2,922.47
62	194.7787	3,019.07
63	197.9203	3,117.25
64	201.0619	3,126.99
65	204.2035	3,318.31
66	207.3451	3,421.19
67	210.4867	3,525.65
68	213.6283	3,631.68
69	216.7699	3,739.28
70	219.9115	3,848.45
71	223.0531	3,959.19
72	226.1947	4,071.50
73	229.3363	4,185.39
74	232.4779	4,300.84

Diameter ***Units***	**Circumference** ***Units***	**Area** ***Square Units***
75	235.6194	4,417.87
76	238.7610	4,536.46
77	241.9026	4,656.63
78	245.0442	4,778.36
79	248.1858	4,901.67
80	251.3274	5,026.55
81	254.4690	5,153.00
82	257.6106	5,281.02
83	260.7522	5,410.61
84	263.8938	5,541.77
85	267.0354	5,674.50
86	270.1770	5,808.81
87	273.3186	5,944.68
88	276.4602	6,082.12
89	279.6017	6,221.14
90	282.7433	6,361.73
91	285.8849	6,503.88
92	289.0265	6,647.61
93	292.1681	6,792.91
94	295.3097	6,939.78
95	298.4513	7,088.22
96	301.5929	7,283.23
97	304.7345	7,389.81
98	307.8861	7,542.96
99	311.0177	7,697.69
100	314.1593	7,853.98

3.6 Geometric Formulas

Triangle

A closed, three-sided, plane figure. The sum of the angles in a triangle is always equal to 180 degrees.

Area:

$$A = \frac{b \times a}{2}$$

b = Length of the base
a = Altitude (height)

Square

A closed, four-sided, plane figure. All sides are of equal length and the opposing sides are parallel. All angles are right angles.

Area:

$$A = s^2$$

s = Length of one of the sides

Rectangle

A closed, four-sided, plane figure. The opposing sides are of equal length and are parallel. All angles are right angles.

Area:

$$A = l \times w$$

l = Length of longer side
w = Length of shorter side

Parallelogram

A closed, four-sided, plane figure. The opposing sides are of equal lengths and are parallel. None of the angles are right angles.

Area:

$$A = l \times h$$

l = Length of longer side
h = Height (perpendicular distance between the two longer sides)

Trapezoid

A closed, four-sided, plane figure. Two of the opposing sides are parallel, but are of unequal length.

Area:

$$A = \frac{(a + b)}{2} \times h$$

a = Length of the longest parallel side
b = Length of the shortest parallel side
h = Height (perpendicular distance between the parallel sides)

Regular Pentagon

A closed, five-sided, plane figure. All sides are of equal length, and all angles are equal.

Area:

$$A = 1.720 \times s^2$$

s = Length of one side

Regular Hexagon

A closed, six-sided, plane figure. All sides are of equal length, and all angles are equal.

Area:

$$A = 2.598 \times s^2$$

s = Length of one side

Regular Octagon

A closed, eight-sided, plane figure. All sides are of equal length, and all angles are equal.

$$A = 4.828 \times s^2$$

s = Length of one side

Circle

A closed, curved, plane figure. Every point on the curve is an equal distance from a point within the curve called the center.

Circumference:

$$C = \pi \times d$$

π = A constant, 3.1416
d = Diameter of a circle

Area:

$$A = \pi \times r^2$$

or

$$A = \frac{\pi \times d^2}{4}$$

π = A constant, 3.1416
r = Radius of a circle
d = Diameter of a circle

Ellipse

A closed, plane curve, generated by a point moving in such a way that the sums of the distances from two fixed points is constant.

$$C = 2\pi \sqrt{\frac{a^2 + b^2}{2}}$$

Circumference:

Area:

$$A = \pi ab$$

π = A constant, 3.1416
a = Length of one of the semiaxes
b = Length of the other semiaxis

Sphere

A solid object bounded by a surface, all points of which are a constant distance from a point within, called the center.

Surface area:

$$A = 4\pi r^2$$

Volume:

$$V = \frac{4\pi}{3} \times r^3$$

or

$$V = \frac{\pi}{6} \times d^3$$

π = A constant, 3.1416
r = Radius of a circle
d = Diameter of a circle

Cube

A regular solid figure having six square sides.

Surface area:

$$A = 6 \times s^2$$

Volume:

$$A = s^3$$

s = Length of one of the sides

Rectangular Solid

A solid figure with six rectangular sides.

Surface area:

$$A = 2\ ([l \times w] + [l \times h] + [w \times h])$$

Volume:

$$V = l \times w \times h$$

l = Length
w = Width
h = Height

Cone

A solid figure with a circular base and sides that taper to a point.

Curved surface area:

$$A = \pi r \sqrt{r^2 + h^2}$$

Volume:

$$V = \frac{\pi}{3} \times r^2 h$$

π = A constant, 3.1416
r = Radius of the base
h = Vertical height of the cone

Cylinder

A solid figure with circular ends and parallel sides.

Surface area:

$$A = \pi \times d \times h$$

Volume:

$$V = 0.7854 \times d^2 \times h$$

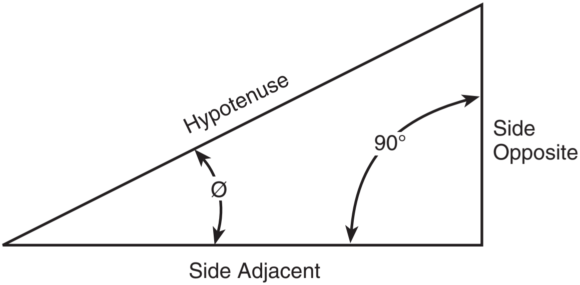
π = A constant, 3.1416
d = Diameter of the end
h = Height of the cylinder

3.7 Trigonometric Functions

Trigonometry is based on the relationship between the angles and the lengths of the sides of a right triangle (a triangle that contains one 90-degree angle).

Since the sum of the angles in any triangle is always 180 degrees, the sum of the two acute angles in a right triangle is always 90 degrees.

The functions considered are those of one of the acute angles, called angle Ø (Theta). The side of the triangle between angle Ø and the right angle is the side adjacent, and the side away from angle Ø is the side opposite. The side of the triangle joining the two acute angles is called the hypotenuse.



The six basic trigonometric functions, the sine (sin), cosine (cos), tangent (tan), cosecant (csc), secant (sec), and cotangent (cot) are the ratios of the lengths of the three sides of a right triangle.

$$\text{Sine (sin) } Ø = \frac{\text{side opposite}}{\text{hypotenuse}}$$

$$\text{Cosine (cos) } Ø = \frac{\text{side adjacent}}{\text{hypotenuse}}$$

$$\text{Tangent (tan) } Ø = \frac{\text{side opposite}}{\text{side adjacent}}$$

$$\text{Cosecant (csc) } Ø = \frac{1}{\sin Ø} = \frac{\text{hypotenuse}}{\text{side opposite}}$$

$$\text{Secant (sec) } Ø = \frac{1}{\cos Ø} = \frac{\text{hypotenuse}}{\text{side adjacent}}$$

$$\text{Cotangent (cot) } Ø = \frac{1}{\tan Ø} = \frac{\text{side adjacent}}{\text{side opposite}}$$

Degrees		Sines	Cosines	Tangents	Cotangents		
0°	00'	0.0000	1.0000	0.0000		90°	00'
	30'	0.0087	0.9999	0.0087	114.59		30'
1°	00'	0.0175	0.9998	0.0175	57.290	89°	00'
	30'	0.0262	0.9997	0.0262	38.188		30'
2°	00'	0.0349	0.9994	0.0349	28.636	88°	00'
	30'	0.0436	0.9990	0.0437	22.904		30'
3°	00'	0.0523	0.9986	0.0524	19.081	87°	00'
	30'	0.0610	0.9981	0.0612	16.350		30'
4°	00'	0.0698	0.9976	0.0699	14.301	86°	00'
	30'	0.0785	0.9969	0.0787	12.706		30'
5°	00'	0.0872	0.9962	0.0875	11.430	85°	00'
	30'	0.0958	0.9954	0.0963	10.385		30'
6°	00'	0.1045	0.9945	0.1051	9.5144	84°	00'
	30'	0.1132	0.9936	0.1139	8.7769		30'
7°	00'	0.1219	0.9925	0.1228	8.1443	83°	00'
	30'	0.1305	0.9914	0.1317	7.5958		30'
8°	00'	0.1392	0.9903	0.1405	7.1154	82°	00'
	30'	0.1478	0.9890	0.1495	6.6912		30'
9°	00'	0.1564	0.9877	0.1584	6.3138	81°	00'
	30'	0.1650	0.9863	0.1673	5.9758		30'
10°	00'	0.1736	0.9848	0.1763	5.6713	80°	00'
	30'	0.1822	0.9833	0.1853	5.3955		30'
11°	00'	0.1908	0.9816	0.1944	5.1446	79°	00'
	30'	0.1994	0.9799	0.2035	4.9152		30'
12°	00'	0.2079	0.9781	0.2126	4.7046	78°	00'
	30'	0.2164	0.9763	0.2217	4.5107		30'
13°	00'	0.2250	0.9744	0.2309	4.3315	77°	00'
	30'	0.2334	0.9724	0.2401	4.1653		30'
14°	00'	0.2419	0.9703	0.2493	4.0108	76°	00'
	30'	0.2504	0.9681	0.2586	3.8667		30'
15°	00'	0.2588	0.9659	0.2679	3.7321	75°	00'
	30'	0.2672	0.9636	0.2773	3.6059		30'
16°	00'	0.2756	0.9613	0.2867	3.4874	74°	00'
	30'	0.2840	0.9588	0.2962	3.3759		30'
17°	00'	0.2924	0.9563	0.3057	3.2709	73°	00'
	30'	0.3007	0.9537	0.3153	3.1716		30'
18°	00'	0.3090	0.9511	0.3249	3.0777	72°	00'
	30'	0.3173	0.9483	0.3346	2.9887		30'
		Cosines	**Sines**	**Cotangents**	**Tangents**	**Degrees**	

Degrees		Sines	Cosines	Tangents	Cotangents		
19°	00'	0.3256	0.9455	0.3443	2.9042	71°	00'
	30'	0.3338	0.9426	0.3541	2.8239		30'
20°	00'	0.3420	0.9397	0.3640	2.7475	70°	00'
	30'	0.3502	0.9367	0.3739	2.6746		30'
21°	00'	0.3584	0.9336	0.3839	2.6051	69°	00'
	30'	0.3665	0.9304	0.3939	2.5386		30'
22°	00'	0.3746	0.9272	0.4040	2.4751	68°	00'
	30'	0.3827	0.9239	0.4142	2.4142		30'
23°	00'	0.3907	0.9205	0.4245	2.3559	67°	00'
	30'	0.3987	0.9171	0.4348	2.2998		30'
24°	00'	0.4067	0.9135	0.4452	2.2460	66°	00'
	30'	0.4147	0.9100	0.4557	2.1943		30'
25°	00'	0.4226	0.9063	0.4663	2.1445	65°	00'
	30'	0.4305	0.9026	0.4770	2.0965		30'
26°	00'	0.4384	0.8988	0.4877	2.0503	64°	00'
	30'	0.4462	0.8949	0.4986	2.0057		30'
27°	00'	0.4540	0.8910	0.5095	1.9626	63°	00'
	30'	0.4617	0.8870	0.5206	1.9210		30'
28°	00'	0.4695	0.8829	0.5317	1.8807	62°	00'
	30'	0.4772	0.8788	0.5430	1.8418		30'
29°	00'	0.4848	0.8746	0.5543	1.8040	61°	00'
	30'	0.4924	0.8704	0.5658	1.7675		30'
30°	00'	0.5000	0.8660	0.5774	1.7321	60°	00'
	30'	0.5075	0.8616	0.5890	1.6977		30'
31°	00'	0.5150	0.8572	0.6009	1.6643	59°	00'
	30'	0.5225	0.8526	0.6128	1.6319		30'
32°	00'	0.5299	0.8480	0.6249	1.6003	58°	00'
	30'	0.5373	0.8434	0.6371	1.5697		30'
33°	00'	0.5446	0.8387	0.6494	1.5399	57°	00'
	30'	0.5519	0.8339	0.6619	1.5108		30'
34°	00'	0.5592	0.8290	0.6745	1.4826	56°	00'
	30'	0.5664	0.8241	0.6873	1.4550		30'
35°	00'	0.5736	0.8192	0.7002	1.4281	55°	00'
	30'	0.5807	0.8141	0.7133	1.4019		30'
36°	00'	0.5878	0.8090	0.7265	1.3764	54°	00'
	30'	0.5948	0.8039	0.7400	1.3514		30'
37°	00'	0.6018	0.7986	0.7536	1.3270	53°	00'
	30'	0.6088	0.7934	0.7673	1.3032		30'
		Cosines	Sines	Cotangents	Tangents	Degrees	

Degrees		Sines	Cosines	Tangents	Cotangents		
38°	00'	0.6157	0.7880	0.7813	1.2799	52°	00'
	30'	0.6225	0.7826	0.7954	1.2572		30'
39°	00'	0.6293	0.7771	0.8098	1.2349	51°	00'
	30'	0.6361	0.7716	0.8243	1.2131		30'
40°	00'	0.6428	0.7660	0.8391	1.1918	50°	00'
	30'	0.6494	0.7604	0.8541	1.1708		30'
41°	00'	0.6561	0.7547	0.8693	1.1504	49°	00'
	30'	0.6626	0.7490	0.8847	1.1303		30'
42°	00'	0.6691	0.7431	0.9004	1.1106	48°	00'
	30'	0.6756	0.7373	0.9163	1.0913		30'
43°	00'	0.6820	0.7314	0.9325	1.0724	47°	00'
	30'	0.6884	0.7254	0.9490	1.0538		30'
44°	00'	0.6947	0.7193	0.9657	1.0355	46°	00'
	30'	0.7009	0.7133	0.9827	1.0176		30'
45°	00'	0.7071	0.7071	1.0000	1.0000	45°	00'
		Cosines	**Sines**	**Cotangents**	**Tangents**	**Degrees**	

Section 4: Aircraft Drawings

4.1 Types of Aircraft Drawings

There are a number of types of drawings used in aircraft manufacture and maintenance. Each type of drawing has a definite function and purpose.

Sketches

These are rough drawings made without the use of instruments. They are used to convey only a specific bit of information and include the minimum amount of detail needed to manufacture the part.

Detail Drawings

Detail drawings are made with the use of instruments, or on a computer. They include all of the information needed to fabricate a part, including dimensions.

Assembly Drawings

An assembly drawing shows all of the components in an assembly. The components are shown in exploded view to display the way they are assembled. A parts list is included showing the reference number, part number, description, quantity per assembly, and model usage for each component.

Installation Drawings

These drawings show the location of the parts and assemblies on the completed aircraft and identifies all of the detail parts used in the installation.

Sectional Drawings

These show the way a component would appear if it were cut through the middle. Different types of sectional lines and cross-hatching show the different types of materials used in the component.

A half-sectional drawing shows a part as it would appear with only one half a sectional view and the other half a plain view.

Cutaway Drawing

A cutaway drawing shows the outside of a component with part of it cut away to show the parts on the inside.

Exploded-View Drawing

Exploded-view drawings are similar to assembly drawings. All of the parts in a component are spread out to show what each looks like and their relationship to other parts.

Schematic Diagram

A schematic diagram shows the relative location of all of the parts in a system but does not give the physical location in the aircraft. Schematic diagrams are extremely useful in troubleshooting a system.

Block Diagram

Block diagrams show the various functions of a system but do not include any details. Lines connecting the blocks show the direction of flow of signals or other forms of information. Block diagrams help explain the way a complex system works, and they are often used in troubleshooting.

Repair Drawings

These are drawings used to show the way a repair is made. They are used in aircraft manufacturer's maintenance and repair manuals to illustrate typical repairs. No dimensions are given, but enough information is provided that an experienced technician can use the drawing as a guide to make an airworthy repair.

Wiring Diagrams

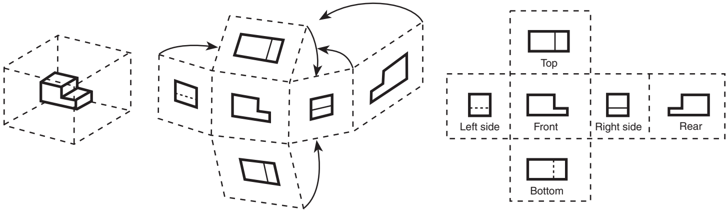
Wiring diagrams show all of the wires in a particular section of an aircraft electrical system. The parts list accompanying the drawing provides the wire size, wire number, and the part number of the terminals on each end of each wire.

Pictorial Diagrams

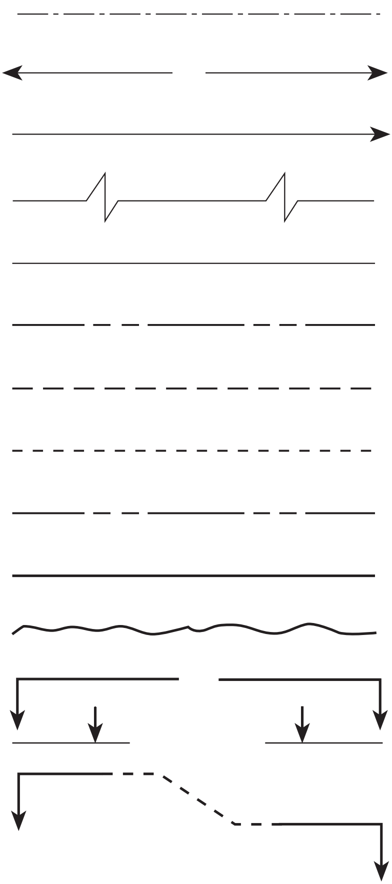
Pictorial diagrams show the components as they actually appear, rather than using conventional symbols. Pictorial diagrams are often used for electrical systems in Pilot's Operating Handbooks.

Orthographic Projections

There are six possible views in an orthographic projection:

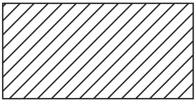


4.2 Meaning of Lines

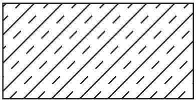


Centerline	Thin
Dimension line	Thin
Leader line	Thin
Long break line	Thin
Sectioning and extension line	Thin
Phantom and reference line	Medium
Hidden line	Medium
Stitch line	Medium
Datum line	Medium
Outline or visible line	Thick
Short break line	Thick
Viewing-plane line	Thick
Cutting-plane line for complex or offset views	Thick

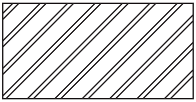
4.3 Material Symbols



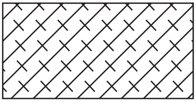
Cast iron



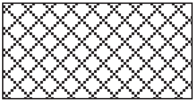
Copper, brass, and copper alloys



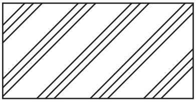
Steel and wrought iron



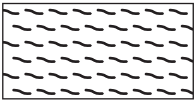
Aluminum, magnesium and their alloys



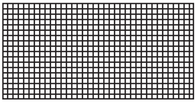
Babbit, lead, zinc and their alloys



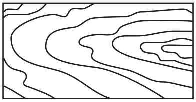
Rubber, plastic, electrical insulation



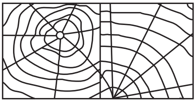
Fabric and flexible materials



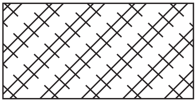
Electrical windings



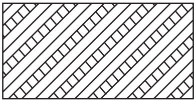
Wood, with the grain



Wood, across the grain



Titanium



Beryllium

4.4 Location Identification

Fuselage Stations

Locations along the length of a fuselage are identified by fuselage station (FS) numbers which represent the distance in inches from FS-0, a point chosen by the aircraft manufacturer from which all longitudinal measurements are made. For example, FS-199 is 199 inches aft of FS-0.

Water Lines

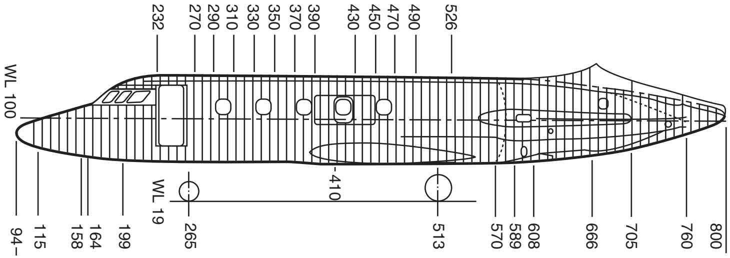
Vertical locations are identified by water lines (WL). Water line zero (WL-0) is a line chosen by the aircraft manufacturer as a vertical reference line. Locations above WL-0 are positive and those below are negative. WL+20 is a plane 20 inches above WL-0.

Butt Lines

Lateral locations are identified by butt lines (BL, or buttock lines) that are distances to the left or right in inches from BL-0, a vertical plane through the center of the fuselage. BL-36R is a vertical plane 36 inches to the right (when facing forward) from BL-0.

Wing and Horizontal Stabilizer Stations

These stations are locations in inches left or right, along the wing or stabilizer span measured from the center line of the fuselage, BL-0.

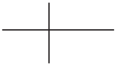


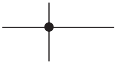
Fuselage stations and water lines

Section 5: Aircraft Electrical Systems

5.1 Electrical Symbols

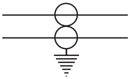
Conductors

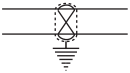

Conductors, crossing but not connected


Conductors, crossing and connected


Spare conductor with end insulated

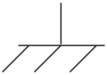

Shielded conductor


Shielded double conductor

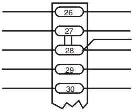

Shielded and twisted double conductor


Coaxial conductor


Ground connection (earth ground)


Chassis ground connection (not necessarily at ground potential)

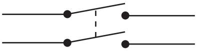

Terminal strip



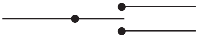
Terminal strip

Switches

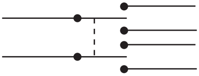
Single-pole, single-throw switch



Double-pole, single-throw switch

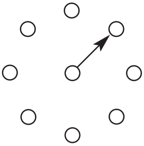


Single-pole, double-throw switch

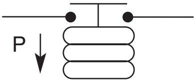


Double-pole, double-throw switch

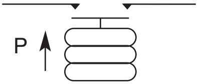
Single-pole, double-throw switch — normally closed, momentarily open



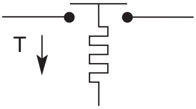
Eight-position rotary switch



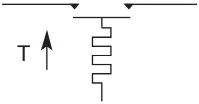
Pressure-actuated switch — closes on decreasing pressure



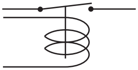
Pressure-actuated switch — closes on increasing pressure



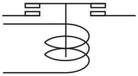
Temperature-actuated switch — closes on decreasing temperature



Temperature-actuated switch — closes on increasing temperature



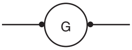
Relay switch



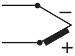
Solenoid switch

Power Sources

Battery



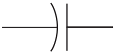
Generator



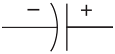
Thermocouple

Piezoelectric crystal

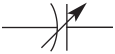
Capacitors



Fixed, nonelectrolytic capacitor



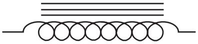
Electrolytic capacitor



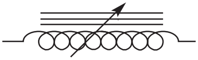
Variable capacitor

Inductors

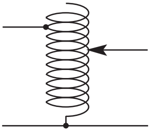
Air-core inductor



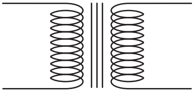
Iron-core inductor



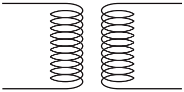
Variable inductor



Autotransformer



Iron-core transformer



Air-core transformer

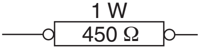
Resistors

Fixed resistor

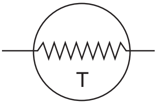
Variable resistor—rheostat

Variable resistor—potentiometer

Tapped resistor



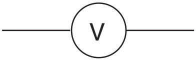
Resistor installed external to LRU (line replaceable unit)



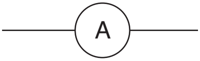
Temperature-sensitive resistor

Heater element resistor

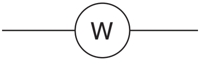
Indicators



Voltmeter

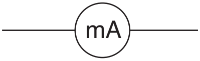


Ammeter

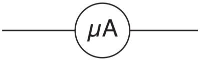


Wattmeter

Ohmmeter



Milliammeter

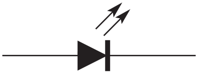


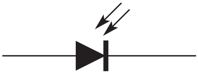
Microammeter

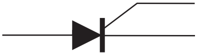
Semiconductor Devices

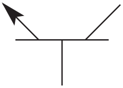

Diode

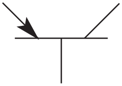

Zener diode

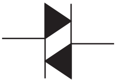

Light emitting diode

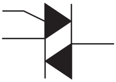

Light sensing diode


Silicon controlled rectifier


NPN bipolar transistor

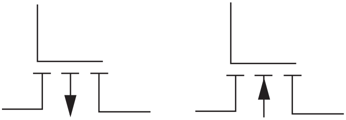

PNP bipolar transistor


Diac


Triac

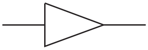

P-channel N-channel

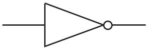
Junction field effect transistor

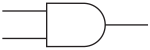

P-channel N-channel

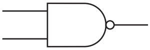
Insulated gate field effect transistor

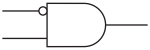
Logic Devices

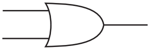

Buffer or amplifier

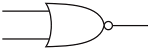

Inverter

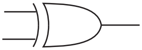

AND gate

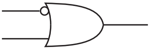

NAND gate


AND gate with one input having an active low

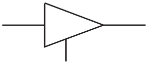

OR gate


NOR gate

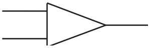

EXCLUSIVE OR (XOR) gate



OR gate with one input having an active low



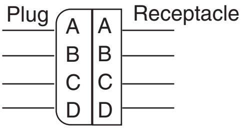
Three-state buffer



Operational amplifier

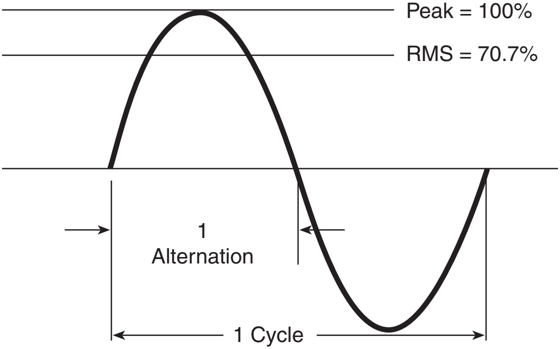
Connectors

Wire splice



Quick-disconnect connector

5.2 Alternating Current Terms and Values



Peak value: The maximum amplitude of current or voltage in one alternation.

Peak-to-peak value: The voltage or current measured from a positive peak to a negative peak.

rms value: Root mean square, or effective value. This is 0.707 times peak value. One amp rms of sine wave AC produces the same amount of heat as one amp of DC. One amp rms of sine wave AC has a peak value of 1.414 amp.

Cycle: One complete series of values of alternating current in which the voltage or current starts from zero, rises to a positive peak, drops back through zero to a negative peak, and then returns to zero.

Alternation: One half cycle of alternating current.

Period: The time required for one cycle of alternating current.

Frequency: The number of cycles of alternating current that occur in one second.

Phase: The angular relationship between the current and voltage in an AC circuit. Inductance and capacitance in a circuit cause the current to either lag or lead the voltage.

Power: Power in an AC circuit is determined by the voltage and the amount of current that is in phase with the voltage.

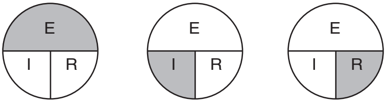
Power factor: The percentage of current in an AC circuit that is in phase with the voltage.

5.3 Ohm's Law Relationships

Ohm's law gives us the relationship between voltage, current, resistance, and power in an electrical circuit. When we know any two values, we can find either of the others by using the appropriate formula.

E = Voltage (volts)
I = Current (amps)
R = Resistance (ohms)
P = Power (watts)

To visualize the relationships, use these circles. The shaded value is the product or the quotient of the unshaded values.



To Find	**Known Values**	**Formula**
E	I & R	$E = I \times R$
E	P & I	$E = \frac{P}{I}$
E	P & R	$E = \sqrt{P \times R}$
I	E & R	$I = \frac{E}{R}$
I	P & E	$I = \frac{P}{E}$
I	P & R	$I = \sqrt{\frac{P}{R}}$

To Find	Known Values	Formula
R	E & I	$R = \frac{E}{I}$
R	E & P	$R = \frac{E^2}{P}$
R	P & I	$R = \frac{P}{I^2}$
P	I & E	$P = I \times E$
P	I & R	$P = I^2 \times R$
P	E & R	$P = \frac{E^2}{R}$

5.4 Electrical Formulas

Formulas Involving Resistance

Resistors in series:

$$R_T = R_1 + R_2 + R_3 + \cdots$$

R_T = Total resistance
R_1, R_2, R_3 = Value of individual resistances

Resistors of the same value in parallel:

$$R_T = \frac{R}{n}$$

R_T = Total resistance
R = Value of a single resistor
n = Number of resistors

Two resistors of different value in parallel:

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

R_T = Total resistance
R_1 = Value of first resistor
R_2 = Value of second resistor

To find the value of one resistor in a parallel combination when the total resistance and the value of the other resistor are known:

$$R_1 = \frac{-R_T \times R_2}{R_T - R_2}$$

R_T = Total resistance
R_1 = Value of first resistor
R_2 = Value of second resistor

More than two resistors of different values in parallel:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}}$$

R_T = Total resistance
R_1, R_2, R_3, R_4 = Value of each resistor

The total resistance of any number of resistors connected in parallel may be found by using a calculator with a reciprocal (1/x) key.

Enter the problem in this sequence:

$$(R_1)\ (1/x) + (R_2)\ (1/x) + (R_3)\ (1/x) + (R_4)\ (1/x) = (1/x)$$

The number displayed after the (1/x) key is pressed the last time is the value of the total resistance.

Some calculators use a (x^{-1}) key for the reciprocal function. In this case, the formula would be entered:

$$(R_1^{-1} + R_2^{-1} + R_3^{-1} + R_4^{-1}) = RT$$

Formulas Involving Capacitance

$$C = 0.2235\left(\frac{KA}{D}\right)(N - 1)$$

Capacity of a capacitor:
C = Capacity in picofarads
K = Dielectric constant
A = Area of plates in square inches
D = Thickness of dielectric in inches
N = Number of plates

Capacitors in parallel:

$$C_T = C_1 + C_2 + C_3 + \cdots$$

C_T = Total capacitance
C_1, C_2, C_3 = Value of individual capacitors

Capacitors of the same value in series:

$$C_T = \frac{C}{n}$$

C_T = Total capacitance
C = Value of a single capacitor
n = Number of capacitors

Two capacitors of different values in series:

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

C_T = Total capacitance
C_1 = Value of one capacitor
C_2 = Value of other capacitor

More than two capacitors of different values in series:

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}}$$

C_T = Total capacitance
C_1, C_2, C_3, C_4 = Value of individual capacitors

The total capacitance of any number of capacitors connected in series may be found by using a calculator with a reciprocal (1/x) key.

Enter the problem in this sequence:

(C_1) (1/x) + (C_2) (1/x) + (C_3) (1/x) + (C_4) (1/x) = (1/x)

The number displayed after the (1/x) key is pressed the last time is the value of the total capacitance.

Charge stored in a capacitor:

$$Q = C \times E$$

Q = Charge in coulombs
C = Capacitance in farads
E = Voltage across the capacitor in volts

Energy stored in a capacitor:

$$W = \frac{(C \times E^2)}{2}$$

W = Stored energy in joules (watt-seconds)
C = Capacitance in farads
E = Applied voltage in volts

Capacitive reactance:

$$X_C = \frac{1}{2\pi FC}$$

X_C = Capacitive reactance in ohms
2π = A constant, 6.2832
F = Frequency in hertz
C = Capacitance in farads

Because there are constants in both the numerator and the denominator, this formula can be changed to:

$$X_C = \frac{159{,}200}{FC}$$

X_C = Capacitive reactance in ohms
159,200 = A constant (1,000,000 ÷ 2π)
F = Frequency in hertz
C = Capacitance in microfarads

Formulas Involving Inductance

Inductors in series with no mutual inductance:

$$L_T = L_1 + L_2 + L_3 + \cdots$$

L_T = Total inductance
L_1, L_2, L_3 = Value of each inductor

Two inductors of different size in parallel with no mutual inductance:

$$L_T = \frac{L_1 \times L_2}{L_1 + L_2}$$

L_T = Total inductance
L_1, L_2 = Value of individual inductors

More than two inductors of different size in parallel with no mutual inductance:

$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \frac{1}{L_4}}$$

L_T = Total inductance
L_1, L_2, L_3, L_4 = Value of individual inductors

The total inductance of any number of inductors connected in parallel with no mutual inductance may be found by using a calculator with a reciprocal (1/x) key.

Enter the problem in this sequence:

(L_1) (1/x) + (L_2) (1/x) + (L_3) (1/x) + (L_4) (1/x) = (1/x)

The number displayed after the (1/x) key is pressed the last time is the total inductance.

Mutual inductance of two coils:

$$L_M = \frac{L_A - L_O}{4}$$

L_M = Mutual inductance in the same units as that of the individual inductances
L_A = Total inductance of the two coils with their fields aiding
L_O = Total inductance of the two coils with their fields opposing

Mutual inductance of two inductors connected in series with fields aiding:

$$L_T = L_1 + L_2 + 2M$$

L_T = Total inductance
L_1 = Inductance of the first inductor
L_2 = Inductance of the second inductor
M = Mutual inductance

Total inductance of two inductors connected in series with fields opposing:

$$L_T = L_1 + L_2 - 2M$$

L_T = Total inductance
L_1 = Inductance of the first inductor
L_2 = Inductance of the second inductor
M = Mutual inductance

Coefficient of coupling:

$$K = \frac{M}{\sqrt{L_1 \text{ x } L_2}}$$

K = Coefficient of coupling
M = Mutual inductance
L_1 = Inductance of first inductor
L_2 = Inductance of second inductor

Energy stored in an inductor:

$$W = \frac{L \times I^2}{M}$$

W = Stored energy in joules (watt-seconds)
L = Inductance in henries
I = Current in amperes
M = Mutual inductance

Inductive reactance:

$$X_L = 2\pi FL$$

X_L = Inductive reactance in ohms
2π = A constant, 6.2832
L = Inductance in henries
F = Frequency in hertz

Formulas Involving Both Capacitance and Inductance

Resonant Frequency

The resonant frequency of an AC circuit is that frequency which causes the capacitive reactance and the inductive reactance to be the same. It may be found by the formula:

$$F_R = \frac{1}{2\pi\sqrt{LC}}$$

F_R = Resonant frequency in hertz
2π = A constant, 6.2832
L = Inductance in henries
C = Capacitance in farads

Total Reactance

Current in a purely capacitive circuit leads the voltage by 90 degrees, and current in a purely inductive circuit lags 90 degrees behind the voltage.

Capacitive reactance and inductive reactance are 180 degrees out of phase with each other, and they cancel. Total reactance is the difference between the two reactances and is the type of the greater reactance.

$$X_T = X_C - X_L \quad \text{or} \quad X_T = X_L - X_C$$

Impedance

Impedance is the total opposition to the flow of alternating current, and it is the vector sum of capacitive reactance, inductive reactance, and resistance. It is found by the following formulas.

Impedance in a series circuit:

$$Z = \sqrt{R_T^2 + X_T^2}$$

Z = Impedance in ohms
R_T = Total resistance in ohms
X_T = Total reactance in ohms

Impedance in a parallel circuit:

$$Z = \frac{R_T \times X_T}{\sqrt{R_T^2 + X_T^2}}$$

Z = Impedance in ohms
R_T = Total resistance in ohms
X_T = Total reactance in ohms

5.5 Electrical System Installation

Selection of Wire Size

Aircraft electrical wire is measured in American Wire Gauge (AWG) units. The larger the number, the smaller the diameter of the wire. The actual American wire gauge, shown in Figure 5.5.1, is a circular piece of steel with notches cut in its periphery. The width of each notch is the diameter of the wire whose gauge number is beside the notch.

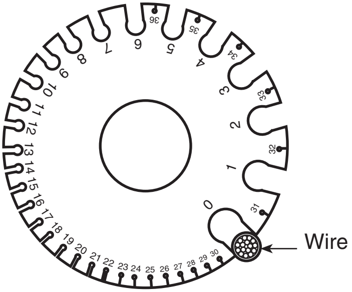


Figure 5.5.1. *An American wire gauge is used to determine the size of an aircraft electrical wire.*

When selecting the proper gauge of wire, consider both the current-carrying capability of the wire and the voltage drop caused by it. The charts in Figure 5.5.2 give the current-carrying capability of copper wire in sizes 20 through 0000, and aluminum wire in sizes 6 through 0000. When wires are routed in bundles, the maximum current is less than when the wire is routed by itself in free air. Wires in a bundle cannot readily dissipate heat.

Nominal system voltage	**Allowable voltage drop**	
	Continuous load	**Intermittent load**
14	0.5	1.0
28	1.0	2.0
115	4.0	8.0
200	7.0	14.0

Figure 5.5.2. *Allowable voltage drop in an aircraft electrical system*

The allowable voltage drop in an aircraft electrical system is determined by both the nominal system voltage and whether the component is operating continuously or intermittently. The chart in Figure 5.5.3 gives the allowable voltage drops for the most commonly used aircraft electrical systems.

To find the correct size copper wire for a continuous load, use the chart in Figure 5.5.3.

For example: Find the size wire needed to supply 30 amps continuously to a component in a 28-volt electrical system. The wire must be 60 feet long.

1. Follow the 30-amp diagonal line down until it crosses the horizontal line for 60 feet in the 28-volt column.
2. These lines cross between the vertical lines for 6-gauge and 8-gauge wires. Always use the larger wire, so choose a 6-gauge wire. Thirty amps of current will not produce more than the allowable 1-volt drop when it flows through 60 feet of 6-gauge wire.
3. The intersection of these two lines is above curve 1, which means that a 6-gauge wire carrying 30 amps of current can be routed in a bundle without causing excessive heat. This can be proved by the chart in Figure 5.5.4, which shows that a 6-gauge copper wire in a bundle can carry 60 amps.

To find the correct size copper wire for an intermittent load, use the chart in Figure 5.5.5.

For example: Find the size wire needed to supply 200 amps to a landing gear motor in a 28-volt electrical system. The wire must be 10 feet long.

1. In this example, the current-carrying capability of the wire is the limiting factor, rather than the voltage drop. Assume the wire will be routed by itself in free air. The chart in Figure 5.5.4 shows that at least a 1-gauge wire must be used. This size wire will carry 211 amps in free air.
2. Follow the 200-amp diagonal line down until it intersects the vertical line for a 1-gauge wire. This intersection is about the location of a horizontal line for 67 feet in the 28-volt column. This means that it would take 67 feet of 1-gauge wire to cause a 2-volt drop (the voltage drop allowed for an intermittent load in a 28-volt system). The wire is only 10 feet long, so there will be much less than the allowable voltage drop.

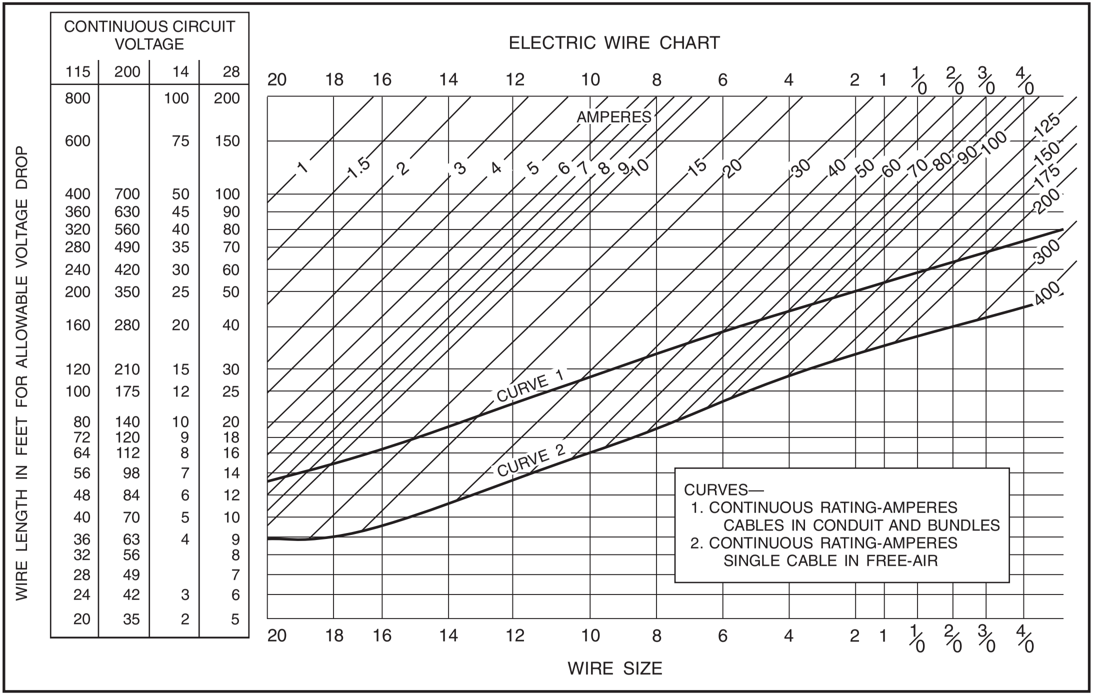


Figure 5.5.3. *Wire selection chart for continuous loads*

Copper wire current-carrying capability		
Wire size (gauge)	Max. amps single wire in free air	Max. amps wire in bundle or conduit
AN-20	11	7.5
AN-18	16	10
AN-16	22	13
AN-14	32	17
AN-12	41	23
AN-10	55	33
AN-8	73	46
AN-6	101	60
AN-4	135	80
AN-2	181	100
AN-1	211	125
AN-0	245	150
AN-00	283	175
AN-000	328	200
AN-0000	380	225

Aluminum wire current-carrying capability		
Wire size (gauge)	Max. amps single wire in free air	Max. amps wire in bundle or conduit
AL-6	83	50
AL-4	108	66
AL-2	152	90
AL-0	202	123
AL-00	235	145
AL-000	266	162
AL-0000	303	190

Figure 5.5.4. *Current-carrying capability of copper and aluminum wire*

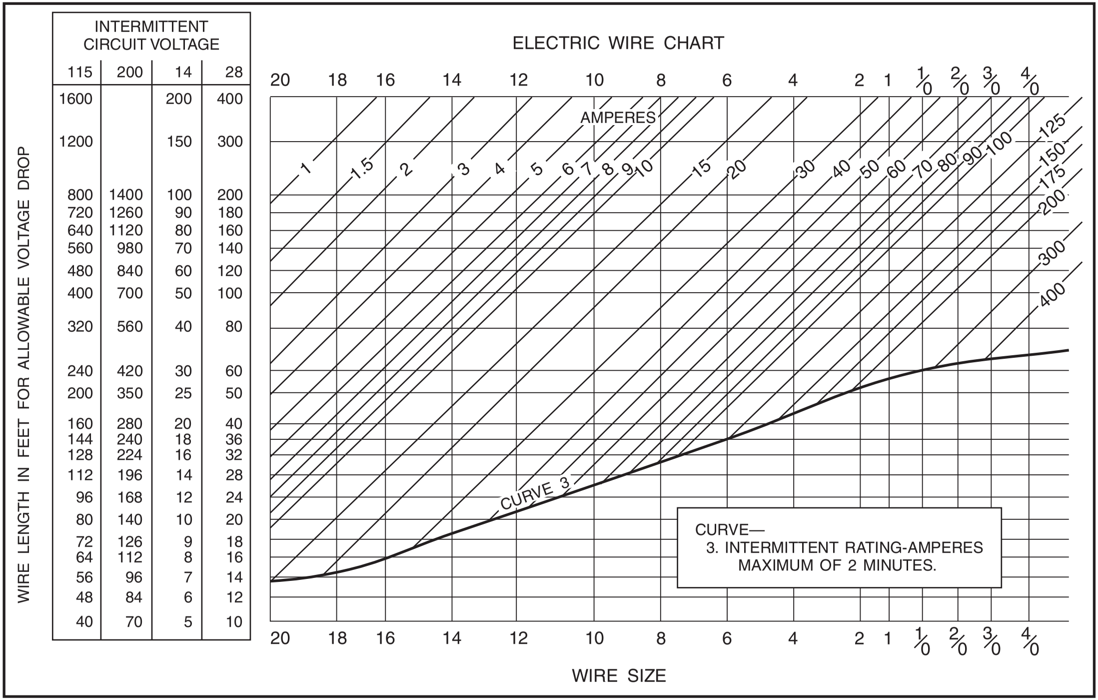


Figure 5.5.5. *Wire selection chart for intermittent loads*

Notes on Wire Installation

1. All wires should be marked along their entire length with the wire identification number specified by the aircraft manufacturer.
2. Wires should have a 6-inch diameter loop near their connection to the component to which they are connected, in order to accommodate any wire tensions that result from aircraft structural deformations during a crash.
3. Electrical wire bundles should be routed along the strongest aircraft structural members, and should not cross areas where there is likely to be severe structural deformation during a crash.
4. When electrical wire bundles pass through a structural member, the holes should be 8 to 12 times the diameter of the bundle. The edges of the hole should be protected with grommets, and the wire bundle should be securely clamped to the structure.

5 If a wire bundle is routed parallel to a fluid line, the wire bundle should be above the fluid line and should not be secured to the line.

6. No more than four wire terminals should be secured to any single stud in a terminal strip. If more wires must be connected at a single point, use more than one stud, and connect the studs with metal bus bars.

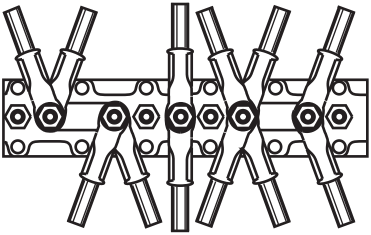


Figure 5.5.6. *Never install more than four wire terminals on any single terminal-strip lug. If more wires should be connected, join two adjacent lugs with a connector strip.*

7. All bonding jumpers should be as short as possible and must not have more than 0.003-ohm resistance. The jumper must not interfere with the free movement of the component that is being bonded.
8. When a ground connection is made to an anodized aluminum alloy component, the oxide film must be removed at the location where the connection is made. After the connection is made, the area must be protected against corrosion.

9. When wire bundles must be routed through areas where they can likely be damaged, they should be protected by routing them through a flexible or rigid conduit.
   a. The conduit must not be installed in such a way that it can be used as a step or a hand hold.
   b. The inside diameter of the conduit must be large enough that the wire bundle does not fill more than 80% of the conduit area.
   c. Drain holes must be provided at the lowest point in a conduit run.
   d. Rigid conduit must not be flattened in the bends enough to decrease its minimum diameter to less than 75 percent of the original diameter.
   e. All burrs must be removed from the ends of the conduit and from any drain holes.
   f. Do not use a smaller bend radius for rigid conduit than is allowed by the chart in Figure 5.5.7.
   g. Do not use a smaller bend radius for flexible aluminum or brass conduit than is allowed by the chart in Figure 5.5.8.

Bend radii allowed for rigid conduit	
Nominal tube O.D. (inches)	**Minimum bend radius (inches)**
1/8	3/8
3/16	7/16
1/4	9/16
3/8	15/16
1/2	1- 1/4
5/9	1- 1/2
3/4	1- 3/4
1	3
1- 1/4	3- 3/4
1- 1/2	5
1- 3/4	7
2	9

Figure 5.5.7. *Minimum bend radius for rigid electrical conduit*

Bend radii allowed for flexible aluminum or brass conduit	
Nominal I.D. of conduit (inches)	Minimum bend radius (inches)
3/16	2-1/4
1/4	2-3/4
3/8	3-3/4
1/2	3-3/4
5/8	3-3/4
3/4	4-1/4
1	5-3/4
1-1/4	8
1-1/2	8-1/4
1-3/4	9
2	9-3/4
2-1/2	10

Figure 5.5.8. *Minimum bend radius for flexible electrical conduit*

10. Securely attach all wire bundles to the aircraft structure with cushioned clamps. There should be no more slack between supports than that which will allow a 1/2-inch deflection.

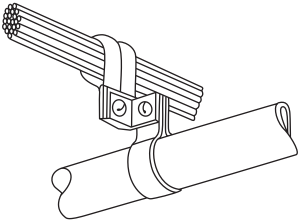


Figure 5.5.9. *Support wire bundles from aircraft tubing with clamps. The clamp around the wire should be cushioned.*

11. Wrap the cord twice around wire bundles secured with individual ties, and secure them with a clove hitch and a square knot.

Switch Derating Factors

Incandescent lamps, motors, relays, and heaters all allow a large amount of current to flow when the switch is first closed. Soon after the current begins to flow, its value drops off to a nominal value. Because of this high inrush, switches in these circuits must be derated. The chart in Figure 5.5.10 shows the derating factors to be used.

Nominal system DC voltage	Type of load	Derating factor
24 volts	Lamp	8
24 volts	Inductive	4
24 volts	Resistive	2
24 volts	Motor	3
12 volts	Lamp	5
12 volts	Inductive	2
12 volts	Resistive	1
12 volts	Motor	2
Example: A switch installed in a 24-volt circuit to control a 100-watt incandescent lamp must have a current rating of more than 33.3 amps.		

Figure 5.5.10. *Switch derating factors*

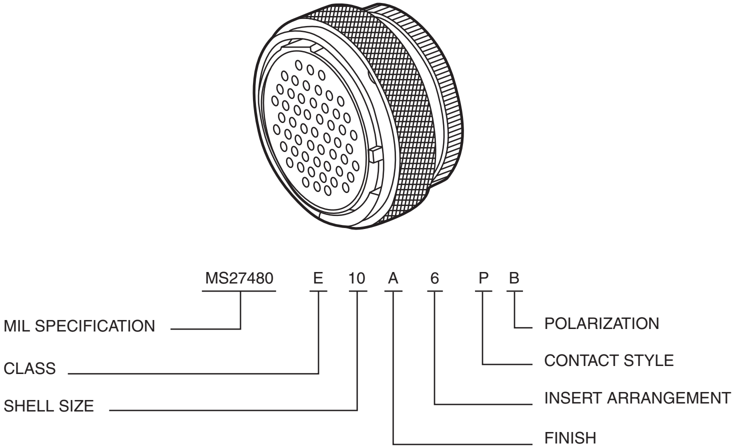
Wire and Circuit Protectors

Fuses and circuit breakers are installed in an aircraft to protect the wiring from overheating due to excessive current. The chart in Figure 5.5.11 shows the size circuit protectors that should be used with the various gauge wires.

AN Copper Wire (gauge)	Circuit breaker (amps)	Fuse (amps)
22	5	5
20	7.5	5
18	10	10
16	15	10
14	20	15
12	25	(30) 20
10	35	(40) 30
8	50	50
6	80	70
4	100	70
2	125	100
1		150
0		150
Values in parenthesis may be substituted when the indicated ratings are not available.		

Figure 5.5.11. *Wire and circuit protector chart*

MS Electrical Connectors



MS27472	WALL MOUNT RECEPTACLE
MS27473	STRAIGHT PLUG
MS27474	JAM NUT RECEPTACLE
MS27475	HERMETIC WALL MOUNT RECEPTACLE
MS27476	HERMETIC BOX MOUNT RECEPTACLE
MS27477	HERMETIC JAM NUT RECEPTACLE
MS27478	HERMETIC SOLDER MOUNT RECEPTACLE
MS27479	WALL MOUNT RECEPTACLE (NOTE 1)
MS27480	STRAIGHT PLUG (NOTE 1)
MS27481	JAM NUT RECEPTACLE (NOTE 1)
MS27482	HERMETIC WALL MOUNT RECEPTACLE (NOTE 1)
MS27483	HERMETIC JAM NUT RECEPTACLE (NOTE 1)
MS27484	STRAIGHT PLUG, EMI GROUNDING
MS27497	WALL RECEPTACLE, BACK PANEL MOUNTING
MS27499	BOX MOUNTING RECEPTACLE
MS27500	90° PLUG (NOTE 1)
MS27503	HERMETIC SOLDER MOUNT RECEPTACLE (NOTE 1)
MS27504	BOX MOUNT RECEPTACLE (NOTE 1)
MS27508	BOX MOUNT RECEPTACLE, BACK PANEL MOUNTING
MS27513	BOX MOUNT RECEPTACLE, LONG GROMMET
MS27664	WALL MOUNT RECEPTACLE, BACK PANEL MOUNTING (NOTE 1)
MS27667	THRU-BULKHEAD RECEPTACLE

Figure 5.5.12. *MS Electrical Connector Information*

NOTE

1. ACTIVE	SUPERSEDES
MS27472	MS27479
MS27473	MS27480
MS27474	MS27481
MS27475	MS27482
MS27477	MS27483
MS27473 WITH MS27507 ELBOW	MS27500
MS27478	MS27503
MS27499	MS27504
MS27497	MS27664

CLASS

E	ENVIRONMENT RESISTING-BOX AND THRU-BULKHEAD MOUNTING TYPES ONLY (SEE CLASS T)
P	POTTING-INCLUDES POTTING FORM AND SHORT REAR GROMMET
T	ENVIRONMENT RESISTING-WALL AND JAM-NUT MOUNTING RECEPTACLE AND PLUG TYPES: THREAD AND TEETH FOR ACCESSORY ATTACHMENT
Y	HERMETICALLY SEALED

FINISH

A	SILVER TO LIGHT IRIDESCENT YELLOW COLOR CADMIUM PLATE OVER NICKEL (CONDUCTIVE), -65°C TO +150°C (INACTIVE FOR NEW DESIGN)
B	OLIVE DRAB CADMIUM PLATE OVER SUITABLE UNDERPLATE (CONDUCTIVE), -65°C TO +175°C
C	ANODIC (NONCONDUCTIVE), -65°C TO +175°C
D	FUSED TIN, CARBON STEEL (CONDUCTIVE), -65°C TO 150°C
E	CORROSION RESISTANT STEEL (CRES), PASSIVATED (CONDUCTIVE), -65°C TO +200°C
F	ELECTROLESS NICKEL COATING (CONDUCTIVE), -65°C TO +200°C
N	HERMETIC SEAL OR ENVIRONMENT RESISTING CRES (CONDUCTIVE PLATING), -65°C TO +200°C

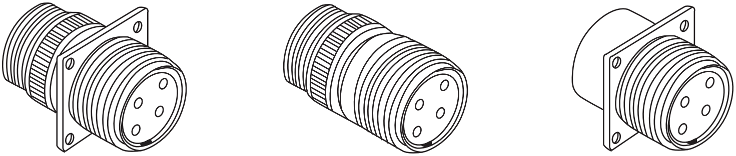
CONTACT STYLE

A	WITHOUT PIN CONTACTS
B	WITHOUT SOCKET CONTACTS
C	FEED THROUGH
P	PIN CONTACTS-INCLUDING HERMETICS WITH SOLDER CUPS
S	SOCKET CONTACTS-INCLUDING HERMETICS WITH SOLDER CUPS
X	PIN CONTACTS WITH EYELET (HERMETIC)
Z	SOCKET CONTACTS WITH EYELET (HERMETIC)

POLARIZATION

A, B C, OR D	NORMAL-NO LETTER REQUIRED

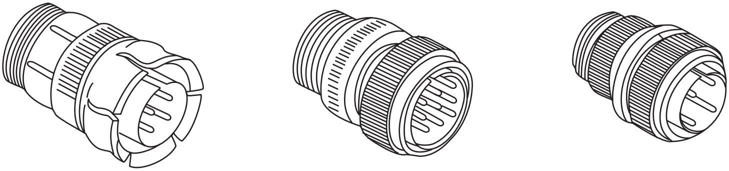
Figure 5.5.12. *MS Electrical Connector Information (continued)*



Wall receptacle

Cable receptacle

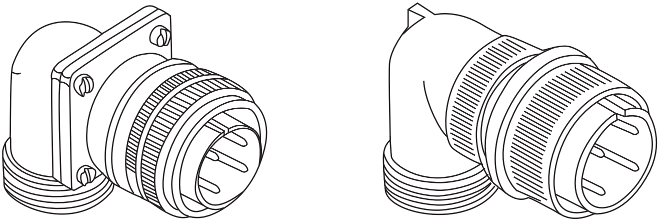
Box receptacle



Quick-disconnect straight plug

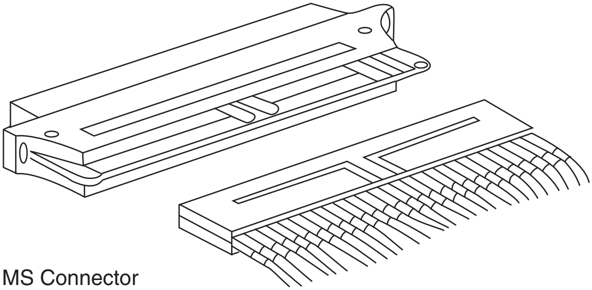
Straight plug

Plug



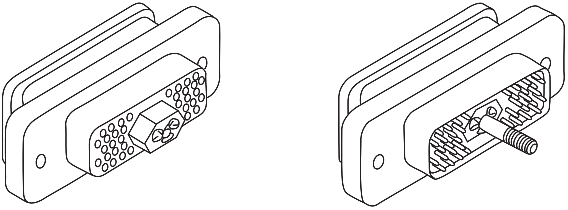
Angle plug

Angle plug



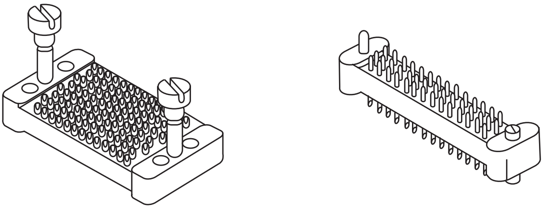
MS Connector

Figure 5.5.13. *Typical MS Electrical Connectors*



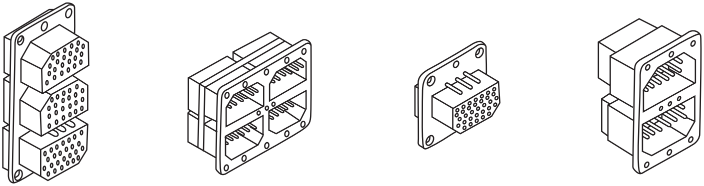
Receptacle

Facing view plug



Receptacle

Plug



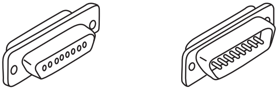
Triple insert receptacle

Quadruple insert plug

Single insert receptacle

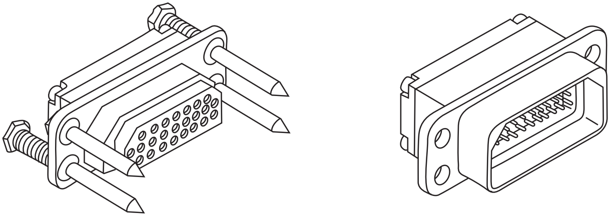
Double insert plug

Figure 5.5.13. *Typical MS Electrical Connectors (continued)*



Receptacle Plug

Typical rack and panel connectors



Receptacle Plug

Figure 5.5.13. *Typical MS Electrical Connectors (continued)*

Resistor Color Code

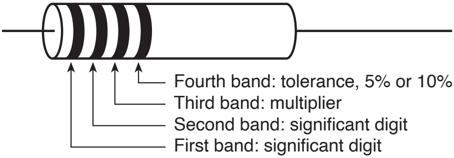
The resistance in ohms of a resistor is designated by a series of colored bands, as shown in Figure 5.5.15 on page 114. The colors will start closer to one end than the other and are decoded starting with this end. There are a different number of colored bands depending on the resistance and tolerance of the resistor.

Three band resistor (20% tolerance):
  First band = first significant digit
  Second band = second significant digit
  Third band = multiplier

Four band resistor (5% and 10% tolerance):
  First band = first significant digit
  Second band = second significant digit
  Third band = multiplier
  Fourth band = tolerance

Five band resistor (2% and tighter tolerance):
  First band = first significant digit
  Second band = second significant digit
  Third band = third significant digit
  Fourth band = multiplier
  Fifth band = tolerance

THREE & FOUR BAND RESISTOR



Note: absence of a fourth band indicates a 20% tolerance resistor.

FIVE BAND RESISTOR

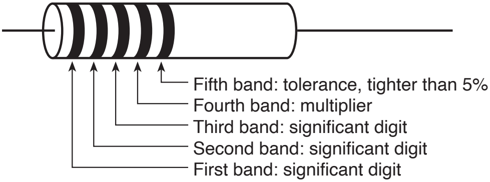
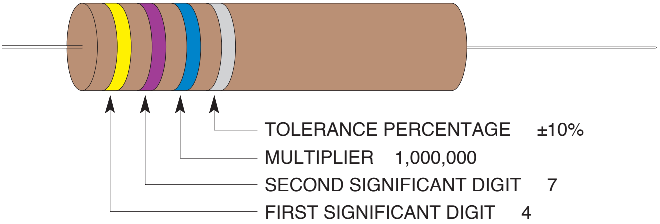


Figure 5.5.14.



Resistance is 47,000,000 ohms (47 MΩ) ±10%

Resistor Color Codes

Color	Digit	Multiplier	Tolerance
Black	0	1	
Brown	1	10	±1%
Red	2	100	±2%
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	±0.5%
Blue	6	1,000,000	±0.25%
Violet	7	10,000,000	±0.10%
Gray	8	100,000,000	±0.05%
White	9	1,000,000,000	
Gold		0.1	±5%
Silver		0.01	±10%
No Color			±20%

A resistor marked red, red, orange, silver has a resistance of 22,000 ohms ± 10%.

A resistor marked brown, green, brown has a resistance of 150 ohms ± 20%.

A resistor marked yellow, violet, black, silver, brown has a resistance of 4.7 ohms ± 1%.

Figure 5.5.15. *Examples of resistor color bands*

Aircraft Storage Batteries

Lead-Acid Batteries

To prevent a lead-acid battery from overheating, limit the charging voltage to 2.35 volts per cell unless the battery manufacturer specifies a different voltage for the specific battery.

The freezing temperature of the electrolyte in a lead-acid battery is determined by its specific gravity as indicated in Figure 5.5.16.

Specific gravity	Freezing point	
	°C	°F
1.300	-70	-95
1.275	-62	-80
1.250	-52	-62
1.225	-37	-35
1.200	-26	-16
1.175	-20	-4
1.150	-15	+5
1.125	-10	+13
1.100	-8	+19

Figure 5.5.16. *The freezing temperature of the electrolyte in a lead-acid battery is determined by its specific gravity.*

When measuring the specific gravity of the electrolyte, a correction must be applied if its temperature is different from the standard of 80°. If the temperature is greater than 80°F, add four points to the specific gravity for each ten degrees. If the temperature is lower than 80°F, subtract four points for each ten degrees. The correction is shown in the chart in Figure 5.5.17.

Other cautions for lead-acid batteries are:

- Neutralize any spilled electrolyte with bicarbonate of soda and water.
- Remove all traces of corrosion and treat any bare metal in the battery box or adjacent structure with an acid-proof paint.
- Be sure the battery box drain is open and if a sump jar is used, be sure the pad is saturated with a solution of bicarbonate of soda and water.
- If electrolyte is to be mixed, always pour the acid into the water. DO NOT pour water into the acid.
- Do not service lead-acid batteries in the same area as is used for servicing nickel-cadmium batteries.

Electrolyte temperature		Points to be subtracted or added to specific gravity reading
°C	°F	
60	140	+24
55	130	+20
49	120	+16
43	110	+12
38	100	+8
33	90	+4
27	80	0
23	70	-4
15	60	-8
10	50	-12
5	40	-16
-2	30	-20
-7	20	-24
-13	10	-28
-18	0	-32
-23	-10	-36
-28	-20	-40
-35	-30	-44

Figure 5.5.17. *Correction for nonstandard temperature of the electrolyte of a lead-acid battery.*

Nickel-Cadmium Batteries

Be sure the top of the battery is clean, and that all of the cell connectors are free from corrosion and are properly torqued.

All NiCad batteries function on the same basic principles. Differences in design and construction may require different maintenance, inspection and servicing procedures that can be found in the battery manufacturer's manual for appropriate guidance. The specific gravity of NiCad batteries varies from 1.240 and 1.300 at room temperature. There is no significant change in the electrolyte during its charge or discharge cycle and for this reason, the battery charge cannot be determined by a specific gravity check of the electrolyte.

The potassium hydroxide electrolyte used in NiCad batteries is extremely corrosive. Protective equipment such as goggles, rubber gloves, and rubber aprons should be used when handling and servicing batteries. Suitable washing facilities must be provided in case electrolyte is spilled on clothing or skin. Any exposure to electrolyte should be rinsed immediately with water, vinegar, lemon juice, or a boric acid solution.

The electrolyte level varies with the state of charge of the battery. Never add electrolyte to the battery while it is installed in the aircraft. Remove the battery, clean and inspect it, and add distilled or demineralized water according to the battery manufacturer's recommendation.

Other cautions for nickel-cadmium batteries are:

- A combination of high battery temperature and overcharging can lead to a condition called "thermal runaway." This is an uncontrollable raise in temperature that can be very destructive to the battery.
- Neutralize spilled electrolyte with a solution of 3 percent acetic acid, vinegar, or lemon juice, and wash the area with fresh water.
- Do not service nickel-cadmium batteries in the same area used for lead-acid batteries.

Lithium-ion Batteries

Lithium-ion (Li-ion) batteries provide a lightweight, high-power alternative to lead-acid and NiCad batteries. The weight of a Li-ion battery can be 60% less than a lead-acid or NiCad battery but comes at the cost of stringent automated monitoring and control requirements due to the risk of thermal runaway and a highly flammable electrolyte.

The required battery monitoring system (BMS) is part of the aircraft electrical system or is contained within the battery assembly. The BMS includes protection circuits that prevent the battery from excessive charge or discharge rates and monitors battery voltage, temperature, state of charge (SOC), and provides maintenance notifications.

Lithium-ion batteries are comprised of multiple sealed cells that are combined to meet voltage and capacity requirements. The cells are sealed and do not require the same servicing of the electrolyte as lead-acid and NiCad batteries, nor are there vapors or gases that are produced during the charging process. However, there are specific handling, servicing, and maintenance considerations.

When handling Li-ion batteries, avoid excessive voltages or currents, avoid internal or external shorts, keep away from high temperatures, and do not discharge below the battery limit. Any of these conditions can damage the battery or shorten its life. Do not store batteries near flammable materials.

Lithium-ion are shipped with a low charge (approximately 30%) and must be fully charged before use. Once installed on an aircraft, the capacity should be checked every 24 months, or as required by the manufacturer. The capacity check is performed by connecting a laptop to the aircraft system or directly to the battery, or by using a battery charger designed for

Li-ion batteries. When performing maintenance, check for new revisions of battery software that may need to be updated. To discharge a battery for shipping, use the recommend battery charger that has automated discharge functionality.

If a battery is not in use, whether on an aircraft on in storage, it should be charged every six months with a constant potential charger. To prolong the life of the battery, always maintain a 20 to 80 percent state of charge. Before using the battery to start an aircraft engine, or for any high current operation, the battery should have an SOC greater than 80 percent.

Section 6: Aircraft Materials

6.1 Composition of Wrought Aluminum Alloys

Percent of alloying elements; aluminum and normal impurities constitute remainder of metal.

Alloy Number	**Silicon**	**Copper**	**Manganese**	**Magnesium**	**Chromium**	**Zinc**
1100	—99.00% aluminum minimum—					
2017		4.0	0.5	0.5		
2024		4.5	0.6	1.5		
2117		2.5		0.3		
3003			1.2			
5052				2.5	0.25	
5056			0.10	5.2	0.10	
6061	0.6	0.25		1.0	0.25	
7075		1.6		2.5	0.30	5.6

6.2 Four-Digit Designation System for Wrought Aluminum Alloys

First digit: Principal alloying element
Second digit: A measure of the limits for impurities
Third and fourth digits: The amount of the alloying element in the metal

Type of Alloy	**Number Group**
Aluminum 99% or greater	1xxx
Copper	2xxx
Manganese	3xxx
Silicon	4xxx
Magnesium	5xxx
Magnesium and silicon	6xxx
Zinc	7xxx
Other elements	8xxx
Unused series	9xxx

Pure aluminum is the softest and most corrosion-resistant form of aluminum, but it is not generally used in aircraft construction or maintenance. 1100 is the most widely used form of commercially pure aluminum used in aircraft maintenance. It can only be used in nonstructural applications, such as fairings.

Copper is alloyed with aluminum to increase its strength and make it heat-treatable, but this makes it susceptible to corrosion. 2024 is the most widely used alloy in this series. To make a 2024 sheet more corrosion-resistant, a thin layer of pure aluminum is rolled onto its surface when the sheet metal is made. This process is called “cladding.” Most of the rivets used in sheet metal construction are made of 2117, 2017, or 2024.

Manganese makes the aluminum stronger and easier to weld. 3003 is the most widely used alloy in this series because it is soft and easy to form. It is used for cowling, propeller spinners, and wheel pants.

Magnesium adds strength to the aluminum, which makes it more difficult to form. 5052 is widely used for fluid lines; in its sheet form it is used for fuel tanks because it is weldable and reasonably corrosion-resistant. 5052 is not heat-treatable.

Magnesium and silicon give aluminum strength, malleability, and weldability. 6061 is used in applications in which heat treatability, ease of forming, medium strength and corrosion-resistance are important.

Zinc gives aluminum high strength, but makes it expensive and difficult to form. 7075 is the alloy used in modern aircraft where high strength and light weight are the primary considerations.

6.3 Weldable and Unweldable Aluminum Alloys

Most aluminum alloys are readily weldable using GTAW or GMAW. However, some are not. Following are the common families of aluminum alloys and their weldability characteristics:

Aluminum Alloy Families	**Weldability Characteristics** (shaded rows are unweldable)
1XXX alloys	Essentially pure aluminum (99%); used to carry electrical current, or for corrosion resistance in specific environments, these are all readily weldable. The most common filler metal is 1100.
3XXX alloys	Comprised of medium-strength alloys that are very formable; often used for heat exchangers and air conditioners. All are readily weldable using either 4043 or 5356 filler metal.
4XXX alloys	Usually used as welding or brazing filler alloys. They are sometimes used as base materials and in that case, they are readily welded with 4043 filler metal.
5XXX alloys	High-strength sheet and plate alloys, all of which are easily welded using 5356 filler metal—although 5183 or 5556 should be used for the stronger alloys such as 5083.
6XXX alloys	Primarily the extrusion alloys, but are available in sheet and plate as well. Prone to be crack-sensitive, but with the proper techniques, they can all be readily welded using 4043 or 5356.
2XXX alloys	High-strength aerospace alloys in sheet or plate form whose chemistry makes most of them unweldable using GTAW or GMAW due to hot cracking. The exceptions are 2219 and 2519, which are both readily welded using 2319 or 4043 filler metal. In any case, never weld 2024—it is very common and very high in strength, but extremely crack-sensitive.
7XXX alloys	High-strength aerospace alloys that, like the 2XXX alloys, most are unweldable using GTAW or GMAW due to hot-cracking and stress-corrosion concerns. The exceptions are 7003 and 7005 extrusion alloys and 7039 plate alloy. All three of these are readily weldable using 5356 filler. Never weld 7075.

6.4 Mechanical Properties of Aluminum Alloys

Bearing strength is the amount of force applied to an installed rivet that will cause the rivet to elongate the rivet hole in the sheet metal.

	Tensile strength, psi		**Brinell hardness 500 kg load, 10 mm ball**
Alloy and temper*	**Ultimate**	**Yield**	
1100-O	13,000	5,000	23
1100-H18	24,000	22,000	44
2017-O	26,000	10,000	45
2017-T4	62,000	40,000	105
2024-O	27,000	11,000	47
2024-T36	72,000	57,000	130
2024-T4	68,000	47,000	120
Alclad 2024-O	26,000	11,000	na
Alclad 2024-T36	67,000	53,000	na
3003-O	16,000	6,000	40
3003-H18	29,000	27,000	10
5052-O	28,000	13,000	47
5052-H38	42,000	37,000	77
6061-O	18,000	8,000	30
6061-T6	45,000	40,000	95
7075-O	33,000	15,000	60
7075-T6	83,000	73,000	150
Alclad 7075-O	32,000	14,000	na
Alclad 7075-T6	76,000	67,000	na

**See* Section 6.5, “Temper Designations”

6.5 Temper Designations for Aluminum Alloys

Heat-Treatable Alloys

-O..........Annealed temper of wrought alloys
-F ....As-fabricated condition for wrought alloys and as-cast for casting alloys
-T2 ....Annealed temper of casting alloys
-T3 ....Solution heat-treated followed by strain hardening; a second digit, if used, indicates the amount of strain hardening
-T4 ....Solution heat-treated followed by natural aging at room temperature
-T5 ....Artificially aged at an elevated temperature
-T6 ....Solution heat-treated followed by artificial aging
-T7 ....Solution heat-treated followed by stabilization
-T8 ....Solution heat-treated followed by strain hardening, then artificial aging
-T9 ....Solution heat-treated followed by artificial aging, then strain hardening

Non-Heat-Treatable Alloys

-O..........Annealed
-H1........Strain hardened by cold-working; a second digit indicates the degree of strain hardening
-H12......1/4 hard
-H14......1/2 hard
-H18......Full hard
-H19......Extra hard
-H2........Strain hardened by cold-working, then partially annealed
-H3........Strain hardened and stabilized

6.6 Temperatures for Heat Treatment of Aluminum Alloys

	Annealing			Heat		Heat treat.	
Alloy	**temp °F**	**time hours**	**Solution temp °F**	**treat. temper**	**Precip. temp °F**	**time hours**	**temper**
1100	650	2-3					
2017	775	2-3	940	-T4			
2024	775	2-3	920	-T4	375	7-9	-T86
2117	775	2-3	940	-T4			
3003	775	2-3					
5052	650	2-3					
6061	775	2-3	970	-T4	320	16-20	-T6
7075	775	2-3	870	-W	250	24-28	-T6

6.7 Bearing Strength (in pounds) of Aluminum Alloy Sheet

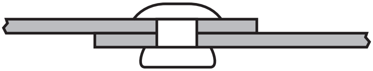
Bearing strength is the amount of force applied to an installed rivet that will cause the rivet to elongate the rivet hole in the sheet metal.

Sheet Thickness (inches)	**Diameter of rivet (inches)**							
	1/16	**3/32**	**1/8**	**5/32**	**3/16**	**1/4**	**5/16**	**3/8**
0.014	71	107	143	179	215	287	358	430
0.016	82	123	164	204	246	328	410	492
0.018	92	138	184	230	276	369	461	553
0.020	102	153	205	256	307	410	512	615
0.025	128	192	256	320	284	512	640	768
0.032	164	245	328	409	492	656	820	984
0.036	184	276	369	461	553	738	922	1,107
0.040	205	307	410	512	615	820	1,025	1,230
0.045	230	345	461	576	691	922	1,153	1,383
0.051	261	391	522	653	784	1,045	1,306	1,568
0.064		492	656	820	984	1,312	1,640	1,968
0.072		553	738	922	1,107	1,476	1,845	2,214
0.081		622	830	1,037	1,245	1,660	2,075	2,490
0.091		699	932	1,167	1,398	1,864	2,330	2,796
0.102		784	1,046	1,307	1,569	2,092	2,615	3,138
0.125		961	1,281	1,602	1,922	2,563	3,203	3,844
0.156		1,198	1,598	1,997	2,397	3,196	3,995	4,794
0.188		1,445	1,927	2,409	2,891	3,854	4,818	5,781
0.250		1,921	2,562	3,202	3,843	5,125	6,405	7,686
0.313		2,405	3,208	4,009	4,811	6,417	7,568	9,623
0.375		2,882	3,843	4,803	5,765	7,688	9,068	11,529
0.500		3,842	5,124	6,404	7,686	10,250	12,090	15,372

6.8 Shear Strength of Aluminum Alloy Rivets

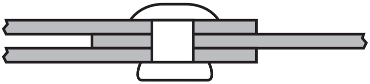
Shear strength is the strain on a rivet that tends to split the rivet into two parts.

Single-Shear Strength (in pounds) of Aluminum-Alloy Rivets



Rivet comp. (alloy)	Strength of rivet (psi)	Diameter of rivet of rivet (inches)							
		1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8
2117-T	27,000	83	186	331	518	745	1,325	2,071	2,981
2017-T	30,000	92	206	368	573	828	1,472	2,300	3,313
2024-T	35,000	107	241	429	670	966	1,718	2,684	3,865

Double-Shear Strength (in pounds) of Aluminum-Alloy Rivets



Rivet comp. (alloy)	Strength of rivet (psi)	Diameter of rivet of rivet (inches)							
		1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/8
2117-T	27,000	166	372	662	1,036	1,490	2,650	4,142	5,962
2017-T	30,000	184	412	736	1,146	1,656	2,944	4,600	6,626
2024-T	35,000	214	482	858	1,340	1,932	3,436	5,368	7,730

6.9 SAE Classification of Steel

Type of steel	**Identification number**
Carbon steels	1xxx
Plain carbon steel	10xx
Free cutting steel	11xx
Manganese steels (Manganese 1.60 to 1.90%)	13xx
Nickel steels	2xxx
3.50% nickel	23xx
5.00% nickel	25xx
Nickel chromium steels	3xxx
9.7% nickel, 0.07% chromium	30xx
1.25% nickel, 0.60% chromium	31xx
1.75% nickel, 1.00% chromium	32xx
3.50% nickel, 1.50% chromium	33xx
Corrosion and heat resisting	30xxx
Molybdenum steels	40xx
Chromium molybdenum steels	41xx
Nickel chromium molybdenum steels	43xx
Nickel molybdenum steels	
1.75% nickel, 0.25% molybdenum	46xx
3.50% nickel, 0.25% molybdenum	48xx
Chromium steels	5xxx
Low chromium	51xx
Medium chromium	52xxx
Corrosion and heat resisting	51xxx
Chromium vanadium steels	6xxx
1.00% chromium	61xx
National emergency steels	8xxx
Silicon manganese steels	9xxx
2.00% silicon	92xx

6.10 Strength of Steel Related to its Hardness

Rockwell C-Scale hardness number	**Brinell hardness number**	**Tensile strength 1,000 psi**
52	500	262
51	487	253
50	475	245
49	464	239
48	451	232
47	442	225
46	432	219
45	421	212
44	409	206
43	400	201
42	390	196
41	381	191
40	371	186
39	362	181
38	353	176
37	344	172
36	336	168
35	327	163
34	319	159
33	311	154
32	301	150
31	294	146
30	286	142
29	279	138
28	271	134
27	264	131
26	258	127
25	253	124
24	247	121
23	243	118
22	237	115
21	231	113
20	226	110
(18)	219	106
(16)	212	102
(14)	203	98
(12)	194	94
(10)	187	90
(8)	179	87
(6)	171	84
(4)	165	80
(2)	158	77
(0)	152	75

Numbers in parentheses ( ) are beyond the normal range of the Rockwell C-Scale.

6.11 Color of Steel for Various Temperatures

Color of Steel	**Temperature of steel**	
	°F	°C
Faint red	900	482
Blood red	1,050	566
Dark cherry	1,075	579
Medium cherry	1,250	677
Cherry (full red)	1,375	746
Bright red	1,550	843
Salmon	1,650	899
Orange	1,725	941
Lemon	1,825	996
Light yellow	1,975	1,079
White	2,200	1,204
Dazzling white	2,350	1,288

6.12 Color of Oxides on Steel at Various Tempering Temperatures

Oxide color	Temperature	
	°F	°C
Pale yellow	428	220
Straw	446	230
Golden yellow	469	243
Brown	491	255
Brown with purple spots	509	265
Purple	531	277
Dark blue	550	288
Bright blue	567	297
Pale blue	610	321

To temper a small tool, first harden it by heating it until it is cherry red, and then quench it in oil or water. Polish the hardened tool and then reheat it until the correct color oxide forms on the polished surface. The first oxides to form are pale yellow, and they progress through darker yellows, brown, purple and shades of blue. When the correct color oxide forms, quench the tool again.

The correct color of oxides for tempering small tools are:

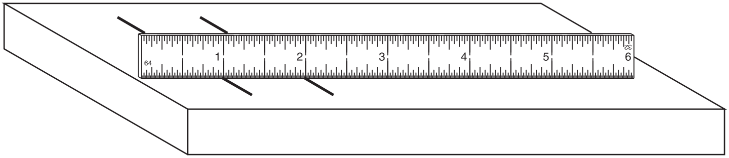
Tool	**Oxide Color**
Scribers, scrapers and hammer faces	Pale yellow
Center punches and drills	Golden yellow
Cold chisels and drifts	Brown
Screwdrivers	Purple

Section 7: Tools for Aircraft Maintenance

7.1 Measuring and Layout Tools

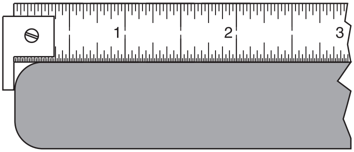
Steel Rule

For greater accuracy, when making a measurement with a steel rule do not use the end of the rule, but measure the distance between two marks away from the end.



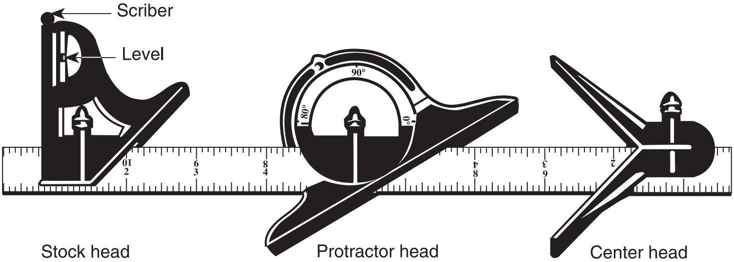
Hook Rule

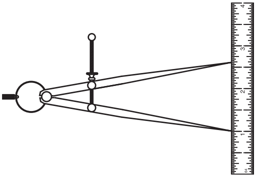
Hook rules are a special type of steel rule that are usually stiff and have a hook on one end accurately aligned with the end of the rule, for measuring from the edge of an object where a radius is involved.



Combination Set

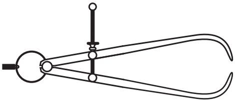
A combination set consists of a 12-inch steel rule with three heads held onto the rule by clamps. The stock head converts the rule into a square to measure 90° and 45° angles. The protractor head can be set to measure any angle between the rule and the bottom of the head. When the two arms of the center head are held against a circular object, the edge of the rule passes across its center.





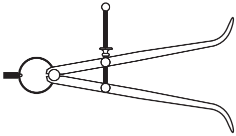
Dividers

Dividers are used to transfer distances from a steel rule to a piece of sheet metal that is being laid out. They are also used for dividing a line into equal increments.



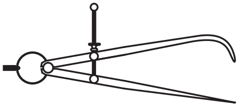
Outside Calipers

On outside calipers, the ends of the legs are pointed inward so that the outside of an object can be measured. Adjust the legs so the ends are exactly the same distance apart as the outside of the object, and then measure the distance between the ends with a steel rule.



Inside Calipers

Adjust the legs of inside calipers so the ends exactly fit into the object being measured, and then measure the distance between the ends with a steel rule.



Hermaphrodite Calipers

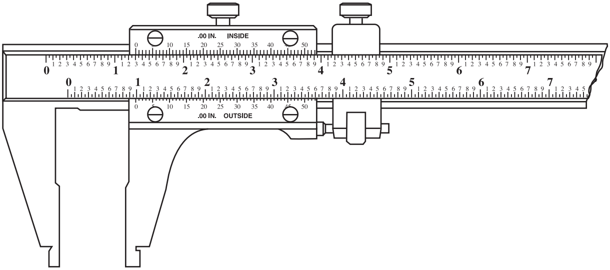
Hermaphrodite calipers are used to scribe a line along a piece of material a specific distance from the edge.

Scriber

Scribers have a needle-sharp point used to mark very fine lines on the surface of a piece of metal to be cut. Scribed lines on highly stressed metal can cause stress risers.

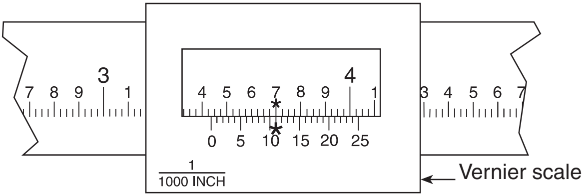
Vernier Calipers

Vernier calipers are used to make rapid and accurate inside and outside measurements over a greater range than that of a micrometer caliper. Each inch on the main scale is divided into 10 numbered increments, each representing 1/10 inch (0.1 inch). One inch on the vernier scale is divided into 25 increments, with each increment representing 1/25 inch or 0.040 inch.

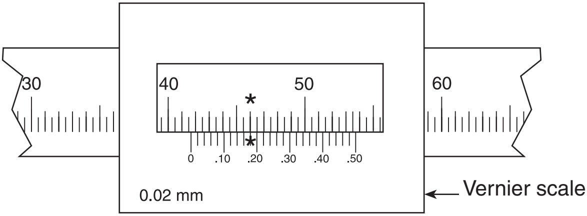


How to Read the Vernier Scale

The vernier scale's "zero" is beyond the main scale's 3-inch mark (3.000). It is also past the 4/10-inch mark (0.400), and past one of the 1/40-inch marks (0.025). Only one mark on the vernier scale aligns with a mark on the main scale: the "11" mark (see asterisk in figure below). Add 0.011 to the total: 3.000 + 0.400 + 0.025 + 0.011 = 3.436 inches.

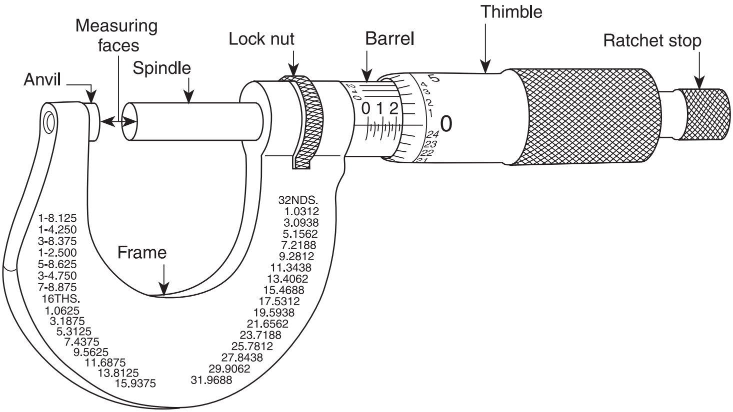


The vernier scale's "zero" is beyond the main scale's 41.5-mm mark. Only one mark on the vernier scale aligns with one of the marks on the main scale: the ".18" mark (see asterisk in figure below). Add 0.18 to 41.5 to get a total reading of 41.68 mm.

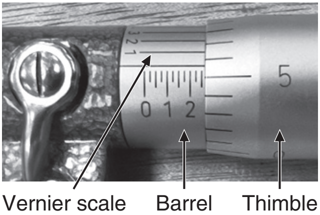


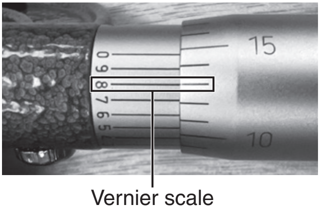
Micrometer Caliper

Micrometer calipers are available as inside and outside calipers, with ranges from 0 to 1 inch, to special calipers that measure up to 60 inches. Standard micrometer calipers can be read to 0.001 inch (one one thousandth of an inch) and vernier micrometer calipers can be read to 0.0001 inch (one ten thousandth of an inch).

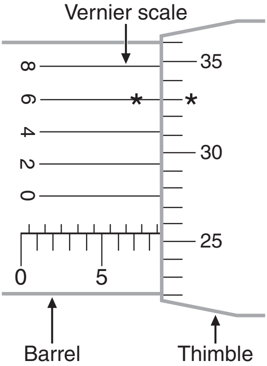


How to Read the Vernier Micrometer Scale

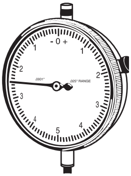




Each complete rotation of the thimble is 0.025 inches and corresponds to the incremental marks on the barrel. The micrometer shown at the right has been screwed out ten full rotations and reads 0.250 on the barrel. The 5 on the thimble has just passed the centerline on the barrel, so the base reading is 0.255. We next look at the vernier marks on the barrel to see which one lines up closest to a mark on the thimble. In this case, we can see that the vernier line marked "8" lines up with a mark on the thimble, so we add 0.0008 to our original reading. The final reading on the micrometer shown above is 0.2558 inches.

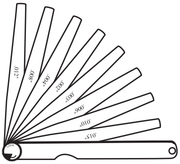


In the metric example, the thimble moved out more than 8.5 mm, and then more than 25 graduations, or 0.25 mm, beyond the reference mark. The vernier mark representing 6 divisions is aligned with one of the marks on the thimble, indicating the spindle moved 0.006 mm beyond 0.25. The total separation of the measuring faces is therefore 8.5 + 0.25 + 0.006 = 8.756 millimeters.



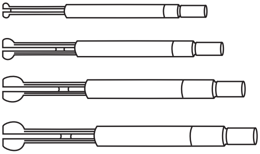
Dial Indicator

Dial indicators are used to measure end-play in shaft installations, gear backlash, bevel gear preload, and shaft out-of-round or runout.



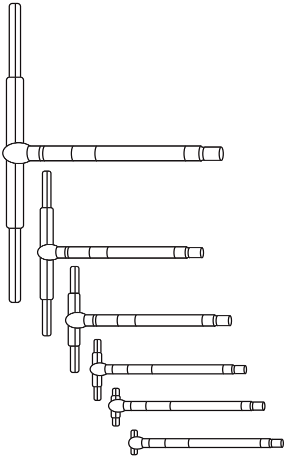
Feeler Gauges

Feeler gauges are used for measuring clearances in valve trains and breaker points, gear backlash, piston ring end-gap and side clearance, and the flatness of objects when used with a precision surface plate.



Small-Hole Gauges

Small holes, up to approximately 1/2-inch in diameter, may be accurately measured with small-hole gauges. Place a ball-type small-hole gauge into the hole to be measured and twist the knurled end of the handle to expand the ball end until it exactly fits in the hole. Remove the gauge and measure its diameter with a vernier micrometer caliper.



Telescoping Gauges

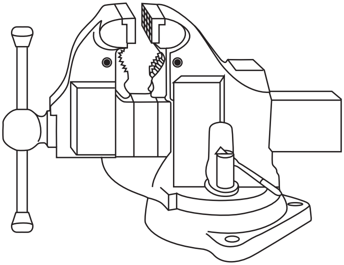
Select the gauge with the proper range and place it in the hole. Loosen the knurled end of the handle to release the hardened steel plungers in the telescoping head. This allows an internal spring to force the plungers out against the walls of the cylinder bore. Hold the gauge so the T-head is perpendicular to the inside wall of the bore and tighten the end of the handle. Remove the gauge and measure the distance between the ends of the plungers with a vernier micrometer caliper.

7.2 Holding Tools

Vises

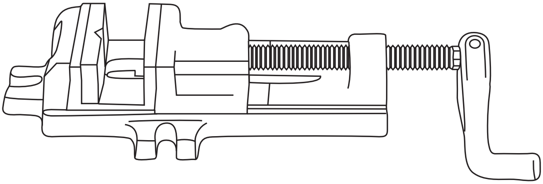
Bench Vise

Bench vises normally have replaceable serrated jaws to hold the material without slipping and are mounted on a swiveling base. The size of a vise is indicated by the width of the jaws, which normally range from 3-1/2 to 6 inches.



Drill Press Vise

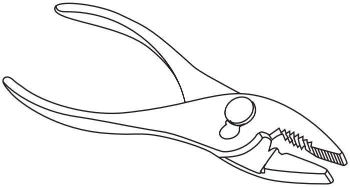
Drill-press vises have a flat bottom with slots which allow them to be bolted to the table of a drill press.

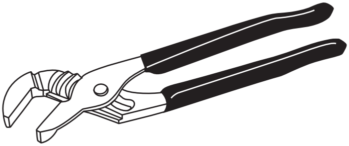


Pliers

Combination/Slip Joint Pliers

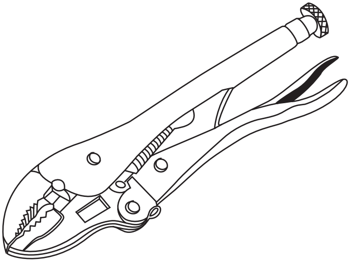
Standard pliers that have serrated jaws for gripping round objects and flat jaws for holding flat materials. When the jaws are open wide, the handle pivot may be slipped from one pivot hole to the other, allowing the jaws to open wider to hold larger objects.





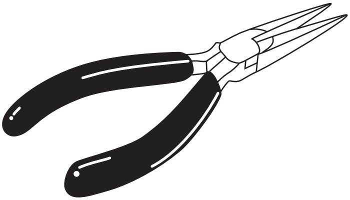
Water Pump Pliers

Also called adjustable-joint pliers. The long handles are for applying force to the jaws and torque to the object being turned. Available with a slip-joint adjustment or a tongue and groove type of adjustment that cannot slip, in lengths from 4-1/2 inches with parallel jaws that open to 1/2 inch, to 16 inches with jaws that open to more than 4 inches.



Vise-Grip® Pliers

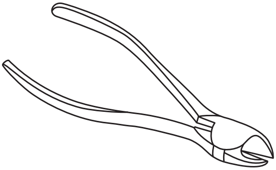
These patented locking pliers have a knurled knob in the handle that adjusts the opening of the jaws. When the handles are squeezed together, a compound-lever action applies a tremendous force to the jaws, and an over-center feature holds them tightly locked on the object between the jaws.



Needle-Nose Pliers

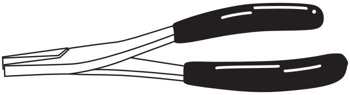
Used to hold wires or small objects and to make loops or bends in electrical wires. Some have straight jaws and others are bent to reach into obstructed areas; available in lengths from 4-1/2 to more than 10 inches.

7.3 Safety Wiring Tools



Diagonal Cutting Pliers

Diagonal cutters, or “dikes,” are used to cut safety wire and cotter pins. The name of these pliers is derived from the shape of the jaws that have an angled cutting edge.



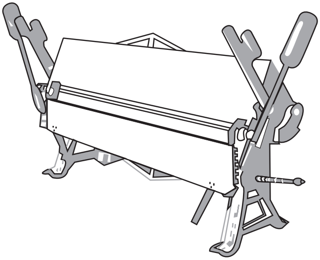
Duckbill Pliers

Duckbill pliers have long handles and wide serrated jaws that hold safety wire firmly while it is being twisted.

Safety Wire Twisting Tool

This safety-wiring tool grips wire securely, and the jaws lock on the wire; when the knob in the handle is pulled out, the tool twists the safety wire with a uniform twist. Can be used to give wire a left-hand or right-hand twist.

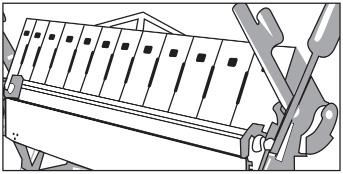
7.4 Bending and Forming Tools



Tools for Making Straight Bends and Curves

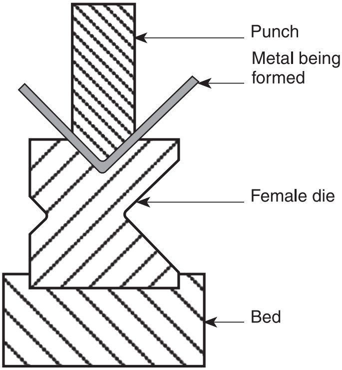
Cornice Brake

The cornice, or leaf brake is a heavy shop tool used to make straight bends across a piece of sheet metal. The bend radius appropriate for the thickness and temper of the metal can be chosen by using the appropriate radius block on the upper jaw of the brake.



Box Brake

A box, or finger brake is similar to a cornice brake, except the upper jaw is made up of a number of heavy steel fingers so all four sides of a box can be folded up.

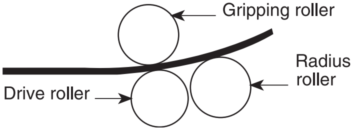


Press Brake

A press brake is used when a large number of duplicate pieces of material must be made with exactly the same amount of bend. The metal is placed over the female die whose inside radius is the same as the outside radius of the finished bend. A matching male die, or punch, with the correct radius forces the material into the die with energy stored in a large flywheel or with hydraulic pressure. Angles and channels are formed on press brakes.

Slip Roll Former

Used for making large radius bends across a piece of sheet metal. The metal is clamped between the drive roller and the gripping roller, and the handle is turned to pull the metal through the machine against the radius roller, which is adjusted to control the radius of the bend.



Forming Compound Curves in Sheet Metal

English Wheel

Aluminum alloy sheets are formed by stretching them, which is initially done with a soft mallet and a sandbag, resulting in a rough surface that must be smoothed out. The smoothing is done by moving the stretched aluminum sheet back and forth between the two rollers in an English wheel. The upper roller is a large cast-iron wheel with a highly polished and very slightly concave surface. A smaller, lower wheel is adjustable so it can be moved closer to or further from the upper wheel. The lower wheel has a convex surface, and there are a number of wheels available with differing radii to vary the radius of the metal being formed. The metal being worked is moved back and forth between the two wheels to smooth and form it.

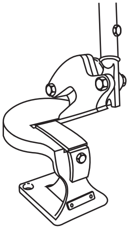
7.5 Cutting Tools

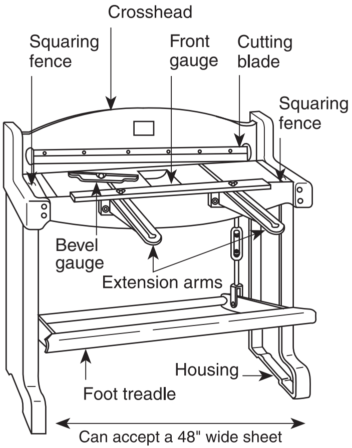
Personal protection equipment: The technician using these tools, and any personnel close to the work area, must wear safety glasses for eye protection.

Shears

Throatless Shears

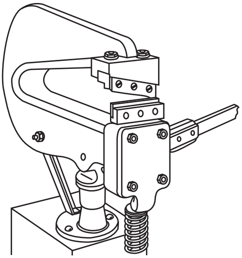
Throatless shears have two short cutting blades that cut much like a pair of scissors. The lower blade is fixed to the base and the upper blade is operated by a long handle.





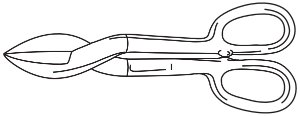
Squaring Shears

Foot-treadle-operated shears can make a straight cut across aluminum alloy sheets up to approximately 0.051-inch thickness and mild steel of 22-gauge or thinner. Power-operated shears that use a small electric motor to store a large amount of energy in a heavy flywheel can cut much thicker sheets. Place the metal to be cut on the bed and square it by holding it against the squaring fence. Lock the hold-down clamp in place to hold the metal tight on the table and keep your fingers out of the way of the blade. The blade is angled so that it slices its way through the sheet when the foot-treadle is pressed or when the energy stored in the flywheel forces the blade down.



Scroll Shears

Used to pierce a piece of sheet metal and cut irregular curves on the inside of the sheet without having to cut through to the edge. The upper blade has a sharp point for piercing the metal and is fixed to the frame of the shears; the lower blade is raised against the upper by the compound action of a hand-operated handle.



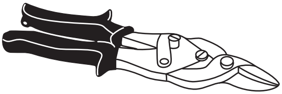
Hand Shears

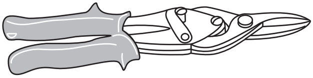
Tin Snips

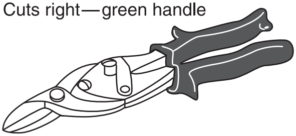
Used to cut sheets of aluminum alloy up to about 0.032-inch thick to roughly the size needed to fabricate a part. Final cutting and trimming is done with other tools.

Compound Shears

Also known as aviation shears or Dutchman shears. They have short serrated blades, actuated by a compound action from the handles. There are three shapes of blades, one designed to cut to the left, one to cut to the right, and one to make straight cuts. The serrated blades leave a rough edge that must be filed off to prevent stress risers. The handles of these shears are often color coded. Shears with red handles cut to the left, green handles cut to the right, and yellow handles cut straight.


Cuts left—red handle

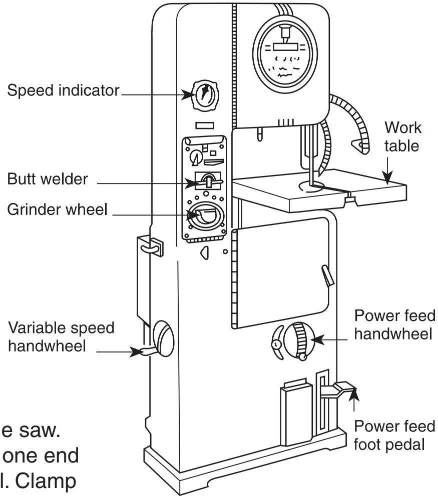

Cuts straight—yellow handle

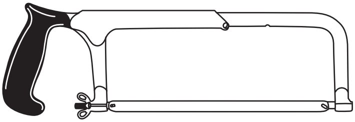

Cuts right—green handle

Saws

Band Saw

This contour band saw has a work table adjusted for tilt, and a variable-speed drive that allows the cutting speed of the blade to be adjusted to meet the requirements for the material being cut. It also has a cutter, welder, and grinder that allows the saw to be used for cutting inside a piece of sheet material without cutting through to the edge. Drill or punch a hole in the area to be sawed and remove the blade from the wheels of the saw. Cut the blade in two and place one end through the hole in the material. Clamp the two ends of the blade in the butt welder. Electric current flows through them, and heats them enough to melt the ends so they flow together. Shut the current off and allow the joint to cool, then grind it smooth. Reinstall the blade over the wheels, and cut the inside of the material.

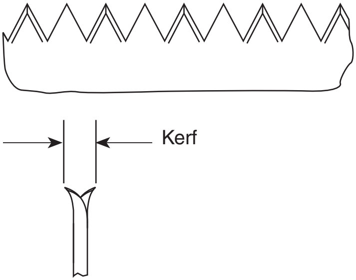




Hacksaw

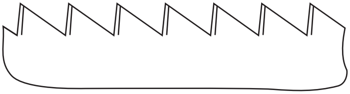
A hacksaw uses a narrow replaceable blade held under tension in a steel frame. The blades are available in 10 and 12-inch lengths and from 14 to 32 teeth per inch. A blade should be chosen that will allow at least two teeth to be on the material at all times. When cutting, pressure should be applied on the forward stroke and relaxed on the return stroke.

Wood Saws



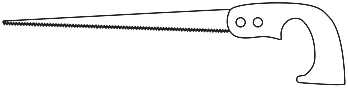
Crosscut Saw

A crosscut saw is a handsaw used for cutting across the grain of wood. The teeth, or points, are filed so they have a knife-like cutting edge on the same side of each alternate tooth. The teeth are set by bending every other tooth to one side and the alternate teeth to the opposite side. The set of the teeth results in a cut that is wider than the saw blade. This widened cut, called the kerf, keeps the blade from binding in the cut.



Ripsaw

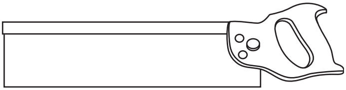
Ripsaws are similar to crosscut saws except for the shape and number of the teeth. They have fewer teeth per inch than a crosscut saw and the teeth are shaped to act as chisels and dig into the wood fibers.



Compass, or Keyhole Saw

A compass, or keyhole saw is a small saw with teeth similar to those of a crosscut saw. The blade is thin and tapered so it can enter a drilled hole and cut curves or circles.

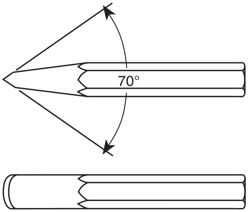
Backsaw



Backsaws have teeth similar to crosscut saws, but much smaller with more teeth per inch and less set. The blade has a stiffener across its back to keep it from bending. Backsaws produce a smooth cut across the grain for wood stringers or capstrips and they are often used with a miter box.

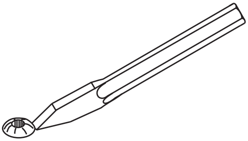
Chisels

Flat Chisel



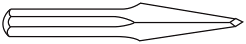
Made of a piece of hardened steel that is ground with a cutting angle of 70°. The cutting edge is ground to a convex shape to concentrate the force of the hammer blows at the point the cut is being made.

Cape Chisel



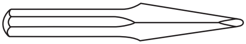
Cape chisels have a narrow cutting edge used to remove the head of a solid rivet after the head has been drilled through.

Diamond Point Chisel



These are forged to a sharp-cornered square, and the end is ground to an acute angle to form a sharp pointed cutting edge. They are used for cutting V-shaped grooves, and for cutting the sharp corners in square or rectangular grooves.

Round Nose Chisel



These chisels look much like diamond-point chisels except the cutting edge is ground to a circular point. They are used for cutting radii in the bottom of grooves.

Files

Flat file: Rectangular cross-section, tapered toward point in both width and thickness.

Hand file: Rectangular cross-section, sides parallel, tapers in thickness. One edge is safe (there are no teeth cut on it). Used for finishing flat surfaces.

Half-round file: Flat side and rounded side. Tapers in both width and thickness. Used to file the inside of large radius curves.

Triangular, or three-square file: Double-cut with triangular cross-section, tapered. Used to file acute internal angles and to restore damaged threads.

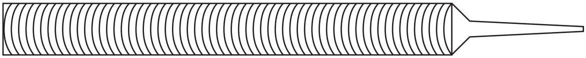
Round file: Commonly called a rattail file. Circular cross-section, tapered in length. Used to file the inside of circular openings and curved surfaces.

Knife file: Tapered in both width and thickness, cross-sectional shape much like a knife blade. Used for filing work with acute angles.

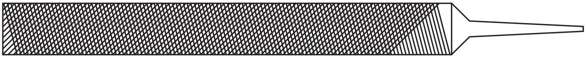
Vixen file: Curved teeth across file; used for removing large amounts of soft metal.

Wood rasp: Resembles file, except teeth formed in rows of individual round-point chisels. Used to remove large amounts of wood; they do not leave a smooth surface.

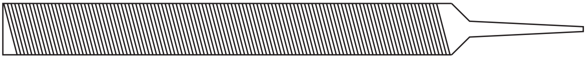
Vixen file



Double-cut file



Single-cut file

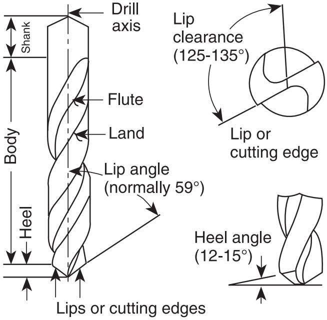


7.6 Hole Cutting Tools

Personal protection equipment: The technician using these tools, and any personnel close to the work area, must wear safety glasses for eye protection.

Twist Drills

Twist drills are available in two materials, carbon steel and high-speed steel. Carbon drills cost less and have a shorter life than high-speed drills and therefore they have limited use. High-speed drills are made of alloy steel and maintain their sharpness even when they are hot. They are available in three groups of sizes: number, letter, and fraction.



Twist Drill Sizes

Number or Letter	Fraction	Decimal Equivalent
80		0.0135
79		0.0145
	1/64	0.0156
78		0.0160
77		0.0180
76		0.0200
75		0.0210
74		0.0225
73		0.0240
72		0.0250
71		0.0260
70		0.0280
69		0.0290
68		0.0310
	1/32	0.0313
67		0.0320
66		0.0330
65		0.0350
64		0.0360
63		0.0370
62		0.0380
61		0.0390
60		0.0400
59		0.0410

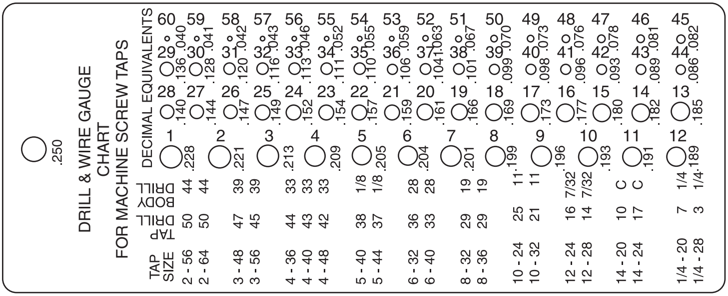
Number or Letter	Fraction	Decimal Equivalent
58		0.0420
57		0.0430
56		0.0465
	3/64	0.0469
55		0.0520
54		0.0550
53		0.0595
	1/16	0.0625
52		0.0635
51		0.0670
50		0.0700
49		0.0730
48		0.0760
	5/64	0.0781
47		0.0785
46		0.0810
45		0.0820
44		0.0860
43		0.0890
42		0.0935
	3/32	0.0937
41		0.0960
40		0.0980
39		0.0995
38		0.1015
37		0.1040
36		0.1065
	7/64	0.1094
35		0.1100
34		0.1110
33		0.1130
32		0.1160
31		0.1200
	1/8	0.1250
30		0.1285
29		0.1360
28		0.1405
	9/64	0.1406
27		0.1440
26		0.1470
25		0.1495
24		0.1520
23		0.1540
	5/32	0.1562
22		0.1570
21		0.1590
20		0.1610
19		0.1660

Number or Letter	Fraction	Decimal Equivalent
18		0.1695
	11/64	0.1719
17		0.1730
16		0.1770
15		0.1800
14		0.1820
13		0.1850
	3/16	0.1875
12		0.1890
11		0.1910
10		0.1935
9		0.1960
8		0.1990
7		0.2010
	13/64	0.2031
6		0.2040
5		0.2055
4		0.2090
3		0.2130
	7/32	0.2187
2		0.2210
1		0.2280
A		0.2340
	15/64	0.2344
B		0.2380
C		0.2420
D		0.2460
E	1/4	0.2500
F		0.2570
G		0.2610
	17/64	0.2656
H		0.2660
I		0.2720
J		0.2770
K		0.2810
	9/32	0.2812
L		0.2900
M		0.2950
	19/64	0.2969
N		0.3020
	5/16	0.3125
O		0.3160
P		0.3230
	21/64	0.3281
Q		0.3320
R		0.3390
	11/32	0.3438
S		0.3480

Number or Letter	Fraction	Decimal Equivalent
T		0.3580
	23/64	0.3594
U		0.3680
	3/8	0.3750
V		0.3770
W		0.3860
	25/64	0.3906
X		0.3970
Y		0.4040
	13/32	0.4062
Z		0.4130
	27/64	0.4219
	7/16	0.4375
	29/64	0.4531
	15/32	0.4688
	31/64	0.4844
	1/2	0.5000

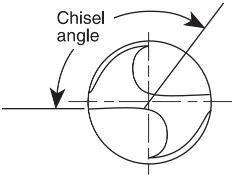
Drill Gauge

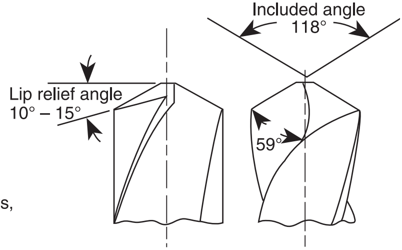
To identify the size of the drill, find the hole that exactly fits the drill; the number beside the hole is the size of the drill.



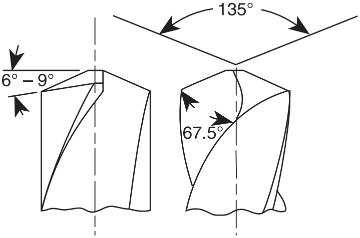
Twist Drill Sharpening

Twist drills are perhaps the simplest cutting tool used by an AMT but it is important that they be properly sharpened for the material they are used on. The point angles shown here are for aluminum alloys and brass, hard and tough metals, and transparent plastics and wood. When sharpening a drill, be sure that the lengths of the lips, or cutting edges, are the same, and the included angle and lip relief angle are correct for the material to be drilled.

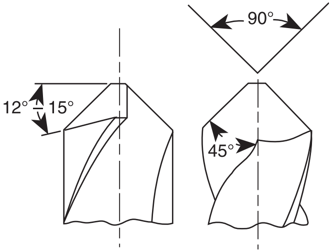




General purpose point for aluminum alloys, brass, and laminated plastics. The chisel angle should be between 125° and 135°.



Point ground for hard and tough metals. The chisel angle should be between 115° and 125°.

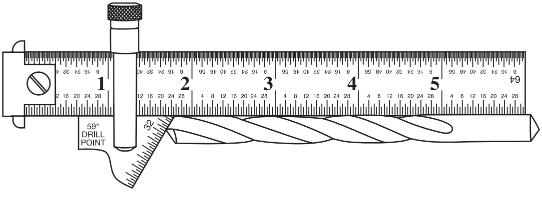


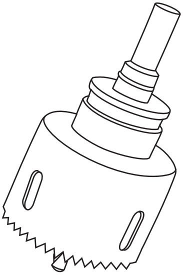
Point ground for transparent plastics and wood. The chisel angle should be between 125° and 135°.

Material	**Included angle**	**Lip relief angle**
Aluminum, mild steel, brass	118°	10° – 15°
Hard and tough materials	135°	6° – 9°
Plastics, wood	90°	12° – 15°

Drill Point Gauge

Because the points of most drills used in routine aviation maintenance are ground to an included angle of 118°, or 59° either side of center, a handy drill point gauge is available to determine that the angle is proper and the lips are of the same lengths.

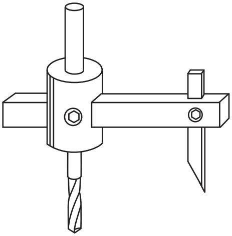




Large Hole Cutters

Hole Saws

Used to cut large-diameter holes in thin sheet metal or wood. Different diameter saws can be installed, available from 9/19-inch up to more than 4 inches. A shank fits into a drill press or a hand drill motor, and the pilot drill has a short section of flutes with a longer smooth shank. This allows the drill to cut the pilot hole, then when the saw reaches the material, the shank of the pilot drill is in the hole and therefore does not enlarge the hole, yet holds the saw centered.

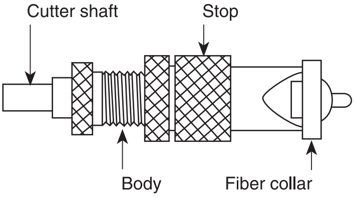


Fly Cutter

Used to cut large holes in thin sheet metal, but not limited to specific size holes. A cutting tool is mounted in the arm of the fly cutter, and the arm is adjusted so the tip of the cutter is exactly the radius of the desired hole from the center of the pilot drill. The shank of the fly cutter is chucked in a drill press, and the pilot drill cuts the guide hole.

Operate the drill press at a slow speed, and feed the cutter into the work very slowly and carefully so it cuts rather than grabs.

WARNING: It is important when cutting holes in thin sheet metal to support the metal on a piece of scrap plywood and clamp the metal and plywood firmly to the drill press table. This prevents the metal from becoming a lethal spinning knife if the cutter should dig into it.

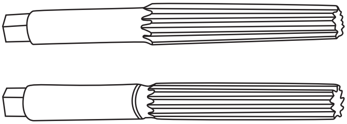


Countersink

A stop countersink cuts a countersink to the correct depth. Place the proper cutter in the tool and adjust the fiber collar so it contacts the skin when the countersink hole is the correct depth. To determine the correct adjustment of the skirt, make some test countersinks in scrap material until the recess is just deep enough so the top of the fastener is flush with the metal surface.

Reamers

A special cutting tool with sharp knife-edge blades, or flutes, cut into its periphery that are extremely hard and easily chipped. When preparing a hole for a close-tolerance bolt, drill the hole about one to three thousandths of an inch (0.001 to 0.003 inch) smaller than the outside diameter of the reamer. Be sure that the reamer is perfectly aligned with the hole and turn it steadily in its proper cutting direction to prevent it from chattering. Never turn the reamer backward after it has begun to cut as this will dull the reamer. Fixed-diameter reamers enlarge the hole to the most accurate dimensions, but expansion reamers may be used to ream a hole slightly larger than a fixed reamer. The hex on the end of the cutter is turned to increase the diameter of the cutters which can be measured with a vernier micrometer caliper.



Fixed-diameter reamers

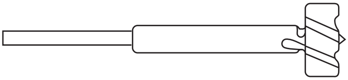
Expansion reamer

Drills for Wood and Composite Materials

Auger Bits

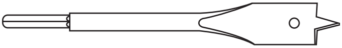
Auger bits are turned with a bow-type brace. The feed screw in the end of the bit screws into the wood and pulls the bit in. Sharp cutting edges parallel with the axis of the bit cut a circle in the wood and the cutting edge perpendicular to the axis of the bit cuts the chips from within the circle. The chips travel up the spiral flutes and out of the hole.

Forstner Bits



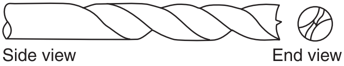
Mounted in a drill press and used for boring flat-bottom holes in wood. The vertical cutting edge cuts a circle the size of the hole being bored and the horizontal edge cuts the chips from the area within the circle.

Flat Wood-Boring Bits



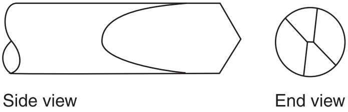
Available in sizes from 1/4-inch to more than one inch. These bits are chucked into an electric or pneumatic drill motor. The pointed pilot keeps the bit centered in the hole as the cutting edge of the bit cuts the chips and moves them out of the hole.

Brad-Point Drills



Brad-point drills are used for cutting Kevlar reinforced material. The drill is chucked into a high-speed electric or pneumatic drill motor and pressed into the material with little pressure. The cutting edges cut the fibers and produce a fuzz-free hole.

Spade Drill



Used to drill graphite materials, these provide ample space for the graphite dust to leave so it will not enlarge the hole. Spade drills are turned at a high speed in an electric or pneumatic drill motor, using very little pressure.

7.7 Threads and Threading Tools

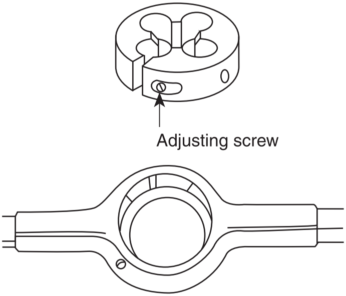
Unified and American Standard Thread Form

There are a number of forms of threads used on bolts and screws, but the Unified and American Standard Thread form has been accepted as the standard for most aircraft hardware. This thread form is available in both fine (UNF) and coarse (UNC) threads.

	Threads/inch	
Screw size	**UNF**	**UNC**
#0	80	
#2	64	56
#4	48	40
#6	40	32
#8	36	32
#10	32	24
#12	28	24
Bolt size		
3/16	32	24
1/4	28	20
5/16	24	18
3/8	24	16
7/16	20	14
1/2	20	13
9/16	18	12
5/8	18	11
3/4	16	10
7/8	14	9
1	14	8

Thread-Cutting Tools

Cut threads are formed with a die as shown at right. The adjusting screw is screwed in to spread the split in the die in order to shallow the threads being cut. The die is put in the die stock, and the four set screws are tightened to hold the die in place. The die is then placed over the end of the rod to be threaded and turned to cut the threads. The depth of the threads can be increased by screwing out on the adjusting screw.



Taps

Threads are cut inside a hole using a series of taps. A taper tap is used to start the threads as the first several threads are ground back so the tap will enter the hole and easily begin to cut the threads. For thick material, a plug tap is used to follow the taper tap. If the threads are to extend all the way to the bottom of a blind hole, a bottoming tap is used to follow the plug tap. The threads on a bottoming tap are full depth all the way to the end. Taps are held in a tap wrench which is turned with both hands to ensure that the tap is perpendicular to the material as threads are cut.


Taper tap


Plug tap


Bottoming tap

Body and Tap Drill Sizes

For UNF threads

Size and threads	Body diameter	Body drill	Preferred hole diameter	Tap drill
0-80	0.060	52	0.0472	3/64
1-72	0.073	47	0.0591	53
2-64	0.056	42	0.7000	50
3-56	0.099	37	0.0810	46
4-48	0.112	31	0.0911	42
5-44	0.125	29	0.1024	38
6-40	0.138	27	0.1130	33
8-36	0.164	18	0.1360	29
10-32	0.190	10	0.1590	21
12-28	0.216	2	0.1800	15
1/4-28	0.250	F	0.2130	3
5/16-24	0.3125	5/16	0.2703	I
3/8-24	0.375	3/8	0.3320	Q
7/16-20	0.4375	7/16	0.3860	W
1/2-20	0.500	1/2	0.4490	7/16
9/16-18	0.5625	9/16	0.5060	1/2
5/8-18	0.625	5/8	0.5680	9/16
3/4-16	0.750	3/4	0.6688	11/16
7/8-14	0.875	7/8	0.7822	51/64
1"-14	1.000	1"	0.9072	59/64

For UNC threads

Size and threads	Body diameter	Body drill	Preferred hole diameter	Tap drill
1-64	0.073	47	0.0575	53
2-56	0.086	42	0.0682	51
3-48	0.099	37	0.078	5/64
4-40	0.122	31	0.0866	44
5-40	0.125	29	0.0995	39
6-32	0.138	27	0.1063	36
8-32	0.164	18	0.1324	29
10-24	0.190	10	0.1476	26
12-24	0.216	2	0.1732	17
1/4-20	0.250	1/4	0.1990	8
5/16-18	0.3125	5/16	0.2559	F
3/8-16	0.375	3/8	0.3110	5/16
7/16-14	0.4375	7/16	0.3642	U
1/2-13	0.500	1/2	0.4219	27/64
9/16-12	0.5625	9/16	0.4776	31/64
5/8-11	0.625	5/8	0.5315	17/32
3/4-10	0.750	3/4	0.6480	41/64
7/8-9	0.875	7/8	0.7307	49/64
1"-8	1.000	1"	0.8376	7/8

For National Taper Pipe Series

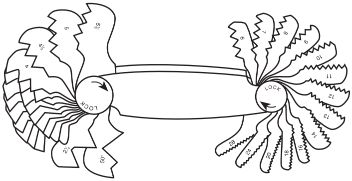
Nominal pipe size (inch)	Threads per inch	Root diameter of pipe	Tap drill
1/8	27	0.3339	Q
1/4	18	0.4329	7/16
3/8	18	0.5676	9/16
1/2	14	0.7013	45/64
3/4	14	0.9105	29/32

For metric threads

Metric threads	Metric tap drill
M2.5 x 0.45	2.05
M3 x 0.5	2.5
M3.5 x 0.6	2.9
M4 x 0.7	3.3
M5 x 0.8	4.2
M6.3 x 1	5.3
M8 x 1.25	6.8
M10 x 1.5	8.5
M12 x 1.75	10.2
M14 x 2	12.0
M16 x 2	14.0
M20 x 2.5	17.5
M24 x 3	21.0

Screw Pitch Gauge

Screw pitch gauges help to identify the thread type and size on a bolt or nut. Each leaf in the gauge has teeth that correspond to bolt or nut threads, with the number of threads per inch stamped on it. To find the number of threads per inch on a bolt or nut, select the leaf with an exact fit to the threads and note the number stamped on the leaf.

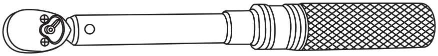


7.8 Torque and Torque Wrenches

NOTE: The strongest threaded joint is one in which the load applied to the fastener when it is installed is greater than the maximum load that will be applied to the joint in service. If a threaded fastener does not fail when it is being properly torqued, it will not fail in service.

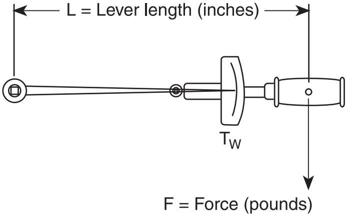
Click-Type Torque Wrench

Twist the handle until a reference mark aligns with a graduation on the shaft of the wrench indicates the desired torque. Place the correct socket on the wrench and put it on the fastener to be torqued. With the wrench perfectly square to the fastener, apply a smooth pull on the wrench until it clicks. Click-type torque wrenches do not limit the amount of torque that can be applied; rather, they indicate the set amount of torque being applied when they click. Stop the pull as soon as the wrench clicks.

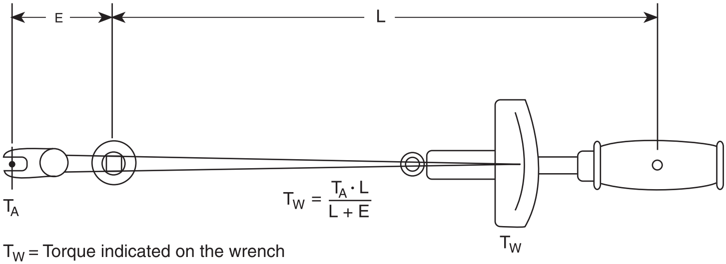


Deflecting-Beam Torque Wrench

It is important that the socket is square on the fitting and the force applied to the wrench is concentrated at the pivot point on the handle. The torque read on the wrench (T_W) measured in inch-pounds is the product of the lever length (L) in inches and the force (F) in pounds.



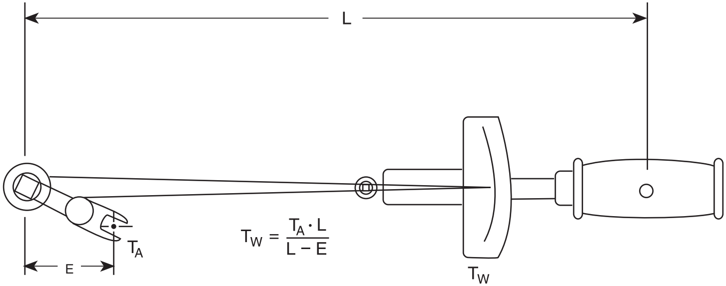
When using an adapter on a torque wrench that adds to the lever length, you must use the formula below to determine the torque reading on the wrench T_W in order to attain the required amount of torque applied to the fastener by the adapter T_A.



$$T_W = \frac{T_A \cdot L}{L + E}$$

T_W = Torque indicated on the wrench
T_A = Torque applied at the adapter
L = Lever length of torque wrench
E = Arm of the adapter

When the extension subtracts from the lever length of the wrench, use this formula.



$$T_W = \frac{T_A \cdot L}{L - E}$$

T_W = Torque indicated on the wrench
T_A = Torque applied at the adapter
L = Lever length of torque wrench
E = Arm of the adapter

Torque Conversions

Inch grams	Inch ounces	Inch pounds	Foot pounds	Centimeter kilograms	Meter kilograms
7.09	0.25				
14.17	0.5				
21.26	0.75				
28.35	1.0				
113.40	4.0	0.25			
226.80	8.0	0.50			
453.59	16.0	1.00	0.08	1.11	
	96.0	6.00	0.50	6.92	
	192.0	12.00	1.00	13.83	0.138
	384.0	24.00	2.00	27.66	0.277
	576.0	36.00	3.00	41.49	0.415
	768.0	48.00	4.00	55.32	0.553
	960.0	60.00	5.00	69.15	0.692
		72.00	6.00	82.98	0.830
		84.00	7.00	96.81	0.968
		96.00	8.00	110.64	1.106
		108.00	9.00	124.47	1.245
		120.00	10.00	138.31	1.383

Recommended Torque Values

Recommended Torque Values for Fine-Thread-Series Steel Fasteners								
	Standard AN and MS steel bolts in tension				High strength MS and NAS steel bolts in tension			
Nut-Bolt size	Nuts tension torque limits (in.-lbs.)		Nut shear torque limits (in.-lbs.)		Nuts tension torque limits (in.-lbs.)		Nut shear torque limits (in.-lbs.)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
8-36	12	15	7	9				
10-32	20	25	12	15	25	30	15	20
1/4-28	50	70	30	40	80	100	50	60
5/16-24	100	140	60	85	120	145	70	90
3/8-24	160	190	95	110	200	250	120	150
7/16-20	450	500	270	300	520	630	300	400
1/2-20	480	690	290	410	770	950	450	550
9/16-18	800	1,000	480	600	1,100	1,300	650	800
5/8-18	1,100	1,300	660	780	1,250	1,550	750	950
3/4-16	2,300	2,500	1,300	1,500	2,650	3,200	1,600	1,900
7/8-14	2,500	3,000	1,500	1,800	3,550	4,350	2,100	2,600
1-14	3,700	4,500	2,200	3,300	4,500	5,500	2,700	3,300
1-1/8-12	5,000	7,000	3,000	4,200	6,000	7,300	3,600	4,400
1-1/4-12	9,000	11,000	5,400	6,600	11,000	13,400	6,600	8,000

Recommended Torque Values for Coarse-Thread-Series Steel Fasteners				
Nut-Bolt size	**Standard AN and MS steel bolts in tension**			
	Nuts tension torque limits (in.-lbs.)		**Nuts shear torque limits (in.-lbs.)**	
	Min.	**Max.**	**Min.**	**Max.**
8-32	12	15	7	9
10-24	20	25	12	15
1/4-20	40	50	25	30
5/16-18	80	90	48	55
3/8-16	160	185	95	110
7/16-14	235	255	140	155
1/2-13	400	480	240	290
9/16-12	500	700	300	420
5/8-11	700	900	420	540
3/4-10	1,150	1,600	700	950
7/8-9	2,200	3,000	1,300	1,800
1-8	3,700	5,000	2,200	3,000
1-1/8-8	5,500	6,500	3,300	4,000
1-1/4-8	6,500	8,000	4,000	5,000

Recommended Torque Values for Fine-Thread-Series Aluminum Alloy Fasteners				
Nut-Bolt size	**Aluminum bolts in tension**			
	Nuts tension torque limits (in.-lbs.)		**Nuts shear torque limits (in.-lbs.)**	
	Min.	**Max.**	**Min.**	**Max.**
8-36	5	10	3	6
10-32	10	15	5	10
1/4-28	30	45	15	30
5/16-24	40	65	25	40
3/8-24	75	110	45	70
7/16-20	180	280	110	170
1/2-20	280	410	160	260

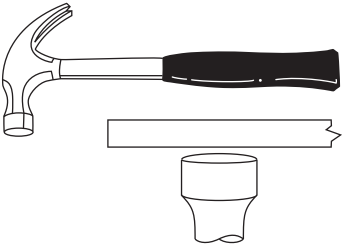
The International System of Units (SI) is the modern form of the metric system, and is used in many countries; however, the U.S. continues to use the U.S. customary system. The SI unit for torque is newton meters (N·m); in the U.S. customary units, it is foot-pounds force (ft-lb$_f$).

1 N·m = 0.738 ft-lb$_f$
1 ft-lb$_f$ = 1.355 N·m
1 inch-pound (in-lb$_f$) = 0.1129 N·m

In some of the European countries, torque is measured in m.daN which is a deci newton/meter (1/10 of a N·m).

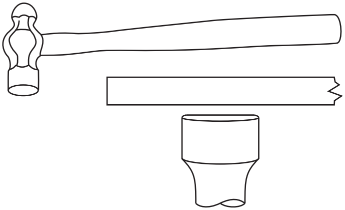
1.m.daN = 7.38 ft-lb$_f$ or 88.5 in-lb$_f$

7.9 Pounding Tools



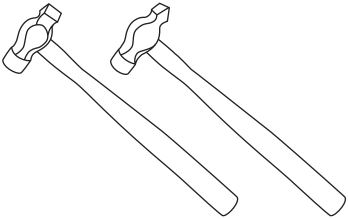
Carpenter's Claw Hammer

This hammer is used for driving and removing nails, but is seldom used when working on an aircraft. It is not designed for use in metal working because its face is slightly crowned to concentrate the force when driving nails.



Ball Peen Hammer

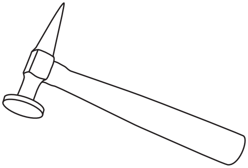
This is the most widely used hammer for general aviation maintenance; available with head weights from a few ounces to several pounds. The face of the hammer is flat with slightly rounded edges, and the opposite end of the head is rounded like a ball.



Metalworking Hammers

Straight Peen and Cross Peen Hammers

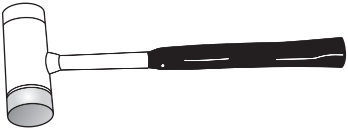
These are similar to the ball peen except the peen end is in the form of a wedge. The wedge on a straight peen hammer is parallel to the handle; the wedge on a cross peen hammer is across the handle.



Body, or Planishing Hammer

To form compound curves in sheet aluminum, the metal may be stretched by hammering it into a sandbag, then smoothed out by hammering it over a smooth steel dolly block with a planishing, or body hammer, a lightweight hammer with a large-area smooth face.

Mallets and Soft-Face Hammers



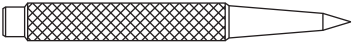
Sheet aluminum is formed by first stretching it, then smoothing it so the stretched metal forms the desired curves. The initial stretching is done by pounding the metal into a sandbag or around a form with a soft-face hammer, or mallet. These hammers may have replaceable faces of soft metal, resilient plastic, or coils of rawhide. Some hammer faces are domed to better stretch the metal; some are flat for the initial smoothing.

Sledge Hammers

Sledge hammers are long-handled, heavy-head hammers that have two parallel flat faces. They are wielded with two hands and used for heavy pounding work, or for driving stakes in the ground.

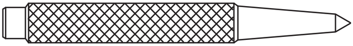
7.10 Punches

Prick Punch



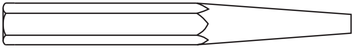
Has a sharp point; used to mark the exact location for drilling a hole in a piece of sheet metal. The point of the prick punch is placed at this location, and the punch is tapped with a lightweight hammer, leaving a small indentation at the location for the hole.

Center Punch



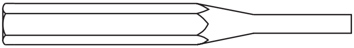
Similar to a prick punch, but its point is more blunt. It is ground to an angle of approximately 60°, which is correct for starting a properly ground twist drill to cut. The point is placed in the indentation formed by the prick punch, and the punch is hit with a hammer to create a depression for holding the drill as it begins to cut.

Drift, or Starting Punch



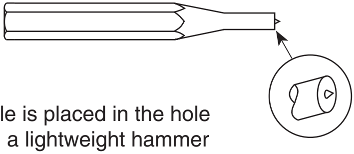
Has a tapered shank; used to drive bolts from their holes and to align parts for assembly. Especially useful when installing wings or other large airplane components. The wing is put in place, and a drift punch is used to align the holes in the wing spars and the fuselage before the bolts are put in place.

Pin Punch



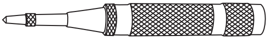
Used to remove rivets after the manufactured head has been drilled through. A punch of the proper size is placed in the drilled hole, and the rivet head is broken off. The punch is then tapped with a lightweight hammer to punch the rivet shank from the hole. Also used to align components being assembled.

Transfer Punch



Used to locate rivet holes when making a new aircraft skin using the old skin as a pattern. A transfer punch whose outside diameter is the same as the diameter of the rivet hole is placed in the hole in the old skin. The punch is tapped with a lightweight hammer and the sharp point in the center of the flat end makes a small indentation; this transfers a location for a center punch to the new skin.

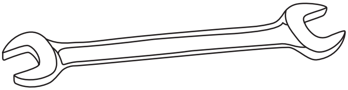
Automatic Center Punch



Used when a large number of holes must be marked. A spring inside the handle is adjusted by twisting the handle. Place the point in the indentation made by a prick punch and press the punch into the metal. As you press, the spring is compressed, and when the proper compression is reached, the spring automatically releases and drives the point into the metal.

7.11 Wrenches

Open End Wrench

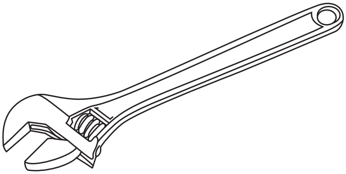


Open end wrenches have parallel jaws on each end. These jaws are angled 15° to the axis of the wrench to allow the wrench to be flipped over to get a new grip on the fastener when turning it in a confined space. Most have different-sized openings on the ends.

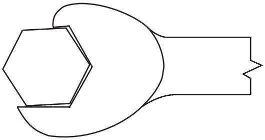
U.S. wrench sizes (inches)	**Metric wrench sizes (mm)**
1/4 - 5-16	6 - 8
3/8 - 7/16	7 - 9
1/2 - 9/16	10 - 11
5/8 - 3/4	12 - 14
11/16 - 13/16	13 - 15
3/4 - 7/8	16 - 18
25/32 - 13/16	17 - 19
15/16 - 1	20 - 22
1-1/16 - 1-1/8	21 - 23
1-1/4 - 1-5/16	24 - 26

Adjustable Open End Wrench

Adjustable end wrenches have one fixed jaw and one jaw that slides in a groove and moves by a worm gear that is rotated by the user. Important: Place the wrench on the fastener so the pull is away from the fixed jaw. When the wrench is held in this way, the strain is placed on the tip of the fixed jaw and at the base of the movable jaw where it is the strongest.

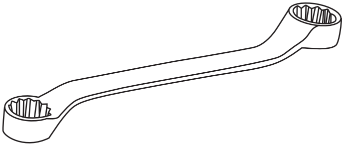


Ratcheting Open End Wrench



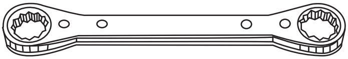
A ratcheting open end wrench allows a fastener to be turned down or removed without having to lift the wrench at each turn. It looks like an ordinary open end wrench except one of the jaws is much shorter than the other. When you pull the wrench toward you the pressure is applied near the end of the long jaw and the root of the short jaw. When the direction of wrench movement is reversed the short jaw moves around to the next flat.

Box End Wrench



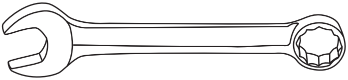
Much more torque can be applied with a box end wrench than with an open end, as they cannot be sprung open. Available in both 6-point and 12-point ends, with gripping surfaces offset so the wrench can be flipped over to get a new grip on the fastener while working in close quarters. The handles of some box end wrenches are offset so they extend upward, for clearance, when the box of the wrench is flat.

Ratcheting Box Wrench



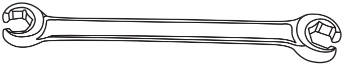
These have two thin 6- or 12-point open sockets mounted in the ends, in the same way as the box ends of a standard box end wrench. The outside of the sockets have ratchet teeth cut in them, and the ratchet pawls are inside the wrench handle—to get a new grip on the fastener, just ratchet the handle for a new grip each time the pawl slips over a ratchet tooth. To reverse the wrench, remove it and flip it over. Made with both straight and offset handles.

Combination Wrench



This wrench has a box end and an open end of the same size handy for removing tight fasteners. The box end is used to apply maximum torque for breaking the fastener loose, then the open end is used as it is much quicker to get a new grip with an open end than with a box end.

Flare Nut Wrench

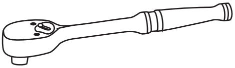


Flare nut wrenches resemble a straight box end wrench that has a portion of the box removed so the wrench will slip over the fluid line to loosen or tighten the fitting. These are weaker than box end wrenches and should not be used in place of a box end wrench for general nut tightening or loosening.

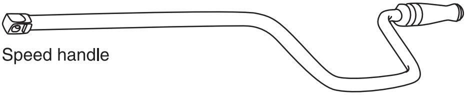
Socket Wrenches

Socket Wrench Handles

The ratchet-type allows a socket to be placed on a fastener, and by moving the handle back and forth, it is possible to tighten or loosen the fastener without removing the socket. The break-over handle, or breaker bar, is a long handle with the socket drive mounted on a pin that allows its angle relative to the handle to be varied. Break-over handles can apply the maximum torque to a fastener to tighten or loosen it. Speed handles, or speeders, resemble a crank that allows a fastener to be rapidly spun into place. Very little torque can be applied with a speed handle.

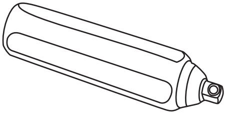

Ratchet handle


Break-over handle, or breaker bar


Speed handle

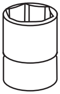
Hand Impact Tool

Used to break loose nuts and screws that have been corroded or rusted to the extent that an ordinary socket or screwdriver cannot budge them. Especially useful when fitted with a screwdriver bit to loosen structural screws in stressed inspection plates. The recess in the screw is cleaned out, and the screwdriver bit is installed on the driver and placed in the recess. The end of the driver is struck with a ball peen hammer; the blow rotates the screwdriver bit and at the same time prevents it from jumping out of the recess.

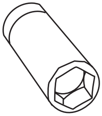


Typical Socket Wrenches

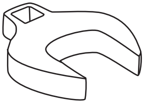
Available in 6- and 12-point openings, and in U.S. and metric sizes. Varieties are shallow sockets, semi-deep sockets, and deep sockets. Sockets with universal joints are available, as well as universal joints that can be placed between a normal socket and a drive. Crowfoot wrenches with an open end or a flare-nut end can be mounted on an extension to reach fasteners that cannot be reached by any other type of wrench.



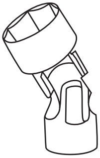
Shallow socket



Deep socket



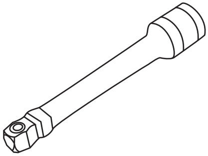
Crowfoot



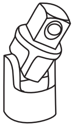
Universal socket

Extensions and Adapters

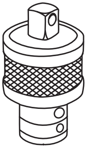
Straight extensions are available from less than 2 inches long to more than 36 inches. Some extensions are made of double-wrapped steel wire and are flexible so the socket can be oriented at any angle relative to the drive handle. Universal joints allow any socket to be used as a universal socket. Ratchet adapters can be installed between a handle and a socket, or an extension and a socket, so the socket can be ratcheted. Some extensions have a small undercut area at the socket end. This allows the attached socket to "wobble" and therefore accept a slight misalignment.



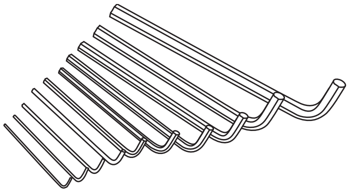
Straight extension



Universal joint



Ratchet adapter

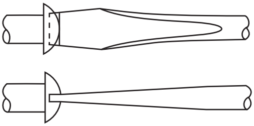


Allen Wrenches

Allen wrenches are made of hardened tool steel with a hexagonal cross section, in the shape of the letter L with a long and a short leg. They normally come in sets and have dimensions across their flats of from 1/16 inch to 5/8 inch.

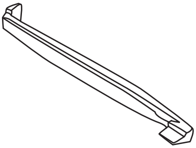
7.12 Screwdrivers

Slot Screwdrivers



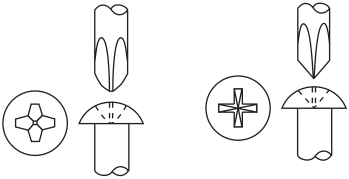
Slot-head screws have limited use in aircraft because they cannot be installed or removed with power screwdrivers—the blade slips out of the screw slot and can damage the component. Mostly they have been replaced with recessed-head screws. The blade of a slot screwdriver must be properly sharpened to prevent damage to the screw or the component in which the screw is installed. The sides of the tip should be ground parallel with the shank, and the edges should be sharp to grip the screw at the bottom of the slot.

Offset Screwdriver



Used to turn screws in locations that a straight screwdriver cannot reach. Some offset screwdrivers have a straight slot driver on one end and a Phillips driver on the other.

Recessed-Head Screwdrivers



Phillips Reed & Prince

Power screwdrivers require a screw head that will not allow the bit to slip out. Two types of recessed-head, or cross point screws have been used in aviation maintenance for decades: the Phillips and the Reed & Prince. The point of the Phillips screwdriver is blunt, and the sides of the point have a double taper. The Reed & Prince has a sharp point and a single taper.

A crosshead screwdriver is useless on a screw head with a single slot; it is used to drive and remove screws that match its design. Screw heads that feature Phillips drivers may be rounded or flat, but like single-slotted screws, they come in a variety of sizes including width and thickness of the intersecting slots.

Phillips Head Screwdriver Sizes

Phillips head screwdrivers come in sizes indicated by numbers rather than measurements, as is the case with regular or flathead screwdrivers. Screws, too, are designated according to number, from 0 to 24. Screws may be machined to fit single-slotted drivers or crosshead drivers. Flathead, single-slotted drivers are measured in inches and fit a particular size of screw, in some cases more than one. Phillips head screwdrivers are built to work with the same screws, only those with crossheads instead.

Since there are only five sizes of Phillips head screwdrivers, they each fit at least two sizes of screw—but some can fit up to five, as with the #2. The numbering system is one way to determine which screwdriver works with which screw (the other way requires trial and error):

Phillips head drivers	Phillips screw number
#0	0, 1
#1	2, 3, 4
#2	5, 6, 7, 8, 9
#3	10, 12, 14, 16
#4	18, 20, 24

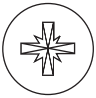
Screw Heads for Special Structural Screws

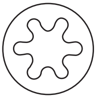
The airlines and the military use screws with other types of recessed heads that hold the point of the screwdriver bit more tightly to prevent its slipping out when used with a power screwdriver. Screwdriver bits are made to fit all of these special screws. The Pozidriv screwdriver tips are an improvement on the Phillips because the tip is not as tapered, with wedges that ensure a tight fit in the screw head. Phillips screwdriver bits should not be used on Pozidriv screws as they will ride up out of the recess and round the corners of both the screw head and the screwdriver bit. The spline head screw was developed by the Bristol Wrench Company.

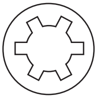

Hi-Torque®


Torq-Set®


Tri-Wing®


Pozidriv®


Torx®


Spline

Section 8: Aircraft Hardware

8.1 Standards

In the past, most manufacturers used standard aircraft parts that had been engineered and approved by the Army and Navy, with their specifications issued as AN standards. AN standard parts were easy to identify and their numbering system was relatively simple. But with the introduction of the turbine engine and high-speed, high-performance aircraft, aircraft hardware has become a much more complex and critical field. AN standards were replaced by Air Force-Navy standards; then other standards were developed—some of the more important standards are listed below:

AN—Air Force / Navy Standards
NAS—National Aerospace Standards
MS—Military Standards
AMS—Aeronautical Material Specifications
SAE—Society of Automotive Engineers
MIL—Military Specifications

The task of looking at markings on a part and measuring it to determine its part number is now a thing of the past. Many parts look alike, but their materials or tolerances can be quite different. **Any replacement hardware must be the part number specified in the aircraft or engine parts manual, and each piece of hardware must be purchased from a source known to be reputable.** Look-alike parts that might be of inferior strength can jeopardize the safety of an aircraft. The most commonly used parts and pertinent facts about their proper use are listed in this Section. AMTs should become familiar with the parts manuals for the aircraft and engines he or she is working on to find the correct part number for each piece of hardware used.

8.2 Threaded Fasteners

Bolts

The most common type of threaded fastener, available in a number of materials such as nickel steel, aluminum alloy, corrosion-resistant steel, and titanium. Different types of heads for special purposes and different thread pitches adapt them to special functions.

Genuine A/C Hardware AN3–AN20 Bolts

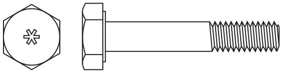
Diameter/Head Size/Hole Sizes

AN # BASIC	THREAD DIA/PITCH	DIA. MAX	DIA. MIN	WRENCH SIZE	HOLE, SHANK +.010. -.000	HOLE, HEAD +.010. -.000	COMMONLY USED STEEL COTTER	COMMONLY USED STAINLESS COTTER
AN3	10–32	.189	.186	3/8"	.070	.046	MS24665-132	MS24665-151
AN4	1/4–28	.249	.246	7/16"	.076	.046	MS24665-132	MS24665-151
AN5	5/16–24	.312	.309	1/2"	.076	.070	MS24665-210	MS24665-229
AN6	3/8–24	.374	.371	9/16"	.106	.070	MS24665-283	MS24665-300
AN7	7/16–20	.437	.433	5/8"	.106	.070	MS24665-283	MS24665-300
AN8	1/2–20	.499	.495	3/4"	.106	.070	MS24665-285	MS24665-302
AN9	9/16–18	.562	.558	7/8"	.141	.070	MS24665-353	MS24665-370
AN10	5/8–18	.624	.620	15/16"	.141	.070	MS24665-355	MS24665-372
AN12	3/4–16	.749	.744	1+1/16"	.141	.070	MS24665-355	MS24665-372
AN14	7/8–14	.874	.869	1+1/4"	.141	.070	MS24665-357	MS24665-374
AN16*	1"–14	.999	.993	1+1/2"	.141	.070	MS24665-359	MS24665-376
AN17	1"–12	.999	.993	1+1/2"	.141	.070	MS24665-359	MS24665-376
AN18	1 1/8–12	1.124	1.118	1+5/8"	.141	.070	MS24665-359	MS24665-376
AN20	1 1/4–12	1.249	1.243	1+7/8"	.141	.070	MS24665-360	MS24665-377

*The thread pitch 1"–14 became INACTIVE FOR DESIGN after June 1966.

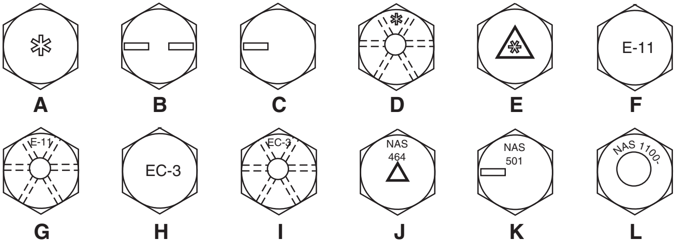
Table reproduced with permission from General Aircraft Hardware Company catalog (www.gen-aircraft-hardware.com)

Hex-Head Bolts



The standard bolt used in airframe and powerplant construction, designed for both tensile and shear loads. They depend on the proper application of torque for the strength of the joint. Available with both UNC and UNF threads, made of SAE 2330 nickel steel, 2024 aluminum alloy, corrosion resistant steel, and titanium. Most have a medium (class 3) fit and most of the steel bolts are cadmium-plated. Also available with holes drilled through the head for safety wire, and/or with a hole through the shank for a cotter pin. The material or bolt type is identified by marks on the head. Close-tolerance bolts, identified by a triangle, are ground to a fit of ±0.0005 inch and the ground surface is not plated, but is protected from rust with grease.

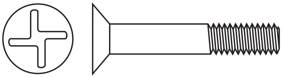
Bolt Head Identification Marks



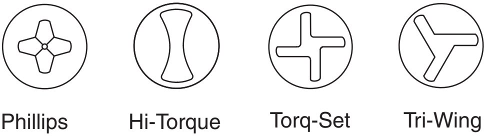
A AN3-AN20—Standard alloy steel hex-head aircraft bolt
B AN3DD-AN20DD—Standard aluminum alloy hex-head aircraft bolt
C AN3C-AN20C—Standard corrosion resistant steel hex-head aircraft bolt
D AN73-AN81—Drilled-head aircraft bolt
E AN173-AN182—Close-tolerance bolt
F AN101001-AN103600—Alloy steel hex-head aircraft bolt
G AN103701-AN104600—Drilled-head aircraft bolt
H AN104601-AN105500—Corrosion resistant steel drilled-head aircraft bolt
I AN107301-AN108200—Corrosion resistant steel drilled-head aircraft bolt
J NAS464—Close-tolerance bolt
K NAS501—Corrosion resistant steel hex-head aircraft bolt
L NAS1103-NAS1112—Alloy steel hex-head aircraft bolt

Flush-Head Bolts

Many modern aircraft applications require high-strength bolts with heads that can be flush with the outside skin of the aircraft. Most bolts in the NAS and MS series have a 100° head, but some have an 82° head. These high-strength bolts are made of alloy steel and titanium and some have self-locking inserts in the threads.

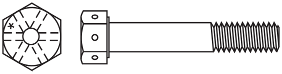


Head Recesses



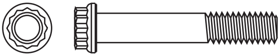
Drilled-Head Bolts

Drilled-head airframe bolts are used in locations where a high tensile strength is required and where the bolt is safetied with safety wire. There is no hole in the shank for a cotter pin.



Twelve-Point, Washer-Head Bolts

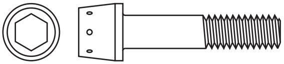
Designed for special high-strength and high-temperature airframe and powerplant applications; available in both NAS and MS series. The heads of many of these bolts are drilled for safety wire.



Internal Wrenching Bolts

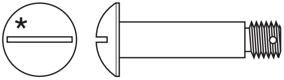
These are the typical high-strength alloy steel bolts used in special airframe applications where severe loads are imposed on the structure. They have a radius between the shank and the head, and a special chamfered, heat-treated steel washer (such as the NAS 143C) is used under the head to provide a bearing surface. Turned with a hex wrench which fits into the socket in the head.

NAS144, MS2004



Clevis Bolts

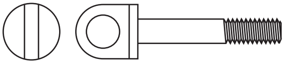
AN21 to AN36 series



Designed for shear loads only. To prevent them from being used for tensile loads, the head is shallow and has a slot or recess for turning with a screwdriver. The threads are short to take a thin nut, and there is a notch between the threads and the shank. Most have a drilled shank so a cotter pin can be used to prevent the nut from backing off. A typical application is the attachment of a cable to a control horn: the bolt is installed and the nut is tightened just enough that the cable terminal is free to move on the horn.

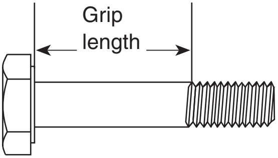
Eye Bolts

AN42 to AN49 series



Used to attach wires and cables to aircraft structure; made of alloy steel, cadmium-plated, and available with or without drilled shanks.

Bolt Installation



Almost all hex-head bolts have a round, smooth, washer-like bearing surface just below the head. This surface prevents the edges of the head from damaging the surface of the component into which the bolt is installed. If there is no such surface, a washer should be placed under the head. Also, always place a washer under the nut to provide a good bearing surface and prevent damage to the component as the nut is tightened.

The bolt length should be chosen so that the grip length (the length of the unthreaded shank) is the same as the thickness of the materials being joined. The nut must never be screwed down against the last thread on the bolt. If the grip length is too long, use plain washers to act as shims to prevent the nut reaching the last thread. **Bolts must be installed in exactly the way the aircraft or engine maintenance manual specifies.** If there is no information of this nature, bolts should be installed with the head upward, forward, or inboard. These orientations normally aid in preventing the bolt from falling out if the nut were not screwed on.

Some bolts have holes drilled in the threaded portion of the shank for cotter pins to secure a castellated nut. If a self-locking nut is to be used on a drilled shank bolt, be sure that the edges of the hole are chamfered to prevent the sharp edges from cutting threads in the nut insert.

Bolt Fits

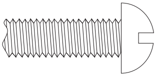
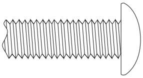
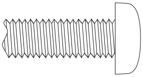
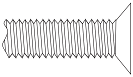
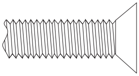
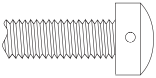
If there is any looseness or play in a threaded joint, vibration can produce a cyclic stress that can further loosen the fastener and lead to destruction. Aircraft design engineers calculate the stresses that will affect every joint, and the fasteners are designed to produce a stress within the joint greater than any anticipated applied stress. This bolt stress is determined by the fit of the bolt in the bolt hole, and by the torque applied (*see* Pages 162–165). The maintenance manual usually specifies the drill size for all bolt holes. If no drill size is specified, it is normally satisfactory to use the next larger number drill (smaller number) than the shank diameter of the bolt being installed. Example: a #12 drill (0.1890) can be used for a 3/16-inch (0.1875) bolt. Some manuals specify a type of drive fit for the bolt in which the hole is drilled slightly undersize and reamed to the diameter that will provide the desired fit (*see* table below):

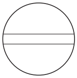
Type of fit	**How to drill/ream hole**
Loose fit	Use a drill number one size larger than the diameter of bolt. Hole is 0.002 to 0.005 inch larger than bolt shank.
Push fit	Reamed fit—allows bolt to be forced into the hole by hard, steady push against bolt head.
Tight-drive fit	Requires bolt to be driven into the hole with sharp blows from a 12- or 14-ounce hammer.
Interference fit	Bolt diameter is larger than reamed diameter of hole. The component with the hole must be heated to expand the hole—the bolt is chilled with dry ice to shrink it. When bolt is installed, and the component and the bolt reach the same temperature, the bolt cannot be moved.

Screws

Normally differ from a bolt because they have a slot or recess in the head so they can be turned with a screwdriver rather than a wrench, and their threads extend all of the way to the head. However, this distinction has been blurred: a number of high-strength bolts also exist with flush heads so they can be installed on the outside of an aircraft structure and not cause wind resistance.

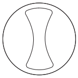
Aircraft Screw Heads

	**Round head** Normally used for nonstructural applications and are made in steel and brass. Most have a class 2 fit; available with both coarse and fine threads. Slot heads and Phillips recessed heads are the most common.
	**Truss head** Flatter than round heads, used to replace round heads for new designs. Available with slot or Phillips recessed heads.
	**Pan head** A low disc with a rounded, high outer edge with large surface area.
	**100° Flush head** Used for applications where high strength and a smooth surface are necessary. Available in both NAS and MS series; may have Phillips, Hi-Torque, or Torq-Set heads.
	**82° Flush head** Found on some AN screws; used for a flush installation where high strength is not necessary.
	**Fillister head** Used where surface smoothness is not necessary. Often drilled for safety wire.

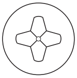


Slot

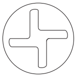
Tri-wing® recess
(Registered trademark of Phillips Screw Company)



Hi-Torque recess



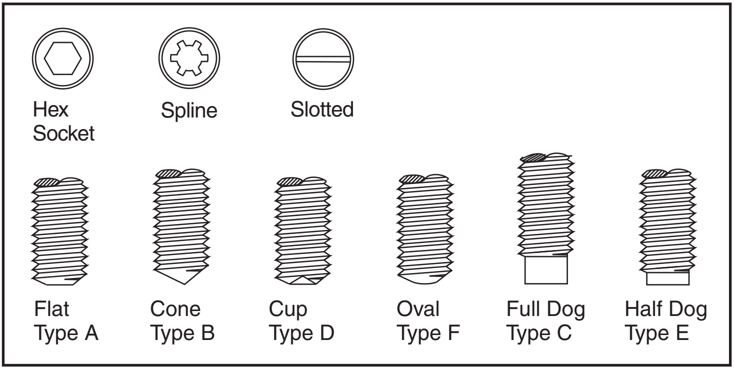
Phillips recess



Torq-Set recess

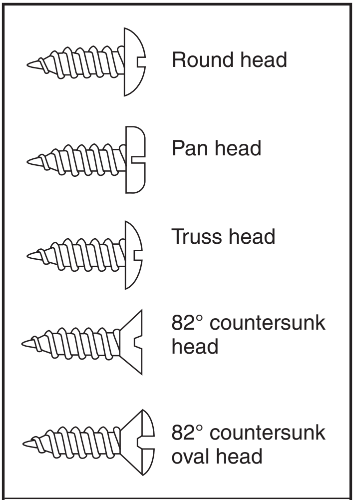
Set Screws

A special type of headless screw used for such applications as securing wheels or pulleys to shafts, or indexing a wheel on a splined shaft. The cup and cone points bite into the shaft for a tight grip. The full dog and half dog points are used to ride in a spline to allow lengthwise movement while preventing rotation.



Self-Tapping Sheet-Metal Screws

Used in the installation of cowling and inspection plates for some lighter aircraft. Often called PK screws because the first ones to become popular were made by the Parker-Kaylon company. Available in the AN, MS, and NAS series. They may have either a sharp point (Type A) or a blunt end (Type B), and are made with either a slot or a Phillips recessed head in sizes 4, 6, 8, and 10.



All of the screws shown are Type A, having a sharp point.

Nuts

These components have internal threads that screw down over a bolt to provide the clamping action that holds all the components in a bolted joint tightly together.

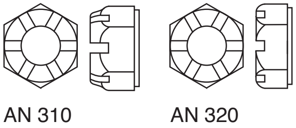
Nonlocking Nuts

- No built-in provision for automatically locking them to the bolt.
- Must use a cotter pin, safety wire, or a check nut to prevent them from turning.

AN310 and AN320

- Secured to bolts by cotter pins passed through bolt holes and slots in the nuts.
- AN310—thick nut used for tensile loads.
- AN320—thin nut used only for shear loads.
- Available in cadmium-plated nickel steel, aluminum alloy, and corrosion resistant steel.

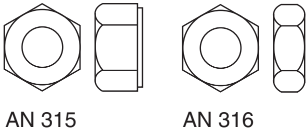
Castellated, or Castle Airframe Nuts



AN315 and AN316

- AN315—used on a bolt with no cotter pin hole; thick, for tensile loads.
- AN316—check nut used to lock the AN315 to a bolt.
- The AN315 nut is screwed down on the bolt and tightened with the proper torque, then the AN316 nut is screwed down on top of it and tightened.
- Tightening the AN316 applies a tensile stress to the bolt which holds the nuts tightly together, preventing vibration from loosening the joint.

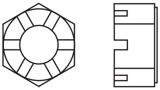
Plain Airframe Nuts



AN355

- Slotted nut; locked onto bolt or stud with a cotter pin or safety wire through the slots and through a bolt or stud hole.
- Designed for use on engines; not approved for use on aircraft structures.
- Being replaced with AN121551 through AN121600 series nuts.

Slotted Engine Nut



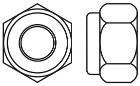
AN 355

Self-Locking Nuts

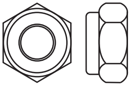
Vibration is an ever-present problem in aircraft operation, and some method must be used to prevent nuts from loosening on bolts or studs. This is often done with cotter pins or safety wire through holes in the bolt or stud and slots in the nuts. Self-locking nuts were devised to save the time needed to safety these nuts. These are classified by the temperature they are designed to withstand. Low-temperature nuts should not be used where temperatures exceed 250°F, but high-temperature nuts are good to temperatures as high as 1,400°F.

Low-temperature locking nuts:

1. Has a fiber or nylon insert locked into the end of the nut, with a hole slightly smaller than the major diameter of the bolt used.
2. Screws down freely until the insert is reached, then a wrench is required to turn it further.



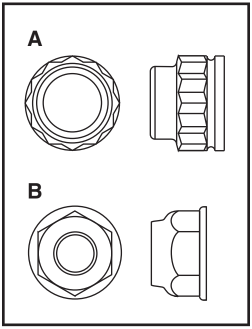
MS20365
(AN365)



MS20364
(AN364)

3. The bolt does not cut threads in the insert, rather it distorts the insert causing it to grip the bolt threads. This gripping action plus the opposition to turning caused by the insert produces a force between the nut and bolt threads which prevents the nut from loosening.
4. Self-locking nuts should not be used in any application where the nut and bolt are subject to rotation (such as in attaching a control cable to a control horn).
5. A self-locking nut can be reused as long as a wrench is required to turn it on the bolt.
6. To ensure that the insert grips all of the bolt threads, the complete chamfer on the end of the bolt must stick out beyond the insert; if the bolt is not chamfered, at least one complete thread should show beyond the insert.

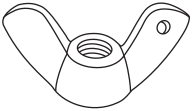
High-temperature locking nuts:



- The fiber or nylon insert cannot tolerate high temperatures, therefore several methods have been devised to lock all-metal nuts to the bolt—two of the most popular methods are distorting the pitch of the threads, and compressing the end of the nut.
- Some nuts, such as the 12-point nut in view A, have a thinned section near the end that is compressed enough to distort the pitch of the threads. As the nut is screwed down on the bolt, it turns easily until the bolt threads encounter the distorted area, then a wrench is needed to turn it further. This type of nut is widely used in aircraft engine and missile applications and is suitable for applications to temperatures as highas 1,400°F.
- The nut in view B is made of relatively thin steel, with the end of the nut formed into an elliptical shape. As it screws down on the bolt threads the ellipse rounds out, and the spring action of the nut grips the bolt threads.

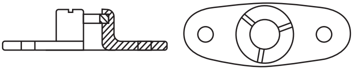
Not all nuts used in aviation construction are of the hex or 12-point configuration. There are many types of nuts that are fixed to the structure that do not require a wrench for installation with screws or bolts.

Wing Nuts



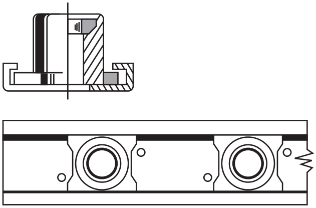
1. For special aircraft applications that require a nut that can be turned without the use of any tools.
2. Not normally required to produce a great deal of force, so they do not need much torque for installation.
3. Used to secure objects that must be frequently removed.

Anchor Nuts



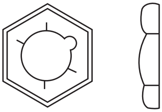
1. For use on inspection plates that are retained with screws from the outside of the aircraft, with no access to the nuts on the inside.
2. Available in both low- and high-temperature styles.
3. Riveted around the screw hole in the aircraft structure so that the inspection plate screws can be screwed into the anchor nut without having to hold the nut with a wrench.

Channel Nuts



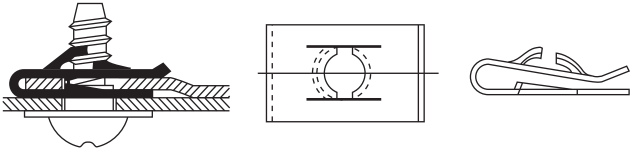
1. A form of anchor nut used when it is necessary to have a number of nuts inside the aircraft structure for attaching components such as access panels.
2. The channel is riveted to the structure, and the nuts ride loosely inside the channel; this looseness allows for slight movement to align the nut with the screw.
3. The body of the nut is square so it will not turn as the screw is driven into it.
4. The ESNA (Elastic Stop Nut series) nuts use fiber or nylon inserts to grip the screws and prevent them from loosening.
5. On the Boots series nuts, the pitch of the last threads at the nut end is distorted with respect to the nut threads in the body. The difference in the thread pitch grips the screw tightly so they will not loosen.

Pressed-Steel Nuts



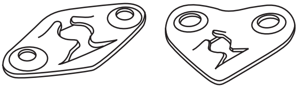
1. Saves cost and weight in aircraft construction.
2. The best example is the Pal nut, a thin nut used primarily on engines as a check nut to prevent a plain nut from loosening.
3. The plain nut is tightened to the proper torque, then the Pal nut is installed over it and tightened only snugly.
4. The thin steel of the nut rides in the threads of the bolt, and as the nut is tightened it exerts a force on the threads that holds the nut so tight against the plain nut, that normal vibration cannot loosen it.

Tinnerman Type U Speed Nut



5. The Type U Speed nut is a popular pressed-steel nut for cowling and other applications on light aircraft. It is slipped over a screw hole in the fixed portion of the cowling, and a self-tapping sheet metal screw is passed through the mating hole in the removable part. As the screw is tightened, it forces down the edge of the spring steel nut and holds the screw tight so vibration will not loosen it. Prevents the hole in the soft sheet aluminum of the cowling from being enlarged by repeated installation and removal of the screws.
6. Anchor nuts are available in pressed-steel—two of the more popular configurations are the plain type and the corner type, both available for round-head and flat-head screws. Anchor nuts for flat-head screws are dimpled so the dimpled hole of the inspection plate will nest in it.

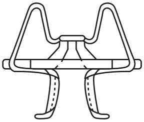
Pressed Steel Anchor Nuts



Instrument Nuts

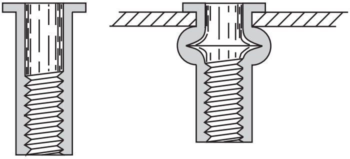
1. This nut can be slipped into the mounting holes and will receive the. screw and not turn when the nut is tightened.
2. For mounting instruments on the front side of the panel, the same type of nut is available with the legs just long enough to go through the panel metal.

Pressed-Steel Instrument Mounting Nut



Rivnuts

1. Developed to attach rubber deicer boots to the thin metal of aircraft wings and empennage leading edge surfaces.



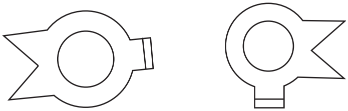
2. Special tubular nuts are screwed onto a mandrel in the puller, and inserted in the hole in the aircraft skin.
3. The handles of the puller are squeezed together and the Rivnut tube is collapsed, tightly gripping the skin.
4. The mandrel of the puller is screwed out, then the machine screw used to attach the boot can be screwed in.

5. Many Rivnuts have a key under the head that fits into a notch cut into the edge of the hole in the skin to prevent the Rivnut from turning when the screw is inserted or removed.

Threaded Fastener Safetying

All threaded fasteners with the exception of self-locking nuts are secured with some form of safety device.

Locking Washers

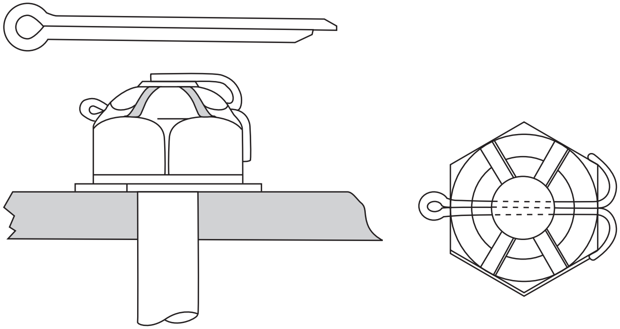


- Fit over the bolt or stud.
- Tab fits into a hole or slot in the body of the component.
- Plain nut installed and torqued;
  the triangular-shaped tabs are bent up against the flats of the nut.
- Nut cannot back off of the stud, stud cannot back out of the component.

Cotter Pins

- Castellated nuts are safetied on bolts with cotter pins passed through the castellations and the hole in the shank of the bolt.
- Available as AN380 in low-carbon steel, and AN381 in corrosion-resistant steel.
- Be sure to check the airframe or engine maintenance or parts manual to get the correct part number for the correct pin.

Cotter Pin Installation



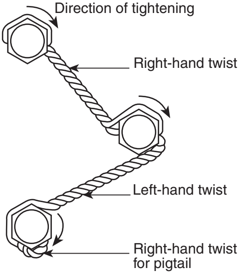
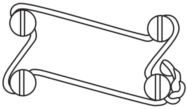
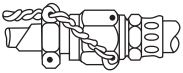
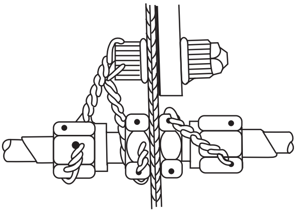
Installation:

1. First check the alignment of the slots in the nut with the hole in the bolt at the minimum recommended torque. If they are not aligned, continue to tighten. This normally ensures the hole and slots will align within the allowable torque range. If there is no alignment by the time maximum torque is reached, remove the nut and install a different thickness plain washer under the nut and retorque. It is not recommended that maximum torque be exceeded for alignment.
2. When the nut is properly torqued, slip the correct cotter pin through the slots in the nut and the hole in the bolt shank.
3. Spread the pin and pull the head tightly into the slot of the nut.
4. Fold one of the legs back against the end of the bolt shank and cut it off with a pair of diagonal cutters so it does not extend past the edge of the bolt shank.
5. Cut the other leg of the pin so it does not extend beyond the edge of the nut and fold it securely down against the flat of the nut.
6. As a final check, be sure that the cotter pin is tight, with no looseness or play, and that the ends of the pin are tight against the bolt and nut (so they cannot cut you if you rub your hand over them).
7. If it is important that the cotter pin not protrude beyond the end of the bolt shank, the pin may be inserted with the split vertical and the ends folded back against the flats of the nut. The pin should be tight in the slot and the ends cut off so they leave no sharp edges.

Safety Wire and Safety Wire Twisting

- Safety wire is available in copper, brass, stainless steel, and galvanized or tinned steel.
- Sizes include .020, .025, .032 (most commonly used), and .041
- Be sure to use the size and material wire specified by the equipment manufacturer, and safety as specified in the appropriate maintenance manual.
- Safety wire twisting can be done by hand or with a pair of duckbill pliers, but one of the reversible safety wire twisting tools makes the job much faster and more uniform.

Some tips for twisting safety wire:

	• Safety wire should be twisted in a direction that will hold the loop of wire down along the side of the fastener. • Bolt heads are safetied in such a way that the loosening tendency of one will pull on the wire in a tightening direction on the other.
	• When there is a clearance problem, safety wire may be passed over the end of the stud rather than around the nut.
	• Fillister-head screws may be safetied with a single wire.
	• To safety the adjustment of a control rod: after the length of the rod is adjusted, the socket end of the rod is safetied to the check nut, and then to the holes in the hex of the male end of the rod.
	• Safety a coupling nut on a flexible line to a straight connector brazed on a rigid tube, as shown.
	• Safety coupling nuts to a bulkhead fitting as shown: the coupling nut on the right is safetied to the hex on the bulkhead fitting. The bulkhead nut is tightened against the bulkhead and is safetied to a fixed point with the safety wire pulling on the nut in the direction of tightening. The coupling nut is safetied to the same fixed point.

There are many different applications for safety wiring in modern aircraft and engines, and some basic principles apply to all installations:

1. Before safety wiring a fastener, be sure that it is properly torqued.
2. Be sure to use the method of safety wiring specified in the airframe or engine maintenance manual.
3. Install the wire so that it always pulls the fastener in the direction of tightening. This will prevent the fastener from backing off if it should loosen.
4. Loop the wire around the outside of the fastener so that it is routed under the wire protruding from the hole. This causes the loop to stay down and prevents slackening. The direction of twist should reverse from run to run, and from run to pigtail. This reversal is done to hold the loop of wire down around the fastener.
5. Be sure that the twists are tight and even, and the twisted wire between the fasteners is taut but not too tight. The recommended number of twists per inch depends upon the diameter of wire.

Wire diameter	Twists per inch
0.020 – 0.025	8 – 14
0.032 – 0.041	6 – 11
0.051 – 0.060	4 – 9

6. Be sure that the pigtail at the end of the wire is no more than 3/4 inch long and has a minimum of 4 twists. Double the pigtail back, cut the end off, and bend it under so it will not snag or cut anything that rubs across it.

Safety Cable

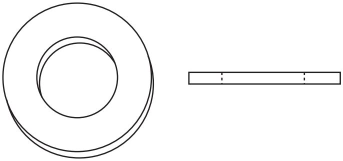
Safety Cable™ is a safe, cost effective, easy-to-install fastener retention system, effective on even the most complex, hard to reach components. This two-step procedure is replacing the process of lockwiring fasteners. It permits manufacture and repair in half the time required for lockwire, reduces rework and inspection while eliminating installation hazards through removal of any sharp edges that can injure operators or tear protective clothing.

The system consists of a proprietary cable, ferrules and a patented, all-in-one tensioning, crimping and cutting tool. After a cable is threaded through the fasteners and a loose ferrule inserted, the crimping tool tensions the assembly, crimps the loose ferrule and cuts the excess cable flush to the ferrule, all in one motion.

8.3 Washers

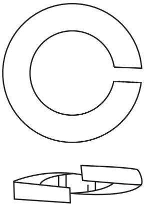
Plain washers, (examples of)	Uses	Description
AN 960	• Provides smooth bearing surface for nut. • Serves as shim for bolt grip purposes. • Prevents sharp edges under lock washers from damaging material clamped.	• Steel or aluminum alloy • Hole with plain edges
AN 143C	• Used under the heads of high-strength internal-wrenching bolts such as NAS 144 (because of the radius between the head and shank).	• Steel • Hole has chamfered edges
AN 970	• When bolting wood structures together: spreads force applied by bolt and nut over large area of the wood.	• Large area (outside diameter larger than AN 960)

AN 960 Plain Washer

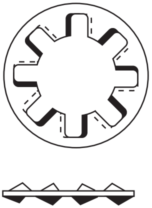


Lock Washers, Types	**Uses**	**Description**
Split lock washer	• Prevent vibration from loosening nut by producing a stress between the nut and the material being clamped. • Not to be used on aircraft structure where failure of washer might result in damage or danger to aircraft or personnel. • Primarily used under large nuts.	• Heavy spring steel • Cut and twisted
Shakeproof lock washer	• Teeth are twisted to produce the needed stress. • Primarily used with machine screws.	• Thin spring steel with internal or external teeth

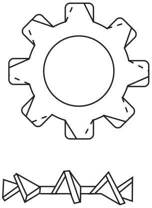
Lock Washers



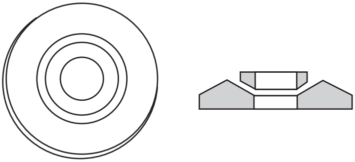
Split



Internal shakeproof



External shakeproof

Ball Socket and Seat Washers	**Uses**	**Description**
AN 950 AN 955	Used together as a pair to help clamp when it is impossible to get perfect alignment between the bolt and material.	• Ball socket • Seat washer
AN 950 and AN 955 ball socket and seat washers 		

8.4 Special Rivets

Solid rivets, the most widely used fasteners in aircraft construction, and their identification are covered in Section 9 *Metal Aircraft Fabrication*. Other types of rivets for special uses in aircraft materials and construction are listed below.

Blind Rivets

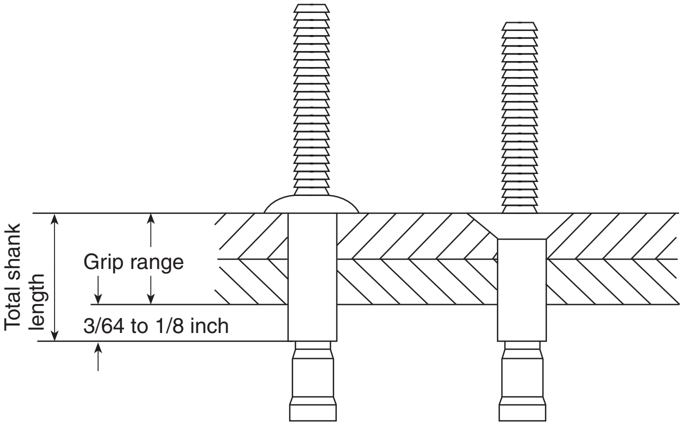
Often it is necessary to install rivets where there is access to only one side of the material, as opposed to solid rivets which require access to both sides for driving. There are a number of rivets that meet this need, such as the blind rivet types listed below.

> **NOTE:** When using a blind rivet in a repair, it must be the rivet specified in the maintenance manual for the specific repair. The common pull-type Pop rivets such as those found in most hardware stores are not approved for use on certificated aircraft.

Friction-Lock Rivets

- Made by the Townsend Division of Textron, approved for aircraft structure.
- May be used to replace a solid rivet in some instances, but normally must have a diameter one size larger than the rivet it replaces.

Self-Plugging, Friction-Lock Cherry Rivets



To install a friction-lock rivet:

1. Insert it in the prepared hole, then grip and pull the serrated stem with a special tool.
2. This pulls the tapered plug up into the hollow shank and swells it to form the upset head inside the structure.
3. Continued pulling snaps the stem off and leaves the plug inside the shank.
4. Cut off the broken-off stem and file it flush with the rivet head.

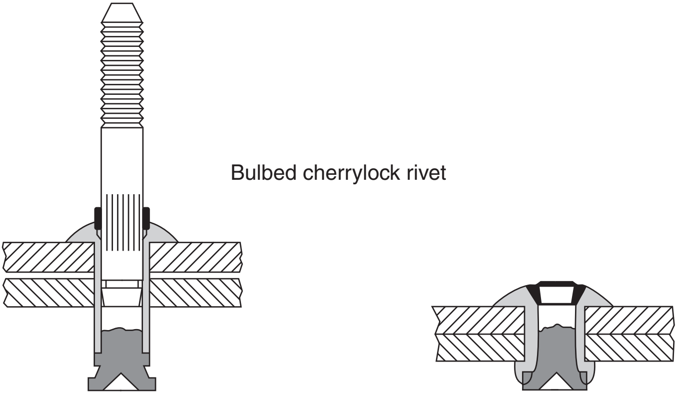
NOTE: Plug is held in the shank only with friction—it is possible that vibration can shake it out and weaken the joint.

5. To remove friction-lock rivets, punch the stem out of the rivet. Using a drill the diameter of the rivet shank, drill the head and tap the shank out of the skin with a properly fitting pin punch.

Mechanical-Lock Rivets

- Normally approved to replace solid rivets on a size-for-size basis because the stem is locked into the hollow rivet shank and it cannot vibrate out.
- As strong or stronger than a solid rivet of the same diameter.
- Available with both universal heads and 100° countersunk heads.
- Standard and oversize diameters.
- Lengths measured in increments of 1/16 inch.

Mechanical-locked rivets



(Before stem is pulled out)

(After stem is pulled out)

Installed in the same way as the friction-lock rivet:

1. As the stem is pulled, the head is forced firmly against the skin and the skins are pulled tightly together.
2. The shear ring on the bottom of the stem upsets the shank, forms the blind head inside the structure and swells the shank to completely fill the rivet hole.
3. Continued pulling of the stem shears off the shear ring and pulls the end of the stem up to form the bulbed head.
4. The locking collar is forced into the groove in the stem, holding it tight, preventing it vibrating loose.
5. The stem then breaks off flush with the rivet head.

CherryMax Rivets, Olympic-Lok Rivets, Huck Rivets

- Mechanical-locking blind rivets that are approved for use in aircraft structure.
- All function on the same principle as that described for the Bulbed Cherrylock rivet.

To remove mechanical-locked rivets:

1. File the head to weaken the locking ring.
2. Tap the stem out with a properly fitting pin punch.
3. Drill through the head of the rivet and tap the shank out of the hole with a pin punch.

High-Strength Pin Rivets

Pin rivets are a group of fasteners that have the strength of a bolted joint but are lighter weight and easier to install than a bolt, and are installed in locations where they are not likely to need to be removed.

Hi-Shear Rivet

- Has a heat-treated alloy steel pin equivalent or superior in strength to the AN bolt that it is approved to replace.

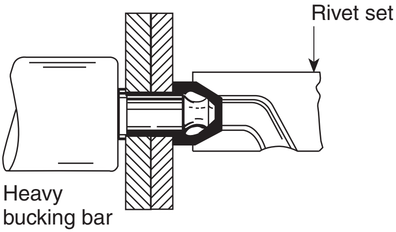
To install a Hi-Shear rivet:

1. Tap pin into a hole that has been drilled and reamed to an interference fit.
2. The grip length of the pin must be such that no more than 1/16-inch protrudes from the material.
3. A collar is placed over the end of the pin and special rivet set in a rivet gun swages the collar down into the groove of the pin.

- Hi-Shear pin rivets are removed by splitting the collar with a small, sharp chisel and tapping the pin from the hole.

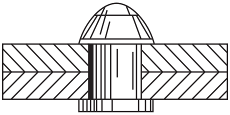
Hi-Shear Pin Rivet

Installation:

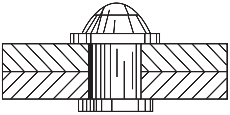


Inspection:

Proper Installation

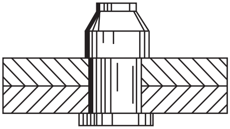


Correctly-driven pin rivet.

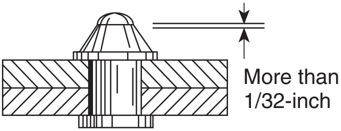


0.032-inch steel washer may be used to adjust grip length of pin.

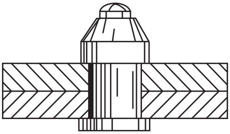
Improper Installation



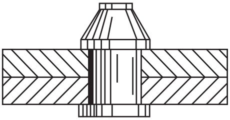
Collar is underdriven. It may be driven more.



Collar is overdriven. If there is more than 1/32-inch between shearing edge of pin and top of collar, collar should be removed and a new one installed.



Pin is too long. Remove collar, install washer, or use shorter pin.

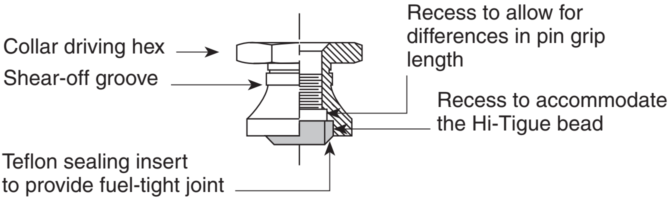


Pin is too short. Remove collar and use longer pin.

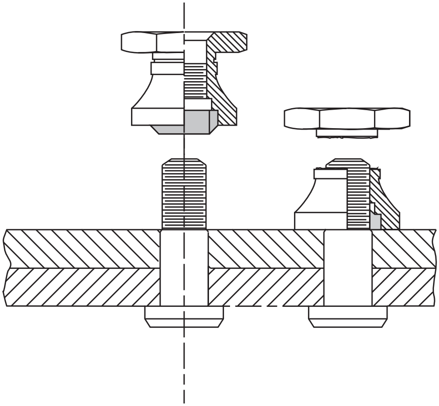
Hi-Lok Fasteners

- Hi-Lok/Hi-Tigue fasteners are a product of the Hi-Shear Corporation; they are an improvement of the Hi-Shear pin rivet.
- Consists of a special precision-threaded pin, with either a flush or protruding head and a special collar.
- The pin is inserted in a reamed hole to provide a slight (up to 0.002-inch) interference fit.
- Of the two counterbores in the collar, the smaller and deeper one compensates for differences of material thickness by providing space for the threads when the grip length is long. The larger counterbore accommodates the bead of the Hi-Tigue pin.
- A Teflon insert forms a fluid-tight seal between the pin and the collar, allowing use in fuel tanks without the need for any sealant.

Hi-Lok/Hi-Tigue Fastener



Installation of a protruding-head Hi-Lok Fastener

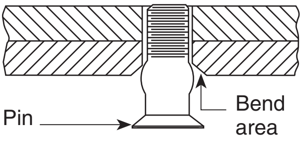


Installation:

1. The collar is started on the pin by hand, then continued by an electric or pneumatic driving tool. The tool has a hex wrench tip that fits into a hexagonal hole in the end of the pin to hold it and prevent its turning while the collar is being driven.
2. A socket that exactly fits the collar driving hex turns it; as the collar contacts the surface of the material being joined, it pulls the pin up tightly and clamps the structural parts together.
3. Continued turning of the driving hex breaks it off at the shear-off groove, ensuring that the minimum-weight fastener is properly torqued without the need of an accurately-calibrated torque wrench.

Hi-Tigue Fasteners

Hi-Tigue Fastener



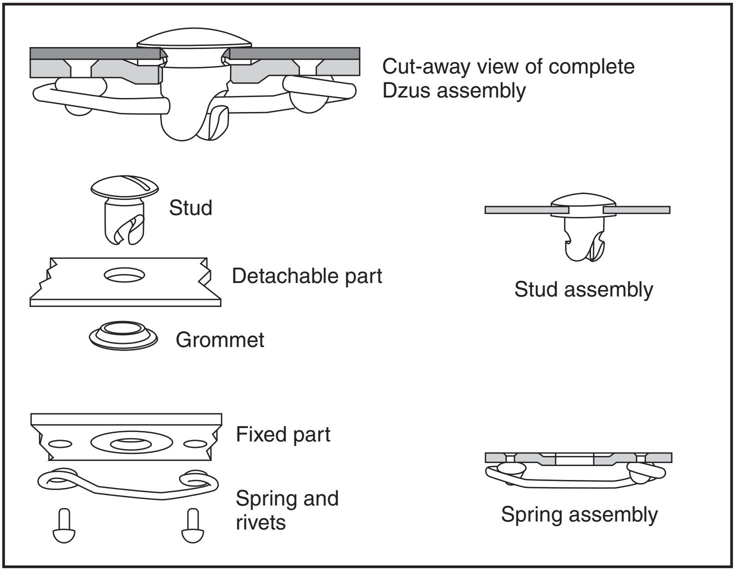
- Similar to the Hi-Lok, except the pin has a slightly enlarged bead near the threaded area of the pin.
- The hole should be drilled and reamed so the bead area will have between a 0.002 and 0.004-inch interference fit.
- The pin is driven into the prepared hole with a conventional rivet gun and the opposite side of the material is supported by a draw bar whose hole just fits over the pin.
- The interference fit holds the pin while the collar is driven and therefore does not need to be held with a hex wrench (as is done with the Hi-Lok pin).

Both the Hi-Lok and Hi-Tigue fasteners can be driven with an open end or box wrench, and the Hi-Lok pin can be held with an Allen wrench. Both fasteners may be removed by unscrewing the collar using a pair of vise-grip pliers or cutting away the collar with a hollow mill-type cutter. The pin may be reused if it is not damaged.

8.5 Cowling Fasteners

Aircraft cowling require fasteners that allow the pilot to open the cowling for preflight inspection without requiring special tools. Some fasteners hold the cowling tightly in place, yet allow it be opened with a quarter of a turn with a screwdriver, or even with a coin. The Dzus (pronounced zoos) fastener is one of the oldest and most popular cowling fastener.

Other fasteners, notably the Camloc and Airloc, are different physically but operate on the same principle as the Dzus, and are used for the same applications. Both of these fasteners turn a cross pin in the stud into a cam-shaped receptacle. In the Camlok fastener, the pin is spring loaded, and in the Airloc, the receptacle is made of spring steel.



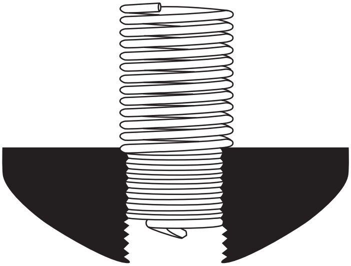
- A wire spring is riveted across the hole in the fixed part of the cowling and a notched stud is assembled in the detachable part.
- The stud is held in its hole with an aluminum grommet that is swaged into the hole so it fills the notch just under the head of the stud, allowing it to turn but preventing it from falling out.

- When the cowling is closed, the stud fits through the hole in the fixed part and the notch straddles the spring.
- A clockwise quarter turn forces the cam-shaped notch to pull the spring up and hold the detachable part of the cowling tight against the fixed structure.

8.6 Thread Repair Hardware

There are a number of aluminum castings in an aircraft, particularly in the engine. These castings are relatively soft and the threads are easy to strip out, so provisions are made to repair the damage rather than replace the expensive component.

Helicoil Insert



One of the handiest and most useful thread repair tools is the Helicoil insert. Damaged threads are drilled out with a special drill and new threads are tapped in using a special Helicoil tap.

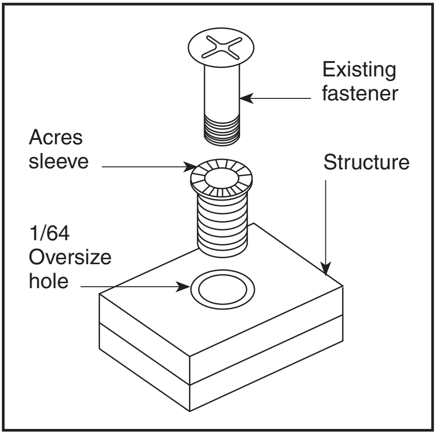
Helicoil inserts are used not only in repair work, but some engine manufacturers use them rather than bushings for the threads in the spark plug holes. The inserts give more durable threads than the cast aluminum cylinder head and may be replaced if they are ever damaged.

1. The insert, a coil of stainless steel wire with a diamond-shaped cross-section, is placed on the insertion tool with the slot in the end of the tool straddling a driving tang at the end of the insert.
2. As the insert is screwed into the new threads, it is wound tighter and its outside diameter decreases enough that it can screw in easily.
3. When the insert is screwed in all the way, the tool is reversed, the driving tang breaks off and the spring force of the insert expands it outward, holding it tightly in the threads.
4. The inside of the insert now acts as the new threads into which the bolt can be screwed.

Acres Sleeves

Corrosion often damages the threaded area in aluminum alloy castings; these can be repaired with Acres sleeves.

1. The damaged hole is drilled out 1/64-inch oversize to clean up the damage or corrosion.
2. A bonding agent is applied to the outside of the insert and it is pressed into the hole.
3. When the bonding agent cures the threads on the inside, the sleeve allows the original fastener to be installed.
4. Grooves around the outside of an Acres sleeve allows it to be broken off to a length correct for the material into which it is inserted and to hold the bonding agent.



Section 9: Metal Aircraft Fabrication

9.1 Sheet Metal Layout and Forming

Definitions

bend radius (BR)—The radius of the *inside* of the bend.

bend allowance—The actual amount of metal used in the bend.

setback (SB)—The distance between the bend tangent line and the mold line.

K—A multiplier used to find the bend allowance for bends of angles other than 90°.

neutral line—The line through a material that has no stresses imposed by a bend; material along the neutral axis neither shrinks nor stretches when the material is bent.

mold line—The extension of the flat side of an object beyond the radius.

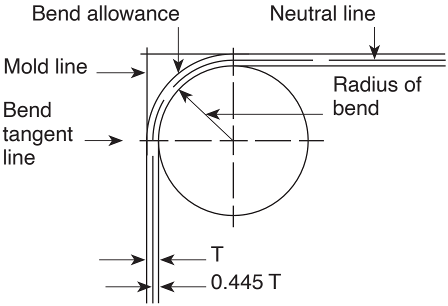
sight line—A line drawn on a sheet metal layout that is placed directly below the nose of the radius bar in a leaf brake.

open angle—A bend in which the metal is bent less than 90°.

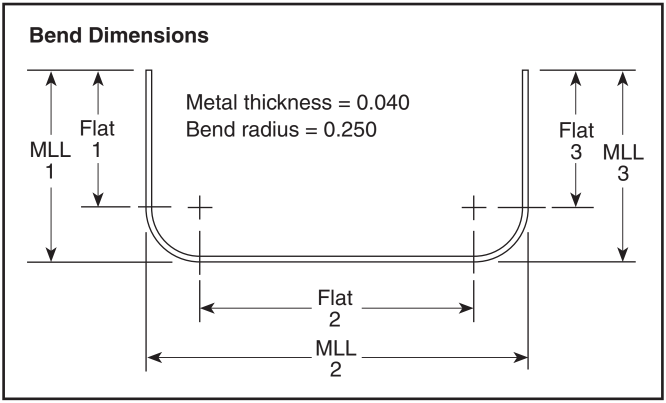
closed angle—A bend in which the metal is bent more than 90°.

bend tangent line—The line in a sheet metal layout that marks the end of a flat surface and the beginning of the bend.

Bend Nomenclature



Layout Procedure



Example

MLL 1 = 1.00 inch
MLL 2 = 2.00 inch
MLL 3 = 1.00 inch

BR = 0.25 inch
Thickness = 0.040 inch

1. Find the setback by adding the bend radius and the metal thickness.

$$SB = (BR + MT) \times K$$
$$= (0.250 + 0.040) \times 1$$
$$= 0.290 \text{ inch}$$

The value of the constant K can be found in the chart on Pages 212 through 214.

For a 90° bend, $K = 1$

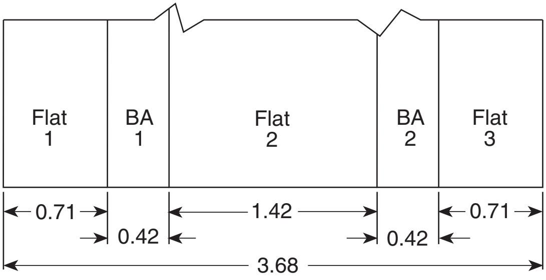
2. Find the length of flat 1 by subtracting the setback from mold line length 1.

$$\text{Flat } 1 = \text{MLL } 1 - \text{setback}$$
$$= 1.00 - 0.290$$
$$= 0.710$$

3. Find the bend allowance by using the chart on Pages 214 through 216.

Follow the 0.040 metal thickness row across to the column for 1/4-inch bend radius. The top number is the amount of bend allowance for a 90° bend, and the bottom number is the amount of material used for each degree of bend. In the example, a 90° bend in a piece of 0.040 sheet metal using a 1/4-inch bend radius requires 0.421 inch of metal.

Flat Pattern Layout



4. Find the length of flat 2 by subtracting two setbacks from mold line length 2.

   Flat 2 = MLL 2 – 2 setbacks

   = 2.00 – 2(0.290)

   = 1.42 inch

5. Bend allowance 2 is the same as bend allowance 1.

   BA 2 = 0.421 inch

6. Find the length of flat 3 by subtracting the setback from mold line length 3.

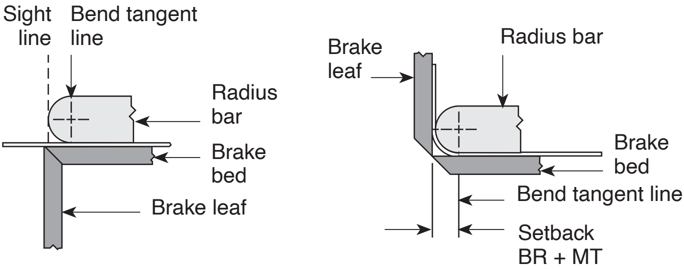
   Flat 3 = MLL 3 – Setback

   = 1.00 – 0.290

   = 0.710 inch

7. Cut the material 3.68 inches wide and as long as needed. Mark the bend tangent lines with a sharp-pointed soft lead pencil.

Correct placement of metal in the brake



1. Clamp the metal in the brake with the bend tangent lines even with the beginning of the radius of the radius bar.
2. You can determine this position by drawing a sight line inside the bend allowance material. Draw this line one bend radius from the bend tangent line.
3. Position the material so this sight line is directly below the edge of the radius block when viewing it perpendicular to the surface of the metal.
4. When the brake leaf is raised, the metal will form smoothly around the radius bar.

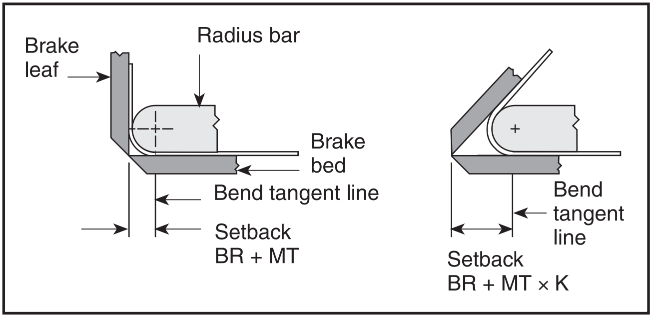
9.2 Minimum Bend Radii for 90° Bends in Aluminum Alloys

Alloy and Temper	**Sheet Thickness**							
	0.020	**0.025**	**0.032**	**0.040**	**0.050**	**0.063**	**0.071**	**0.080**
2024-O[1]	1/32	1/16	1/16	1/16	1/16	3/32	1/8	1/8
2024-T4[1,2]	1/16	1/16	3/32	3/32	1/8	5/32	7/32	1/4
5052-O	1/32	1/32	1/16	1/16	1/16	1/16	1/8	1/8
5052-H34	1/32	1/16	1/16	1/16	3/32	3/32	1/8	1/8
6061-O	1/32	1/32	1/32	1/16	1/16	1/16	3/32	3/32
6061-T4	1/32	1/32	1/32	1/16	1/16	3/32	5/32	5/32
6061-T6	1/16	1/16	1/16	3/32	3/32	1/8	3/16	3/16
7075-O	1/16	1/16	1/16	1/16	3/32	3/32	5/32	3/16
7075-W	3/32	3/32	1/8	5/32	3/16	1/4	9/32	5/16
7075-T6[1]	1/8	1/8	1/8	3/16	1/4	5/16	3/8	7/16

[1] Clad sheet may be bent over a slightly smaller radii than the corresponding tempers of bare alloy sheets.

[2] Immediately after quenching, this alloy may be formed over appreciably smaller radii.

9.3 Setback



Setback for a 90° bend is the bend radius plus the metal thickness (BR + MT). For any angle other than 90°, the sum of the bend radius and the metal thickness must be multiplied by the value of “K” found in the setback (K) chart below.

Setback (K) Chart

Degrees	K
1	0.00873
2	0.01745
3	0.02618
4	0.03492
5	0.04366
6	0.05241
7	0.06116
8	0.06993
9	0.07870
10	0.08749
11	0.09629
12	0.10510
13	0.11393
14	0.12278

Degrees	K
15	0.13165
16	0.14054
17	0.14945
18	0.15838
19	0.16734
20	0.17633
21	0.18534
22	0.19438
23	0.20345
24	0.21256
25	0.22169
26	0.23087
27	0.24008
28	0.24933

Degrees	K
29	0.25862
30	0.26795
31	0.27732
32	0.28674
33	0.29621
34	0.30573
35	0.31530
36	0.32492
37	0.33459
38	0.34433
39	0.35412
40	0.36397
41	0.37388
42	0.38386
43	0.39391
44	0.40403
45	0.41421
46	0.42447
47	0.43481
48	0.44523
49	0.45573
50	0.46631
51	0.47697
52	0.48773
53	0.49858
54	0.50952
55	0.52057
56	0.53171
57	0.54295
58	0.55431
59	0.56577
60	0.57735
61	0.58904
62	0.60086
63	0.61280
64	0.62487
65	0.63707
66	0.64941
67	0.66188
68	0.67451
69	0.68728
70	0.70021
71	0.71329
72	0.72654
73	0.73996
74	0.75355
75	0.76733
76	0.78128
77	0.79543
78	0.80978
79	0.82434
80	0.83910
81	0.85408
82	0.86929
83	0.88472
84	0.90040
85	0.91633
86	0.93251
87	0.80978
88	0.96569
89	0.9827
90	1.0000
91	1.0176
92	1.0355
93	1.0538
94	1.0724
95	1.0913
96	1.1106
97	1.1303
98	1.1504
99	1.1708
100	1.1917
101	1.2131
102	1.2349
103	1.2572
104	1.2799
105	1.3032
106	1.3270
107	1.3514
108	1.3764

Degrees	K
109	1.4019
110	1.4281
111	1.4550
112	1.4826
113	1.5108
114	1.5399
115	1.5697
116	1.6003
117	1.6318
118	1.6643
119	1.6977
120	1.7320
121	1.7675
122	1.8040
123	1.8418
124	1.8807
125	1.9210
126	1.9626
127	2.0057
128	2.0503
129	2.0965
130	2.1445
131	2.1943
132	2.2460
133	2.2998
134	2.3558
135	2.4142
136	2.4751
137	2.5386
138	2.6051
139	2.6746
140	2.7475
141	2.8239
142	2.9042
143	2.9887
144	3.0777

Degrees	K
145	3.1716
146	3.2708
147	3.3759
148	3.4874
149	3.6059
150	3.7320
151	3.8667
152	4.0108
153	4.1653
154	4.3315
155	4.5107
156	4.7046
157	4.9151
158	5.1455
159	5.3995
160	5.6713
161	5.9758
162	6.3137
163	6.6911
164	7.1154
165	7.5957
166	8.1443
167	8.7769
168	9.5144
169	10.385
170	11.430
171	12.706
172	14.301
173	16.350
174	19.081
175	22.904
176	26.636
177	38.188
178	57.290
179	114.590
180	Infinite

9.4 Bend Allowance Chart

The top number in each group of numbers (at the intersections of the metal thickness rows and bend radius columns) is the bend allowance for a 90° bend. The bottom number is the bend allowance for each degree of bend.

Metal Thickness	Radius of bend (inches)						
	1/32	**1/16**	**3/32**	**1/8**	**5/32**	**3/16**	**7/32**
0.020	.062	.113	.161	.210	.259	.309	.358
	.000693	.001251	.001792	.002333	.002874	.003433	.003977
0.025	.066	.116	.165	.214	.263	.313	.362
	.000736	.001294	.001835	.002376	.002917	.003476	.004017
0.028	.068	.119	.167	.216	.265	.315	.364
	.000759	.001318	.001859	.002400	.002941	.003499	.004040
0.032	.071	.121	.170	.218	.267	.317	.366
	.000787	.001345	.001886	.002427	.002968	.003526	.004067
0.038	.075	.126	.174	.223	.272	.322	.371
	.000837	.001396	.001937	.002478	.003019	.003577	.004118
0.040	.077	.127	.176	.224	.273	.323	.372
	.000853	.001411	.001952	.002493	.003034	.003593	.004134
0.051		.134	.183	.232	.280	.331	.379
		.001413	.002034	.002575	.003116	.003675	.004215
0.064		.144	.192	.241	.290	.340	.389
		.001595	.002136	.002676	.003218	.003776	.004317
0.072			.198	.247	.296	.346	.394
			.002202	.002743	.003284	.003842	.004283
0.078			.202	.251	.300	.350	.399
			.002249	.002790	.003331	.003889	.004430
0.081			.204	.253	.302	.352	.401
			.002272	.002813	.003354	.003912	.004453
0.091			.212	.260	.309	.359	.408
			.002350	.002891	.003432	.003990	.004531
0.094			.214	.262	.311	.361	.410
			.002374	.002914	.003455	.004014	.004555
0.102				.268	.317	.367	.416
				.002977	.003518	.004076	.004617

Metal Thickness	Radius of bend (inches) 1/32	1/16	3/32	1/8	5/32	3/16	7/32
0.109				.273	.321	.372	.420
				.003031	.003572	.004131	.004672
0.125				.284	.333	.383	.432
				.003156	.003697	.004256	.004797
0.156					.355	.405	.453
					.003939	.004497	.005038
0.188						.417	.476
						.004747	.005288

Metal Thickness	Radius of bend (inches) 1/32	1/16	3/32	1/8	5/32	3/16	7/32
0.020	.406	.455	.505	.554	.603	.702	.799
	.004515	.005056	.005614	.006155	.006695	.007795	.008877
0.025	.410	.459	.509	.558	.607	.705	.803
	.004558	.005098	.005657	.006198	.006739	.007838	.008920
0.028	.412	.461	.511	.560	.609	.708	.805
	.004581	.005122	.005680	.006221	.006762	.007862	.008944
0.032	.415	.463	.514	.562	.611	.710	.807
	.004608	.005149	.005708	.006249	.006789	.007889	.008971
0.040	.421	.469	.520	.568	.617	.716	.813
	.004675	.005215	.005774	.006315	.006856	.007955	.009037
0.051	.428	.477	.527	.576	.624	.723	.821
	.004756	.005297	.005855	.006397	.006934	.008037	.009119
0.064	.437	.486	.536	.585	.634	.732	.830
	.004858	.005399	.005957	.006498	.007039	.008138	.009220
0.072	.443	.492	.542	.591	.639	.738	.836
	.004924	.005465	.006023	.006564	.007105	.008205	.009287
0.078	.447	.496	.546	.595	.644	.745	.840
	.004963	.005512	.006070	.006611	.007152	.008252	.009333
0.081	.449	.498	.548	.598	.646	.745	.842
	.004969	.005535	.006094	.006635	.007176	.008275	.009357
0.091	.456	.505	.555	.604	.653	.752	.849
	.005072	.005613	.006172	.006713	.007254	.008353	.009435
0.094	.459	.507	.558	.606	.655	.754	.851
	.005096	.005637	.006195	.006736	.007277	.008376	.009458

Metal Thickness	Radius of bend (inches)						
	1/32	1/16	3/32	1/8	5/32	3/16	7/32
0.102	.464	.513	.563	.612	.661	.760	.857
	.005158	.005699	.006257	.006798	.007339	.008439	.009521
0.109	.469	.518	.568	.617	.665	.764	.862
	.005213	.005754	.006312	.006853	.007394	.008493	.009575
0.125	.480	.529	.579	.628	.677	.776	.873
	.005338	.005878	.006437	.006978	.007519	.008618	.009700
0.156	.502	.551	.601	.650	.698	.797	.895
	.005579	.006120	.006679	.007220	.007761	.008860	.009942
0.188	.525	.573	.624	.672	.721	.820	.917
	.005829	.006370	.006928	.007469	.008010	.009109	.010191
0.250	.568	.617	.667	.716	.764	.863	.961
	.006313	.006853	.007412	.007953	.008494	.009593	.010675

The empirical formula for bend allowance for each degree of bend is:

Bend Allowance = (0.01743 R) + (0.0078 T)
R = Bend Radius
T = Metal Thickness

9.5 Rivets and Riveting

Solid rivets are the most widely-used fastening devices for sheet metal aircraft construction.

Personal protection equipment: The technician using these tools, and any personnel close to the work area, must wear safety glasses for eye protection. Also ear buds, ear plugs, or other appropriate ear protection should be worn to prevent both short-term and long-term hearing problems.

Alternatives to Riveting

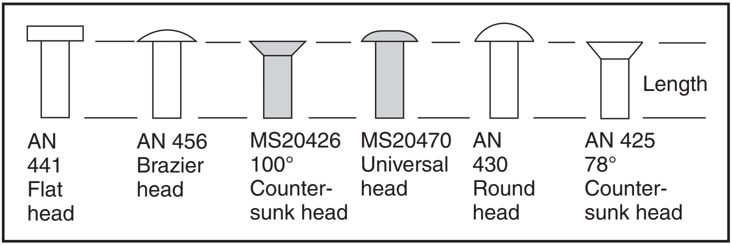
- Milled skins reduce the number of stringers and stiffeners, and eliminate the need for many rivets.
- Composite structure is bonded and does not require rivets.
- Welding has not proven to be a viable alternative because of the nature of sheet aluminum alloy.

Aircraft Solid Rivets

Most of the rivets used in aircraft structure range in diameter from 3/32-inch to 1/4-inch and most are made of an aluminum alloy. They are available with either a protruding head or a flush head.

Rivet Head Shapes

After WW II, aircraft manufactures adopted the universal head rivet to replace all protruding head rivets, and the 100° countersunk head rivet to be used for almost all flush riveting requirements.



- AN 441 — Used in internal structure
- AN 456 — Replaced with MS20470

- MS20426 — Most widely-used flush rivet
- MS20470 — Most widely used protruding head rivet
- AN 430 — Replaced with MS20470
- AN 425 — Replaced with MS20426

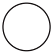
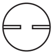
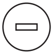
Rivet Material

- Nonstructural applications of 1100 or 3003 aluminum may be riveted with the soft 1100 (A) rivet.
- Bare or clad 2024-T4 aluminum alloy is generally riveted with 2117 (AD) rivets. AD rivets may be driven as they are received from the manufacturer without additional heat treatment.
- When greater strength is needed than can be provided by an AD rivet, a 2017 (D) or 2024 (DD) rivet may be used. Both D and DD rivets require heat treatment before they are driven. These rivets are soft enough to drive immediately after they are removed from the quench bath, but will begin to harden within 10 minutes if left at room temperature. The hardening can be delayed for several days if they are immediately stored in a sub-zero refrigerator.
- Magnesium structural parts may be joined with 5056 aluminum alloy (B) rivets. B rivets may be driven as received from the manufacturer.
- High-strength aluminum alloy with zinc as its chief alloying agent must be riveted with 7050-T73 and 7075-T73 rivets.
- Titanium structure must be riveted with titanium rivets.

Rivet Diameter

- Diameter chosen must allow a riveted joint to fail by the rivets shearing rather than the sheet metal tearing at the rivet holes.
- A general rule of thumb is for the rivet diameter to be three times the thickness of the thickest sheet being joined.
- Refer to the charts on Pages 223–224 to select the diameter and number of rivets to use in a repair.
- The columns in these charts represent the rivet diameter, and the rows the metal thickness. The numbers represent the number of rivets per inch for a single lap splice.
- One number in each column is underlined. A riveted joint using rivets listed below the underlined number will fail by the rivets shearing, and those above this underline will fail by tearing out of the rivet holes.

Rivet head markings identify the metal of which rivet is made.

Head Mark	Alloy	Code
Plain 	1100	A
Recessed dot 	2117 T	AD
Raised dot 	2017 T	D
Raised double dash 	2024 T	DD
Raised cross 	5056 H	B
Three raised dashes 	7075 T73	
Raised circle 	7050 T73	E
Recessed large and small dots 	Titanium	
Recessed dash 	Corrosion resistant steel	F
Recessed triangle 	Carbon Steel	

Number of Rivets or Bolts Required for Single-Lap Splices in Bare 2017, Clad 2017, Clad 2024-T3 Sheet, and 2024-T3 Plate, Bar, Rod, Tube and Extrusions

Thickness of metal (inches)	Number of AD protruding head rivets needed per inch width "W"					No. of Bolts
	Rivet Diameter					
	3/32	**1/8**	**5/32**	**3/16**	**1/4**	**AN-3**
0.016	6.5	4.9				
0.020	**6.5**	4.9	3.9			
0.025	6.9	**4.9**	3.9			
0.032	8.9	4.9	3.9	3.3		
0.036	10.0	5.6	**3.9**	3.3	2.4	
0.040	11.1	6.2	4.0	**3.3**	2.4	
0.051		7.9	5.1	3.6	**2.4**	3.3
0.064		9.9	6.5	4.5	2.5	3.3
0.081		12.5	8.1	5.7	3.1	3.3
0.091			9.1	6.3	3.5	3.3
0.102			10.3	7.1	3.9	**3.3**
0.128			12.9	8.9	4.9	3.3

NOTES:

1. For stringers in the upper surface of a wing, or in a fuselage, 80% of the number of rivets shown may be used.
2. For intermediate frames, 60% of the number of rivets shown may be used.
3. For single-lap sheet joints, 75% of the number shown may be used.

Number of Rivets or Bolts Required for Single-Lap Splices in 5052 (All Hardness) Sheet

Thickness of metal (inches)	Number of AD protruding head rivets needed per inch width “W”					No. of Bolts
	Rivet Diameter					
	3/32	**1/8**	**5/32**	**3/16**	**1/4**	**AN-3**
0.016	6.3	4.7				
0.020	6.3	4.7	3.8			
0.025	6.3	4.7	3.8			
0.032	**6.3**	4.7	3.8	3.2		
0.036	7.1	4.7	3.8	3.2	2.4	
0.040	7.9	**4.7**	3.8	3.2	2.4	
0.051	10.1	5.6	**3.8**	3.2	2.4	
0.064	12.7	7.0	4.6	**3.2**	2.4	
0.081		8.9	5.8	4.0	**2.4**	3.2
0.091		10.0	6.5	4.5	2.5	3.2
0.102		11.2	7.3	5.1	2.8	**3.2**
0.128			9.2	6.4	3.5	3.2

NOTES:

1. For stringers in the upper surface of a wing, or in a fuselage, 80% of the number of rivets shown may be used.
2. For intermediate frames, 60% of the number of rivets shown may be used.
3. For single-lap sheet joints, 75% of the number shown may be used.

Examples of Rivet Selection

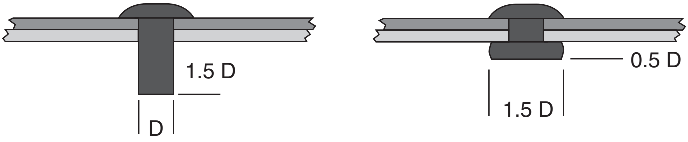
— Use the chart on Page 223 to find the minimum number of rivets needed to make a splice on an intermediate frame using a single-lap joint, 2024 clad sheet aluminum 0.040-inch thick, with 1/8-inch 2117-AD rivets.

1. At the intersection of the 1/8-inch rivet column and the 0.040-inch metal thickness row, notice that 6.2 rivets per inch are needed for full strength. This choice is below the underlined number in this column, indicating the joint will fail by the rivets shearing, as it should, rather than the rivet holes tearing out.
2. According to NOTE 2, an intermediate frame requires only 60% of this number, therefore 3.72 rivets per inch is required for the splice.

— Use the chart on Page 224 to find the minimum number of rivets needed to make a single-lap joint in 5052-H36 sheet aluminum 0.064-inch thick, with 5/32-inch 2117-AD rivets.

1. At the intersection of the 5/32-inch rivet column and the 0.064-inch metal thickness row, notice that 4.6 rivets per inch are needed for full strength. This choice is below the line in this column, indicating the joint will fail by the rivets shearing, as it should, rather than the rivet holes tearing out.
2. A single-lap sheet joint requires only 75% of this number, therefore 3.45 rivets per inch is required for the joint.

Determining the length of a rivet for a properly formed shop head

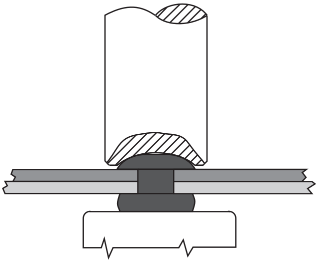


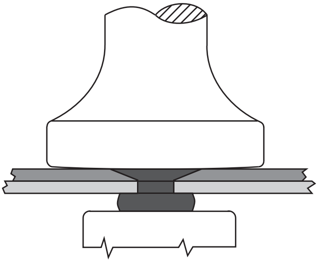
Rivet Length

- The shop head on a rivet should have a diameter of one and one-half times the diameter of the shank, and its thickness should be one-half of the shank diameter.
- To get this size head, the shank should stick through the material by a distance of one and one-half times the shank diameter.

Riveting Tools

Rivet Sets





- Rivet sets fit over the manufactured head of a rivet and are driven by the rivet gun.
- For protruding-head rivets, the cup in the rivet set should have a slightly larger radius than the head of the rivet.
- The rivet set for driving flush rivets is slightly crowned and highly polished so it will not mark the skin.

Bucking Bars

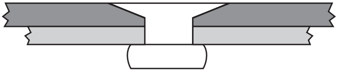
- The rivet set is held tightly against the manufactured head of the rivet, and a bucking bar of hardened and polished steel is held squarely against the end of the rivet shank. The blows from the rivet gun cause the bucking bar to bounce on the end of the rivet shank and flatten it.
- The shape of a bucking bar must be chosen so it can fit squarely on the end of the rivet, and the weight of the bar must be compatible with the rivet diameter.

Bucking bar selection

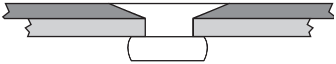
Rivet Diameter (inch)	**Bucking Bar Weight (pounds)**
3/32	2 to 3
1/8	3 to 4
5/32	3.5 to 4.5
3/16	4 to 5
1/4	5 to 6.5

Installing Flush Rivets

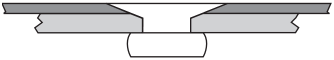
- If the top skin is thicker than the head of the rivet, it should be countersunk to a depth that will cause the top of the rivet to be flush with the skin.



- It is permissible, but not recommended, to countersink the top skin if its thickness is the same as the thickness of the rivet head.



- If the top skin is thinner than the rivet head, the skin should be dimpled either by coin or radius dimpling.

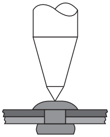


Blind Rivet Code

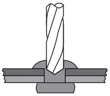
When team riveting, with the gunner unable to see or hear the bucker, this code serves for communications:

One Tap — Start riveting
Two Taps — Rivet OK
Three Taps — Bad rivet, mark it and move to next one.

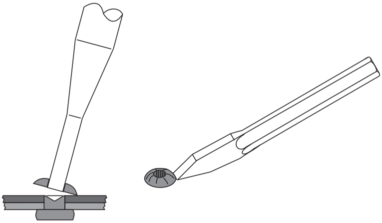
Removal of Damaged Rivets



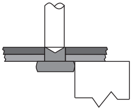
Make center punch mark in center of manufactured head.



Drill through head with drill one size smaller than used for rivet.

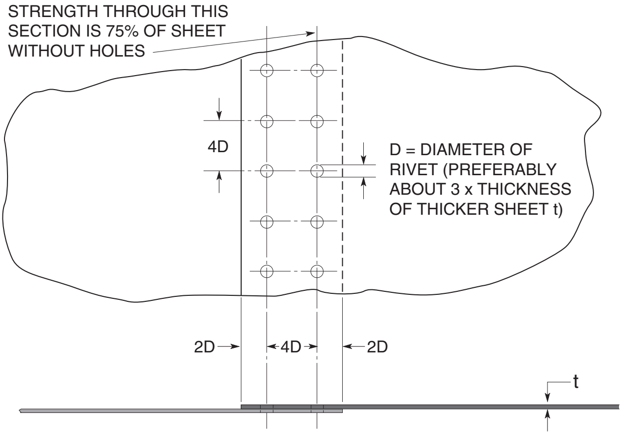


Use pin punch the size of the hole, pry the head off rivet or use cape chisel to cut head off.

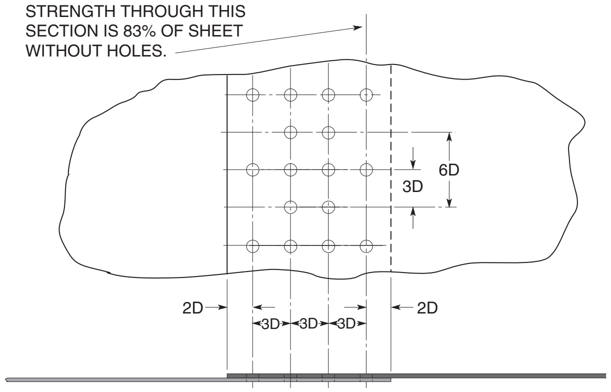


Buck up metal with bucking bar beside shop head and use pin punch to drive shank from the metal.

Minimum Rivet Spacing and Edge Distance



DOUBLE ROW



TRIPLE OR MULTIPLE ROWS

You must determine that the repaired structure will be at least as strong and rigid as the original, and if the repair is made to an external skin it must have no adverse effect on the airflow. To obtain proper strength from a riveted joint, the rivet spacing and edge distance shown here must be observed. If a rivet hole has been damaged when a rivet is being replaced, the next size larger rivet may be used provided the rivet spacing and edge distance are within the limits shown here.

9.6 Aircraft Welding

Types of Welding:

- Gas Welding
- Electric Arc Welding
- Shield Metal Arc Welding (SMAW)
- Gas Metal Arc Welding (GMAW)
- Gas Tungsten Arc Welding (GTAW)
- Electric Resistance Welding
- Spot Welding
- Seam Welding
- Plasma Arc Welding (PAW)

Welding Gases:

- Acetylene
- Argon
- Helium
- Hydrogen
- Oxygen

Characteristics of a Good Weld

A completed weld should have the following characteristics:

1. The seam should be smooth, the bead ripples evenly spaced, and of a uniform thickness.
2. The weld should be built up, slightly convex, thus providing extra thickness at the joint.
3. The weld should taper off smoothly into the base metal.
4. No oxide should be formed on the base metal close to the weld.
5. The weld should show no signs of blowholes, porosity, or projecting globules.
6. The base metal should show no signs of burns, pits, cracks, or distortion.

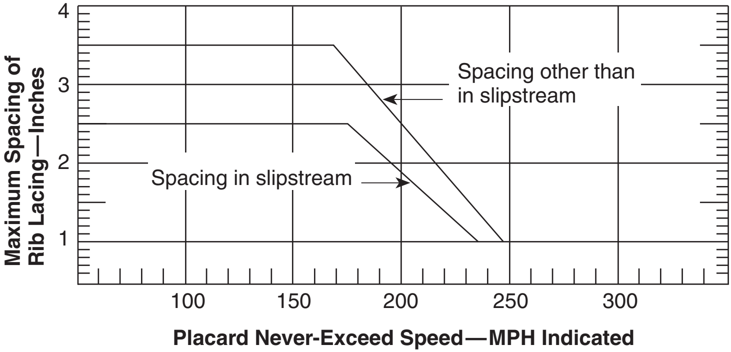
Section 10: Aircraft Fabric Covering

Almost all modern aircraft are of either all-metal or composite construction. Fabric covering is used only on older airplanes and some modern ultralight aircraft.

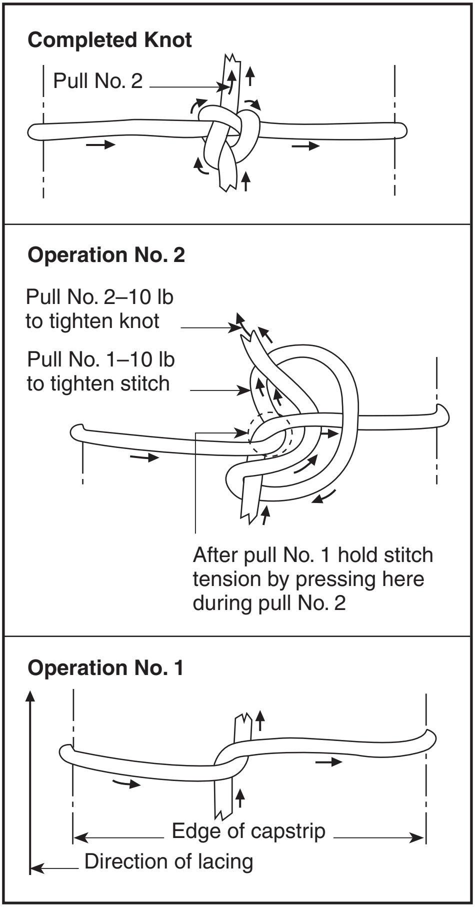
When a fabric-covered aircraft is being recovered, the type of materials crafted in its original manufacture must be used. One of the modern materials (much stronger and of longer-life) may be used if it has been approved as an alteration for the particular aircraft. This approval is normally accomplished with a Supplemental Type Certificate obtained by the manufacturer of the covering system.

10.1 Rib Stitch Spacing

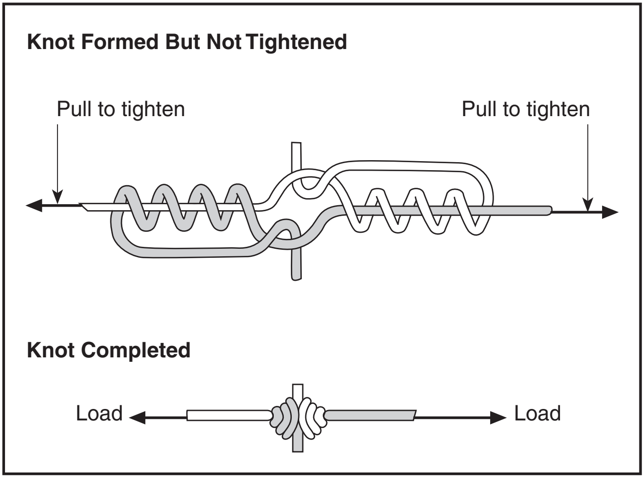
If for any reason the original rib stitch spacing cannot be determined, use the spacing indicated by the chart below. For the purpose of this chart the slipstream is the diameter of the propeller plus one rib on each side.



10.2 Rib Stitch Knots



A modified seine knot is used to tie the rib stitch cord around each rib.



A splice knot is used to join two pieces of waxed rib stitch cord.

Section 11: Corrosion Detection and Control

11.1 Types of Corrosion

There are several types of corrosion that attack aircraft. Some types, like iron rust, continue to eat the metal until it is all gone; but others, like aluminum oxidization, form a dense film that prevents oxygen from reaching the metal, and the corrosive action almost stops.

Appearance of Corrosion on Various Metals

Alloy	**Type of Attack to Which Alloy is Susceptible**	**Appearance of Corrosion Product**
Magnesium	Highly susceptible to pitting	White, powdery, snowlike mounds and white spots on the surface
Low alloy steel	Surface oxidation and pitting, surface, and intergranular	Reddish-brown oxide (rust)
Aluminum	Surface pitting, intergranular, exfoliation, stress-corrosion and fatigue cracking, and fretting	White to gray powder
Titanium	Highly corrosion resistant; extended or repeated contact with chlorinated solvents may result in degradation of the metal's structural properties at high temperature	No visible corrosion products at low temperature. Colored surface oxides develop above 700°F (370°C)
Cadmium	Uniform surface corrosion; used as sacrificial plating to protect steel	From white powdery deposit to brown or black mottling of the surface

(continued)

Appearance of Corrosion on Various Metals		
Alloy	**Type of Attack to Which Alloy is Susceptible**	**Appearance of Corrosion Product**
Stainless Steels (300–400 series)	Crevice corrosion; some pitting in marine environments; corrosion cracking; intergranular corrosion (300 series); surface corrosion (400 series)	Rough surface; sometimes a uniform red, brown stain
Nickel-base (Inconel, Monel)	Generally has good corrosion-resistant qualities; susceptible to pitting in sea water	Green powdery deposit
Copper-base brass, bronze	Surface and intergranular corrosion	Blue or blue-green powdery deposit
Chromium (plate)	Pitting (promotes rusting of steel where pits occur in plating)	No visible corrosion products; blistering of plating due to rusting and lifting
Silver	Will tranish in the presence of sulfur	Brown to black film
Gold	Highly corrosion-resistant	Deposits cause darkening of reflective surfaces
Tin	Subject to whisker growth	Whisker-like deposits

11.2 Oxidation

Type	**Reaction Upon Exposure to Air**	**Protect Against**
Aluminum Oxidation	• When pure aluminum is exposed to the air, a chemical reaction takes place between the metal and the oxygen. • Aluminum oxide forms on the surface and produces a dull, rough appearance. • Once the oxide forms, it insulates the surface from the air and any further reaction continues at a greatly reduced rate, or almost stops.	• Protect aluminum alloys from oxidation by electrolytically or chemically forming a hard oxide film on its surface.
Iron Oxidation	• When any metal containing iron is exposed to the air, iron oxide (or, rust) forms. Iron oxide is porous, and the iron will continue to react rust until it is completely destroyed.	Protect metals containing iron from rust: • *temporarily* by covering the surface with oil or grease, or • *permanently* by plating it with cadmium or chromium, or by covering it with paint.

11.3 Surface and Pitting Corrosion

When unprotected metal is exposed to an atmosphere containing industrial contaminants, exhaust or battery fumes, corrosion will form on the surface giving it a dull appearance.

Reaction	Results	Appearance
• Contaminants react with the metal, changing microscopic amounts of it into the salts of corrosion.	• If these deposits are not removed and the surface protected, pits of corrosion will form at localized anodic areas. Corrosion will continue in these pits, changing the metal into salts.	• Pitting corrosion shows up as small blisters on the surface of the metal. • Blisters are full of white powder.

11.4 Intergranular Corrosion

Aluminum alloys are made of tiny grains of aluminum and the various alloying elements.

- Heating the metal causes the alloying elements to go into a solid solution with the aluminum.
- Quenching the metal in cold water locks the alloying elements and the aluminum together into the tiny grains.

Reactions	1. As the metal cools, the grains enlarge. A delay in quenching for even a few seconds will allow the grains to become large enough to produce anodic and cathodic areas that allow intergranular corrosion to form.
Results	2. Corrosion started on the surface can reach the boundaries of some enlarged grains, and continue inside the metal. Electrolyte travels from the surface through the porous salts and along the grain boundaries.
Appearance	3. Intergranular corrosion is difficult to detect because it is inside the metal. It sometimes, but not always, shows up as a blister on the surface.
Detection	4. Intergranular corrosion can be detected by ultrasonic or X-ray inspection; once it is detected, the only sure fix is the replacement of the part.

Exfoliation Corrosion

- An extreme form of intergranular corrosion.
- Occurs chiefly in extruded materials such as channels or angles where the grain structure is layer-like, or laminar.
- Occurs along the grain boundaries, and causes the material to separate or delaminate. By the time it shows up on the surface, the strength of the metal has been destroyed.

11.5 Stress Corrosion

A type of intergranular corrosion that forms in a metal subjected to a tensile stress in the presence of a corrosive environment.

1. Stresses may come from improper quenching after heat treatment, from a fitting or bushing that has been pressed into a structural part with an interference fit, or from tapered pipe fittings.
2. Cracks caused by stress corrosion grow rapidly as the corrosive attack concentrates at the end of the crack, rather than along its sides as it does in other types of intergranular corrosion.
3. Visual inspection may indicate the presence of stress corrosion; but to determine the extent of the damage, dye penetrant, eddy current, or ultrasonic inspection must be used.

11.6 Galvanic Corrosion

Occurs any time two dissimilar metals are in electrical contact in the presence of an electrolyte. The rate at which corrosion occurs depends on the galvanic groups of the two metals. The greater the difference between the groups, the more active the corrosion.

Galvanic Grouping of Metals	
Group I	Magnesium and magnesium alloys
Group II	Aluminum, aluminum alloys, zinc, cadmium, and cadmium-titanium plate
Group III	Iron, steel (except stainless steel), lead, tin and their alloys
Group IV	Copper, brass, bronze, copper-beryllium, copper-nickel, chromium, nickel, nickel-base alloys, cobalt-base alloys, graphite, stainless steels, titanium, and titanium alloys

Galvanic Corrosion	
Cause	• Forms where dissimilar metal skins are riveted together, and where aluminum alloy inspection plates are attached with steel screws.
Results	• The material in the lower number group is the anode, and is the one corroded. When a steel screw (Group III) is used in 2024 aluminum alloy (Group II) the aluminum alloy will become the anode and is corroded. • When a sheet of 2024-T3 aluminum alloy (Group II) is riveted to a piece of magnesium alloy (Group I) the magnesium will corrode.

11.7 Concentration Cell Corrosion

Two types of concentration cell corrosion affect aircraft structure:

1. Low oxygen concentration cell corrosion attacks areas where oxygen is excluded from the surface. These areas are in the faying surface of riveted joints where skins overlap, under the ferrules on aluminum alloy tubing, and under nameplates and decals on aluminum alloy components.
2. High metal-ion concentration cell corrosion attacks areas in the open along the edges of lap joints in aircraft skins. Most generally, both types of corrosion occur at the same time in the same general areas of an aircraft structure.

11.8 Fretting Corrosion

Fretting corrosion forms between two surfaces that fit tightly together, but can move slightly relative to one another. These surfaces are not normally close enough together to shut out oxygen, so the protective oxide coatings can form on the surfaces. However, this coating is destroyed by the continued rubbing action.

- When the movement between the two surfaces is small, the debris between them does not have an opportunity to escape, and it acts as an abrasive further eroding the surfaces. Fretting corrosion around rivets in a skin is indicated by dark deposits streaming out behind the rivet heads.
- By the time fretting corrosion appears on the surface, enough damage is usually done that the parts must be replaced.

11.9 Filiform Corrosion

Filiform corrosion consists of threadlike filaments of corrosion on the surface of metals that are coated with organic substances such as paint films.

- Does not require light, electrochemical differences within the metal, or bacteria, but takes place only in relatively high humidity, between 65% and 95%.
- The threadlike filaments are visible under clear lacquers and varnishes, but also occur under opaque paint films such as polyurethane enamels, especially when an improperly cured wash primer has left some acid on the surface beneath the enamel.

11.10 Corrosion Control

The thin, highly reactive aircraft structural metals make them especially vulnerable to corrosion. Once corrosion has started in a structure, it opens the way for more, and the corrosion spreads until the structure is destroyed.

Corrosion cannot be prevented, but it can be controlled by eliminating one or more of the basic requirements for its formation:

1. Prevent the electrical potential difference within the metal.
2. Insulate the conductive path between areas of potential difference.
3. Eliminate any electrolyte that could form a conductive path on the surface of the metal.

Corrosion itself is highly complex, but its control is mainly a matter of good housekeeping:

1. Keep the structure clean and dry, and immediately repair any breaks in the finish.
2. Promptly remove any corrosion that is found, and treat the surface from which the corrosion was removed in order to neutralize any residue and inhibit further corrosion formation.

NOTE: Modern surface treatments, sealers, and finishes are complex, and they will not tolerate any improper procedures in mixing or application. It is imperative that the specific instructions from the manufacturer of these products be followed in detail.

Section 12: Nondestructive Inspection

12.1 Visual Inspection

NDI

The complexity, high cost, and long life of modern aircraft and engines have made nondestructive inspection, or NDI, an extremely important aspect of aviation maintenance.

Visual Inspection

Visual inspection, the least expensive and most widely-used inspection method, is an important adjunct to all other types of inspection. There are two basic types: surface inspection and internal inspection.

Surface Visual Inspection

- Requires a strong flashlight, a 2X to a 10X magnifying glass, and a mirror, preferably one with a ball joint.
- Flashlights used in an explosive environment such as in fuel tanks must be explosion proof. Flashlights with krypton and halogen bulbs give out far more light than standard incandescent bulbs.
- Cracks and deformations show up most clearly when the light is shined on the surface toward the viewer at a low angle to the surface.
- Any suspect area must be clean and free of all paint—and if warranted, inspected with some other NDI method such as a penetrant or eddy current inspection.

Internal Visual Inspection

Borescopes have made internal visual inspection practical as it is no longer necessary to disassemble an engine or a piece of airframe structure to see inside of it. Three types of internal visual inspection instruments are commonly used in aircraft maintenance shops:

1. A **rigid-tube borescope** has a controllable power source to regulate the intensity of the light produced by a lamp in the end of the scope tube. An orbital scan control on the body of the instrument allows different areas within the component to be scanned.
   a) Insert the tube into the appropriate inspection port and adjust the light.
   b) Aim the instrument at the area to be inspected and focus it to get the sharpest image.

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2. **Flexible fiber-optic scopes** consist of a light guide and an image guide made of bundles of transparent fibers enclosed inside a protective sheath. A power supply with a controllable light source is connected to the light guide, and an eyepiece lens allows the user to view the area at the end of the image guide. Bending and focusing controls guide the probe inside the component and focus the lens to get the clearest image of the area.
3. **Borescopes with video-imaging capability** have a sensor in the tip of the probe which acts as a miniature video camera. The image is digitized, enhanced, and displayed on a video monitor. Then it is recorded on video tape or a disk to provide a permanent record of the interior of the component.

12.2 Tap Testing

The tap test is an age-old technique for inspecting adhesively bonded composite parts such as honeycomb panels for flaws, delaminations, or damage. In this technique, you take a hand-held mass, such as a coin or a machined piece of metal, and tap on the surface:

- Tap the area to be inspected with the edge of the coin or metal piece.
  - —if there is no delamination, the coin will make a clear ringing sound.
  - —if there is delamination, the sound will be a dull thud.
- The coin-tap procedure is not quantitative, but it gives you an indication of whether or not further investigation is needed.

It is a simple and cheap method, but is also subjective, inaccurate, and highly affected by the inspector's hearing and background noise. Electronic digital tap hammers have been developed that are designed to significantly improve the classic tap testing method by eliminating reliance on the technician's auditory interpretation skills. The results are shown as a numerical display on a computer screen and can also be fed into a spreadsheet program.

12.3 Penetrant Inspection

Fluorescent and visible-dye penetrant inspection can be used on nonporous metallic or nonmetallic materials to detect faults that extend to the surface and are too small to be seen with normal visual inspection.

1. Part being inspected must be thoroughly clean and dry so the penetrant can get into any surface faults.
2. Penetrant must remain on the surface long enough to completely fill any existing fault. This is called the dwell time and it depends upon:
   a) The size of the anticipated fault
   b) The temperature of the part being inspected
3. Allow the appropriate dwell time, then wash the penetrant off the surface, taking care to not wash it out of any possible faults.

3 types of penetrants:	
Oil base (with additives)	—with a fluorescent dye and an emulsifier added, to make the penetrant removable with a hot water bath.
Oil base	—does not contain the emulsifier, so a separate emulsifier must be used.
Solvent-removable penetrant	—not removable with water, must be cleaned from the surface with a solvent. Solvent-removable penetrant can seep into smaller faults than the other two types.

4. After the penetrant has been removed from the surface, cover the area being inspected with a developer that acts as a blotter to draw some of the penetrant from hidden flaws. This developer may be:
   a) A dry powder
   b) A quick-drying spray that leaves a white chalky surface.
5. If the dye is fluorescent, inspect the part with an ultraviolet, or black light. Any penetrant drawn from a fault shows up as a bright line, usually yellow-green, against a dark background.
6. If the dye is visible under ordinary light, a fault will show up as a highly visible red mark on the white background.
7. As soon as the inspection is completed, remove all traces of the inspection materials, clean and dry the surface.

12.4 Magnetic Particle Inspection

Surface and subsurface faults in a ferromagnetic part can be detected with magnetic particle inspection.

1. Magnetize the part to be inspected. Any flaw or fault within the component interrupts the magnetic lines of flux and forms a north and south pole.
2. Cover the area being inspected with very fine iron oxide particles.
3. The iron oxide is attracted to the magnetic poles where it forms a visible indication of the fault.
4. There are two ways of magnetizing a part. Overhaul manuals specify the way a part must be magnetized and the amount of current to be used for the magnetization:

Circular magnetization — by passing DC through the part.	• Lines of magnetic flux encircle the part at right angles to the flow of current. • Used for detecting faults that are parallel to the length of the part.
Longitudinal magnetization — by holding the part inside a coil of wire carrying DC.	• Lines of flux extend lengthwise through the part at right angles to the coil. • Used for detecting faults that are perpendicular to the length of the part.

5. The iron oxide used to detect the fault contains a fluorescent dye. It may be applied as a dry powder, or as a suspension in a light oil such as kerosine.
6. The powder is dusted over the part, or the suspension is flowed over the surface being inspected. The oxide particles that are attracted to the poles created by the fault show up as a green mark when viewed under a black light.
7. Two types of magnetic particle inspection:
    - Continuous: the magnetizing current flows all the time the part is being inspected.
    - Residual: the part is magnetized and removed from the magnetic field, then inspected.

8. After inspection is completed, thoroughly demagnetize the part, in either of two ways:
    a) Place the part in an AC magnetic field and slowly remove it from the field.
    b) Place the part in a magnetic field made by pulses of DC of reversing polarity that is programmed to decrease its intensity.
        —The *reversing polarity of the field* causes the magnetic domains within the material to continually change their orientation.
        —The *decreasing field strength* allows them to remain in a disoriented condition.

12.5 Eddy Current Inspection

Eddy current inspection checks for faults inside a metal by detecting a change in its conductivity caused by the presence of a fault. This method is especially suited for detecting intergranular corrosion.

How it works

A test probe containing an AC excited coil induces an eddy current into the material being tested.

1. Excite the coil with the proper frequency of AC.
2. Place the probe on the surface being inspected so it can induce a changing magnetic field in the metal.
3. The changing magnetic field induces eddy currents in the metal. The amount of current is determined by four things:
    a) the conductivity of the metal which is a function of its alloy type, grain size, degree of heat treatment, and tensile strength.
    b) the permeability of the metal.
    c) the mass of the material.
    d) the presence of any faults or voids.

What it is suited for

1. Identifying metals by comparison of their alloy type, degree of heat treatment, and tensile strength.
2. Detection of cracks or hidden faults. This is an ideal way to check aircraft wheels for cracks in the bead seat area. These cracks close up when the stress is off the wheel and are almost impossible to detect visually, but show up with eddy current inspection.

Method

1. Place the test probe on a piece of metal (known to be good) of the type being inspected, and zero the indicator.
2. Place the probe on the metal being inspected.
   - —If there are no internal faults, the indicator will again zero.
   - —If there are any faults within the metal, a different amount of current will be induced and the indicator will show the difference.

Detection of corrosion

The mass of sound material changes when corrosion is present, either internally or on the opposite side of a skin being inspected.

1. Hold the eddy current probe against a part of the skin that is known to be free of corrosion and zero the meter.
2. Move the probe over the area being inspected. If corrosion is present, the meter will move off zero.
3. To inspect for corrosion around fastener holes, insert the small probe into a hole known to be free of corrosion and zero the indicator. When the probe is inserted into a hole where there is corrosion, the indicator will move off zero.

12.6 Ultrasonic Inspection

Ultrasonic waves are vibrations at frequencies between about 200 kilohertz (200,000 hertz) and 25 megahertz (25,000,000 hertz). In this frequency range, these waves are not perceptible to the human ear, but in all other ways they behave the same as vibrations we can hear.

1. A piezoelectric crystal transducer excited at the proper frequency of AC is held against the structure being inspected.
2. The crystal vibrates and sends pulses of energy into the structure. The pulses travel until they reach the back surface of the material or until they strike a fault; then they reflect back to the transducer.
3. A cathode ray tube (CRT) with a horizontal base line is used as the indicator. The pulse entering the test specimen produces a pip along the base line representing the front surface, and a second pip representing the back surface.
4. Any fault within the material reflects some of the energy before it reaches the back surface and forms a third pip between the other two.

12.7 Radiography

The technician should review the safety procedures before conducting a radiographic inspection.

Radiographic inspection is useful for checking the inside of an aircraft structure, as it does not require major disassembly. It is not recommended as an exploratory type of inspection, but is most appropriate for examining an area for a type of damage with known characteristics. There are two types of radiographic inspection: X-rays and gamma rays.

X-Rays

X-rays are a form of high-energy, short-wavelength, electromagnetic radiation.

1. An electron is emitted from the cathode in an X-ray tube and accelerated to a high speed. When this electron strikes a target containing many electrons, it collides and some of its energy is converted into X-rays.

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2. Because X-rays have such high frequency they are able to pass through many materials that are opaque to visible light. As they pass through, they are absorbed in an amount proportional to the density of the material.
3. After passing through a material, the X-rays still have enough energy to expose a piece of photographic film.
4. The amount of current used to drive the electrons from the cathode determines the intensity of the X-ray beam and its ability to expose the film.
5. The voltage supplied to the anode of the X-ray tube determines the amount of energy the beam contains. The higher the voltage, the more energy, and the deeper the X-rays will penetrate the material being inspected.
6. Low-powered X-rays are called soft X-rays, and those that are produced by high voltage are called hard X-rays.
7. Soft X-rays are used to inspect for corrosion.

Gamma Rays

Gamma rays are composed of high-energy photons emitted by the nucleus of certain chemical isotopes such as those of Cobalt, Cesium, Iridium, and Thulium that are in the process of disintegration.

1. Unlike X-rays, gamma rays cannot be shut off or controlled; therefore the source of these rays must be kept in a radiation-proof container shielded with lead.
2. When gamma rays are needed for an inspection, the equipment is set up and the active isotopes are exposed.

Inspection—Steps

1. The penetrating energy of X-rays and gamma rays passing through the material being inspected exposes a sheet of photographic film or causes a fluorescent screen to glow.
2. Discontinuities or faults within the material alter its density and thus the amount of radiation allowed to pass. The more dense the material, the less radiation passes through, and the less the film is exposed. Areas of low penetration appear on the film as light areas.
3. After a sheet of film is exposed to the radiation, it is developed and fixed as with any other photographic film, and its indication is interpreted by an experienced inspector. Damage and faults are detected by comparing the image on the developed film with the indication of a sound structure.

Considerations

1. Radiographic inspection:
   - —is more costly,
   - —requires more elaborate equipment, and
   - —requires more safety considerations than other types of nondestructive inspection, but
   - —it can be used to inspect the inside of complex assemblies without disassembling them.
2. The factors of radiographic exposure are so interdependent that it is necessary to consider all of them for any particular inspection. These factors include, but are not limited to:
   - Material thickness and density
   - Shape and size of the object
   - Type of defect to be detected
   - Characteristics of X-ray machine used
   - The exposure distance
   - The exposure angle
   - Film characteristics
   - Type of intensifying screen, if one is used

Safety

Radiation from X-rays and radioisotope sources produce changes in living tissue when they pass through it. Personnel must keep outside the high energy beam at all times.

1. When radiation strikes the molecules of the body, the effect may be no more than to dislodge a few electrons; however, an excess of these changes can cause irreparable harm.
2. The degree of damage depends on which body cells have been changed. This is determined by the amount of radiation received and by the percentage of the total body exposed.
3. Protection for working with radiation equipment:
   - —wear a radiation-monitor film badge, which is developed at the end of a given period to determine the amount of radiation absorbed
   - —have periodic blood-count tests.

Section 13: Aircraft Control Systems

13.1 Types of Control Systems

Torque Tubes

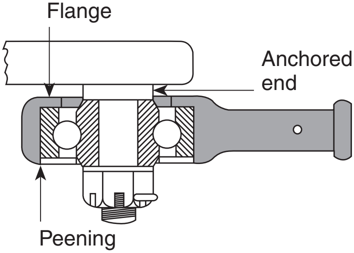
The control in the cockpit is connected to the control surface with a hollow aluminum alloy torque tube. Rotation of the tube transmits a torque force to the surface. Wing flaps are often moved with torque tubes.

Push-Pull Rods

Elevators, some ailerons and flaps, and helicopter rotor controls are operated by rigid push-pull rods. These are hollow aluminum alloy tubes with rod-end bearings or clevises at the ends.

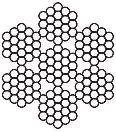
Push-pull rod assembly

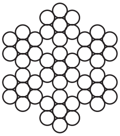
- Install rod-end bearings with the flanged side of the bearing housing next to the structure to which it is attached.
- Rod-end bearings have a "witness hole" to indicate when the rod is screwed in far enough to supply full strength. If the rod is screwed in sufficiently far, the threads will cover the hole.

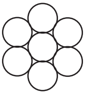


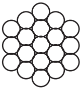
Proper rod-end bearing attachment

13.2 Control Cables


Extra flexible


Flexible


Non-flexible


Non-flexible

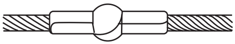
Type of Cable	Strands/ Wires	Material	Application
Extra flexible	7 x 19	Stainless steel Galv. carbon steel	Cables that pass over pulleys
Flexible	7 x 7	Stainless steel Galv. carbon steel	Straight cable runs Slight change in direction allowed
Non-flexible	1 x 19 1 x 7	Stainless steel Galv. carbon steel	Straight cable runs No change in direction allowed

13.3 Control Cable Terminals

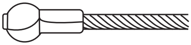
Swaged terminals are made of stainless steel and have a tubular end into which the cable fits. The cable is slipped into the tube and the assembly is swaged, forcing the metal of the tube into the cable so it grips the strands of wire. A "go-no go" gauge or a micrometer caliper is used to determine when the terminal has been properly swaged. The swaging process should reduce the diameter of the tubular end to a dimension specified by the terminal manufacturer. When properly swaged, the cable will break before it pulls out of the terminal.

Nicopress sleeves are installed on cables in some lighter aircraft. A properly installed Nicopress terminal provides the full strength of the cable.

1. Slip a copper Nicopress sleeve over the cable and loop the free end around a bushing or a thimble eye and slip it into the opposite side of the sleeve.
2. Make three crimps with a special Nicopress tool. The first crimp is in the center of the sleeve, the next is at the end nearest the eye, and the last crimp is near the opposite end.
3. Use a "go-no go" gauge to determine that the sleeve has been sufficiently crimped.

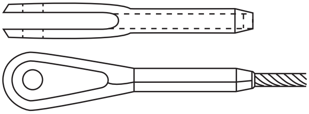


AN663 Double shank ball end

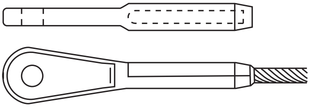


AN664 Single shank ball end

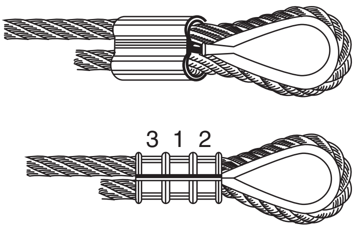
AN666 Threaded cable terminal



AN667 Fork end cable terminal



AN668 Eye end cable terminal



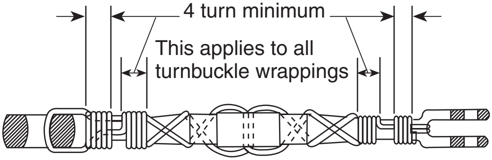
Nicopress sleeve for terminating an aircraft control cable. The lower illustration shows the proper sequence for crimping the sleeve onto the cable.

13.4 Turnbuckles

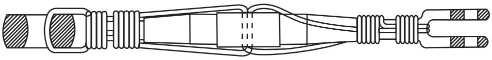
- Control cable tension is adjusted with turnbuckles that are installed in at least one cable in each run.
- A turnbuckle consists of a bronze barrel and terminals that screw into each end. The threads in one end of the barrel are left-hand and those in the other end are right-hand. The end having the left-hand threads is normally identified with a groove around its end.
- A turnbuckle will produce its full strength only when the threads on the terminal are sufficiently engaged. No more than three threads on the terminals should be exposed. If the cable tension is too high when more than three threads are exposed, a longer barrel should be used.

Turnbuckle Safetying

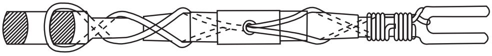
It is important that turnbuckles be properly safetied to prevent them from becoming unscrewed and changing the control cable tension.



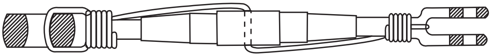
Double wrap (spiral)



Double wrap



Single wrap (spiral)



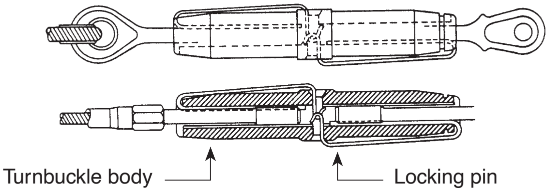
Single wrap

Methods of safetying turnbuckles

Turnbuckle Safetying Guide

Cable size	Type of wrap	Diameter of safety wire	Material (annealed)
1/16	Single	0.040	Copper, brass
3/32	Single	0.040	Copper, brass
1/8	Single	0.040	Stainless steel, monel and K monel
1/8	Double	0.040	Copper, brass
1/8	Single	0.057 min.	Copper, brass
5/32 and greater	Double	0.040	Stainless steel, monel and K monel
5/32 and greater	Single	0.057 min.	Stainless steel, monel and K monel
5/32 and greater	Double	0.0512	Copper, brass

Clip-Locking Turnbuckles



There is a slot in the threads of the terminal and one in each end of the barrel.

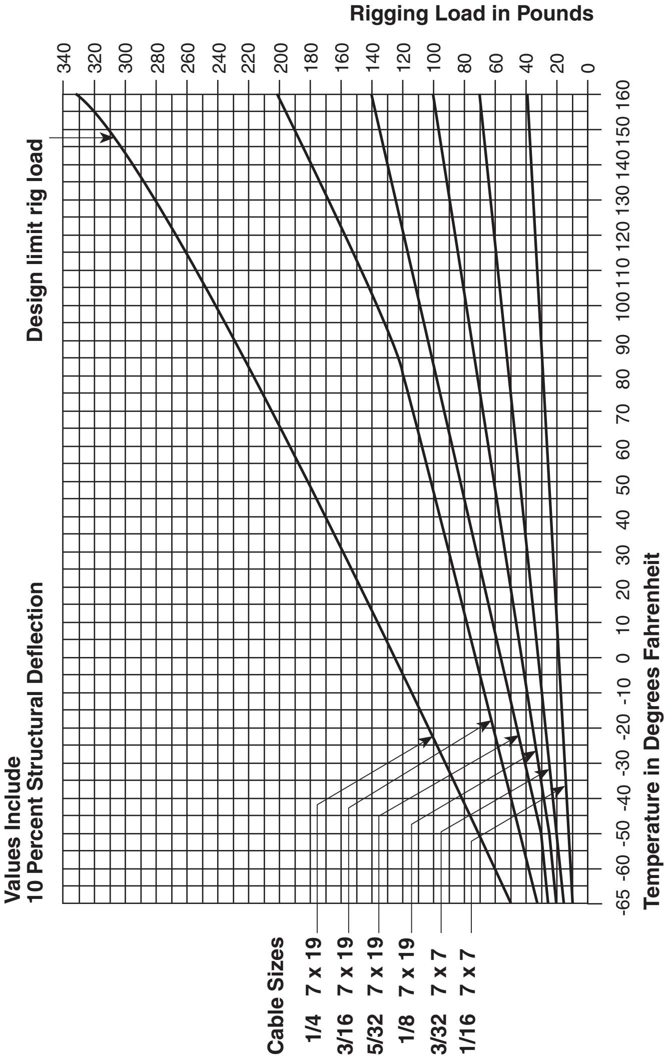
1. After the cable tension has been adjusted, align the slots in the turnbuckle body and the swaged terminal.
2. Insert the straight end of the locking clips into the slots in each end of the barrel.
3. Insert the hooked ends of the clips into the hole in the side of the barrel and press them in until the ends of the hook seat on the edge of the hole.

13.5 Control Cable Tension

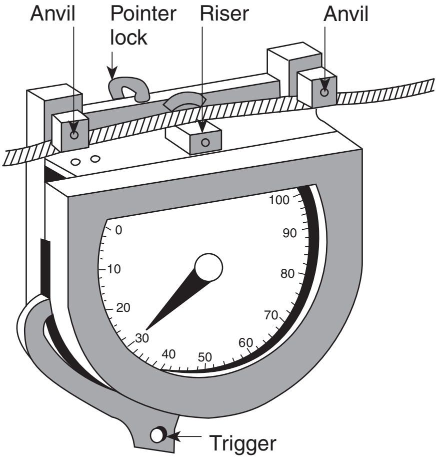
1. It is important that control cable tension be within the range specified in the aircraft maintenance manual. If the tension is too high, the controls will be stiff and the pulleys will wear excessively. If the tension is too low, there is danger of the cable getting out of the pulley groove and becoming fouled.
2. Large all-metal aircraft contract as they cold-soak at high altitude where the air is extremely cold. The control cables do not change their dimensions as much as the airframe does, so automatic tension adjusters are used to maintain a constant cable tension as temperature changes.
3. Small aircraft do not have automatic adjusters but rely on the cables being properly adjusted to the proper tension determined by the aircraft manufacturer.

To find the correct rigging load for a 1/8 inch 7x19 cable at 90°F:

1. Follow the vertical line for 90°F upward until it intersects the curve for 1/8 inch 7x19 cable (the third curve up).
2. From this point of intersection, draw a horizontal line to the right to the Rigging Load scale. This shows that the correct rigging load for this temperature is 75 pounds.



Control cable tension chart



Cable tension is measured with a tensiometer:

1. Install the correct riser for the size of cable being checked, and clamp the tensiometer over the cable.
2. Use the chart furnished with the tensiometer to relate the indication on the tensiometer scale to the diameter of the cable, in order to find the cable tension in pounds.

Section 14: Aircraft Fluid Lines

Fuel, hydraulic fluid, compressed air, lubricating oil, and other fluids are carried in an aircraft and all must be routed through the proper size and type of fluid line. There are two basic types of fluid lines: rigid and flexible.

14.1 Rigid Fluid Lines

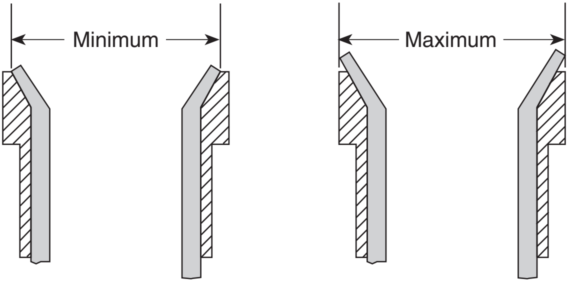
Materials recommended for rigid fluid lines

Application	Material
Low pressure	1100- and 3003-half hard aluminum alloy
High pressure	2024-T and 5052-O aluminum alloy
Oxygen systems	Corrosion resistant steel Fittings are brazed or silver soldered to lines

- Rigid fluid lines

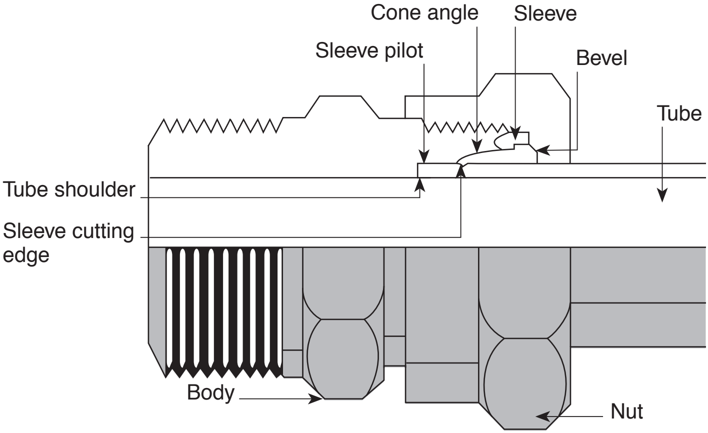
  —are measured by their outside diameter in increments of 1/16-inch. For example, number 8 tubing has an outside diameter of 8/16- or 1/2-inch.

  —are connected to fittings with either a flared or a flareless fitting. Flared fittings have a flare angle of 37°; they must not be mixed with automotive fittings which have a flare angle of 45°.



When a piece of tubing is flared, the minimum diameter of the outside of the flare should be no less than the inside diameter of the flare in the sleeve, and the outside diameter should be no greater than the outside of the sleeve.

- Tubing made of 5052-O and 6061-T aluminum alloy in sizes between 1/8- and 3/8-inch may be double flared.



MS flareless fittings—popular for use in high-pressure hydraulic and pneumatic lines

To assemble an MS flareless fitting:

1. Slide the nut and sleeve onto the tube.
2. Place the tube into a presetting tool and tighten the nut as specified by the tubing manufacturer. (The pressure produced by the nut distorts the sleeve so that it bites into the tube.)
3. Remove the tube from the presetting tool and screw it onto the fitting.
4. Tighten the nut finger tight, then turn it with a wrench for 1/6- to 1/3-turn (one hex to two hexes).
5. Do not overtighten the fitting as it may be damaged and the joint will leak.

14.2 Flexible Fluid Lines

- Flexible fluid lines must be able to carry all of the volume of fluid without an excessive pressure drop. They must withstand the pressure and the vibration they will encounter.
- When a particular hose is specified in an aircraft parts list or service manual, only that hose or an approved substitute may be used when the hose is replaced.
- The size of a flexible hose is approximately its inside diameter in 1/16-inch increments. This dimension refers to the outside diameter of a rigid tube that has equivalent flow characteristics. For example, a -8 hose has flow characteristics equivalent to the same length of -8, or 1/2-inch (8/16) rigid tubing.
- Flexible fluid lines have a linear stripe, called a lay line, running along their length. Its purpose is to help prevent twisting the hose during installation. If this line spirals around the hose, the hose has been twisted.

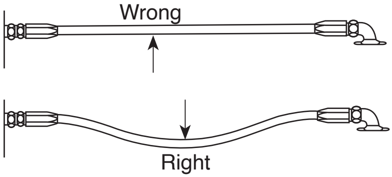
Types of Flexible Fluid Lines

Type/Name	Description and Identification	Approved for use/ Suitability
Low-pressure hose MIL-H-5593	• Synthetic rubber inner liner, a cotton braid ribbed synthetic rubber outer cover. • Broken yellow lay line, letters "LP," manufacturer's code/date marking.	• Approved for pressures up to 300 psi. • Primarily used in instrument installations.
Medium-pressure hose MIL-H-8794	• Seamless synthetic rubber inner liner, synthetic-rubber-impregnated cotton braid reinforcement, steel-wire braid reinforcement. • Encased in a rough synthetic-rubber-impregnated cotton braid.	• Suitable for carrying fluids under pressure of up to 1,500 psi.

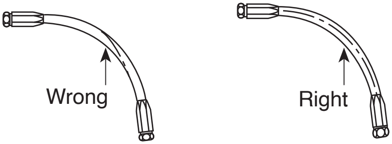
(continued)

Type/Name	Description and Identification	Approved for use/ Suitability
High-pressure hose MIL-H-8788	• Seamless synthetic rubber inner tube, either two or three carbon-steel wire-braid reinforcements. • Smooth synthetic rubber cover.	• Suitable for operating with pressures up to 3,000 psi.
Extra-high-pressure hose	• Reinforced with layers of spiral wound stainless steel wire. • Encased in a special synthetic rubber outer layer.	• Suitable for use with pressures between 3,000 and 6,000 psi and temperatures up to 400°F.
Teflon hose Tetrafluoethylene, TFE	• Chemically resistant TFE inner liner, braided stainless steel outer covering.	• Unaffected by any fuel, petroleum or synthetic base oils, alcohol, coolants, or solvents commonly used in aircraft and it retains these characteristics even at elevated temperatures.

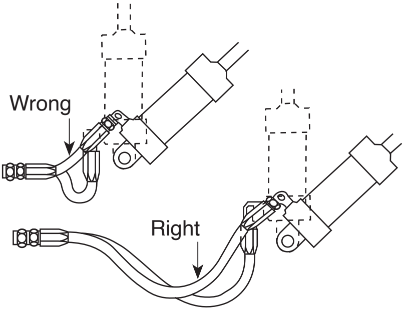
14.3 Installation of Flexible Hose



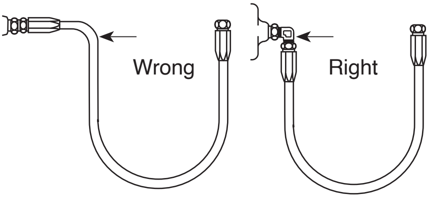
Flexible hose should be approximately 5% to 8% longer than the distance between the fittings. This slack allows for contraction as the line expands its diameter and shortens its length when pressurized.



Flexible hose should be installed with no twists. The lay line spirals around the hose if it is twisted.



Flexible hose should be installed on a movable actuator in such a way that the hose is not crimped in any position of the actuator.



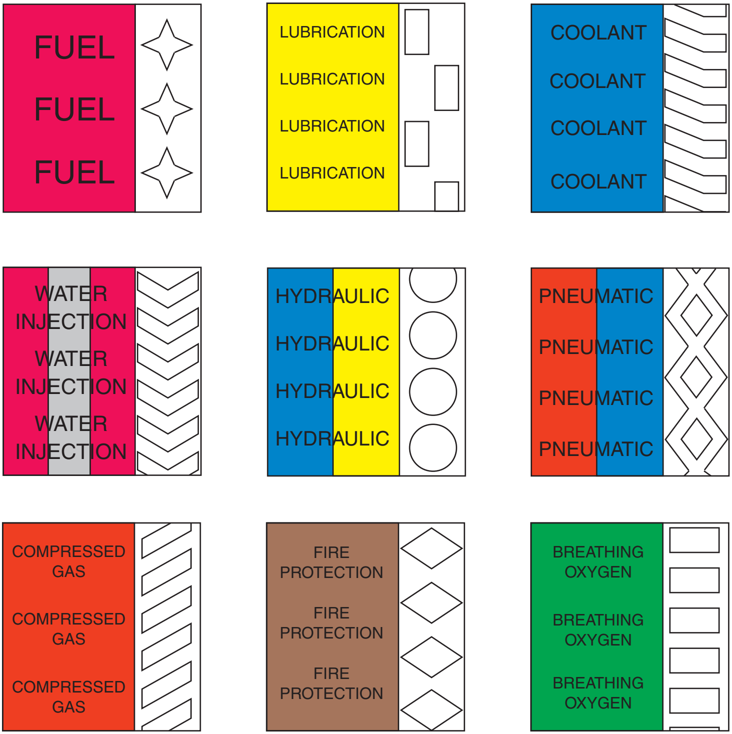
Elbow fittings should be used to keep flexible hose from having to be bent at a sharp angle.

Improper, and proper installation of flexible hose

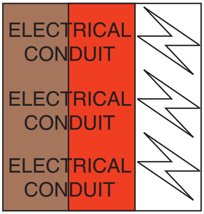
14.4 Fluid Line Identification

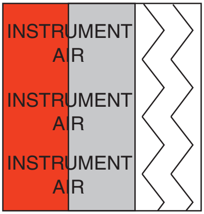
- Fluid-carrying lines in an aircraft are identified with a series of colored and coded bands.
- One or two colors identify the fluid in the lines, and the name of the fluid is written in the colored area.
- To aid color-blind technicians, a coded stripe also identifies the fluid.

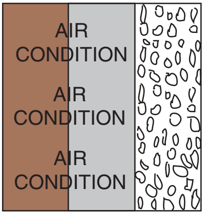
Fluid Line Identification

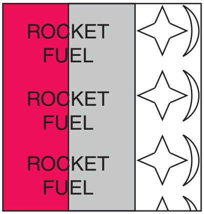


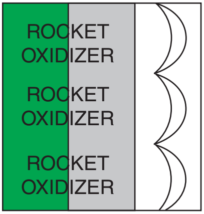
Fluid Line Identification

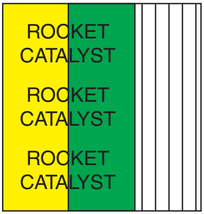


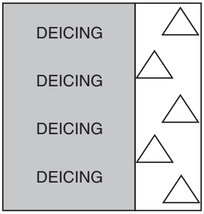












WARNING

Section 15: Oxygen System Servicing

15.1 Oxygen System Servicing

1. Be sure to use **no** petroleum lubricants on oxygen system components.
2. Service aircraft oxygen systems only with oxygen approved for use in aircraft.
3. When servicing an oxygen system from a cascade-type servicing cart, charge the system from the cylinder having the lowest pressure first. When the pressure stabilizes, record the pressure on the cylinder, shut it off and open the valve on the cylinder having the next lowest pressure. Continue this process until you have the desired pressure in the system. Use the chart below to determine the final charging pressure, based on the ambient temperature.
4. Do not allow installed oxygen cylinders to become completely empty. When there is no oxygen in a cylinder, air containing water vapor can enter.

Filling Pressure for 1,850 PSI Oxygen Cylinders

Ambient temperature and the heat of compression affect the pressure of oxygen in a cylinder. To end up with 1,850 psi in the cylinder after the oxygen has cooled from the filling process, the following filling pressures should be used:

Ambient Temperature (°F)	Filling Pressure (psi)
0	1,650
10	1,700
20	1,725
30	1,775
40	1,825
50	1,875
60	1,925
70	1,975
80	2,000
90	2,050
100	2,100
110	2,150
120	2,200
130	2,250

Section 16: Aircraft Weight and Balance

16.1 Locating the Center of Gravity

- Position the airplane on the scales with the parking brake off.
- Place chocks around the wheels to keep the airplane from rolling.
- Subtract the weight of the chocks (called tare weight) from the scale reading to determine the net weight at each weighing point.

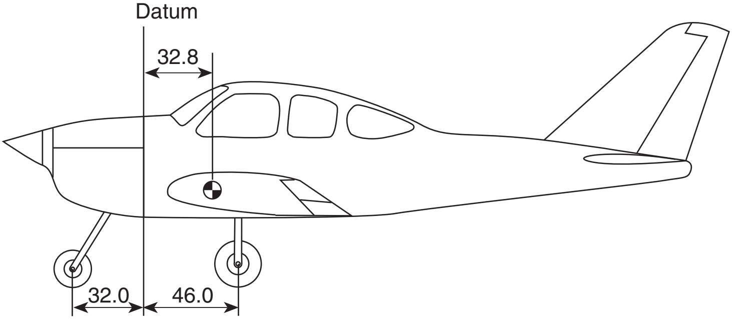


Figure 16.1. *The datum is at the engine firewall.*

- Determine the arm of each weighing point by measuring its distance from the datum.
- Find the moment of each weighing point by multiplying its net weight by its arm.

Nose wheel net weight = 340 pounds
Arm of the nose wheel = -32 inches
Moment of the nose wheel = -10,880 pound-inches

Main wheel net weight = 1,666 pounds
Arm of the main wheels = 46 inches
Moment of the main wheels = 76,636 pound-inches

Total weight = 2,006 pounds
Total moment = 65,756 pound-inches

Find the CG by adding the weight and moment of each weighing point to find the total weight and total moment. Then divide the total moment by the total weight to find the CG relative to the weighing points.

$$\text{CG} = \frac{\text{Total Moment}}{\text{Total Weight}}$$

$$= \frac{65{,}756}{2{,}006}$$

$$= 32.8 \text{ inches aft of the datum}$$

The CG is 32.8 inches aft of the datum or 13.2 inches ahead of the main-wheel weighing points.

16.2 Datum Forward of the Airplane—Nose Wheel Landing Gear

In Figure 16.2, the datum is considered to be 100 inches ahead of the leading edge of the wing. The distance (D) between the main-wheel weighing points and the datum is +128 inches. The weight of the nose wheel (F) is 340 pounds, the distance (L) between the main wheel and the nose-wheel weighing points is 78.0 inches, and the total weight (W) is 2,006 pounds.

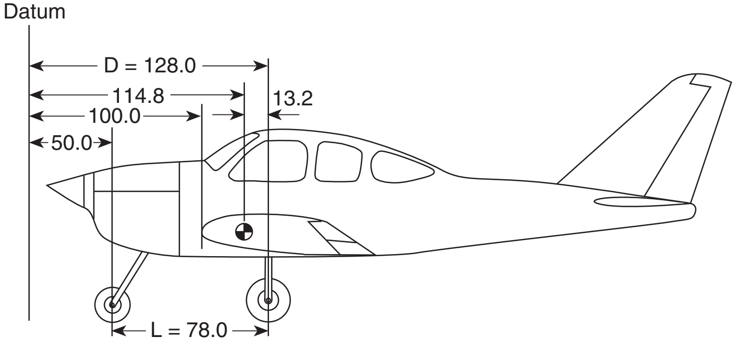


Figure 16.2. *The datum is ahead of the airplane.*

To locate the CG of an airplane relative to the datum that is 100 inches ahead of the wing leading edge, use the formula:

$$CG = D - \left(\frac{F \times L}{W}\right)$$

$$= 128.0 - \left(\frac{340 \times 78}{2,006}\right)$$

$$= 114.8 \text{ inches aft of datum}$$

The CG is 114.8 inches aft of the datum, which is 13.2 inches ahead of the main-wheel weighing points. This proves that the location of the datum has no effect on the location of the CG, as long as all measurements are made from the same location.

16.3 Datum Aft of the Main Wheels—Nose Wheel Landing Gear

In Figure 16.3, the datum is at the trailing edge of the wing at the wing root. The distance (D) between the main-wheel weighing points and the datum is +75 inches. The weight of the nose-wheel (F) is 340 pounds, the distance (L) between the main wheel and the nose-wheel weighing points is 78.0 inches, and the total weight (W) is 2,006 pounds.

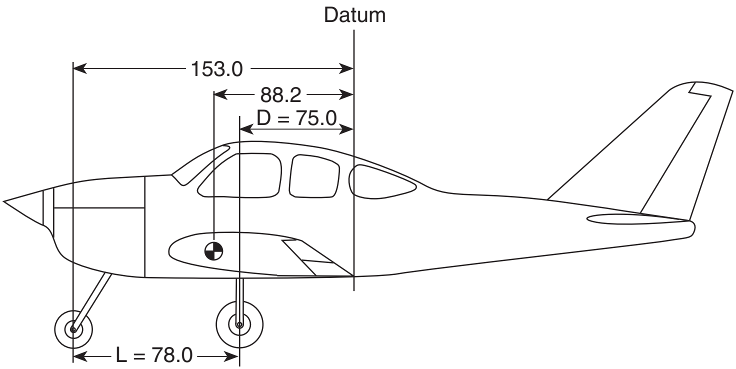


Figure 16.3. *The datum is aft of the main wheels at the intersection of the wing trailing edge and the fuselage.*

$$CG = -\left(D + \frac{F \times L}{W}\right)$$

$$= -\left(75 + \frac{340 \times 78}{2{,}006}\right)$$

$$= -88.2 \text{ inches ahead of the datum}$$

The CG is 88.2 inches ahead of the datum, which is 13.2 inches ahead of the main-wheel weighing points.

16.4 Datum Forward of the Main Wheels—Tail Wheel Landing Gear

In Figure 16.4, the datum is at the leading edge of the wing at the wing root. The distance (D) between the main-wheel weighing points and the datum is +7.5 inches. The weight of the tail wheel (R) is 67 pounds, the distance (L) between the main wheel and the tail-wheel weighing points is 222.0 inches, and the total weight (W) is 1,218 pounds.

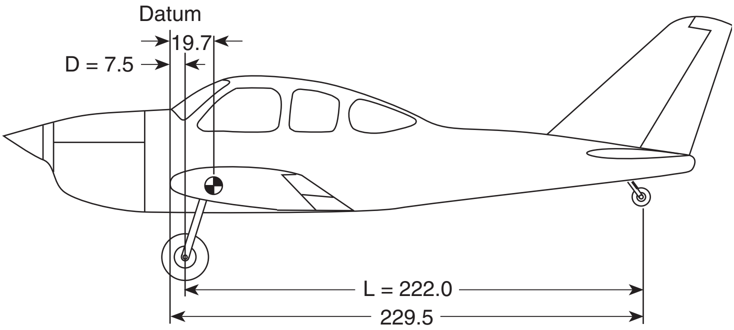


Figure 16.4. *The datum is the leading edge of the wing at the wing root.*

$$\begin{aligned} CG &= D + \left(\frac{R \times L}{W}\right) \\ &= 7.5 + \left(\frac{67 \times 222}{1{,}218}\right) \\ &= 19.7 \text{ inches aft of the datum} \end{aligned}$$

The CG is 19.7 inches behind the datum, which places it 12.2 inches behind the main-wheel weighing points.

16.5 Datum Aft of the Main Wheels—Tail Wheel Landing Gear

In Figure 16.5, the datum is at the trailing edge of the wing at the wing root. The distance (D) between the main-wheel weighing points and the datum is 80 inches. The weight of the tail wheel (R) is 67 pounds, the distance (L) between the main wheel and the tail-wheel weighing points is 222.0 inches, and the total weight (W) is 1,218 pounds.

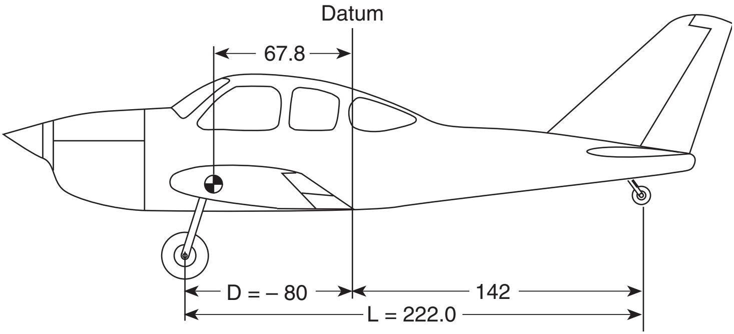


Figure 16.5. *The datum is the trailing edge of the wing at the wing root.*

$$CG = -D + \left(\frac{R \times L}{W}\right)$$

$$= -80 + \left(\frac{67 \times 222}{1{,}218}\right)$$

= 67.8 inches ahead of the datum

The CG is 67.8 inches ahead of the datum, which is 80 inches behind the main-wheel weighing points. The CG is 12.2 inches behind the main-wheel weighing point.

16.6 Location of CG with Respect to the Mean Aerodynamic Chord

Knowing the location of the CG relative to the datum is important to the technician, because it is easy to locate physically. But the pilot and flight engineer are more concerned with location of the CG relative to the aerodynamic characteristics of the wing. The reference for this location is in percentage of the wing chord.

The chord of a tapered wing airplane is not easy to determine; therefore the mean aerodynamic chord (MAC) is used, and the allowable CG range is expressed as percentages of the MAC.

The MAC is the chord of an imaginary airfoil that has all of the aerodynamic characteristics of the actual airfoil. It can also be thought of as the chord drawn through the geographic center of the plan area of the wing (*see* Figure 16.6).

For example, the aircraft weight and balance data states that the leading edge of MAC (LEMAC) is at station 1022, and the trailing edge of MAC (TEMAC) is at station 1198. A weight and balance computation determines that the CG is located at station 1070, the location expressed in percentage of MAC is found using this formula:

$$\text{CG in \%MAC} = \frac{\text{Distance aft of LEMAC} \times 100}{\text{MAC}}$$

$$= \frac{48 \times 100}{176}$$

$$= 27.3\%\ \text{MAC}$$

The CG of the airplane is located at 27.3% MAC.

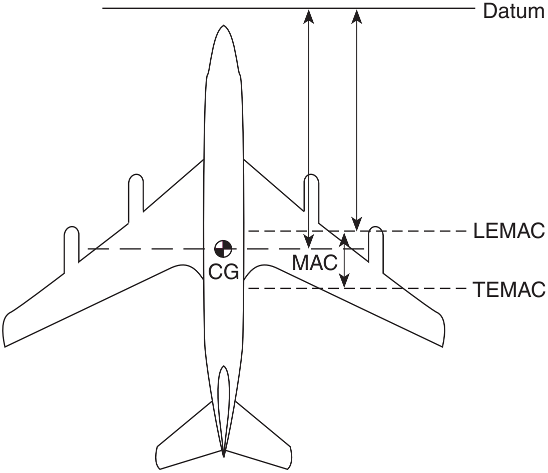


Figure 16.6. *The MAC is the chord drawn through the geographic center of the plan area of the wing.*

Section 17: Composites

17.1 Resin Systems—Typical Properties

Each resin system has its own combination of features or properties, which determine their suitability for a given purpose, e.g., maximum service temperature, smoke properties, adhesive properties, etc. The following is a list of the major resin families and general description of their properties.

Polyester resin	Cured by *polymerization* Environmentally resistant Inexpensive Poor adhesive properties High styrene emissions Poor smoke properties
Vinyl ester resin	Cured by *polymerization* Modified polyester resin Better adhesive properties than polyester Better corrosion resistance than polyester High styrene emissions Poor smoke properties
Epoxy resin	Cured by *cross-linking* Excellent strength and adhesive properties Good environmental resistance Wide variety of formulations and properties Most common in aerospace applications Poor smoke properties
Phenolic resin	Cured by *cross-linking* Good chemical and electrical properties Poor adhesive properties Good smoke properties Fairly brittle
Bismaleimide resin	Cured by *cross-linking* Often referred to as BMI Good hot/wet performance High service temperature Process similar to epoxy

(continued)

Cyanate ester resin	Cured by *cross-linking* High service temperature (after post-cure) Minimal micro cracking Expensive
Polyimide resin	Cured by *cross-linking* High service temperature Good smoke properties Difficult to process Expensive

Polymerization begins in polyester and vinyl ester resins at the time of manufacture. An inhibitor is added to the material to keep it in a liquid state until it is ready for use. When the user adds a small quantity of an initiator (catalyst) such as MEKP, it counteracts the effect of the inhibitor and allows the resin to cure and become solid.

Cross-linking occurs in most other thermoset resin systems. It is a one-time chemical reaction in which liquid resin molecules (component A) form links to hardener molecules (component B). As these links form, the resin gels, cures, and ultimately becomes a solid.

Warning: These curing processes generate heat. If sufficient amounts are left in a container for too long there is a substantial risk of an uncontrolled exothermic reaction. Such reactions can generate large amounts of toxic smoke or possibly start a fire. Always consult the manufacturer's data sheet and material safety data sheet (MSDS) for details.

17.2 Resin Mix Ratios

In order for any resin system to develop its full strength after it is cured it must first be mixed properly. The amount of hardener that should be added to a resin system is usually measured by weight, not volume, and is expressed as a ratio (e.g., 100:30). Assuming the unit of measurement is grams, this means to 100 grams of resin, add 30 grams of hardener for a total of 130 grams of mixed material.

For example, if a total of 210 grams of mixed resin is needed and the mix ratio is 100:42, the amount of components A and B to be weighed out may be determined using the following formula:

$$\text{Part A} = \frac{210\text{ grams}}{100 + 42} \times 100 = 148\text{ grams}$$

$$\text{Part B} = \frac{210\text{ grams}}{100 + 42} \times 42 = 62\text{ grams}$$

Therefore, 148 grams of component A added to 62 grams of component B will result in 210 grams of mixed resin with the proper mix ratio.

The importance of understanding mix ratios cannot be stressed enough. Most high performance resin systems will tolerate mix ratio errors up to 3 percent. Errors beyond 3 percent may dramatically reduce a resin's ability to perform properly in service.

17.3 Fiber/Resin Ratio Formulas

Optimum strengths are derived from composite materials when fiber reinforcements (glass, aramid, carbon, etc.) are combined with a particular amount of matrix material (resin). Too much resin makes the laminate heavier and stiffer than it should be; not enough resin causes its physical properties to suffer tremendously. When designing composite parts, engineers often use "fiber volume" as a means to express how much fiber and resin make up a component. This works fine for engineering, but is of little use to mechanics conducting repairs in the field.

Since most mechanics have access to a scale, a more practical method is to use the relative weight of the fiber and its associated resin. The relationship of the weight of the fibers to the weight of the resin can then be expressed as a ratio. For example, a 60:40 fiber/resin ratio indicates that 60% of the weight of the laminate is attributed to the reinforcing fibers and 40% is attributed to the resin. Understanding the relationship between fiber and resin weights can aid in developing optimum strength properties in wet lay-up repairs. Below are common fiber/resin ratio ranges for various fiber types.

(continued)

	Fiberglass	**Carbon/Graphite**	**Aramid**
Resin lean	70:30	48:52	39:61
Resin rich	60:40	42:58	33:67

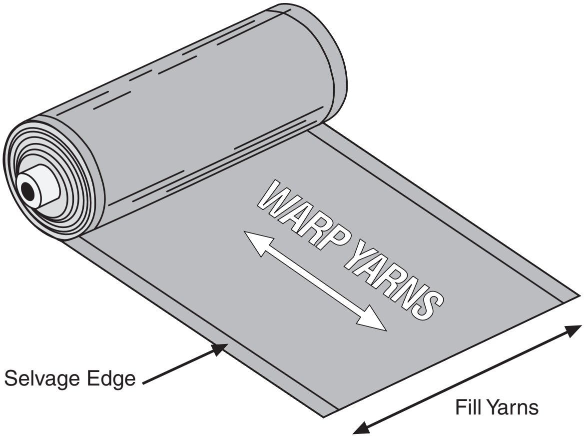
17.4 Reinforcing Fibers

The most common advanced composite fibers used in the aerospace industry today are carbon and graphite fibers, fiberglass, and aramid, or Kevlar® fiber. Each of these has certain properties that make the material unique and particularly well-suited for certain applications.

Carbon/Graphite	High modulus (stiffness) Broad range of strength and modulus combinations Electrically conductive
Aramid (Kevlar®)	Light weight High tensile strength Impact / abrasion resistant Absorbs moisture
Fiberglass	Excellent physical properties Readily available Inexpensive Variety of chemistries available for different purposes

17.5 Textile and Fiber Terminology

Roll of Fabric or Prepreg



Filaments

The smallest element of composite fibers, typically 3 to 25 microns in diameter depending on the type of fiber.

Strands

An intermediate step used in the production of fiberglass yarns only. Filaments are twisted into strands, which are then twisted into yarns.

Yarns/tows

Bundles of filaments numbering from 25 to 24,000. Yarns are twisted to aid in the manufacture of woven cloth (see 17.6 “Yarn Part Numbering Systems”). Tows are often laid flat and parallel to manufacture carbon, aramid, or fiberglass unidirectional tape.

Warp yarns

Yarns running the length of a roll of fabric. Always used when referencing ply orientation.

Fill yarns

Transverse yarns on a roll of fabric.

Selvage edge

Stitching along the long edge of a roll of fabric to keep it from fraying.

Warp face

Harness satin weaves only. The face of a fabric on which one sees primarily warp yarns.

Fill face

Harness satin weaves only. The face of a fabric on which one sees primarily fill yarns.

17.6 Yarn Part Numbering Systems

Composite structures rely on reinforcing fibers to carry the majority of the loads imposed on them. In structures made from woven materials, the fibers are usually gathered into yarns. Since the size, construction, and number of the yarns is critical to the structure's ability to conduct a load properly, it is important to understand how these yarns are described. Each of the major fiber types — fiberglass, carbon, and aramid (Kevlar®) — have their own part numbering system for yarns.

Carbon

A number suffixed by the letter "K" (thousand) is used to indicate how many thousands of filaments make up the yarn. For instance, a 6K yarn is made up of six thousand filaments.

Aramid (Kevlar®)

Aramid yarns are described by their denier weight, which appears as a number suffixed by "de." The denier weight is the weight, in grams, of nine thousand meters of the yarn, the lower the denier, the finer the yarn. For example, a yarn designated as 1140 de indicates that nine thousand meters of that yarn weighs 1,140 grams.

Fiberglass

Given the wide variety of fiberglass materials produced, a more exact system for identifying yarns is required. An example of a fiberglass yarn part number is given below followed by descriptions of each of its components.

For example, **ECG 150 2/3**

First letter—Characterizes the chemical composition of the glass, e.g., E-glass (electrical), C-glass (chemical resistant), S-glass (structural), etc.

Second letter—Describes the filament type. "C" indicates a continuous filament as opposed to a staple filament (S), or a texturized continuous filament (T).

Third letter—A letter code representing the individual filament diameter. "G" indicates an individual filament diameter range of .00035 to .000399 inches. Contact fiberglass manufacturer for additional letter codes.

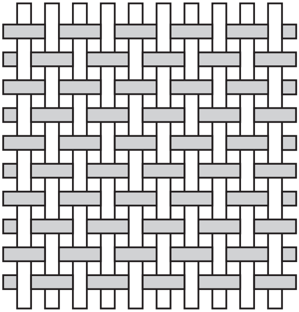
First number—The number of yards, divided by one hundred, required to net one pound of the basic yarn strand. In the example, multiplying 150 by one hundred equals 15,000 yards of strand in one pound.

Second number—The "2/3" shows the number of basic strands in the yarn. The first digit represents the original number of twisted strands. The second digit shows how many of these are twisted together to make one yarn. To find the total number of strands in a yarn, multiply the two digits together (a zero is always multiplied as a one).

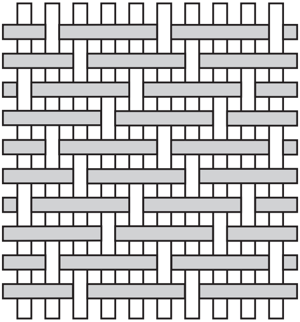
17.7 Fabric Weave Styles

Plain weave

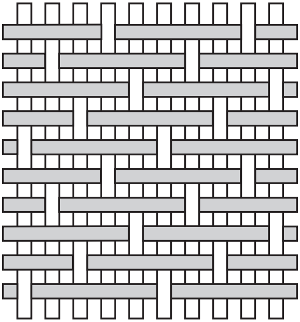
The simplest, most basic of the weave styles. Warp and fill yarns are interlaced over and under each other in an alternating pattern. These fabrics are stable and lightweight, but typically have poor drape properties.



Plain weave



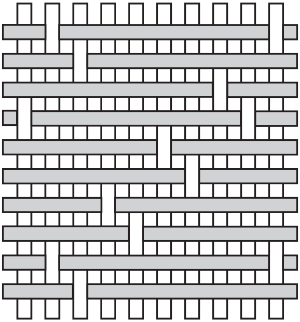
Four-harness



Five-harness

Harness satin weaves

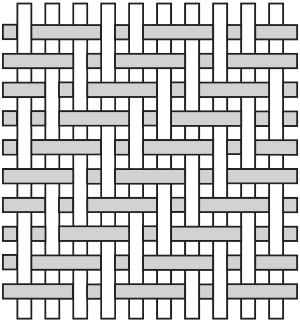
A warp or fill yarn "floats" over a number of yarn intersections before interlacing under just one yarn. This creates the appearance of all the yarns on one side of the fabric "traveling" in a single direction, and the yarns on the opposite side "traveling" 90 degrees out (*see* 17.4, "warp face" and "fill face"). Harness satins have excellent drape and are characterized by the number of yarns a yarn "floats" over, plus the yarn it goes under. Common weave styles include four-harness satin (over three yarns, under one), five-harness satin (over four yarns, under one), and eight-harness satin (over seven yarns, under one).



Eight-harness satin

Twill weave

These relatively stable fabrics offer increased drape properties over plain weaves. The weave pattern is characterized by the appearance of a diagonal rib caused by warp yarns floating over two fill yarns (2 x 2 twill) and then, under two. A 4 x 4 twill has a similar appearance and better drape properties.



Twill weave

17.8 Common Weave Style Numbers and Features

It is important to remember that the weave style number is meaningless without knowing the fiber type. For instance, 120 style aramid is in no way similar to 120 style fiberglass. The aramid is a plain weave and the fiberglass is a four harness satin.

Fiberglass Style number	Characteristics Weave style - Weight - Yarn count (W x F)
120	4 harness satin - 3.1 oz. - 60 x 58
1581	8 harness satin - 8.7 oz. - 57 x 54
7500	plain weave - 9.3 oz. - 56 x 54
7781	8 harness satin - 8.7 oz. - 16 x 14
Aramid Style number*	Characteristics Weave style - Weight - Yarn count (W x F)
348 (181)	8 harness satin - 4.9 oz. - 50 x 50
350 (120)	plain weave - 1.7 oz. - 34 x 34
352 (281)	plain weave - 5.0 oz. - 17 x 17
353 (285)	4 harness satin - 5.0 oz. - 17 x 17
Carbon Style number	Characteristics Weave style - Weight - Yarn count (W x F)
130	plain weave - 3.74 oz. - 24 x 24
282	plain weave - 5.8 oz. - 12 x 12
286	4 harness satin - 5.8 oz. - 12 x 12
433	5 harness satin - 8.4 oz. - 18 x 18
584	8 harness satin - 11.0 oz. - 24 x 24
IM7 Graphite	
SGP193-P	plain weave - 5.7 oz. - 11 x 11
SGP203-CS	4 harness satin - 6.0 oz. - 12 x 12
SGP370-8H	8 harness satin - 11.0 oz. - 21 x 21

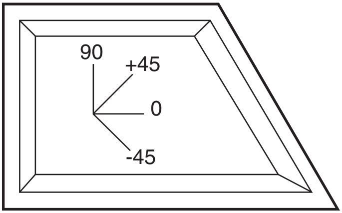
* Numbers in parentheses are older style numbers

17.9 Ply Orientation Conventions

Ply orientation convention symbols are used in manufacturers' structural repair manuals to coordinate the drawing of the component to the ply tables, which list ply orientations.

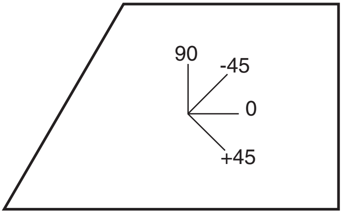
There are two types of convention symbols, clockwise and counterclockwise. The counterclockwise warp clock is drawn from the manufacturer's standpoint where the plies are viewed from the inside looking out, toward the tool surface. The clockwise warp clock is drawn from the repair standpoint where the plies are viewed from the outside, or tool surface, looking in.

Counterclockwise



Inside looking out

Clockwise



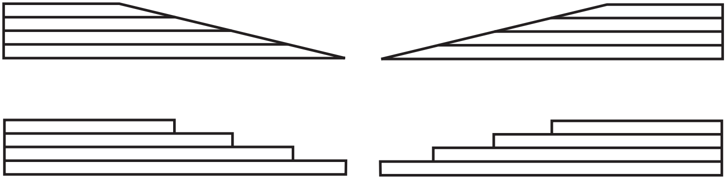
Outside looking in

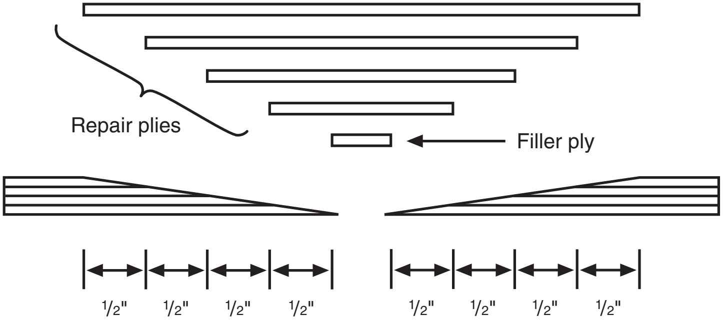
17.10 Damage Removal–Scarfing and Stepping

Once the damaged area of a laminate has been removed, it must be prepared in such a way that allows the repair plies to conduct loads much like the original structure did. Like sheet metal repairs, composite repairs rarely restore a structure to 100% of its original strength, but poorly prepared areas can yield composite repairs that perform well below acceptable standards. Always consult the manufacturer's SRM or other acceptable data for repair specifics.

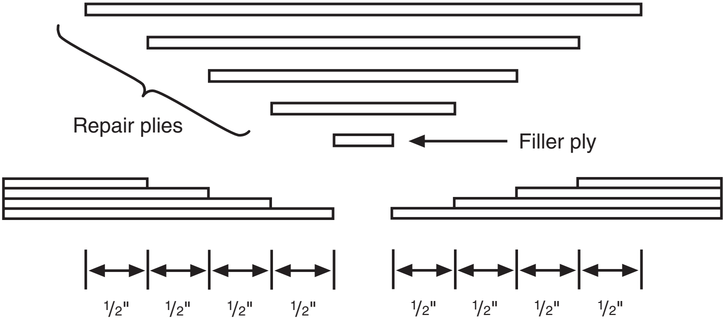
While scarfed, or taper-sanded repairs have been demonstrated to conduct loads more effectively, step-sanded repairs are still found in many aircraft SRMs. Usually, they are both expressed as a specific dimension per ply, e.g., scarf 1/2 inch per ply. On some newer aircraft taper sanding is expressed as a scarf ratio.

In a scarf ratio of 40:1 for example, the “1” represents the thickness of the laminate and the “40” represents the distance the scarf will cover, in this case 40 times the thickness of the laminate.





Typical scarf repair



Typical step repair

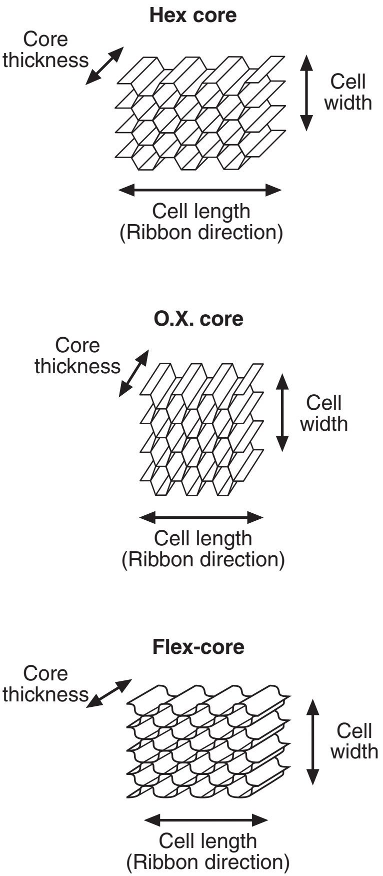
17.11 Core Materials

Core materials for composite applications can generally be divided into two categories, foam core and honeycomb core. Foam core materials generally have good properties at a relatively low cost, they are easy to machine, and their closed cell construction offers excellent resistance to water and fluid ingress. While there are many foam chemistries, the three most common are Polyvinylchloride (PVC), Polyurethane, and Polymethacrylimide (PMI). Available densities range from less than 2 pounds per cubic foot (pcf) to 60 pcf.

Honeycomb core is used extensively on modern aircraft due to its exceptional physical properties and light weight. Fabrics are used to make carbon and fiberglass honeycomb, while Nomex® and Kevlar® cores are made from a pressed, paper-like form of the materials. The three most common core cell configurations are; hex core (hexagonal), for flat or nearly flat panels; O.X. core (over-expanded) for simple curves; and flex-core for complex geometries. When honeycomb is specified, the following information needs to be provided:

- Material
- Cell shape (Hex-core, O.X. core, Flex-core, etc.)
- Cell size

Core Cell Configurations



Core illustrations courtesy of Hexcel

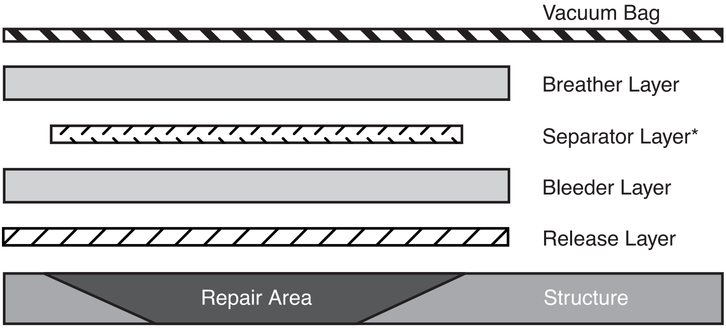
- Density
- Wall thickness and alloy (for aluminum core)

Cell sizes range from 1/16" to 1", with 1/8", 3/16", 1/4", with 3/8" being the most common. Honeycomb densities range from 1.0 lb/ft^3 to 55 lb/ft^3.

17.12 Bleeder Schedules

Bleeder schedules are used in conjunction with vacuum bag processing to remove resin that is in excess of the desired fiber/resin ratio (see 17.3) and to remove air and volatiles from the resin system as it cures. There are many types of materials available to perform the various functions in a bleeder schedule, so the potential combinations are infinite. However, a typical bleeder schedule might contain the following elements:

- Release layer—Allows resin and gasses to pass through and releases from the cured part/repair.
- Bleeder material—Absorbent material to hold resin.
- Separator layer—Prevents resin from saturating breather materials. A separator may not be necessary depending on resin quantity and flow characteristics.
- Breather material—Provides gas path for extraction of air and volatiles.
- Vacuum bag—Used with sealant tape to achieve vacuum.



*Separator layer, if used, should allow breather and bleeder materials to make contact beyond the edge of the repair to allow air and volatiles to escape.

Section 18: Turbine Engines

18.1 Turbine Operating Principles

- The mass of air is accelerating within the engine by the use of a continuous cycle (Brayton Cycle). Air enters the inlet where it is subjected to changes in temperature, velocity, and pressure. As the compressor section of the engine compresses the air, the pressure increases along with temperature. When the airflow exits the compressor section, it flows through the diffuser where the air velocity is slowed down and pressure is increased by a divergent duct.
- 25% of the air passes into the combustion area (burner) of the engine, while 75% of the airflow is used to cool the combustion area. Part of the 75% of the airflow is used to dilute the hot gases exiting the combustion section. The air now flows into a turbine inlet guide vane, which directs the flow into the turbine wheel.
- The airflow turns the turbine wheel, which is mechanically connected to the compressor. After the gases flow past to the compressor turbine, the remaining energy is used to drive more turbine wheels, which can turn the propeller, fan, or a shaft. The exhaust gas then passes through the exhaust section, which directs the unused exhaust gases overboard.

18.2 Types of Turbine Engines

- *Turbojet:* The earliest production engines were turbojets. All of the early jet airliners used turbojets. They have been phased out of commercial service due to their high fuel consumption and noise levels, but are still used in many military applications.
- *Turbofan:* Modern commercial passenger aircraft use turbofan engines, which produce high thrust levels yet still maintain good fuel efficiency. A version of the turbofan, designed with lower bypass ratios (sometimes equipped with an afterburner sections), is used on many modern military aircraft.
- *Turboprop:* A turboprop engine is a turbine engine that turns a conventional propeller. This type of engine offers high fuel efficiency compared to other turbine engines; however, the propeller limits maximum aircraft speed. It is popular on business aircraft and small, short-range airliners.

- *Turboshaft:* Turboshaft engines, used on helicopters, are gas turbine engines that drive a transmission and rotor system. A variation of the turboshaft is the auxiliary power unit (APU), which is used to provide power to start the main engines, and also to provide electrical power and compressed air for heating and cooling the aircraft on the ground.

18.3 Turbine Engine Sections

- *Air inlet:* Conducts incoming air to the compressor with minimum energy loss.
- *Compressor (cold) section:* Supplies air in sufficient quantity to satisfy the requirements of the combustion burners (must also increase the pressure of the mass of air received).
- *Combustion section:* Raises the temperature of the air passing through the engine located between the compressor and the turbine section.
- *Turbine section:* Transforms a portion of the kinetic energy (velocity) of the exhaust gases into a mechanical energy to drive the gas generator, compressor, and accessories.
- *Exhaust (hot) section:* Must direct flow of hot gases rearward in such a manner as to prevent turbulence.
- *Accessory section:* Provides space for the mounting of accessories necessary for operation and control of the engine.

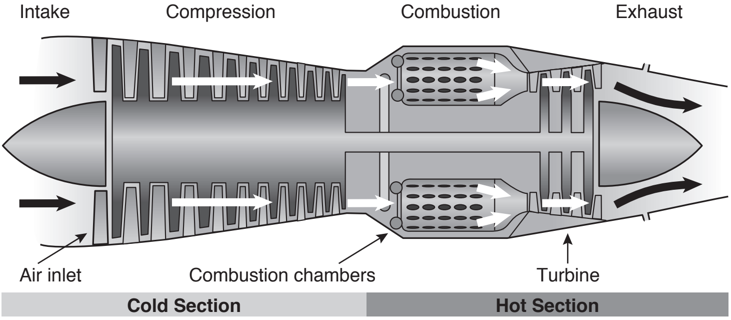
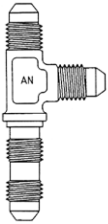


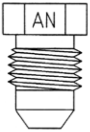
Figure 8.1. *Basic components of a turbojet engine*

Appendices

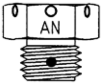
Appendix 1: Hydraulic Fittings



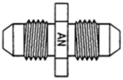
AN804
Bulkhead Tee, Bulkhead on run



AN806
Pressure Plug

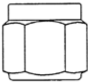


AN814
Bleeder Plug



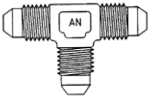
AN815
Union

AN816
Pipe to 37° Flare, Straight

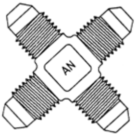


AN818
Tube Nut

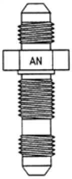
AN821
90° Elbow



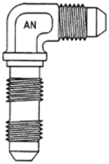
AN824
Tee



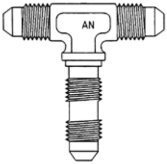
AN827
Cross



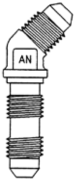
AN832
Bulkhead Straight



AN833
Bulkhead 90°

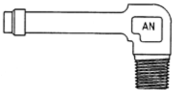


AN834
Bulkhead Tee, Bulkhead on side

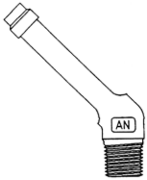


AN837
Bulkhead 45°

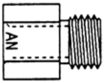
AN840
Straight Nipple



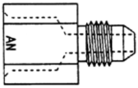
AN842
90° Nipple



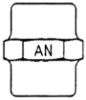
AN844
45° Nipple



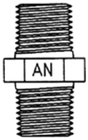
AN893
Female Straight
to Male Straight



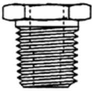
AN894
Female
Straight
to Male 37°



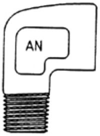
AN910
Female Straight



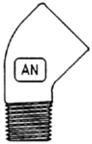
AN911
Male Straight



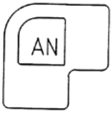
AN912
Pipe to Pipe
Bushing



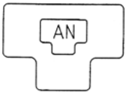
AN914
Male to Female 90°



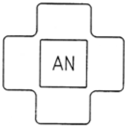
AN915
Male to Female 45°



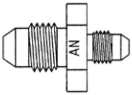
AN916
Female 90°



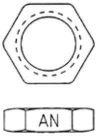
AN917
Female Tee



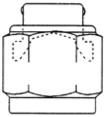
AN918
Female Cross



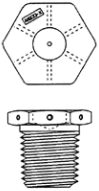
AN919
Male to Male,
37° Flare



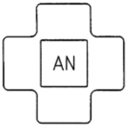
AN924
Bulkhead Nut



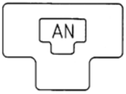
AN929
Pressure Cap



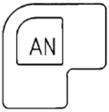
AN933
External Hex Plug



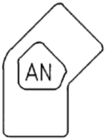
AN937
Straight Thread
Cross



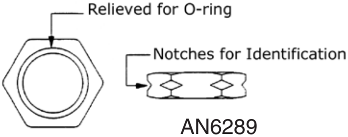
AN938
Straight Thread
Tee



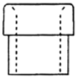
AN939
Straight Thread
90° Elbow



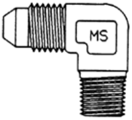
AN941
Straight Thread
45° Elbow



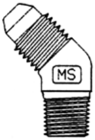
AN6289
Bulkhead Nut



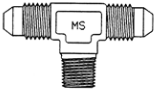
MS20819
Sleeve



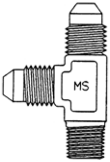
MS20822
Pipe to 37°
Flare, 90°



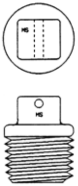
MS20823
Pipe to 37°
Flare, 45°



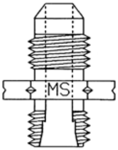
MS20825
Tee, Pipe on Side



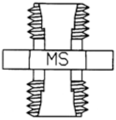
MS20826
Tee, Pipe on Run



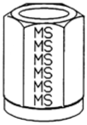
MS20913
Square Plug,
replaces AN913



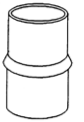
MS21900
37° Flare to Flareless



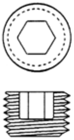
MS21902
Flarelelss Union



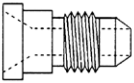
MS21921
Flareless Nut



MS21922
Flareless Sleeve



MS27769
Hex Plug,
replaces AN932

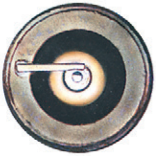


NAS1564
Female 37°
to Male 37°

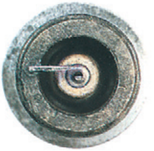
Appendix 2: Engines

Fine-Wire Spark Plugs

Normal: Indicates short service time and correct heat range. Clean, regap and test before reinstalling.



Worn Out—Normal: Indicates normal service life, electrodes show normal erosion, ground electrodes about half original thickness. Install new spark plugs.



Worn Out—Severe: Extensively eroded center and ground electrodes indicate abnormal engine power operation or plugs long overdue for replacement. Install new spark plugs.

Lead Fouled: Hard, cinder-like deposits from poor fuel vaporization, high T.E.L. content in fuel or engine operating too cold. Clean, regap, test and reinstall.

Carbon Fouled: Black, sooty deposits from excessive ground idling, idle mixture too rich or plug type too cold. If heat range is correct, clean, regap, test and reinstall.

Oil Fouled: Wet, oily deposits may be caused by broken or worn piston rings, excessive valve guide clearances, leaking impeller seal or engine still in break-in period. Repair engine as required. Clean, regap, test and reinstall plugs.

Massive Electrode Plugs

Normal: Indicates short service time and correct heat range. Clean, regap and test before reinstalling.

Worn Out—Normal: Indicates normal service life, electrodes show normal erosion, ground electrodes about half original thickness. Install new spark plugs.

Worn Out—Severe: Excessively eroded center and ground electrodes indicate abnormal engine power operation. Check fuel metering. Install new spark plugs.

Lead Fouled: Hard, cinder-like deposits from poor fuel vaporization, high T.E.L. content in fuel or engine operating too cold. Install new spark plugs.

Carbon Fouled: Black, sooty deposits from excessive ground idling, idle mixture too rich or plug type too cold. If heat range is correct, clean, regap, test and reinstall.

Oil Fouled: Wet, oily deposits may be caused by broken or worn piston rings, excessive valve guide clearances, leaking impeller seal or engine still in break-in period. Repair engine as required. Clean, regap, test and reinstall plugs.

Courtesy Champion Aviation Products

Spark Plug Color Identifier

Painted between spark plug hole and rocker box.

Gray or unpainted	Short reach spark plug
Yellow	Long reach spark plug

Cylinder Color Code Identifiers

Painted around cylinder base by the hold down nuts or on fins between push rods:

Gray or unpainted	Standard steel barrels
Orange	Chrome plated cylinder barrels
Blue	Nitride hardened cylinder barrels
Green	Steel cylinder 0.010 oversize
Yellow	Steel cylinder 0.020 oversize
White	Rebarreled cylinder
Platinum	CermiNil® cylinder barrels
Two orange bands	CermiChrome® cylinder barrels

Appendix 3: Lead Acid Aircraft Batteries

Adapted from "Concorde Aircraft Battery Owner/Operator Manual," courtesy Concorde Battery Corporation

Safety Summary for Lead Acid Aircraft Batteries

Warning: Low Capacity Hazard

Aircraft batteries are certified to have a certain minimum capacity for emergency operations in the event of a electrical generator system failure. Never use a battery that has less than 80% of rated capacity.

Warning: Electric Burn Hazard

Lead acid batteries are capable of delivering high currents if the terminals are shorted. The resulting heat can cause severe burns and is a potential fire hazard. Take the following precautions:

a. Do not place tools or metal objects across battery terminals.

b. Do not wear conductive rings, belt buckles, watches or other jewelry when servicing batteries.

c. Wear insulated gloves and use insulated tools when servicing batteries.

d. Install battery terminal protectors whenever the battery is not connected in the aircraft or to the test equipment.

Warning: Danger of Exploding Batteries

Lead acid batteries can produce explosive mixtures of hydrogen and oxygen while on charge or discharge, which can explode if ignited. Take the following precautions:

a. Never install batteries in an airtight or sealed enclosure and make sure installation is adequately ventilated.

b. Do not smoke, use an open flame, or cause sparking near a battery.

c. Wear proper eye and face protection when servicing batteries.

d. Make sure work area is well ventilated.

e. Do not constant-current charge a battery when it is installed in an aircraft.

f. Connect cables securely to the battery terminals to avoid arcing.

Warning: Danger of Chemical Burns

Lead acid batteries contain sulfuric acid which can cause severe burns to body tissue. Take the following precautions:

a. Never remove or damage vent valves.

b. Avoid contact of the electrolyte with skin, eyes or clothing.

c. Do not touch eyes after touching a battery.

d. In the event of acid in the eyes, flush thoroughly with clean cool water for several minutes and get professional medical attention immediately.

e. Refer to battery material safety data sheet (MSDS) for additional information.

Caution: Danger of Equipment Damage

To prevent damage to the connector, arc burns, or explosion, batteries should never be connected or disconnected while being charged or discharged. Batteries must be connected or disconnected only when the circuit is open.

Ensure the aircraft battery switch, external power source, or the charger/analyzer is in the "OFF" position before connecting or disconnecting the battery. Battery terminal protectors should be installed whenever the battery is not connected in the aircraft or to the test equipment.

Valve Regulated Lead Acid—Absorbent Glass Mat (VRLA-AGM) Batteries

Adapted from "Concorde RG® Series Aircraft Battery Owner/Operator Manual"

Battery Description

Concorde RG® Series aircraft batteries are made using valve regulated lead acid cells. Each cell is sealed with a pressure relief valve that regulates the internal pressure and prevents gases from escaping. The positive and negative plates are sandwiched between layers of glass mat consisting of glass microfibers of varying length and diameter. This blend features superior wicking characteristics and promotes maximum retention of the electrolyte. Electrolyte is absorbed and held in place by the capillary action between the fluid and the absorptive glass mat (AGM) fibers.

By design, the AGM separator is only about 90–95% saturated with electrolyte. The void space provides the channels by which oxygen travels from the positive to the negative plates during charging. When the oxygen gas reaches the negative plate, it reacts with lead to form lead oxide and water. This reaction at the negative plate suppresses the generation of hydrogen that otherwise would come off the negative plate. In this manner, virtually all of the gas is recombined inside the cell, eliminating the need to add water, resulting in "maintenance free" operation.

Pressure Relief Valve

The pressure relief valve (PRV) is designed to open when the internal pressure of a cell is approximately 1.5 psi above the external pressure. The PRV prevents excessive pressure buildup when the battery is being charged, and automatically reseals once the pressure is released.

A slight bulge in the battery container can occur when the internal pressure increases slightly, but not enough to open the PRV. Alternately, if the PRV opens at altitude and the battery is then returned to the ground, the external pressure can be greater than the internal pressure, resulting in a concave battery container. Both of these conditions are normal and do not affect the battery's operation.

CAUTION: Do not remove the pressure relief valves on an RG® battery and do not add water or electrolyte. The recombinant gas design eliminates the need to replenish water and electrolyte. Removing the pressure relief valve voids the warranty.

Valve-Regulated Cells

The RG® Series of aircraft batteries consist of 6 or 12 valve-regulated lead acid cells connected in series to make a nominal 12-volt or 24-volt battery, respectively. The cells are contained in a plastic or metallic container equipped with an electrical receptacle for mating to the aircraft. In some models, externally mounted temperature sensors are present that interface to the aircraft charging and/or electrical system. Some models also include heaters to warm the battery for operation in extreme cold temperature environments.

Technical characteristics of the various battery models are detailed on Concorde's website at www.concordebattery.com. If internet access is not available, contact Concorde for assistance.

Storage

1. Batteries are serviced and charged at the factory prior to shipment.
2. To prolong shelf life, batteries should be stored in a cool location, ideally below 20°C (68°F).
3. The open circuit voltage (OCV) of a fully charged battery is approximately 26.0 volts (13.0 volts for 12-volt batteries). As the battery state of charge drops due to self discharge, its OCV also declines.
4. Batteries should be boost-charged when the OCV declines to 25.0 volts (12.5 volts for 12-volt batteries).

5. Batteries with an OCV below 25.0 volts (12.5 volts for 12-volt batteries) due to improper or inadequate boost-charging must be capacity tested before being placed in service.
6. Refer to the applicable component maintenance manual (CMM) for detailed instructions on boost-charging and capacity testing.

Transportation

The battery should be packaged in its original container. If the original container is not available, follow local packaging regulations applicable to the mode of transport.

Concorde RG® Series batteries are exempt from U.S. DOT hazardous materials regulations ("Hazmat," in 49 CFR Parts 105 through 180), IATA Dangerous Goods regulations, and IMDG (International Maritime Dangerous Goods) Code. When properly packaged, they can be shipped as non-hazardous via any method. For more details, refer to the battery MSDS and the transportation information on Concorde's website (www.concordebattery.com). If internet access is not available, contact Concorde for assistance.

Preparation For Installation

1. Remove battery from the shipping carton and visually inspect the battery for signs of damage. Do not use the battery if it appears to be damaged. Contact Concorde for assistance.
2. Measure the battery's open circuit voltage (OCV) with a calibrated digital multimeter (DMM).
3. If the OCV equals or exceeds 25.5 volts (12.75 volts for 12-volt batteries), the battery can be installed in the aircraft without charging.
4. If the OCV equals or exceeds 25.0 volts and is less than 25.5 volts (12.5 and 12.75 volts for 12-volt batteries), apply a boost charge before installation. The battery can then be installed in the aircraft.
5. If the OCV is below 25.0 volts (12.5 volts for a 12-volt battery), perform a capacity test before installing in the aircraft.
6. Refer to the applicable CMM for detailed instructions on boost-charging and capacity testing.

Installation

Note: The following instructions are generic. See aircraft maintenance manual or STC (Supplemental Type Certificate) for instructions specific to a particular aircraft model.

> **WARNING:** Lead acid batteries are heavy, with some models exceeding 50 pounds. Use appropriate lifting devices or equipment. Use battery handles where provided.

1. Remove existing battery (if present):
   - Set master switch to the OFF position.
   - Disconnect any external power supply.
   - Open battery compartment access panel(s).
   - Disconnect battery quick disconnect plug or remove terminal bolts and disconnect battery cables from battery terminals. Always disconnect the ground cable first and install the ground cable last.
   - Disconnect battery ventilation tubes, if any.
   - Unlock battery hold-down clamps or remove battery hold-down bars.
   - Disengage battery and install terminal protection to prevent accidental shorting of terminals.
   - Carefully remove from battery compartment.

2. Install replacement battery:
   - Inspect the battery for damage. Cracks in metal or plastic containers are not permitted. Dents in metal containers that impinge on the interior plastic container are not acceptable. If defects are found, contact an authorized service center or contact Concorde for assistance.
   - Verify battery terminals are protected from shorting.
   - Set master switch to the OFF position.
   - Disconnect any external power supply.
   - Open battery compartment access panels.
   - Ensure the battery container or tray is clean and dry.
   - Install battery in battery container or tray.
   - Engage battery hold-down hardware, torque and safety wire, per aircraft maintenance manual.
   - Connect battery vent tubes to aircraft ventilation system, if present.

- Remove battery terminal protection.
- Connect battery quick disconnect plug and any auxiliary connectors.
- For ring terminals, install with bolt and bevel lock washer provided with the battery. Torque terminal bolts as noted on the battery label. Always disconnect the ground cable first and install the ground cable last.

CAUTION: On batteries with internally threaded terminals, use an open-end wrench on the flat portion of the terminals while torquing the terminal bolts. Failure to do so may result in the rupture of the battery seal at the terminal and premature failure of the battery.

Use only the hardware provided with the battery. Do not use stainless steel or steel washers between the ring terminal and the battery terminal.

- Replace electrical compartment access panel.
- Update aircraft weight and balance data, if necessary.
- Perform an operational test.
- Annotate battery logbook with battery serial number, date of installation and aircraft hours.

Operation

Applications

Aircraft batteries are used to start engines and auxiliary power units (APUs), to provide emergency backup power for essential avionics equipment and lighting systems, to ensure no-break power for navigation units and fly-by-wire computers, and to provide ground power capability for maintenance and preflight checkouts. Most of these functions are critical to safe operation of the aircraft, so the state of health (SOH) of an aircraft battery is of utmost importance.

Aircraft batteries are certified to have a particular minimum capacity for emergency operations in the event of an electrical generator system failure. If the battery is used to satisfy essential or emergency power requirements, its capacity must be tested periodically to ensure airworthiness. See the “Servicing” section below (page 334) for capacity test instructions.

Battery Charging

The aircraft’s electrical system automatically charges the battery when the engine(s) are running. Most aircraft allow charging using external power as well.

The battery charging system in most aircraft is of the constant voltage type. With constant voltage charging, the battery will accept charging current inversely proportional to its state of charge (that is, the lower the state of charge, the higher the charging current). When the battery reaches full charge, the charging current tapers off to a very low value (typically 0.5% of the C1 capacity), and remains at that level to keep the battery on a "float charge." Therefore, an ammeter reading of the charging current (if present) is useful in determining the approximate state of charge of the battery.

Temperature Compensation

Battery service life can be prolonged by compensating the charging voltage based on the battery temperature. For aircraft that have an adjustable voltage regulator, Table 1 provides recommended settings.

Table 1. Recommended Voltage Regulator Settings

	Voltage regulator setting (volts DC)	
Battery temperature	**12V system**	**24V system**
Below 0°C (32°F)	14.5–14.75	29.0–29.5
0 to 15°C (32 to 59°F)	14.25–14.5	28.5–29.0
16 to 30°C (60 to 86°F)	14.0–14.25	28.0–28.5
31 to 45°C (87 to 113°F)	13.75–14.0	27.5–28.0
Above 45°C (113°F)	13.5–13.75	27.0–27.5

Ground Power Units

When aircraft are powered by ground power units, be sure that the DC output voltage is adjusted to the range shown in Table 1. Through the years there have been many reports of overcharged batteries due to ground power units being set too high. High charging voltages will shorten the battery service life significantly.

Open Circuit Voltage

The battery state of charge (SOC) can be determined (approximately) from reading the battery's open circuit voltage (OCV). To get an accurate OCV, the battery needs to be stabilized on open circuit (no charging or discharging current) for at least 4 hours. Once the stabilized OCV is measured, the SOC can be determined from Table 2.

Table 2. State of Charge versus Open Circuit Voltage

Open circuit voltage		
12V battery	**24V battery**	**State of charge (%)**
12.9 or above	25.8 or above	100%
12.6	25.2	75%
12.3	24.6	50%
12.0	24.0	25%
11.7 or below	23.4 or below	0%

Note: The battery state of charge should not be confused with state of health (*see* Glossary, page 350). A battery at 100% state of charge may or may not have good state of health (that is, the actual capacity may or may not be considered airworthy). The only reliable method to determine battery state of health is by capacity test (*see* "Servicing," page 334).

Aircraft Storage

When an aircraft is placed in storage or remains dormant for an extended time, it is best to disconnect the battery connector. This practice will eliminate unnecessary drain on the battery if parasitic loads are present. Parasitic loads can deplete battery capacity and result in battery sulfation (*see* next section).

Sulfated Batteries

Lead acid batteries become sulfated when they remain in a discharged state for extended periods of time. The longer the time period and the greater the depth of discharge, the worse the sulfation becomes. Sulfation may be reversible or irreversible, depending on the severity.

Sulfation is evidenced by a low open circuit voltage (below 12.5 volts for a 12-volt battery or 25.0 volts for a 24-volt battery) after the battery has been subjected to a full recharge using normal (constant voltage) charging conditions.

To prolong the battery service life, conditions leading to sulfation should be prevented as much as possible. For example, if the master switch is inadvertently left on and the battery becomes deeply discharged, it should be charged as soon as possible. Another example is parasitic loads that drain the battery capacity during extended dormant periods as described under "Storage" (above). Whichever is the cause, if the battery appears to be sulfated, it should be removed from the aircraft and subjected to a capacity test.

Cold Weather Operation

In cold climates, the state of charge in a storage battery should be kept at a maximum. A fully charged battery will not freeze even under the most severe weather conditions, but a discharged battery will freeze very easily. Table 3 gives the freezing point of electrolyte at various states of charge.

Table 3. Electrolyte Freezing Point versus Battery State of Charge

Battery state of charge (%)	Approximate electrolyte freezing temperature
100%	-70°C (-94°F)
75%	-47°C (-53°F)
50%	-25°C (-13°F)
25%	-13°C (9°F)
0%	-6°C (21°F)

Unlike flooded batteries, Concorde RG® Series batteries will not be damaged when frozen. However, frozen batteries are not capable of charging or discharge except at very low rates. The battery must first be warmed above the freezing point, and then fully charged to prevent refreezing.

Operating an aircraft battery in cold weather is equivalent to using a battery of lower capacity. For example, a fully charged battery at 25°C (77°F) may be capable of starting an engine twenty times. At -18°C (0°F) the same battery may start the engine only three times. Low temperatures also increase the time necessary for charging a battery. A battery which could be recharged in an hour at 25°C (77°F) while flying may require 5 hours for charging when the temperature is -18°C (0°F).

CAUTION: When the ambient temperature is below 0°C (32°F), the engine(s) should be started using battery power instead of a ground power unit. This procedure warms the battery and improves its charge acceptance. If the battery is not used to start the engine(s) in cold temperatures, the battery might not have sufficient emergency power during flight.

Note: Some RG® series batteries contain internal heaters that are powered by the aircraft electrical system. Once the aircraft is powered up, the heaters warm the battery to improve its charge acceptance in cold weather. If the main battery contains a heater, it is not necessary to use battery power to start the engine(s) if a ground power unit is available.

In summary, during cold weather, keep batteries fully charged. Make every effort to conserve battery power. Consider using a heated battery to improve charge acceptance.

Ventilation Systems

Airplanes are often equipped with a battery ventilation system. The ventilation system provides for removal of gasses and acid fumes from the battery via vent tubes on the battery case. Ventilation systems are usually a necessity when flooded type batteries are used, but the amount of gas and acid fume generation is minimal from Concorde RG® Series valve regulated batteries. In some installations, the venting system is eliminated as part of the aircraft modification when changing from a flooded battery to a valve-regulated battery. However, if the venting system is present, it should be connected when installing Concorde RG® Series batteries.

CAUTION: Never install an RG® series battery in a sealed or airtight enclosure. Combustible gases are emitted during charge and must be permitted to escape.

Servicing

Charging Battery While Installed

Batteries may be charged while installed on the aircraft with the following restrictions:

1. Battery charger meets the requirements specified in the CMM, or it is specifically approved by Concorde.
2. The battery compartment is well ventilated.

As an extra precaution, the battery should be disconnected from the aircraft electrical system if there is any possibility the charging source might put out excessive voltage that could damage equipment connected to the battery bus.

Scheduled Inspections

If the battery is used to satisfy essential or emergency power requirements, its capacity must be tested periodically to ensure airworthiness. In general, a battery is considered airworthy if it has at least 80% of rated capacity. Concorde and the FAA recommend 85% as the pass/fail criteria to provide a margin of safety. The battery should be removed from the aircraft to perform a capacity test. Refer to the applicable CMM for detailed instructions regarding frequency of inspections and capacity test procedures.

Unscheduled Inspections

The battery should be subjected to a capacity test under any of the following conditions:

1. Abnormally slow engine starting,
2. Abnormally high charging current (greater than 5% of C1 capacity) after several hours of charging, or
3. Battery becomes excessively hot (case temperature above 55°C/131°F).

Repairs

The cells and other internal components of most RG® Series batteries are non-repairable. The battery assembly must be replaced when internal components fail or wear out. If external repairs are needed to the battery assembly (i.e., missing labels, dents, scratches, etc.), send it to an authorized repair facility or contact Concorde for assistance.

Note: Some RG® series batteries have replaceable subassemblies, and the CMM for these batteries include an illustrated parts list for the replaceable components.

Temperature Sensors

Some battery models are equipped with externally mounted temperature sensors. Instructions for inspection and testing of Concorde temperature sensors are contained in separate maintenance manual supplements for each type of temperature sensor. These maintenance manual supplements are available on Concorde's website. If internet access is not available, contact Concorde for assistance.

Servicing Parallel Batteries

In some aircraft, two identical batteries are used in parallel for starting engines. The recommended practice is to replace both batteries even if only one has low capacity. The replacement batteries should be of the same or similar age and usage history. When batteries of different ages are used in parallel, the newer battery will work harder due to lower resistance, which accelerates aging of the newer battery.

Disposal

Concorde RG® Series batteries contain lead, sulfuric acid, and other hazardous materials. Never discard batteries in the trash or in a landfill.

The battery materials are 100% recyclable. Dispose spent batteries and assemblies in accordance with local ordinances and regulations.

Some RG® series batteries have outer shells made of aluminum, steel or titanium. These outer shells must be removed before the battery is sent to the smelter. Make sure the recycling collector is aware of this requirement.

See battery material safety data sheet (MSDS) for additional information.

Dry Charged (Vented) Lead Acid Batteries

Adapted from "Concorde CB Series Aircraft Battery Owner/Operator Manual"

Battery Description

Concorde CB Series aircraft batteries contain flooded lead acid cells. Each cell consists of positive plates made of lead dioxide, negative plates made of spongy lead, and a flooded electrolyte made of sulfuric acid and water. The positive and negative plates are sandwiched between layers of microporous polyethylene separator to prevent the plates from shorting together.

When the plates are connected to an external load, electrons flow from the negative plate to the positive plate. The loss of electrons at the negative plate causes an oxidation reaction that converts the spongy lead into lead sulfate. The gain of electrons at the positive plate causes a reduction reaction that converts the lead dioxide into lead sulfate. This process will continue until a major portion of each plate is converted to lead sulfate and the battery is fully discharged.

During the charging process, current is passed through the cells in the reverse direction. The reverse current causes a reverse of the chemical reaction, returning the positive plates to lead dioxide and the negative plates to spongy lead. When this process is complete, the battery is fully charged.

Chemical Reaction and Battery State of Charge

In lead acid cells, the sulfuric acid participates in the chemical reaction at each plate. When the plates are discharged, the amount of sulfuric acid in the electrolyte decreases. Conversely, as the plates are charged, the amount of sulfuric acid in the electrolyte increases. As the sulfuric acid concentration changes, the specific gravity of the electrolyte changes. Therefore, the specific gravity can be used to measure the approximate state of charge of the battery. When the plates are fully charged, the specific gravity will be in the range of 1.275 to 1.300. When the plates are fully discharged, the specific gravity will be approximately 1.100.

Gas Venting and Water Replenishment

When flooded lead acid cells are being charged, oxygen gas is generated at the positive plates and hydrogen gas is generated at the negative plates. These gases are released from the cell through a specially designed vent valve. The release of these gases causes water to be lost from the cell and the electrolyte level gradually declines.

To prevent the cell from drying out, flooded cells therefore require periodic water replenishment. This is in contrast to valve regulated lead acid cells, which internally recombine the gases and do not require periodic water replenishment. (*Note:* For more information on valve regulated batteries, refer to the RG® Series Owner/Operator Manual, Document No. 5-0324.)

Lead Acid Cells

The CB Series of aircraft batteries consist of 6 or 12 flooded lead acid cells connected in series to make a nominal 12-volt or 24-volt battery, respectively. The cells are contained in a plastic container equipped with electrical terminals or a receptacle for mating to the aircraft.

Technical characteristics of the various battery models are detailed on Concorde's website. If internet access is not available, contact Concorde for assistance.

Storage

1. Batteries are dry-charged at the factory prior to shipment and the cell vents are sealed. Do not remove the sealing tape until you are ready to activate the battery.
2. Dry-charged batteries may be stored indefinitely prior to activation. To avoid extra conditioning procedures, batteries should be activated within 4 years from the date of manufacture.
3. Store batteries in a cool, dry location. High humidity and temperature conditions increase the discharge rate of the negative plate and may extend the time of the activation procedure.

Transportation

Batteries should be packaged in their original container. If the original container is not available, follow local packaging regulations applicable to the mode of transport.

CB Series batteries, when furnished without electrolyte packs, are exempt from U.S. DOT hazardous materials (Hazmat) regulations, IATA Dangerous Goods regulations, and IMDG Code. When properly packaged, they can be shipped as non-hazardous via any method. For more details, refer to the battery MSDS and the transportation information on Concorde's website. If you are unable to access the internet, contact Concorde.

CB Series batteries, when furnished with electrolyte packs, must be shipped as Hazmat regulated under the designation UN2796 (Corrosive). After activation with electrolyte, batteries must be shipped as Hazmat regulated under the designation UN2794 (Corrosive). Transport requires proper packaging and paperwork in accordance with U.S. DOT Hazmat regulations, IATA Dangerous Goods regulations, and IMDG Code. For more details, refer to the battery MSDS and the transportation information on Concorde's website.

For transportation details not covered by IATA Dangerous Goods Regulations or IMDG Code, refer to local transport regulations for shipping instructions.

Preparation For Installation

Remove the battery from the shipping carton and visually inspect it for signs of damage. Do not use the battery if it appears to be damaged; contact Concorde for assistance.

Activation of Dry Charged Batteries

CAUTION: This activation procedure only applies to CB Series flooded (dry-charged) batteries. Do not attempt to activate RG® Series valve regulated batteries.

WARNING: The electrolyte contains sulfuric acid which can cause severe burns to body tissue. Avoid contact of the electrolyte with skin, eyes or clothing. In the event of acid in the eyes, flush thoroughly with clean cool water for several minutes and get professional medical attention immediately.

1. Remove the sealing tape from the vents and remove the vent caps.
2. Fill each cell with 1.285 SG electrolyte to a height just above the top of the plates and separators.
3. Mark the activation date (month and year) on the battery with a permanent marker or label.
4. Let the battery cool for one hour, and then add more electrolyte to bring the level 1/4-inch above the top of the plates and separators. Do not fill beyond this level because some electrolyte expansion will occur during charging.
5. Install vent caps.
6. Boost-charge the battery using a constant-current charger at 10% of the C1 rate (e.g., 4.2 amps for 42Ah battery).
7. The battery is fully charged when the voltage stabilizes or decreases slightly and the SG of the electrolyte stabilizes for three successive readings taken at one-hour intervals. This will normally occur within 8 to 12 hours from the start of charging.

CAUTION: Stop the charge if the battery temperature exceeds 120°F. Resume charging after the battery cools down. After activation, complete charging is required for satisfactory performance.

8. After the battery is fully charged, verify the electrolyte SG of each cell is within the range of 1.275 to 1.295. If not within the stated range, adjust the electrolyte by diluting higher SG cells with distilled or deionized water and by adding stronger electrolyte to the lower SG cells. These adjustments should only be made when the battery is on charge and the cells are gassing (bubbling) uniformly. Make sure the final electrolyte level is no higher than the bottom of the vent well.
9. After SG and electrolyte levels have been verified/adjusted, install vent caps.
10. Perform a capacity test to ensure the battery has been adequately activated.
11. Wash and dry the outside of the battery before installation.

Installation

Note: The following instructions are generic. See aircraft maintenance manual or STC for instructions specific to a particular aircraft model.

WARNING: Lead acid batteries are heavy, with some models exceeding 50 pounds. Use appropriate lifting devices or equipment. Use battery handles where provided.

1. Remove existing battery (if present):
    - Set master switch to the OFF position.
    - Disconnect any external power supply.
    - Open battery compartment access panel(s).
    - Disconnect battery quick disconnect plug or remove terminal bolts and disconnect battery cables from battery terminals. Always disconnect the ground cable first and install the ground cable last.
    - Disconnect battery ventilation tubes, if any.
    - Unlock battery hold-down clamps or remove battery hold-down bars.
    - Disengage battery and install terminal protection to prevent accidental shorting of terminals.
    - Carefully remove from battery compartment.
2. Install replacement battery:
    - Inspect the battery for damage. Cracks in metal or plastic containers are not permitted. Dents in metal containers that impinge on the interior plastic container are not acceptable. If defects are found, contact an authorized service center or contact Concorde for assistance.
    - Verify battery terminals are protected from shorting.
    - Set master switch to the OFF position.
    - Disconnect any external power supply.
    - Open battery compartment access panels.
    - Ensure the battery container or tray is clean and dry.
    - Install battery in battery container or tray.
    - Engage battery hold-down hardware, torque and safety wire per aircraft maintenance manual.
    - Connect battery vent tubes to aircraft ventilation system, if present.
    - Remove battery terminal protection.

- Connect battery quick disconnect plug and any auxiliary connectors.
- For ring terminals, install with bolt and bevel lock washer provided with the battery. Torque terminal bolts as noted on the battery label. Always disconnect the ground cable first and install the ground cable last.

CAUTION: On batteries with internally threaded terminals, use an open-end wrench on the flat portion of the terminals while torquing the terminal bolts. Failure to do so may result in the rupture of the battery seal at the terminal and premature failure of the battery.

Use only the hardware provided with the battery. Do not use stainless steel or steel washers between ring terminals and the battery terminal.

- Replace electrical compartment access panel.
- Update aircraft weight and balance data, if necessary.
- Perform an operational test.
- Annotate battery logbook with battery serial number, date of installation and aircraft hours.

Operation

Applications

Aircraft batteries are used to start engines and auxiliary power units (APUs), to provide emergency backup power for essential avionics equipment and lighting systems, to ensure uninterrupted power for navigation units and fly-by-wire computers, and to provide ground power capability for maintenance and preflight checks. Most of these functions are critical to safe operation of the aircraft, so the state of health of an aircraft battery is of utmost importance.

Aircraft batteries are certified to have a particular minimum capacity for emergency operations in the event of an electrical generator system failure. If the battery is used to satisfy essential or emergency power requirements, its capacity must be tested periodically to ensure airworthiness. See the "Servicing" section below (page 345) for capacity test instructions.

Battery Charging

The aircraft's electrical system automatically charges the battery when the engine(s) are running. Most aircraft allow charging using external power as well.

The battery charging system in most aircraft is of the constant voltage type. With constant voltage charging, the battery will accept charging current inversely proportional to its state of charge (that is, the lower the state of charge, the higher the charging current). When the battery reaches full charge, the charging current tails off to a very low value (typically 0.5% of the C1 capacity), and remains at that level to keep the battery on a "float charge." Therefore, an ammeter reading of the charging current (if present) is useful in determining the approximate state of charge of the battery.

Temperature Compensation

Battery service life can be prolonged by compensating the charging voltage based on the battery temperature. For aircraft that have an adjustable voltage regulator, Table 1 provides recommended settings.

Table 1. Recommended Voltage Regulator Settings

	Voltage regulator setting (volts DC)	
Battery temperature	**12V system**	**24V system**
Below 0°C (32°F)	14.5–14.75	29.0–29.5
0 to 15°C (32 to 59°F)	14.25–14.5	28.5–29.0
16 to 30°C (60 to 86°F)	14.0–14.25	28.0–28.5
31 to 45°C (87 to 113°F)	13.75–14.0	27.5–28.0
Above 45°C (113°F)	13.5–13.75	27.0–27.5

Ground Power Units

When aircraft are powered by ground power units, be sure that the DC output voltage is adjusted to the range shown in Table 1. Through the years there have been many reports of overcharged batteries due to ground power units being set too high. High charging voltages will shorten the battery service life significantly.

Open Circuit Voltage

The battery state of charge (SOC) can be determined (approximately) from reading the battery's open circuit voltage (OCV). To get an accurate OCV, the battery needs to be stabilized on open circuit (no charging or discharging current) for at least 4 hours. Once the stabilized OCV is measured, the SOC can be determined from Table 2.

Table 2. State of Charge versus Open Circuit Voltage

State of charge (%)	Open circuit voltage		Electrolyte specific gravity
	12V battery	**24V battery**	
100%	12.9 or above	25.8 or above	1.285
75%	12.6	25.2	1.240
50%	12.3	24.6	1.190
25%	12.0	24.0	1.140
0%	11.7 or below	23.4 or below	1.090

Note: The battery state of charge should not be confused with state of health (*see* Glossary, page 350). A battery at 100% state of charge may or may not have good state of health (that is, the actual capacity may or may not be considered airworthy). The only reliable method to determine battery state of health is by capacity testing (*see* servicing section, page 345).

Aircraft Storage

When an aircraft is placed in storage or remains dormant for an extended time, it is best to disconnect the battery connector. This practice will eliminate unnecessary drain on the battery if parasitic loads are present. Parasitic loads can deplete battery capacity and result in battery sulfation (*see* next section).

Sulfated Batteries

Lead acid batteries become sulfated when they remain in a discharged state for extended periods of time. The longer the time period and the greater the depth of discharge, the worse the sulfation becomes. Sulfation may be reversible or irreversible, depending on the severity.

Sulfation is evidenced by a low open circuit voltage (below 12.5 volts for a 12-volt battery or 25.0 volts for a 24-volt battery) after the battery has been subjected to a full recharge using normal (constant voltage) charging conditions.

To prolong the battery service life, conditions leading to sulfation should be prevented as much as possible. For example, if the master switch is inadvertently left on and the battery becomes deeply discharged, it should be charged as soon as possible. Another example is parasitic loads that drain the battery capacity during extended dormant periods as described under “Storage” (above). Whichever is the cause, if the battery appears to be sulfated, it should be removed from the aircraft and subjected to a capacity test.

Cold Weather Operation

In cold climates, the state of charge of the battery should be kept at a maximum. As the state of charge gets lower, the freezing point increases as shown in Table 3. The electrolyte in a fully charged battery will not freeze even under the coldest weather conditions on this planet, but the electrolyte in a discharged battery is susceptible to freezing in typical cold weather conditions. Frozen batteries are not capable of charging or discharging except at very low rates, and may be permanently damaged after thawing.

Table 3. Electrolyte Freezing Point versus Specific Gravity

Electrolyte specific gravity	**Electrolyte freezing temperature**	
	Celsius (°C)	**Fahrenheit (°F)**
1.300	-70	-94
1.285	-65	-85
1.275	-61	-78
1.250	-52	-62
1.225	-37	-35
1.200	-27	-17
1.175	-20	-4
1.150	-15	+5
1.125	-10	+13
1.100	-8	+18

Operating an aircraft battery in cold weather is equivalent to using a battery of lower capacity. For example, a fully charged battery at 25°C (77°F) may be capable of starting an engine ten times. At -18°C (0°F) the same fully charged battery has lower capacity available and may only be able to start the engine three times. Low temperatures also increase the time necessary for charging a battery. A battery that could be recharged in an hour at 25°C (77°F) while flying may require 5 hours for charging when the temperature is at -18°C (0°F).

CAUTION: When the ambient temperature is below 0°C (32°F), the engine(s) should be started using battery power instead of a ground power unit. This procedure warms the battery and improves its charge acceptance. If the battery is not used to start the engine(s) in cold temperatures, the battery may not have sufficient emergency power during flight.

In summary, during cold weather, keep batteries fully charged. Make every effort to conserve battery power.

Ventilation Systems

Airplanes should be equipped with a battery ventilation system whenever a CB Series battery is installed. The ventilation system provides for removal of gases and acid fumes from the battery via vent tubes on the battery case. Inlet air is taken from a scoop outside the airplane. After passing over the top of the battery, the exit air is carried through another tube to the battery sump. The sump is a glass or plastic jar containing a felt pad and a sodium bicarbonate solution to neutralize the acid fumes.

CAUTION: Never install a CB series battery in a sealed or airtight enclosure. Combustible gases are emitted during charge and must be permitted to escape.

Servicing

Charging Battery While Installed

Batteries may be charged while installed on the aircraft with the following restrictions:

1. Battery charger meets the requirements specified in the CMM, or it is specifically approved by Concorde.
2. The battery compartment is well ventilated.

As an extra precaution, the battery should be disconnected from the aircraft electrical system if there is any possibility the charging source might put out excessive voltage that could damage equipment connected to the battery bus.

Scheduled Inspections

If the battery is used to satisfy essential or emergency power requirements, its capacity must be tested periodically to ensure airworthiness. In general, a battery is considered airworthy if it has at least 80% of rated capacity. Concorde and the FAA recommend 85% as the pass/fail criteria to provide a margin of safety. Refer to the applicable CMM for detailed instructions regarding frequency of inspections and capacity test procedures.

Unscheduled Inspections

The battery should be subjected to a capacity test under any of the following conditions:

1. Abnormally slow engine starting,
2. Abnormally high charging current (greater than 5% of C1 capacity) after several hours of charging, or
3. Battery becomes excessively hot (case temperature above 55°C/131°F).

Repairs

The cells and other internal components of CB Series batteries are non-repairable. The battery assembly must be replaced when internal components fail or wear out. If external repairs are needed to the battery assembly (i.e., missing labels, dents, scratches, etc.), have it serviced in an authorized repair facility or contact Concorde for assistance.

Servicing Parallel Batteries

In some aircraft, two identical batteries are used in parallel for starting engines. The recommended practice is to replace both batteries even if only one has low capacity. The replacement batteries should be of the same or similar age and usage history. When batteries of different ages are used in parallel, the newer battery will work harder due to lower resistance, which accelerates aging of the newer battery.

Disposal

Concorde CB Series batteries contain lead, sulfuric acid, and other hazardous materials. Never discard batteries in the trash or in a landfill.

The battery materials are 100% recyclable. Dispose spent batteries and assemblies in accordance with local ordinances and regulations.

Some CB series batteries have covers or outer shells made of aluminum, which must be removed before the rest of the battery is sent to the smelter. Make sure the recycling collector is aware of this requirement.

See battery material safety data sheet (MSDS) for additional information.

Glossary—Lead Acid Aircraft Battery Terms

activation: The process of filling and charging a dry charged battery to make it ready for service. After activation, the battery is designated as a flooded lead acid battery.

active material: Electrode material that produces electricity during its chemical conversion.

AGM: Absorbent glass mat used as a separator material between positive and negative plates. Electrolyte is absorbed and held in place by the capillary action between the fluid and glass mat fibers.

battery: A combination of two or more chemical cells electrically connected together to produce electric energy. Common usage permits this designation to be applied also to a single cell used independently.

boost charge: A charge applied to a battery that is already near a state of full charge. Usually a charge of short duration.

C1 rate: The one-hour discharge or current rate in amperes that is numerically equal to rated capacity of a cell or battery in ampere hours (Ah). For example, the C1 rate of a battery rated at 42 Ah is 42 amperes.

capacity: The quantity of electricity delivered by a battery under specified conditions, usually expressed in ampere hours.

cell: An electrochemical device composed of positive and negative plates, separator and electrolyte which is capable of storing electrical energy.

charge: The conversion of electrical energy from an external source into chemical energy within a cell or battery.

charge rate: The rate at which current is applied to a battery to restore its capacity.

constant potential (CP) charge: Charging method where the output voltage of the charge source is held constant and the current is limited only by the resistance of the battery or by the capability of the charging source.

constant-current (CC) charge: Charging method where the output current of the charge source is held constant and the voltage is not regulated.

current: The rate of flow of electricity. The unit of measurement is an ampere.

deep discharge: Withdrawal of 50% or more of the rated capacity of a battery.

depth of discharge: The portion of the nominal capacity from a cell or battery taken out during each discharge cycle, expressed in a percentage.

discharge: The conversion of the chemical energy of a battery into electrical energy and withdrawal of the electrical energy into a load.

discharge rate: The rate of current flow from a battery during discharge.

dry charged battery: A lead acid battery made with dry charged plates. The plates are charged and dried before the battery is assembled. Before use, the battery must be filled with acid and charged to activate it.

electrolyte: In a lead acid battery, the electrolyte is sulfuric acid diluted with water. It is a conductor and also a supplier of hydrogen and sulfate ions for the electrochemical reactions occurring at the plates.

end of life: The stage at which the battery or cell meets specific failure criteria.

end point voltage (EPV): The voltage at which the discharge current is terminated when measuring battery capacity. Sometimes called cutoff voltage or voltage end point. Unless otherwise stated, the EPV is equal to 20.0 volts for 24 volt aircraft batteries (10.0 volts for 12 volt batteries).

float charge: A method of maintaining a cell or battery in a charged condition by continuous, long-term constant voltage charging at a level sufficient to balance self discharge.

flooded battery: A lead acid battery in which there is an excess of electrolyte that extends into the headspace above the plates of each cell. A dry charged battery becomes a flooded battery after it is activated with electrolyte.

gassing: The evolution of gas from one or more of the plates in a cell when the battery reaches full charge.

internal impedance: The electrical impedance inside the battery that restricts the flow of current during high rate charging and discharging. The internal impedance depends on the size of the battery, state of charge, temperature and age.

IPP/IPR: The IPP is the peak power current, defined as the current that the battery delivers at 0.3 seconds during a constant voltage discharge equal to half of the nominal voltage. The IPR is the power rating, defined as the current that the battery delivers at 15 seconds during a constant voltage discharge equal to half of the nominal voltage.

lead acid: Term used in conjunction with a battery that utilizes lead and lead dioxide as the active plate materials in a diluted electrolyte solution of sulfuric acid and water. Nominal cell voltage is 2 volts.

lead dioxide: The oxide of lead present in charge positive plates (PbO_2) and is sometimes referred to as lead peroxide.

lead sulfate: A lead salt formed by the action of sulfuric acid on lead oxide during paste mixing and formation. It is also formed electrochemically when a battery is discharged.

load tester: An instrument which measures the battery voltage with an electrical load on the battery to determine its overall condition.

nominal voltage: Approximate voltage of a fully charged cell or battery. For lead acid cells, the nominal voltage is 2 volts. The nominal voltage of a 6-cell battery is 12 volts and that of a 12-cell battery is 24 volts.

open circuit voltage (OCV): The voltage of the battery at rest (no charging or discharging current present). A stable OCV requires a rest of at least four hours.

overcharge: Applying excessive voltage to force current through a cell after all the active material has been converted to the charged state. The result is decomposition of water in the electrolyte into hydrogen and oxygen gas and accelerated grid corrosion.

oxygen recombination: The process by which oxygen generated at the positive plate during charge reacts with the pure lead material of the negative plate to reform water.

parallel connection: A circuit in which battery terminals of like polarity are connected together. The capacity of each battery adds together while voltage remains the same.

rated C1 capacity: The nominal capacity, expressed in ampere hours (Ah), obtained from a fully charged battery when discharged at the one-hour rate to the specified end point voltage at a temperature of 21–25°C (70–77°F).

self discharge: The decrease in the state of charge of a battery, over a period of time, due to internal electrochemical losses. The self-discharge rate accelerates as the temperature increases and as the battery ages.

separator: A porous, insulating material placed between plates of opposite polarities to prevent internal short circuits.

series connection: A circuit in which battery terminals of opposite polarity are connected together. The voltage of each battery adds together while capacity remains the same.

specific gravity (SG): The weight of the electrolyte as compared to the weight of an equal volume of pure water, used to measure the strength or percentage of sulfuric acid in the electrolyte.

state of charge (SOC): The percentage of available capacity in a battery compared to its fully charged capacity. Example: Battery A is discharged and gives 32 Ah of capacity to its EPV. After a full charge, it is discharged again and gives 40 Ah. The SOC of Battery A before the first discharge was 32/40 = 80%. Note that the SOC does not represent the battery's capacity as a percentage of its rated capacity and should not be used to determine airworthiness (see state of health).

state of health (SOH): The percentage of available capacity in a battery when fully charged compared to its rated capacity. Example: Battery B is fully charged and gives 38 Ah capacity to its EPV. Battery B is rated at 42 Ah. The SOH of battery B is 38/42 = 90%.

sulfation: Refers to the formation of lead sulfate within the battery plates when a battery is discharged. If the battery remains discharged, the lead sulfate becomes more resistive which can limit or prevent the recharging of the battery. Sulfated batteries may sometimes be recovered with a special conditioning charge.

valve regulated lead acid (VRLA) battery: A lead acid battery in which there is no free electrolyte and the internal pressure is regulated by a pressure relief valve. This type of battery requires no maintenance of the liquid level and recombines the gases formed on charge within the battery to reform water.

Appendix 4: Aircraft Tires

Aircraft Tire Construction

Tread

The area of the tire that is actually in contact with the ground. The tread of most modern aircraft tires contain circumferential grooves to channel water from between the tire and the runway surface.

Undertread

The layer of rubber designed to enhance the bonding between the carcass body and the tread reinforcing plies in bias tires or the protector plies in radial tires.

Carcass Ply

Fabric cords (generally nylon), sandwiched between two layers of rubber and anchored by wrapping them around the bead wires.

Bead

A bundle of steel wires embedded in rubber and wrapped with rubber-coated fabric, used to anchor the tire to the wheel.

Chafer Strips

Strips of protective fabric or rubber laid over the outer carcass plies in the bead area of the tire to protect the carcass plies from damage when mounting or demounting the tire, and to reduce the effects of wear and chafing between the wheel and the tire bead.

Liner

In a tubeless tire, this is a layer of specially compounded rubber extending from bead to bead to resist the permeation of nitrogen and moisture through to the carcass. With a tube-type tire, a thinner liner material is used to protect the carcass plies from moisture and the tube from chafing. The liner of a tube-type tire is generally insufficient for air retention.

Sidewall

A layer of rubber covering the outside of the carcass plies.

Bias-Ply Tires

The carcass plies laid at angles between 30° and 60° to the centerline of the tire. The succeeding plies are laid with the cord at angles that are opposite to each other. Most modern aircraft tires are bias-ply tires.

Tread Reinforcing Ply

This consists of single or multiple layers of a special nylon fabric and rubber laid midway beneath the tread grooves and top carcass ply to help reduce tread distortion under load.

Radial Tires

Each carcass ply is laid at an angle of approximately 90° to the centerline of the tire. Radial tires have fewer plies than bias tires of the same size because the cord direction is aligned with the burst pressure radial force.

Protector Ply

A ply found in retreadable tires in the crown area just under the tread rubber that provides cut resistance to the underlying belts and carcass plies.

Belt Plies

Plies laid between the tread area and the top carcass ply to restrain the outer diameter of the tire giving the tread surface greater resistance to squirm and wear.

Chine

A deflector molded into the sidewall of a nose-wheel tire to deflect water and slush to the side and away from aft-fuselage mounted engines.

Safety

Aircraft tire and wheel assemblies contain high pressures to support the loads placed on them. All maintenance should be conducted according to the recommendations of the tire, wheel, and aircraft manufacturers.

Before mounting any tire, visually examine the tire and the wheel for any indication of damage.

After a tire has been mounted, inflate it to the recommended inflation pressure. Most aircraft tires rated for over 190 MPH are inflated with nitrogen.

- When inflating tires, be sure to use a suitable inflation cage.
- Keep pressure hose and fittings used for inflation in good condition.
- Allow the tire to remain in the inflation cage for several minutes after reaching its full inflation pressure.

In service, tires should also be treated with care so as to avoid conditions that would damage the tire and wheel assembly or create a dangerous situation for those around the assembly or aircraft.

- Never approach, or allow anyone else to approach, a tire and wheel assembly mounted on an aircraft that has obvious damage until that assembly has been allowed to cool to ambient temperature. This generally takes at least three hours.
- Always approach a tire and wheel assembly from an oblique angle, in the direction of the tire's shoulder.
- Deflate tires before removing the assembly from the aircraft unless it will be immediately remounted (for example, in the case of a brake inspection).
- Always deflate the tires before attempting to dismount the tire from the wheel or disassembling any wheel component.
- Use extreme caution when removing valve cores as they can be propelled from the valve stem at a high rate of speed.
- When tire and wheel assemblies are found with one or more tie bolt nuts damaged or missing, remove the assembly from service.
- While serviceable tires may be shipped fully pressurized in the cargo area of an aircraft, it is preferred to reduce pressure to 25% of their operating pressure.

Tire Care Basics

Storage

Aircraft tires and tubes should always be stored in a dry environment, free from sunlight and ozone-producing appliances such as air compressors and florescent or mercury vapor lights. Tires should always be stored vertically, on their tread. Stacking tires on their sidewall can cause the beads to collapse, making the mounting process difficult.

Inflation Pressure

It is most important that the aircraft's tires be properly inflated at all times. Tire pressure should be checked before each day of flying, always maintaining the operating pressure specified by the airframe manufacturer.

Properly Inflating Tube-Type Tires

Air is usually trapped between the tire and the tube during mounting. Although initial readings show proper pressure, the trapped air will seep out around the valve stem hole in the wheel, and under the tire beads. Within a few days the tube will expand to fill the void left by the trapped air, and the tire may become severely underinflated. Check tire pressure before each flight for several days after installation, adjusting as necessary, until the tire maintains proper pressure.

Tire Growth

During the first 12 hours after mounting and initial inflation, the nylon plies of aircraft tires will generally grow and the inflation pressure of the tire will drop about 6–10%. Adjust as necessary.

Mounting

Wheels

When mounting a tire on a wheel, follow the recommendations and procedures of the wheel manufacturer.

Special care should be given to the following:

- Ensure that the bead seating area of the wheel is clean.
- Mating surfaces of the wheel halves should be free of nicks, burrs, small dents, or other damage. Painted or coated surfaces should be in good condition.
- Be sure fuse plugs, inflation valves, and wheel plugs are in good condition and properly sealed against pressure loss.
- Check O-ring grooves in the wheel halves for damage or debris.
- Check to see that the O-rings have the proper part number.

Tires

Before mounting any tire, check that the tire markings are correct for the required application (size, ply rating, speed rating, part number, and TSO marking).

Visually inspect the outside of the tire for:

- Damage caused by improper shipping or handling.
- Cuts, tears, or other foreign objects penetrating the rubber.
- Permanent deformations.
- Debris or cuts on the bead seating surfaces.
- Bead distortions.
- Cracking that reaches the cords.
- Contamination from foreign substances (oil, grease, brake fluid, etc.) which can cause surface damage.

Inspect the inside of the tire for:

- Foreign material.
- Wrinkles in or damage to the inner liner.

Initial Pressure Retention Check

The initial pressure retention check requires about 15 hours and it should be conducted as follows:

- Inflate the newly mounted tire to specified operating pressure and store it for 3 hours.
- Check the inflation pressure (be sure that the ambient temperature has not changed more than 5°F—a drop of 5°F will reduce inflation pressure by 1%). If the inflation pressure has dropped to less than 90% of the original value, use a soap solution on tire beads, valves, fuse plugs, etc., to find the leakage. Make appropriate repairs and repeat the test.
- After a 12-hour storage period, check the inflation pressure. If the inflation pressure has dropped to less than 95% of the original value, the tire is defective and it must be rejected.

On-Aircraft Tire Inspection

Inflation Pressure

Tire pressure should be checked before the first flight of the day. If this is not possible, wait at least 3 hours after landing to allow the tire to cool to ambient temperature. Never bleed pressure from a hot tire.

Effects of Underinflation

Underinflated tires can creep or slip on the wheel under stress or when brakes are applied. Valve stems can be damaged or sheared off and the tire, tube, or complete wheel assembly can be damaged. Excessive shoulder wear may also be seen. Underinflation can allow the sidewalls of the tire to be crushed, causing bead damage. Severe underinflation may cause ply separation and carcass degradation. This can also cause inner-tube chafing and a resultant blowout.

Effects of Overinflation

Overinflated tires are more susceptible to bruising, cuts, and shock damage, and the ride quality and operating life are reduced. Extremely high inflation pressures may cause the aircraft wheel or tire to explode, or burst. Never operate aircraft tires above rated inflation pressure.

Wear

Removal Criteria

In the absence of specific instructions from the airframe manufacturer, a tire should be removed from service for wear using this criteria based on the fastest wearing location. (*See* illustration at right.)

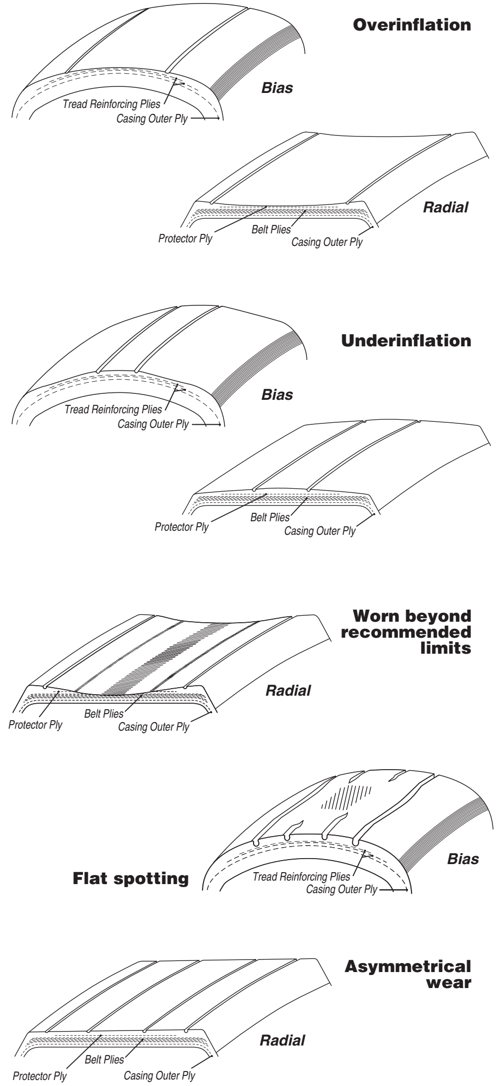
- When the wear level reaches the bottom of any groove along more than 1/8 of the circumference on any part of the tread, or
- If either the protector ply (radial) or the reinforcing ply (bias) is exposed for more than 1/8 of the circumference at a given location.
- Operating a tire at a higher pressure than required will cause increased wear at the center of the tread. This will make the tire more susceptible to bruises, cutting, and shock damage.
- When a tire is consistently operated underinflated, shoulder wear will result. Severe underinflation may cause ply separations and carcass heat build-up, which can lead to thrown treads and sidewall fatigue.
- If a tire is worn into the carcass/body plies, the strength of the tire will be reduced. This may cause the tire to burst or explode.
- Flat spotting is a result of the tire skidding without rotating, and is usually caused by brake lock-up or a large steer angle.
- Asymmetrical wear is a result of the tire operating under prolonged yaw and/or camber.
- Any time an aircraft has made a particularly rough landing or an aborted takeoff, the tire, tube, and wheel should be checked.

Limits for Tire Damages

Tread Cuts

In the absence of specific cut-removal instructions from the airframe manufacturer, tires should be removed when:

- Cuts, embedded objects, or other injuries expose or penetrate the carcass plies (bias) or tread belt layers (radial).
- A cut or injury severs or extends across a tread rib.
- Undercutting at the base of any tread rib cut.
- Round foreign object damage greater than .375" in diameter.



Common tire wear conditions

Courtesy Michelin Aircraft Tire

Bulges or Separations

Any bulge or separation is cause for immediate removal of the tire from service.

Chevron Cutting

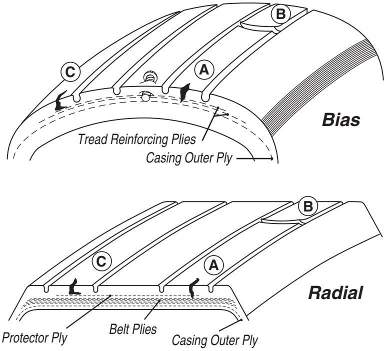
Remove a tire from service if chevron cutting or any other action results in tread chunking which extends to and exposes the reinforcing or protector ply more than one square inch.

Peeled Rib

Remove the tire from service if the reinforcing ply or protector ply is exposed.

Groove Cracking

Remove the tire from service if groove cracking exposes the reinforcing ply or protector ply for more than 1/4" in length.



Remove tire from service when:

A. Depth of cut exposes the casing outer ply (bias) or outer belt layer (radial).

B. A tread rib has been severed.

C. Undercutting occurs at the base of any cut.

Contamination From Hydrocarbons

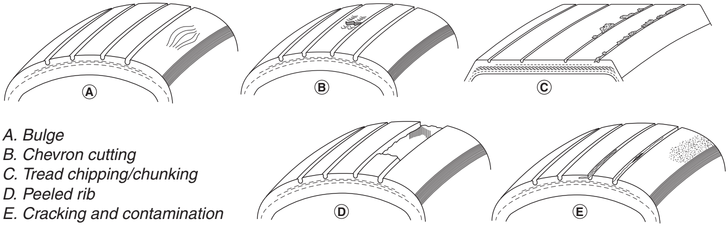
Oil, grease, brake fluids, solvents, etc., can soften or deteriorate rubber components. If a tire comes in contact with any of these, immediately wash the contaminated area with denatured alcohol, then with a soap and water solution. If the contaminated area is soft and spongy compared to an unaffected area of the tire, remove the tire from service.

Sidewall Cuts

If sidewall cords are exposed or damaged, remove the tire from service. Cuts in the rubber that do not reach the cord plies are not detrimental to tire performance and the tire may remain in service.

Weather/Ozone Cracking

Remove the tire from service only if weather or ozone cracks extend to the cord plies.



A. Bulge
B. Chevron cutting
C. Tread chipping/chunking
D. Peeled rib
E. Cracking and contamination

Common damage conditions

Courtesy Michelin Aircraft Tire

Dismounting

Be sure to follow the instructions and precautions published by the wheel manufacturer.

- Before deflating, use colored chalk to mark any damaged or bulge areas.
- Completely deflate the tire or tube before dismounting.
- Use a bead breaker to loosen tire beads from both wheel-half flanges.
  1. Apply bead breaker pressure slowly, or in a series of jogs, to allow time for the tire's beads to slide on the wheel.
  2. If the tire has become fixed to the wheel:
     a. Release bead-breaker pressure and apply a soap solution to the tire/wheel interface.
     b. Allow several minutes for the solution to penetrate between the tire and wheel.
     c. Reapply a reduced breaker pressure to the tire.
     d. Repeat several times if necessary.
  3. If the tire still remains stuck:
     a. Remove the tire/wheel assembly from the bead breaker.
     b. Reinflate the tire in a cage until the bead moves back to its correct position.
     c. Deflate the tire.

4. Continue the dismounting procedure:

- Remove tie bolts and slide out both parts of the wheel from the tire.
- For tube-type tires, remove the tube.

Off-Aircraft Inspection with Tire Dismounted

Follow this procedure:

- Inspect the tread area.
- Inspect both sidewall areas.
- Inspect the bead areas for chafing or damage.
- Inspect the innerliner. Tires with loose, frayed or broken cords or wrinkles should be discarded. Liner blisters, especially in tubeless tires, should be left undisturbed.
- Inspect the inner tube, if applicable. Tubes with leaks, severe wrinkles or creases, or chafing should be discarded.
- Inspect for wheel damage according to the wheel manufacturer's recommendations.

Vibration and Balance

Vibration, shimmy, and other similar conditions are usually caused by improper tire balance but there are a number of other conditions that can cause or contribute to aircraft vibration.

The following inspections will help identify and/or prevent vibration problems:

- Check the tire for proper inflation pressure.
- Ensure that the tire has reached full growth before it is installed on the aircraft.
- Check to see that the tire beads are properly seated.
- Check the tire for flat spotting or uneven wear.
- Verify that the tires are properly mounted.
- Check for air trapped between the tire and tube.
- Check for wrinkles in the tube.
- Check the wheel for an imbalance due to improper assembly.
- Check to see that the wheel has not been bent.
- Check for a loose wheel bearing caused by an improperly torqued axle nut.
- Check for poor gear alignment as evidenced by uneven wear.
- Check for worn or loose landing gear components.

Adapted from the Michelin Aircraft Tire Care and Service Guide, courtesy Michelin Aircraft Tire.

Appendix 5: Aviation Fuels

There are two main types of aviation fuel: Avgas and jet fuel.

Avgas

Aviation gasoline (Avgas) is used in internal combustion engine (piston-engine) airplanes. The different fuel grades of Avgas, that rate the fuel's octane or performance level, are identified by color.

To meet the pressure and temperature requirements of aircraft engines, Avgas contains the additive tetraethyl lead (TEL) to prevent detonation. Environmental concerns have driven the search for a viable replacement for TEL for many years. A recent development that gained FAA approval in 2021 is a 100-octane unleaded Avgas known as G100UL. G100UL may be mixed with other grades of Avgas with no adverse side effects. G100UL is an amber or yellow color and when mixed with blue 100LL the fuel color may turn green. G100UL has a slightly higher density (6.3 lbs/gal) than 100LL (6.0 lbs/gal).

Jet Fuel

Jet fuel is a kerosene-based fuel for use in jet engines, turboprops, and turbo-shaft engines. There are several types of jet fuel:

- Jet A is a special blend of kerosine and is primarily used in the United States. Freezing point -40°C.
- Jet A1 contains additives to lower the freezing point and is the most common jet fuel worldwide. Freezing point -47°C.
- Jet B is a blend of gasoline and kerosine and is occasionally used in very cold climates. It is more dangerously flammable when handling and is not widely used. Freezing point -60°C.

Grades and Identification of Aviation Fuels

Grade	Color	Max TEL (mL/gal)	Notes
80	Red	0.5	No longer manufactured
82UL	Purple	Unleaded	Limited availability
100	Green	4.0	No longer manufactured
100LL	Blue	2.0	Most common Avgas
G100UL	Amber or yellow	Unleaded	Limited availability
Jet fuel	Colorless to straw color	N/A	Available in most areas

Other Fuels

- **Diesel.** The use of diesel engines in aircraft is limited, but they are used by some production aircraft and as retrofit modifications. These engines operate on conventional automotive diesel or jet fuel. Multiple engine development programs are underway with the goal of producing more efficient aircraft engines.
- **Sustainable Aviation Fuel (SAF).** SAFs are environmentally friendly biofuel alternatives to fossil fuels. The use of SAFs is currently limited to developmental trials, but ongoing research is providing encouraging results. Different sources under consideration to produce SAFs include:
  - Plants and algae
  - Used cooking oil
  - Solid waste, including grass and tree branches
  - waste and non-recyclable bottles

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