Part 66 Cat. B1 Module 6

MATERIALS AND HARDWARE

Vilnius-2017

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6.1A AIRCRAFT MATERIALS – FERROUS

Introduction to Properties of Metals

Knowledge and understanding of the uses, strengths, limitations, and other characteristics of structural metals is vital to properly construct and maintain any equipment, especially airframes. In aircraft maintenance and repair, even a slight deviation from design specification, or the substitution of inferior materials, may result in the loss of both lives and equipment. The use of unsuitable materials can readily erase the finest craftsmanship. The selection of the correct material for a specific repair job demands familiarity with the most common physical properties of various metals.

Of primary concern in aircraft maintenance are such general properties of metals and their alloys as hardness malleability, ductility, elasticity, toughness, density, brittleness, fusibility, conductivity contraction and expansion, and many others.

Explanation of Terms

Hardness refers to the ability of a metal to resist abrasion, penetration, cutting action, or permanent distortion. Hardness may be increased by cold-working the metal and, in the case of steel and certain aluminum alloys, by heat treatment, Structural parts are often formed from metals in their soft state and are then heat treated to harden them so that the finished shape will be retained. Hardness and strength are closely associated properties of metals.

Brittleness is the property of a metal which allows little bending or deformation without shattering. A brittle metal is apt to break or crack without change of shape. Because structural metals are often subjected to shock loads, brittleness is not a very desirable property. Cast iron, cast aluminium, and very hard steel are examples of brittle metals.

Malleability is necessary in sheet metal that is worked into curved shapes-such as cowlings, fairings, or wingtips.A metal which can be hammered, rolled, or pressed into various shapes without cracking, breaking, or having some other detrimental effect, is said to be malleable. Copper is an example of a malleable metal.

Ductility is the property of a metal which permits it to be permanently drawn, bent, or twisted into various shapes without breaking. This property is essential for metals used in making wire and tubing. Ductile metals are greatly preferred for aircraft use because of their ease of forming and resistance to failure under shock loads. For this reason, aluminium alloys are used for cowl rings; fuselage and wing skin, and formed or extruded parts, such as ribs, spars, and bulkheads. Chrome molybdenum steel is also easily formed into desired shapes.

Elasticity is that property which enables a metal to return to its original shape when the force which causes the change of shape is removed. This property is extremely valuable because it would be highly undesirable to have a part permanently distorted after an applied load was

Identification of Ferrous Metals

If carbon is added to iron, in percentages ranging up to approximately 1%, the product is vastly superior to iron alone and is classified as carbon steel. Carbon steel forms the base of those alloy steels produced by combining carbon steel with other elements known to improve the properties of steel. A base metal (such as iron) to which small quantities of other metals have been added is called an alloy. The addition of other metals changes or improves the chemical or physical properties of the base metal for a particular use.

Nomenclature and Chemical Compositions of Steels

An index, sponsored by the Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI), is used to identify the chemical compositions of the structural steels. This system uses a 4-numeral series to designate the plain carbon and alloy steels; 5-numerals are used to designate certain types of alloy steels. The first two digits indicate the type of steel, the second digit also generally (but not always) gives the approximate amount of the major alloying element and the last two (or three) digits are intended to indicate the approximate middle of the carbon range (**Fig. 1-1**).

Series	***Types***
10xx	Non-sulphurized carbon steels
11xx	Re-sulphurized carbon steels (free machining)
12xx	Re-phosphorized and re-sulphurized carbon steels (free machining)
13xx	Manganese 1.75%
23xx	Nickel 3.50%
25xx	Nickel 5.00%
31xx	Nickel 2.25%, chromium 0.65%
33xx	Nickel 3.50%, chromium 1.55%
40xx	Molybdenum 0.20 or 0.25%
41xx	Chromium 0.50 or 0.95%, molybdenum 0.12 or 0.20%
43xx	Nickel 1.80%, chromium 0.50 or 0.80%, molybdenum 0.25%
44xx	Molybdenum 0.40%
50xx	Chromium 0.25, or 0.40 or 0.50%
50xxx	Carbon 1.00%, chromium 0.50%
51xxx	Carbon 1.00%, chromium 1.05%
52xxx	Carbon 1.00%, chromium 1.45%
61xx	Chromium 0.60, 0.80, or 0.95%, vanadium 0.12% 0.10% min., or 0.15% min
81xx	Nickel 0.30%, chromium 0.40%, molybdenum 0.12%
86xx	Nickel 0.55%., chromium 0.50 , molybdenum 0.20%
87xx	Nickel 0.55%. chromium 0.05%, molybdenum 0,25%
92xx	Manganese 0.85%, silicon 2.00%, chromium 0 or 0.35%
93xx	Nickel 3.25%, chromium 1.20%, molybdenum 0.12%
94xx	Nickel 0.45%, chromium 0.40%, molybdenum 0.12%

Figure 1-1. SAE numerical index

The list of standard steels is altered from time to time to accommodate steels of proven merit and to provide for changes in the metallurgical and engineering requirements of industry.

Small quantities of certain elements are present in alloy steels that are not specified as required. These elements are considered as incidental and may be present to the maximum amounts as follows: 0.35% copper, 0.25% nickel, 0.20% chromium, and 0.06% molybdenum.

Corrosion is the eating away or pitting of the surface or the internal structure of metals. Because of the thin sections and the safety factors used in aircraft design and construction, it would be dangerous to select a material possessing poor corrosion-resistant characteristics.

Metal stock is manufactured in several forms and shapes, including sheets, bars, rods, tubings, extrusions, forgings, and castings. Sheet metal is made in a number of sizes and thicknesses. Specifications designate thicknesses in thousandths of an inch. Bars and rods are supplied in a variety of shapes, such as round, square, rectangular, hexagonal, and octagonal. Tubing can be obtained in round, oval, rectangular, or streamlined shapes. The size of tubing is generally specified by outside diameter and wall thickness.

The sheet metal is usually formed cold in such machines as presses, bending brakes, draw benches, or rolls. Forgings are shaped or formed by pressing or hammering heated metal in dies. Castings are produced by pouring molten metal into moulds. The casting is finished by machining.

Spark testing is a simpliest common means of identifying various ferrous metals. In this test the piece of iron or steel is held against a revolving grinding stone and the metal is identified by the sparks thrown off. Each ferrous metal has its own peculiar spark characteristics. The spark streams vary from a few tiny shafts to a shower of sparks several feet in length (Few nonferrous metals give off sparks when touched to a grinding stone. Therefore, these metals cannot be successfully identified by the spark test).

Identification by spark testing (**Fig. 1-2**) is often inexact unless performed by an experienced person, or the test pieces differ greatly in their carbon content and alloying constituents.

Wrought iron produces long shafts that are straw coloured as they leave the stone and white at the end. Cast iron sparks are red as they leave the stone and turn to a straw colour. Low-carbon steels give off long, straight shafts having a few white sprigs. As the carbon content of the steel increases, the number of sprigs along each shaft increases and the stream becomes whiter in colour. Nickel steel causes the spark stream to contain small white blocks of light within the main burst.

In some cases there is possible differ between brittle and ductile ferrous metals by fracturing a small specimen (**Fig. 1-3**). The brittle one fractures more homogenously comparing to the ductile. Another one fracturing method (non-exact as well) helps differ between mild steel and cast iron (**Fig. 1-4**).

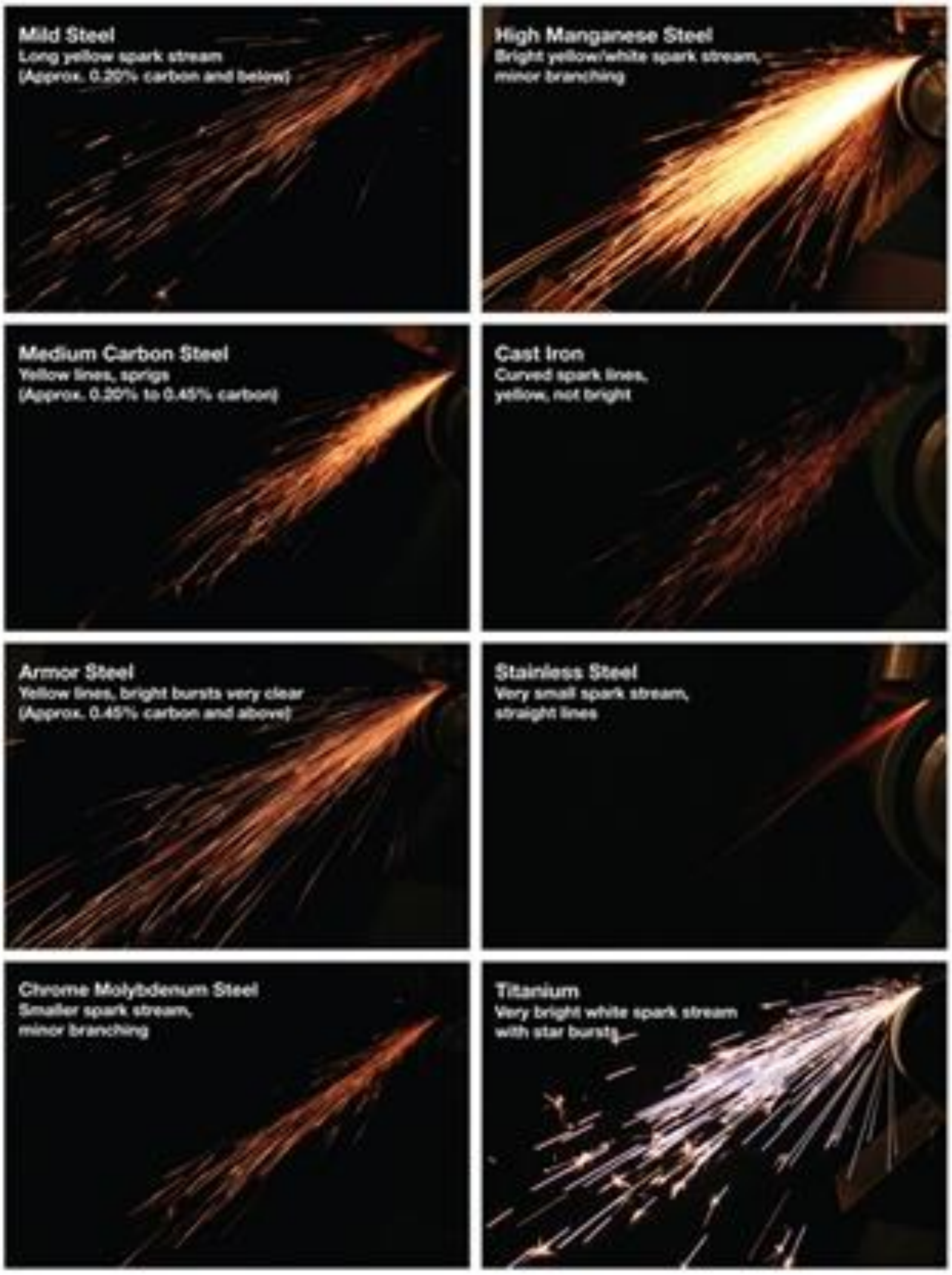


Figure 1-2. Spark testing

Figure 1-3. Brittle (left) and ductile (right) metal fracture

6.1B AIRCRAFT MATERIALS – FERROUS

Testing of Ferrous Materials for Hardness, Tensile Strength, Fatigue Strength and Impact Resistance

Tensile Testing

Tensile testing is the most widely-used mechanical test. It involves applying a steadily increasing load to a test specimen, causing it to stretch until it eventually fractures. Accurate measurements are taken of the load and extension, and the results are used to determine the strength of the material. To ensure uniformity of test results, the test specimens used must conform to standard dimensions and finish as laid down by the appropriate Standards (BSI, DIN, ISO etc).

The cross-section of the specimen may be round or rectangular, but the relationship between the cross-sectional area and a specified "gauge length", of each specimen, is constant. The gauge length, is that portion of the parallel part of the specimen, which is to be used for measuring the subsequent extension during and/or after the test.

Tensile Stress (Strength)

Tensile strength in a material is obtained by measuring the maximum load, which the test piece is able to sustain, and dividing that figure by the original cross-sectional area (c.s.a.) of the specimen. The value derived from this simple calculation is called STRESS.

$$Stress = \frac{Load(N)}{S(mm^2)}$$

Strain

As the load in the tensile test is increased from zero to a maximum value, the material extends in length. The amount of extension, produced by a given load, allows the amount of induced strain to be calculated. Strain is calculated by measuring the extension and dividing by the original length of the material.

$$Strain = \frac{Extension}{Initial\_Length}$$

Load/Extension Diagrams

If a gradually increasing tensile load is applied to a test piece while the load and extension are continuously measured, the results can be used to produce a Load/Extension diagram. A number of different forms of graph may be obtained, depending on the material type and condition. **Fig. 1-5** shows a Load-Extension diagram which typifies many metallic materials when stressed in tension.

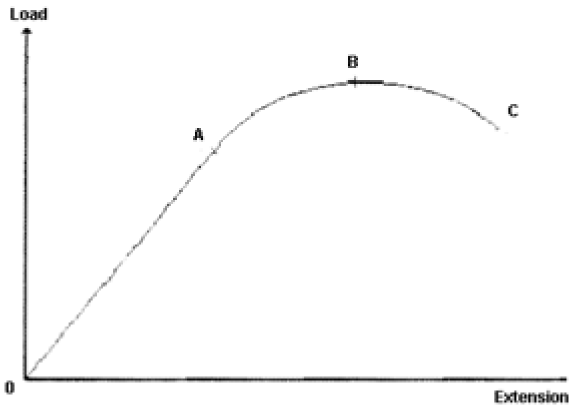


Figure 1-5. Load-Extension diagram

Between points 0 and A, the material is in the Elastic region (or phase), i.e. when the load is removed the material will return to its original size and shape. In this region, the extension is directly proportional to the applied load.

This relationship shown (from point „0“ to point „A“) is known as „Hooke's Law“, which states:

Within the elastic region,
elastic strain is directly proportional to the stress causing it

Point A (**Fig. 1-5**) is the Elastic Limit. Between this point and point B, the material continues to extend until the maximum load is reached (at point B). In this region the material is in the plastic phase. When the load is removed, the material does not return to its original size and shape, but will retain some extension. After point B, the cross-sectional area reduces and the material begins to „neck“. The material continues to extend under reduced load until it eventually fractures at point C.

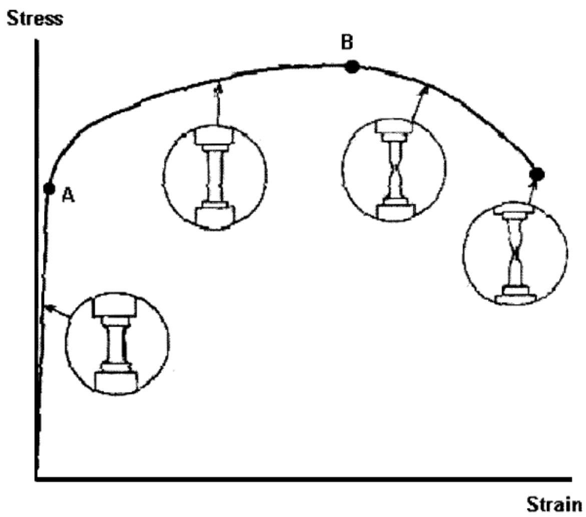


Figure 1-6. Load-Extension diagram for mild steel

An examination of a Stress/Strain graph (**Fig. 1-6**), obtained from the results of a tensile test on mild steel, shows that considerable plastic extension occurs without any increase in load shortly after the

6.2A AIRCRAFT MATERIALS – NON-FERROUS

The term "nonferrous" refers to all metals which have elements other than iron as their base or principal constituent. This group includes such metals as aluminium, titanium, copper, and magnesium, as well as such alloyed metals as Monel and babbit.

Aluminium and Aluminium Alloys

Commercially pure aluminium is a white lustrous metal which stands second in the scale of malleability, sixth in ductility, and ranks high in its resistance to corrosion. Aluminium combined with various percentages of other metals forms alloys which are used in aircraft construction.

Aluminium alloys in which the principal alloying ingredients are manganese, chromium, or magnesium and silicon show little attack in corrosive environments. Alloys in which substantial percentages of copper are used are more susceptible to corrosive action. The total percentage of alloying elements is seldom more than 6 or 7% in the wrought alloys.

Aluminium is one of the most widely used metals in modern aircraft construction. It is vital to the aviation industry because of its high strength-to-weight ratio and its comparative ease of fabrication. The outstanding characteristic of aluminium is its light weight. Aluminium melts at the comparatively low temperature of $1\ 250°F$. It is nonmagnetic and is an excellent conductor.

Commercially pure aluminium has a tensile strength of about $13\ 000\ PSI$, but by rolling or other cold-working processes its strength may be approximately doubled. By alloying with other metals, or by using heat-treating processes, the tensile strength may be raised to as high as $65\ 000\ PSI$ or to within the strength range of structural steel.

Aluminium alloys, although strong, are easily worked because they are malleable and ductile. They may be rolled into sheets as thin as 0.0017 inch or drawn into wire 0.004 inch in diameter. Most aluminium alloy sheet stock used in aircraft construction ranges from 0.016 to 0.096 inch in thickness; however, some of the larger aircraft use sheet stock which may be as thick as 0.356 inch.

The various types of aluminium may be divided into two general classes:

1. The casting alloys (those suitable for casting in sand, permanent mould, or die castings), and
2. The wrought alloys (those which may be shaped by rolling, drawing, or forging).

Of these two, the wrought alloys are the most widely used in aircraft construction, being used for stringers, bulkheads, skin, rivets, and extruded sections.

Aluminium casting alloys are divided into two basic groups. In one, the physical properties of the alloys are determined by the alloying elements and cannot be are determined by the alloying elements and cannot be changed after the metal is cast. In the other, the alloying elements make it possible to heat treat the casting to produce the desired physical properties.

6.2B AIRCRAFT MATERIALS – NON-FERROUS

Hardness Testing

Hardness testing is a method of determining the results of heat treatment as well as the state of a metal prior to heat treatment. Since hardness values can be tied in with tensile strength values and, in part, with wear resistance, hardness tests are a valuable check of heat-treat control and of material properties.

Practically all hardness-testing equipment uses the resistance to penetration as a measure of hardness. Among them the better known hardness testers are the Brinell and Rockwell as well as portable-type hardness tester.

Brinell Tester

The Brinell tester (**Fig. 2-3**) uses a hardened spherical ball, which is forced into the surface of the metal. This ball is 10 millimeters (0.3937 inch) in diameter. A pressure of 3 000 kilograms is used for ferrous metals and 500 kilograms for nonferrous metals.

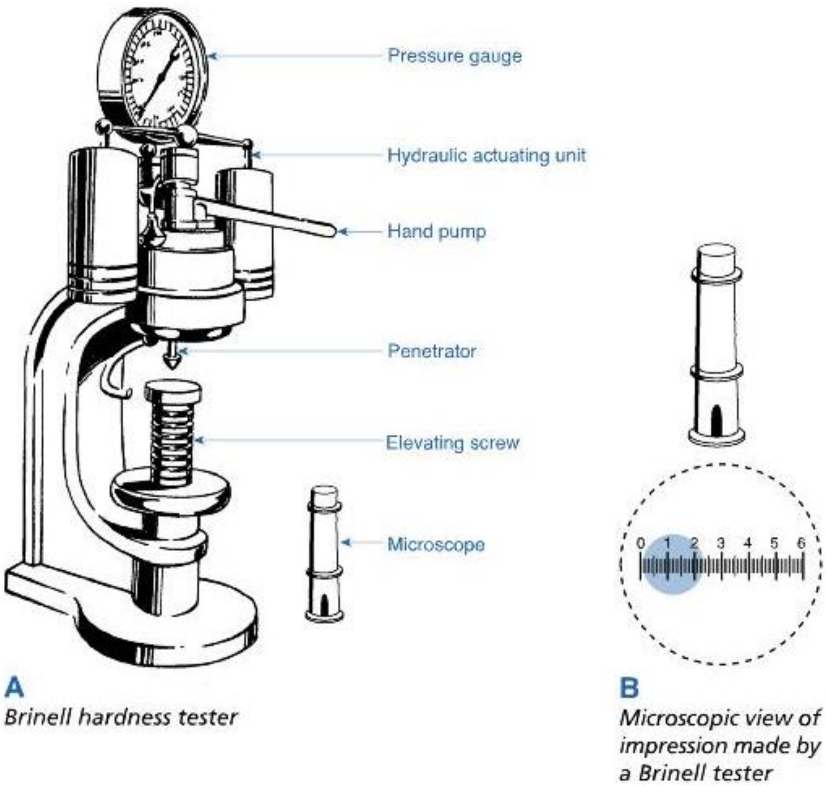


Figure 2-3. Brinell hardness tester

The pressure must be maintained at least 10 seconds for ferrous metals and at least 30 seconds for nonferrous metals. The load is applied by hydraulic pressure. The hydraulic pressure is built up by a hand pump or an electric motor, depending on the model of tester. A pressure gage indicates the amount of pressure. There is a release mechanism for relieving the pressure after the test has been made, and a calibrated microscope is provided for measuring the diameter of the impression in millimeters. The machine has various shaped anvils for supporting the specimen and an elevating screw for bringing the specimen in contact with the ball penetrator. These are attachments for special tests.

In order to determine the Brinell hardness number for a metal, the diameter of the impression is first measured, using the calibrated microscope furnished with the tester. After measuring the diameter of the impression, the measurement is converted into the Brinell hardness number on the conversion table furnished with the tester.

Rockwell Tester

The Rockwell hardness tester (**Fig. 2-4**) measures the resistance to penetration, as does the Brinell tester. Instead of measuring the diameter of the impression, the Rockwell tester measures the depth, and the hardness is indicated directly on a dial attached to the machine. The dial numbers in the outer circle are black, and the inner numbers are red. Rockwell hardness numbers are based on the difference between the depth of penetration at major and minor loads. The greater this difference, the less the hardness number and the softer the material.

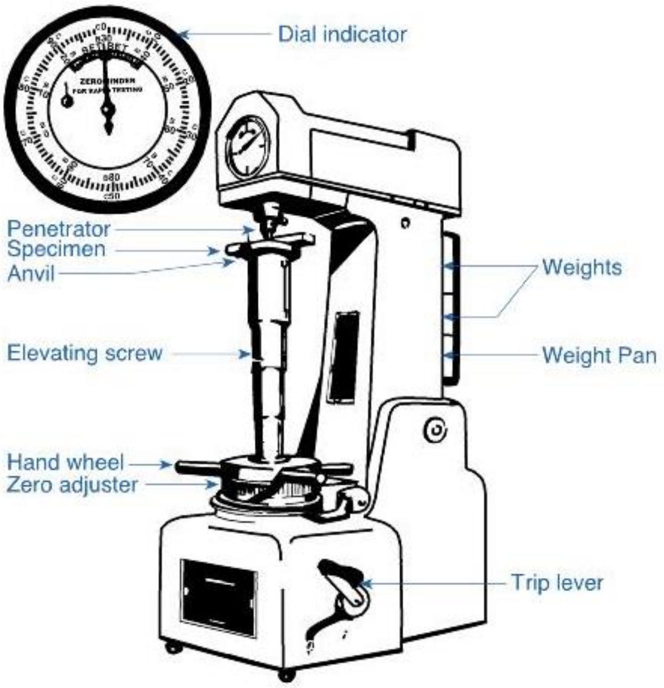
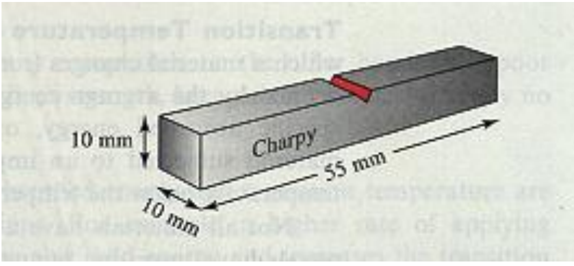


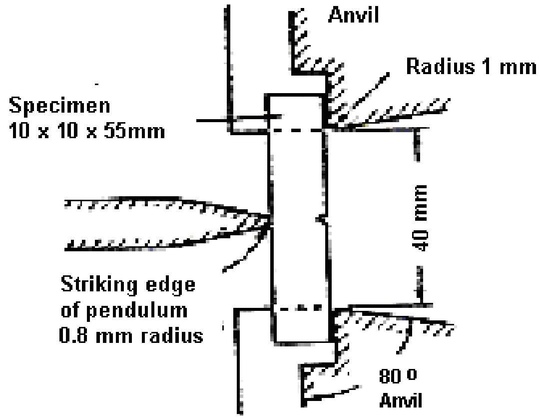
Figure 2-4. Rockwell hardness tester

Two types of penetrators are used with the Rockwell tester, a diamond cone and a hardened steel ball. The load which forces the penetrator into the metal is called the major load and is measured in

The principal difference between two tests is the manner in which the specimen is supported. In the Charpy test the specimen is supported as a simple beam with a notch in the center. The specimen is supported so that the notch is on the vertical face away from the point of impact. **Fig. 2-9** shows the dimensions of the Charpy test specimen and the positions of the striking edge of the pendulum and the specimen in the anvil.



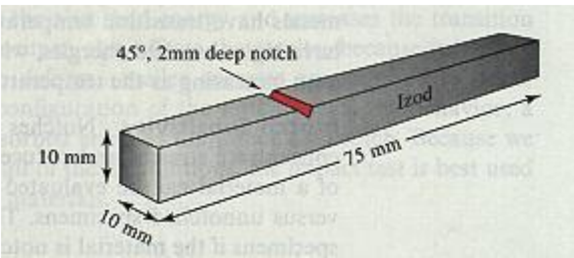
A



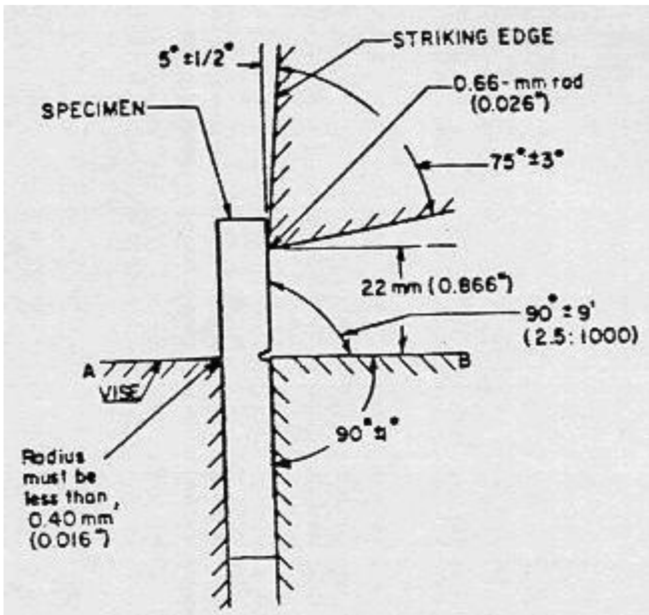
B

Figure 2-9. Charpy specimen (A) and Charpy top view (B)

In the Izod test, the specimen is held on one end and is free on the other end. This way it forms a cantilever beam. **Fig. 2-10** shows the dimensions of the Izod test specimen and the positions of the striking edge of the pendulum and the specimen in the anvil. In this case the notch is just at the edge of the supporting vise and facing into the direction of impact. As with the Charpy, this position places the notch at the location of the maximum tension.



A



B

Figure 2-10. Izod specimen (A) and Izod specimen in anvil (B)

6.3 AIRCRAFT MATERIALS – COMPOSITE AND NON-METALLIC

6.3.1A COMPOSITE AND NON-METALLIC OTHER THAN WOOD AND FABRIC

Plastics are used in many applications throughout modern aircraft. These applications range from structural components of thermosetting plastics reinforced with fibreglass to decorative trim of thermoplastic materials.

Transparent Plastics

Transparent plastic materials used in aircraft canopies, windshields, and other similar transparent enclosures may be divided into two major classes or groups. These plastics are classified according to their reaction to heat. The two classes are:

1. Thermoplastic and
2. Thermosetting.

Thermoplastic materials will soften when heated and harden when cooled. These materials can be heated until soft, and then formed into the desired shape. When cooled, they will retain this shape. The same piece of plastic can be reheated and reshaped any number of times without changing the chemical composition of the material.

Thermosetting plastics harden upon heating, and reheating has no softening effect. These plastics cannot be reshaped after once being fully cured by the application of heat.

In addition to the above classes, transparent plastics are manufactured in two forms, monolithic (solid) and laminated. Laminated transparent plastics are made from transparent plastic face sheets bonded by an inner-layer material, usually polyvinyl butyral. Because of its shatter-resistant qualities, laminated plastic is superior to solid plastics and is used in many pressurized aircraft.

Most of the transparent sheet used in aviation is manufactured in accordance with various military specifications.

A new development in transparent plastics is stretched acrylic. Stretched acrylic is a type of plastic which, before being shaped, is pulled in both directions to rearrange its molecular structure. Stretched acrylic panels have a greater resistance to impact and are less subject to shatter; its chemical resistance is greater, edging is simpler and crazing and scratches are less detrimental.

Individual sheets of plastic are covered with a heavy masking paper to which a pressure-sensitive adhesive has been added. This paper helps to prevent accidental scratching during storage and handling. Care should be taken to avoid scratches and gouges which may be caused by sliding sheets against one another or across rough or dirty tables.

Sheets should be stored in bins which are tilted at approximately 10° from vertical, if possible. If they must be stored horizontally, piles should not be over 18 inches high, and small sheets should be

Core Materials

Core materials are a central member of an assembly. When bonded between two surface skins, they provide a rigid lightweight component. Although balsa wood is still used as a core material on some helicopter rotor blades, the two major core materials used by the aviation industry are honeycomb core and foam core (**Fig. 3-2**). Honeycomb has a greater strength-to-weight ratio, but foam is more durable. If damaged, it has a memory and will return to about 80% of its original strength.

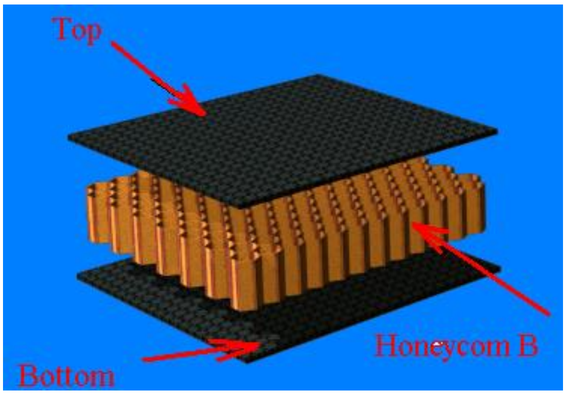
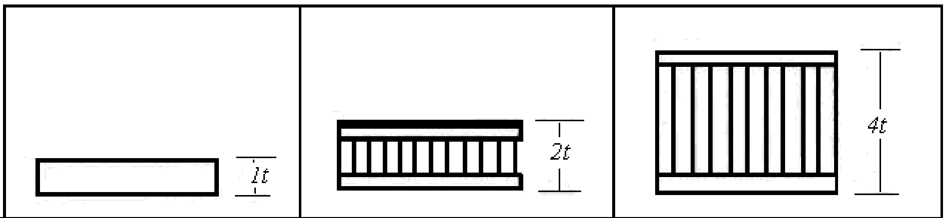


Figure 3-2. Honeycomb sandwich construction

The core-to-skin adhesive rigidly joins the sandwich components and allows them to act as one unit with a high torsional rigidity (**Fig. 3-3**).



Relative stiffness (D)	***100***	***700***	***3700***
Relative strength	***100***	***350***	***925***
Relative weight	***100***	***103***	***106***

Figure 3-3. Advantages of a Honeycomb core

Fig. 3-3 shows a striking example of how a honeycomb core stiffens a structure without materially increasing its weight.

Another sample Honeycomb (**Fig. 3-4**) shows possibilities in non-rectangle constructions. This enables very light and stiffed structural stocks.

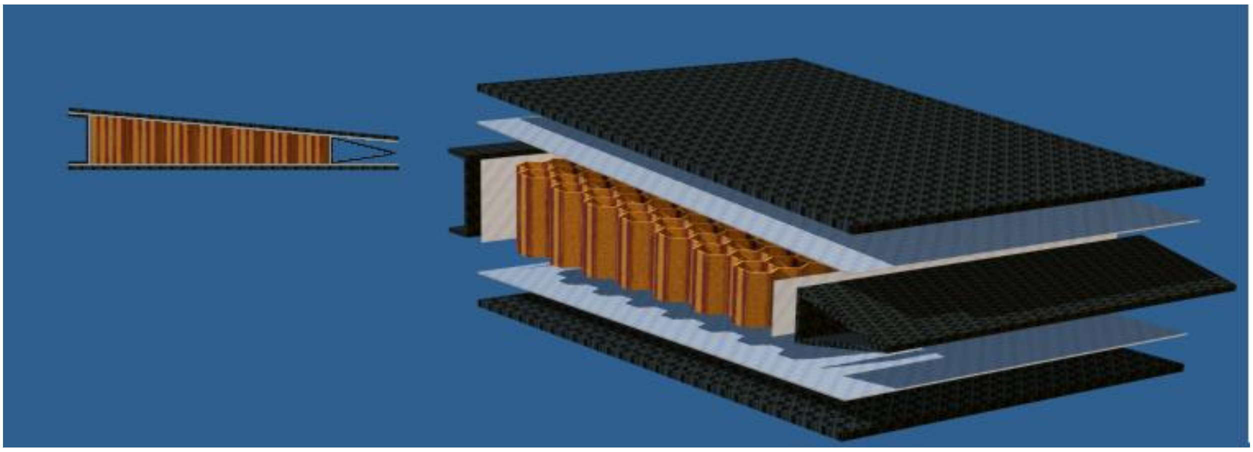


Figure 3-4. Typical Honeycomb sandwich design

General Uses of Composites

A major use for Kevlar is in radial passenger tires. Approximately one pound of Kevlar is used to replace about 5 pounds of steel in a radial tire. There are also significant advantages for Kevlar in truck tires because tires reinforced with Kevlar can withstand numerous recapping.

Kevlar is used in the rubber industry for reinforcing V-belts, drive belts, timing belts (**Fig. 3-5**), electromechanical cables, and various other items.

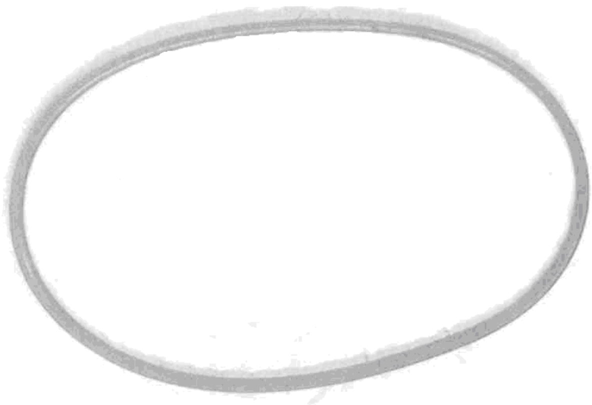


Figure 3-5. Kevlar is used for reinforcing belts

Kevlar has been used for hull reinforcement in boats. It provides weight savings of about 30%, high-impact resistance, and vibration dampening. Other applications typical for composites are in sports and recreation items as tennis racket, ski poles, cross-country and alpine skis. The vibration dampening provided by Kevlar is obviously an advantage for people with tennis elbows.

Uses of Composites in Aircraft

Fig. 3-6 - Fig. 3-7 shows the use (minimal) of composites in various aircraft. Now they are used explicitly in BOEING-787 Dreamliner and AIRBUS-350.

6.3.1B COMPOSITE AND NON-METALLIC OTHER THEN WOOD AND FABRIC

Detection of Defects - Composite Inspection

Composite structures require ongoing inspection intervals along with non-scheduled damage inspection and testing.

When a composite structure is damaged, it must first be thoroughly inspected to determine the extent of the damage, which often extends beyond the immediate apparent defect. Proper inspection and testing methods help determine the classification of damage, which is, whether the damage is repairable or whether the part must be replaced. In addition, classifying the damage helps to determine the proper method of repair. The manufacturer's structural repair manual outlines inspection procedures, damage classification factors, and recommended repair methods.

Today's composite inspection and nondestructive testing procedures typically involve more than one inspection method. Some of the simple composite inspection and testing methods are visual inspection and testing.

Visual Inspection

Visual inspection is the most frequently used inspection method in aviation. Ideally, pilots, ground crew, and maintenance technicians visually inspect the aircraft on a daily basis. This method of inspection is generally used to detect resin-rich areas, resin starvation, edge delamination, fiber break-out, cracks, blistering, and other types of surface irregularities. A strong light and magnifying glass are useful tools for visual inspection. In extremely critical cases, a small microscope is helpful in determining whether the fibers in a cracked surface are broken, or if the crack affects the resin only.

Shining a strong light through the structure, called backlighting, helps in the identification of cracked or broken fibers, and, in some cases, delamination. The delaminated area may appear as a bubble, an indentation in the surface, or a change in color if viewed from the side opposite the light. However, backlighting does not detect entrapped water. In addition, to properly inspect a composite using the backlight method, you must strip the surface of all paint.

Many times, visual inspection alone is not adequate to accurately determine the soundness of a composite structure. In the case of visually inspecting a sandwich structure, many times core crush is not evident from the surface. The surface may not show any residual damage and may have sprung back to its original location, which is one of the main problems with inspecting composite materials. Internal damage is not always evident from the surface, which further necessitates the use of additional, more advanced methods of inspection when damage is suspected.

The maintenance technician is generally the first person to assess damage using visual inspection techniques. After this initial inspection, more advanced forms of inspection and testing may be required to determine the extent of the damage.

Tap Test

The tap test is one of the simplest methods used to detect damage in bonded parts. The laminated part is tapped with a coin or small metallic object, such as a tap hammer, to detect delamination. The tap test is an acoustic test, one in which you listen for sound differences in the part, and is not the most accurate test method. The tap test detects delaminations close to the surface in addition to transitions to different internal structures. A properly prepared, undamaged laminated area produces a sharp, even pitch as compared to a delaminated area, which produces a dull sound.

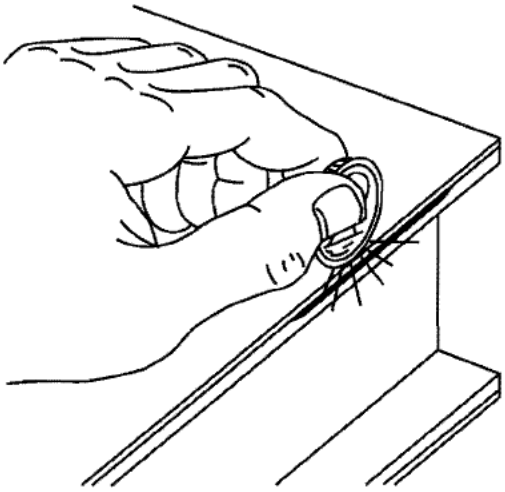


Figure 3-11. Tap test

However, changes in the thickness of the part, reinforcements, fasteners, and previous repairs may give false readings when using the tap test (**Fig. 3-11**). Tap testing will not indicate delamination well below the surface in thick parts. In general, in sandwich structures, if the first laminate is over $^{1}/_{4}$ inch down to the bond line, the tap test should not be used; it may not produce an indication of damage. The tap test should be limited to near surface inspection of bondline defects. Tap testing bondlines of thicker laminates becomes less and less effective as the thickness increases.

Ultrasonic Inspection

Ultrasonic inspection is the most common instrumental NDT method used on composites today. An ultrasonic tester is useful for detecting internal damage such as delaminations, core crush, and other subsurface defects. Two common methods of ultrasonic testing include the pulse echo and through transmission methods.

In the pulse echo method, the tester generates ultrasonic pulses, sends them through the part, and receives the return echo. The echo patterns are displayed on an oscilloscope. An advantage to the pulse echo method is that it only requires access to one side of the structure. However, near-surface defects do not readily allow sound to pass through them, making it difficult to detect defects located under the first defect. The pulse echo method works well on laminates because they do not reduce the magnitude of sound waves as much as a bonded core structure.

The "through transmission" method uses two transducers. One transducer emits ultrasonic waves through the part and the other receives them. Defects located at multiple levels throughout the structure are more easily detected because the receiver, located on the backside of the part, receives the reduced amount of sound waves that pass through the defects. The ratio of the magnitudes of sound vibrations transmitted and received determines the structure's reliability. Testing bonded-core structures usually requires the through transmission method due to the fact that sound waves reduce in magnitude as they travel through the sandwich structure. To effectively test this type of structure, the use of a receiver on the backside of the part dramatically increases the likelihood of detecting a defect (**Fig. 3-12**).

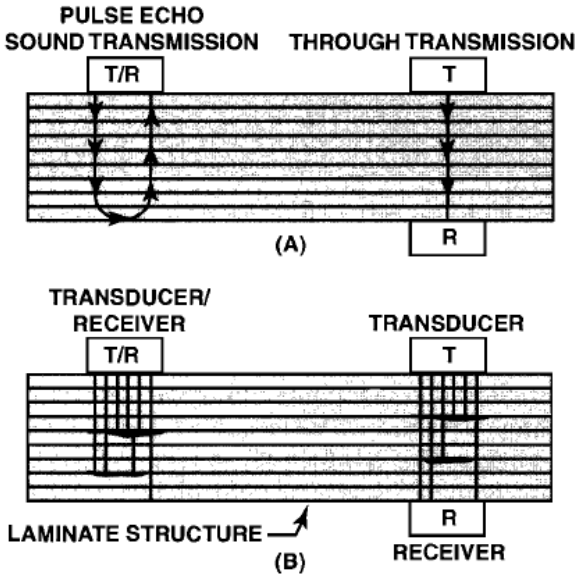


Figure 3-12. The pulse echo method (A) compared with "through transmission" method (B)

As shown in **Fig. 3-12B**, the pulse-echo method does not effectively detect multiple layers of defects. Sound waves do not travel through damage as readily as they do through an intact structure, which makes it difficult for the transducer/receiver to receive the pulse echo back from the lower defects. "Through transmission" inspection provides a more accurate view of the integrity of the composite structure. The receiver that is placed on the backside of the part picks up the low-intensity sound waves that emanate from multiple defects.

Composite Repair

The newer advanced composites use stronger fabrics and resin matrices, which cannot be repaired in the same way as fiberglass. A common misconception of advanced composites is that they can be repaired in the same way as the older fiberglass structures. To repair an advanced composite structure using the materials and techniques traditionally used for fiberglass repairs may result in an unairworthy repair. Such traditional fiberglass repairs allow for excessive weight, increased

Impact Damage

One of the most common cause of impact damage results from careless handling during transportation or storage such as standing parts on edge without adequate protection. Improper handling can cause nicking, chipping, cracking, or breaking away of pieces of the edges or corners. Because the face sheets on sandwich panels are extremely thin, they are especially susceptible to impact damage. An area that has been subjected to impact damage should also be inspected for delamination around the impacted area (**Fig. 3-13**).

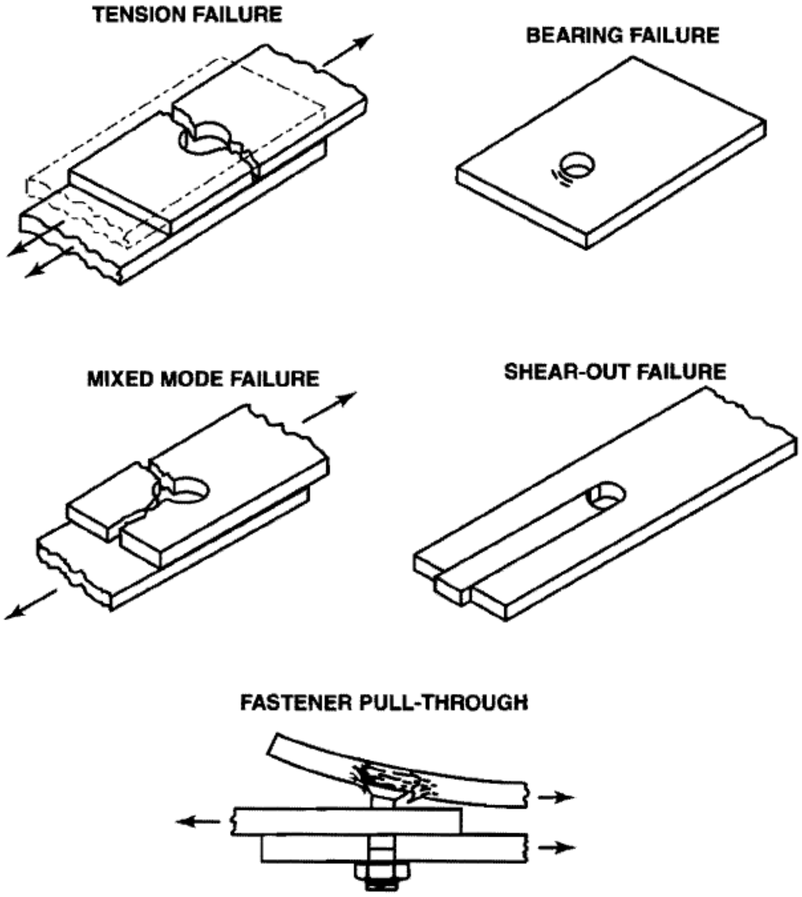


Figure 3-13. Types of damage common to composite structures

Cracks

Cracks can occur in advanced composite structures, just as in metallic ones. Sometimes they can be detected visually while other times require more advanced methods of nondestructive inspection. At times, cracks may appear in the top paint or matrix layer, and not penetrate into the fiber material at all. A crack may also extend into the fiber material and into the core, but appear to be located in the top surface only. A thorough inspection should be made to determine the extent of any cracks.

If the damage is on a sloping surface, bridges must be used under the router to allow it to cut parallel with the undamaged surface (**Fig. 3-19**).

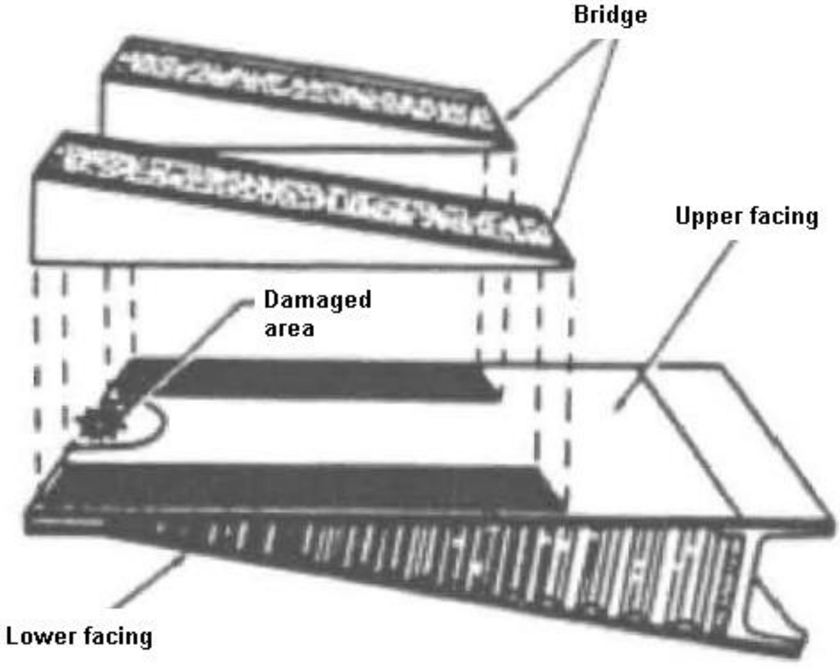


Figure 3-19. Bridges used for router support

If a syntactic foam is used to fill the core, the core material should be *undercut* beyond the edges of the surface opening to anchor the foam within the structure. The routed-out area should be cleaned with a reagent solvent, a solvent that has been chemically purified. The repair area is then air dried thoroughly to assure that the core has not retained any liquid. If liquid is still present the adhesive could break down.

There are several basic techniques used to repair damage. If the damage penetrates only one skin and is barely into the core. Syntactic foam can be used to fill the cavity if the damage is no more than 1 in. in diameter. A piece of plastic is placed over the repair opening (**Fig. 3-20**).

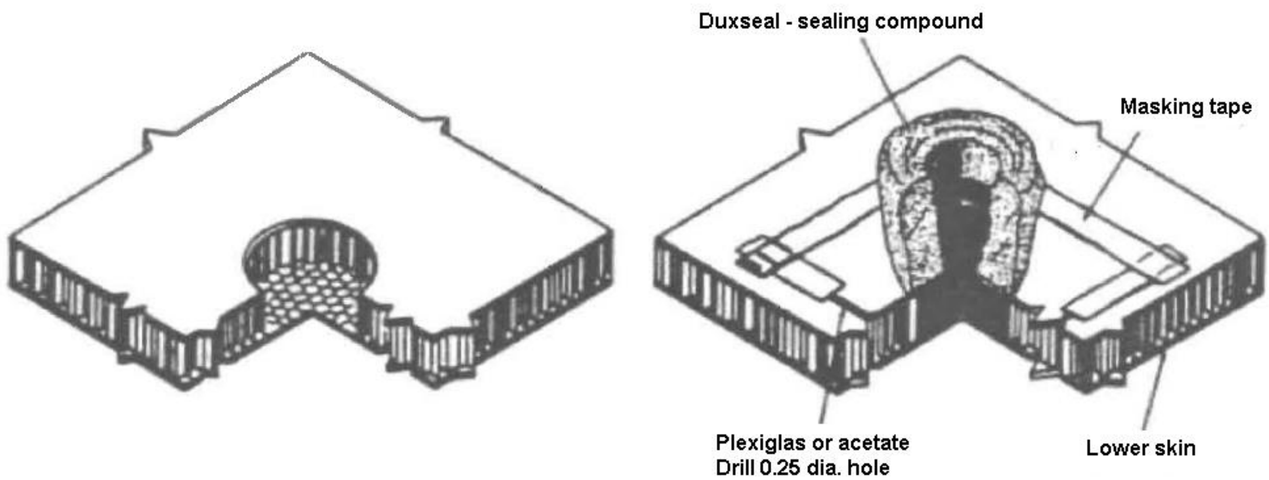


Figure 3-20. A potted repair to the core and skin

6.3.2 WOODEN STRUCTURES

While the trend is undoubtedly toward all-metal or composite aircraft, many small airplanes still exist in which wood was used as the structural material. The inspection and repair of these wooden structures will continue to be the responsibility of the maintenance engineer.

Wood and adhesive materials used in aircraft repair should meet aircraft (AN) quality standards and be purchased from reputable distributors to ensure such quality. Strict adherence to the specifications in the aircraft structural-repair manual will ensure that the structure will be as strong as the original.

Sitka spruce is the reference wood used for aircraft structures because of its uniformity, strength, and excellent shock-resistance qualities. Reputable companies that sell wood for use in aircraft repairs, stringently inspect and verify that the wood product meets the appropriate specifications. To meet the "Aircraft Sitka Spruce" grade specification (**Fig. 3-25**), the lumber must be kiln-dried accordingly to aviation specification.

Wood Substitution

Other types of wood are also approved for use in aircraft structures. However, the wood species used to repair a part should be the same as the original wood whenever possible. If using a wood substitute, it is the responsibility of the person making the repair to ensure that the wood meets all of the requirements for that repair. If a substitute wood product meets the same quality standards as the original wood, it is considered an acceptable alternative.

Standards outline information regarding acceptable wood species substitutions (**Fig. 3-25**). If there is any question about the suitability of a specific piece or type of wood for a repair, it would be wise to get the approval of the aircraft manufacturer before using it on the aircraft.

Plywood

Structural aircraft-grade plywood is more commonly manufactured from African mahogany or American birch veneers that are bonded together in a hot press over hardwood cores of basswood or poplar. Basswood plywood is another type of aviation-grade plywood that is lighter and more flexible than mahogany and birch plywood but has slightly less structural strength. All aviation-grade plywood is manufactured to specifications outlined in MILP-6070, which calls for shear testing after immersion in boiling water for three hours to verify the adhesive qualities between the plies meets specifications.

Laminated Wood

Laminated wood is constructed of two or more layers of solid wood that are bonded together. The lamination process differs from the plywood process in that each layer of laminated wood is bonded with the grain running parallel with each other. Plywood, on the other hand, is constructed of wood

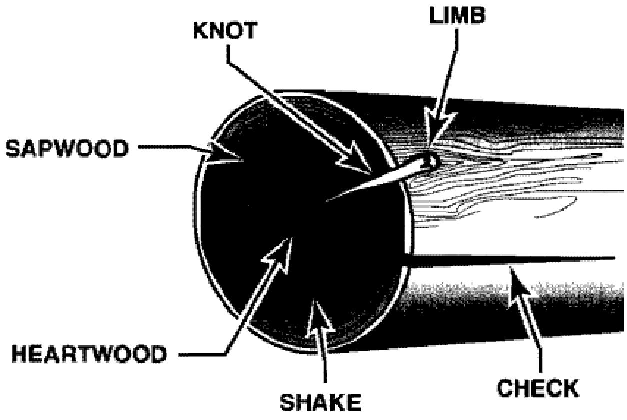


Figure 3-27. Wood defects

Defects Permitted

The permitted defects are named in **Fig. 3-28**.

Cross grain	Spiral grain, diagonal grain, or a combination of the two is acceptable providing the grain does not diverge from the longitudinal axis of the material more than specified in column 3 of **Fig. 3-25**. A check of all four faces of the board is necessary to determine the amount of divergence. The direction of free-flowing ink will frequently assist in determining grain direction
Wavy, curly, and interlocked grain	Acceptable, if local irregularities do not exceed limitations specified for spiral and diagonal grain
Hard knots	Sound hard knots up to ¼-inch in maximum diameter are acceptable providing: 1. They are not in projecting portions of I-beams, along the edges of rectangular or bevelled un-routed beams, or along the edges of flanges of box beams (except in lowly stressed portions); 2. They do not cause grain divergence at the edges of the board or in the flanges of a beam more than specified in column 3 of **Fig. 3-25**; 3. They are in the center third of the beam and are not closer than 20 inches to another knot or other defect (pertains to 3/8-inch knots - smaller knots may be proportionately closer); knots greater than ¼-inch must be used with caution
Pin knot clusters	Small clusters are acceptable providing they produce only a small effect on grain direction
Pitch pockets	Acceptable, in center portion of a beam providing they are at least 14 inches apart when they lie in the same growth ring and do not exceed $1\ ^1/_2$ inch by $^1/_8$ by $^1/_8$-inch depth and providing they are not along the projecting portions of I-beams, along the edges of rectangular or bevelled un-routed beams, or along the edges of the flanges of box beams
Mineral streaks	Acceptable, providing careful inspection fails to reveal any decay

Figure 3-28. The permitted defects of aviation wood

Spliced Joints

The scarf joint is generally used in splicing structural members in aircraft. The two pieces to be joined are bevelled and glued. The slope of the bevel should be not less than 10 to 1*in* solid wood and 12 to 1*in* plywood. The scarf cut is made in the general direction of the grain slope (**Fig. 3-31**).

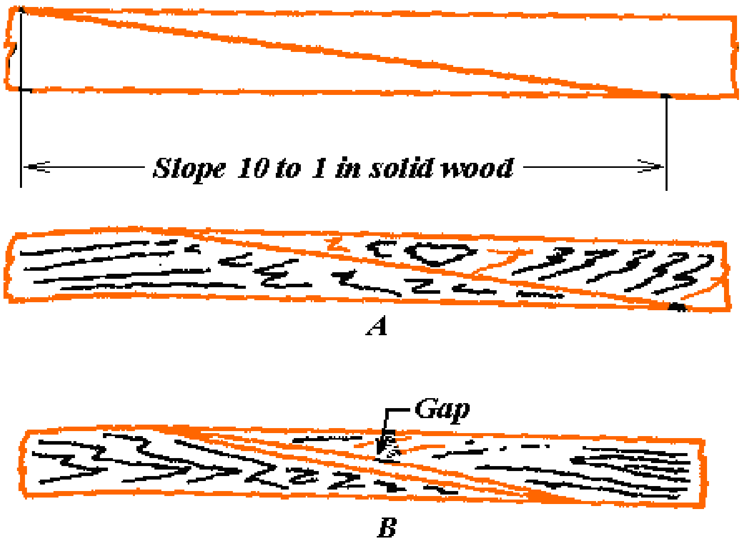


Figure 3-31. Bevelling scarf joint. A- correctly and B – incorrectly bevelled pieces

The other difficulty encountered in making this type of joint is that of obtaining the same bevel on each piece. The strength, of the joint will depend upon the accuracy of the two bevelled surfaces, because an inaccurate bevel will reduce the amount of effective glue area.

A method of producing an accurate scarf joint is illustrated in **Fig. 3-32**.

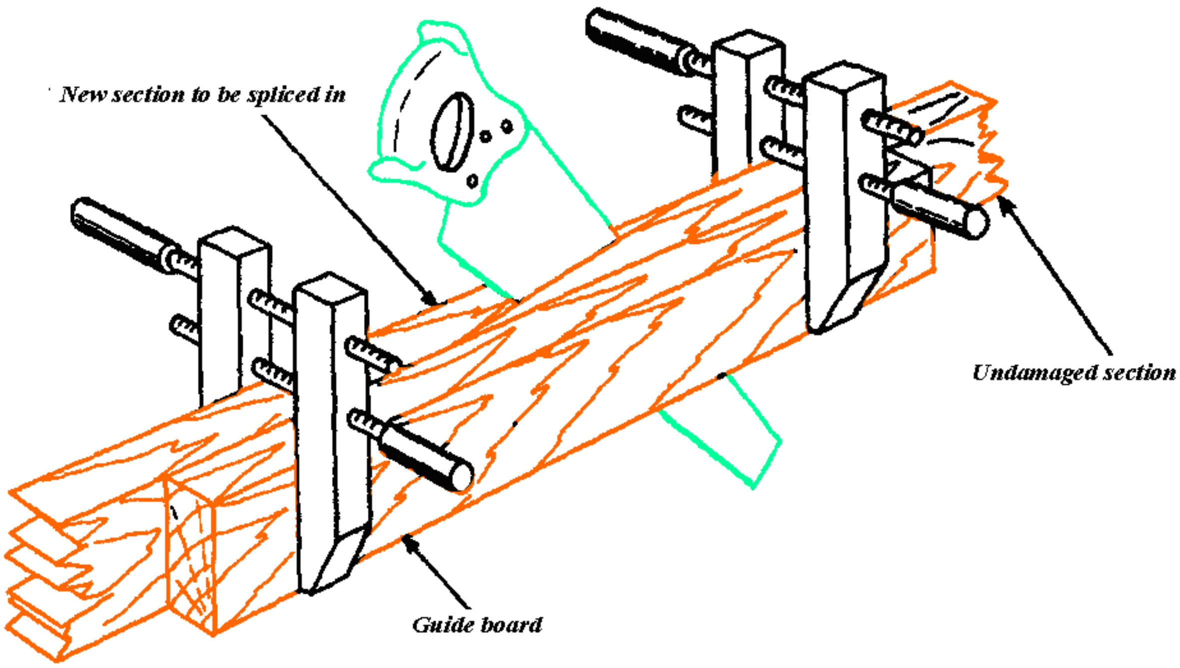


Figure 3-32. Making a scarf joint

Rib Repairs

A cap strip of a wood rib can be repaired using a scarf splice. The repair is reinforced on the side opposite the wing covering by a spruce block which extends beyond the scarf joint not less than three times the thickness of the strips being repaired. The entire splice, including the reinforcing block, is reinforced on each side by a plywood side plate as shown in **Fig. 3-43**.

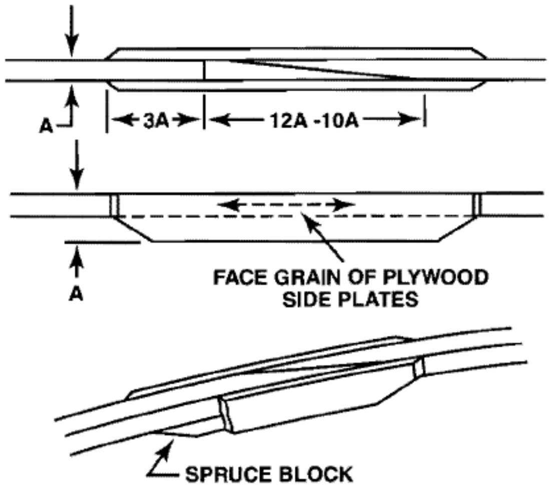


Figure 3-43. A rib cap-strip repair

When the cap strip is to be repaired at a point where there is a joint between it and cross members of the rib, the repair is made by reinforcing the scarf joint with plywood gussets, as shown in **Fig. 3-44**.

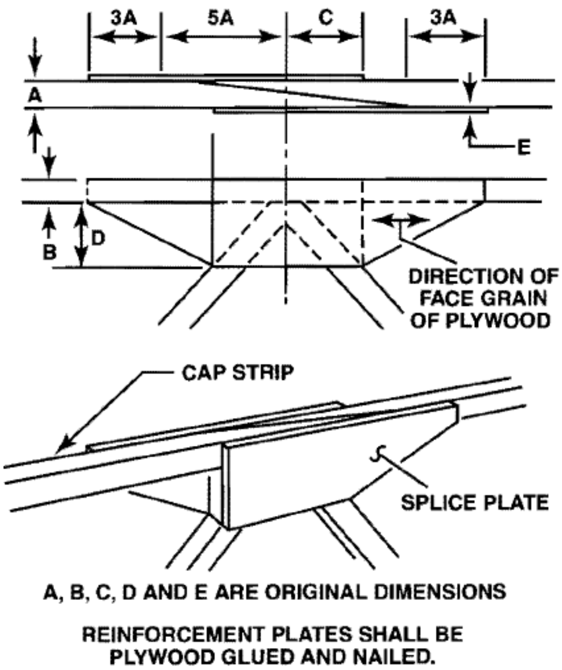


Figure 3-44. A rib repair at a joint

When it is necessary to repair a cap strip at a spar, the joint should be reinforced by a continuous gusset extending over the spar as shown in **Fig. 3-45**.

6.3.3 FABRIC COVERING

Most aircraft in production today are of all-metal or all-composite construction. However, many small aircraft in service still use fabric for covering wings, fuselages, and control surfaces. Cotton fabrics have long been the standard material for covering aircraft. They are still used, but other fabrics, such as linen, Dacron, and fibre glass, are gaining in popularity.

Organic and synthetic fibres are used in the manufacture of fabrics or cloth for covering aircraft. The organic fibres include cotton and linen; the synthetic fibres include fibre glass and heat-shrinkable synthetic fibres.

Three of the most common heat-shrinkable synthetic fibres available are a polyamide, manufactured and marketed under the trade name Nylon; an acrylic fibre called Orion; and a polyester fibre known as Dacron.

Fabric Quality and Strength Requirements

In the original manufacture of a fabric-covered aircraft, the quality and strength of the fabric, surface tape, lacing cord, and thread, etc., are determined by the aircraft's never-exceed speed and the pounds per square foot of wing loading. The never-exceed speed for a particular aircraft is that safe speed beyond which it should never be operated. The aircraft wing loading is determined by dividing its total wing planform area (in square feet) into the maximum allowable gross weight.

All fabric, surface tape, reinforcing tape, machine thread, lacing cord, etc., used for re-covering or repairing an aircraft's cover should be of high-grade aircraft textile material. The materials must also be at least as good a quality and of equivalent strength as those originally used by the aircraft manufacturer.

Acceptable fabrics for covering wings, control surfaces, and fuselages are listed in **Fig. 3-52** and **Fig. 3-53**. Fabrics conforming to AMS (Aeronautical Material Specifications) incorporate a continuous marking of specification numbers along the selvage edges to permit identification of the fabric in the field.

Fabric Terms

The main definitions of the terms used while describing fabrics are shown graphically in **Fig. 3-54**.

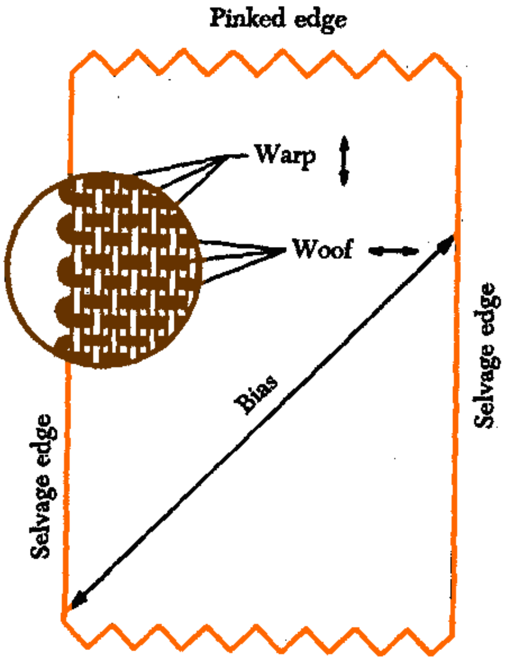


Figure 3-54. Fabric terms

with their additional explanation and some other terms as follows:

Term	Explanation
Warp	The direction along the length of fabric
Warp ends	The woven threads that run the length of the fabric
Filling, woof, or weft	The direction across the width of the fabric
Count	The number of threads per inch in warp or filling
Ply	The number of yards making up a thread
Bios	A cut, fold, or seam made diagonally to the warp or fill threads
Calendering	The process of ironing fabric by threading it wet between a series of hot and cold rollers to produce a smooth finish
Mercerization	The process of dipping cotton yarn or fabric in a hot solution of diluted caustic soda. This treatment causes the material to shrink and acquire greater strength and luster
Sizing	Material, such as starch, used to stiffen the yarns for ease in weaving the cloth
Pinked edge	An edge which has been cut by machine or shears in a continuous series of V's to prevent ravelling
Selvage edge	An edge of cloth, tape, or webbing woven to prevent ravelling

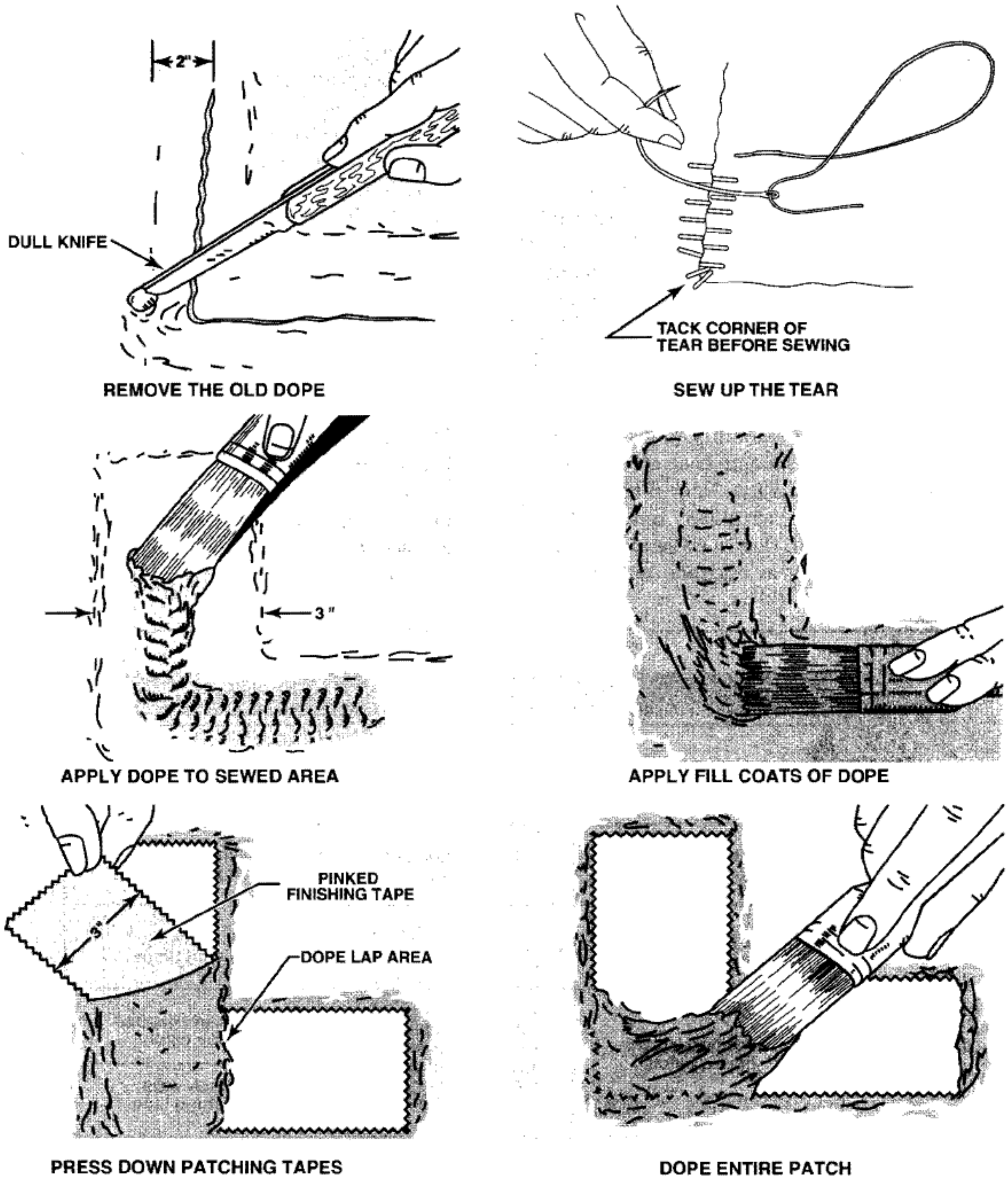


Figure 3-60. Repair of an L-shaped tear in a fabric surface

Doped-in Patch

If the damage to a fabric-covered structure does not extend more than 16 inches in any direction and the aircraft has a never-exceed speed of 150 m.p.h. or less, the damage can be cleaned out to a square, rectangular, or circular opening and repaired with a doped-in patch (**Fig. 3-61**). To start soften the dope around the opening with an appropriate thinner and scrape off the finish layers with a dull knife down to the clear dope coats. The alternative way is to support the underside of the fabric and remove the finish with l80-grit sandpaper. Then, using 400-grit paper, sand away all of the old finish down to the clear dope. In either case the finish is removed up to two inches from the edge of the opening. Care must be taken not to damage any of the good fabric.

6.4A CORROSION

Metal corrosion is the deterioration of the metal by chemical or electrochemical attack and can take place internally as well as on the surface. As in the rotting of wood, this deterioration may change the smooth surface, weaken the interior, or damage or loosen adjacent parts.

Water or water vapour containing salt combines with oxygen in the atmosphere to produce the main source of corrosion in aircraft. Aircraft operating in a marine environment or in areas where the atmosphere contains industrial fumes which are corrosive are particularly susceptible to corrosive attacks.

Corrosion can cause eventual structural failure if left unchecked. The appearance of the corrosion varies with the metal. On aluminium alloys and magnesium it appears as surface pitting and etching, often combined with a grey or white powdery deposit. On copper and copper alloys the corrosion forms a greenish film; on steel it appears as reddish rust. When the grey, white, green, or reddish deposits are removed, each of the surfaces may appear etched and pitted, depending upon the length of exposure and severity of attack. If these surface pits are not too deep, they may not significantly alter the strength of the metal; however, the pits may become sites for crack development. Some types of corrosion can travel beneath surface coatings and can spread until the part fails.

Types of Corrosion

There are two general classifications of corrosion, chemical and electrochemical; however, both types involve two simultaneous changes. The metal that is attacked or oxidized suffers an anodic change, and the corrosive agent is reduced and suffers a cathodic change.

Chemical Corrosion

Pure chemical corrosion results from direct exposure of a bare surface to caustic liquid or gaseous agents. The most common agents causing direct chemical corrosion include:

1. Spilled battery acid or fumes from batteries;
2. Residual flux deposits resulting from inadequately cleaned, welded, brazed, or soldered joints;
3. Entrapped caustic cleaning solutions.

Spilled battery acid become less problematic with the use of nickel-cadmium batteries. The use of these closed units lessens the hazards of acid spillage and battery fumes.

Many types of fluxes used in brazing, soldering, and welding are corrosive and they chemically attack the metals or alloys with which they are used. Therefore, it is important that residual flux be removed from the metal surface immediately after the joining operation. Flux residues are hygroscopic in nature; that is, they are capable of absorbing moisture, and unless carefully removed, tend to cause

6.4B CORROSION

There are many forms of corrosion. The form of corrosion depends on the metal involved, its size and shape, its specific function, atmospheric conditions, and the corrosion-producing agents present.

Oxidation

One of the simpler forms of corrosion is "dry" corrosion or, as it is most generally known, oxidation. When a metal such as aluminum is exposed to oxygen action, a chemical reaction takes place on the surface between the metal and the gas. Two aluminum atoms join three oxygen atoms to form aluminum oxide (Al_2O_3). If the metal is iron or steel, two atoms of iron join three atoms of oxygen to form iron oxide, or rust (Fe_20_3).

There is one big difference between iron oxide and aluminum oxide. The film of aluminum oxide is unbroken and, therefore, once it has formed. further reaction with oxygen slows dramatically. Iron oxide, on the other hand, forms a porous interrupted film. Since the film is not air tight, the metal continues to react with the oxygen in the air until the metal is completely eaten away (**Fig. 4-4**).

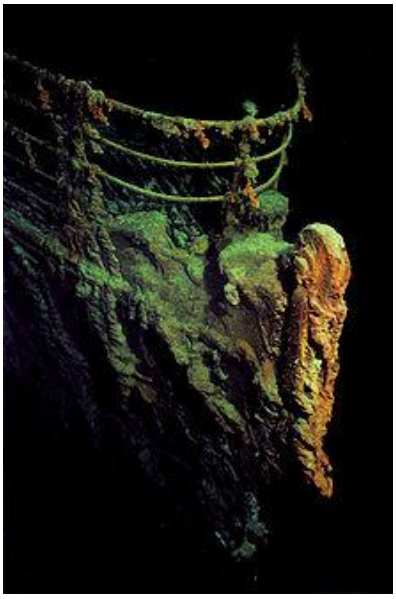
Figure 6.4.4. Corrosion on exposed metal

The best way to protect iron from dry corrosion is to keep oxygen from coming into contact with its surface. This is done temporarily by covering the surface with oil or grease, or permanently with a coat of paint.

Aluminum alloy can be protected from oxidation by the formation of an oxide film on its surface. This film insulates the aluminum from any electrolyte, and prevents further reaction with oxygen. The protection afforded by an aluminum oxide coating is the principal reason for cladding (Alclad) aluminum alloy used in structural applications.

Microbial Corrosion

Microbial corrosion, or bacterial corrosion, is a corrosion caused or promoted by microorganisms, usually chemoautotrophs (**Fig. 4-11**).



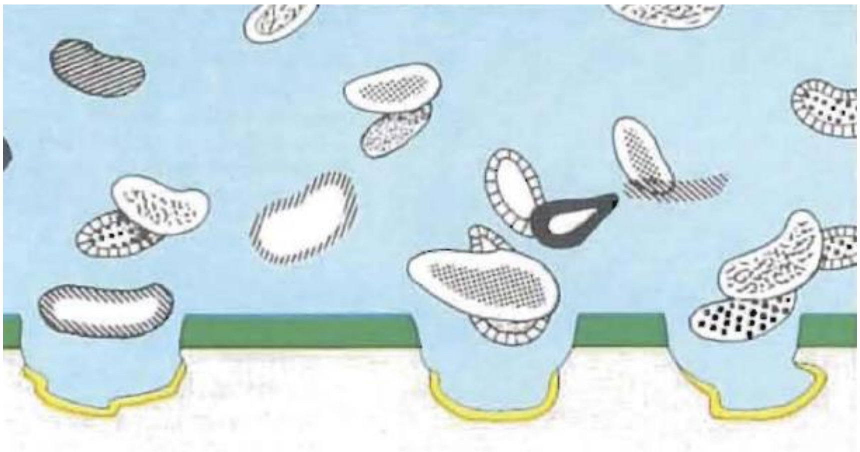


Figure 4-11. Titanic's bow exhibiting microbial corrosion damage in the form of “rusticles” (A) and model microbial corrosion (B)

Primer, Alloy, Fungus location, Anode (corrosion location),

Micro-organisms

It can apply to both metals and non-metallic materials, in both the presence and lack of oxygen. Sulfate-reducing bacteria are common in lack of oxygen; they produce hydrogen sulfide, causing sulfide stress cracking. In presence of oxygen, some bacteria directly oxidize iron to iron oxides and hydroxides, other bacteria oxidize sulfur and produce sulfuric acid causing biogenic sulfide corrosion. Concentration cells can form in the deposits of corrosion products, causing and enhancing galvanic corrosion.

It may be prevented by detail design, protective treatment and assembly techniques as well as use of inhibitors in primers.

Factors Affecting Corrosion

Many factors affect the type, speed, cause, and seriousness of metal corrosion. Some of these factors can be controlled and some cannot.

Climate

The environmental conditions under which an aircraft is maintained and operated greatly affect corrosion characteristics. In a predominately marine environment (with exposure to sea water and salt air), moisture-laden air is considerably more detrimental to an aircraft than it would be if all

6.5 FASTENERS

Aircraft hardware is the term used to describe the various types of fasteners and miscellaneous small items used in the manufacture and repair of aircraft.

The importance of aircraft hardware is often overlooked because of its small size; however, the safe and efficient operation of any aircraft is greatly dependent upon the correct selection and use of aircraft hardware.

Identification

Most items of aircraft hardware are identified by their specification number or trade name. Threaded fasteners and rivets are usually identified by:

AN (Air Force-Navy);

NAS (National Aircraft Standard), or

MS (Military Standard) numbers.

Quick-release fasteners are usually identified by factory trade names and size designations.

Threaded Fasteners

Various types of fastening devices allow quick dismantling or replacement of aircraft parts that must be taken apart and put back together at frequent intervals. Riveting or welding these parts each time they are serviced would soon weaken or ruin the joint. Furthermore, some joints require greater .tensile strength and stiffness than rivets can provide. Bolts and screws are two types of fastening devices which give the required security of attachment and rigidity. Generally, bolts are used where great strength is required, and screws are used where strength is not the deciding factor.

Bolts and screws are similar in many ways. They are both used for fastening or holding, and each has a head on one end and screw threads on the other. Regardless of these similarities, there are several distinct differences between the two types of fasteners. The threaded end of a bolt is always blunt while that of a screw may be either blunt or pointed.

6.5.1 SCREW THREADS

A screw thread, often abbreviated thread, is a helical structure used to convert between rotational and linear movement or force. A screw thread is a ridge wrapped around a cylinder or cone in the form of a helix, with the former being called a straight thread and the latter called a tapered thread. More screw threads are produced each year than any other machine element.

The mechanical advantage of a screw thread depends on its lead, which is the linear distance the screw travels in one revolution. In most applications, the lead of a screw thread is chosen so that friction is sufficient to prevent linear motion being converted to rotary that is so the screw does not slip even when linear force is applied so long as no external rotational force is present. This characteristic is essential to the vast majority of its uses. The tightening of a fastener's screw thread is comparable to driving a wedge into a gap until it sticks fast through friction and slight plastic deformation.

Thread Pairs and Handedness

Every matched pair of threads, external and internal, can be described as male and female. For example, a screw has male threads, while its matching hole (whether in nut or substrate) has female threads (**Fig. 5-1**). This property is called gender.

Figure 5-1. Internal and external threads

The helix of a thread can twist in two possible directions, which is known as handedness (**Fig. 5-2**).

Figure 5-2. The right-hand rule of screw threads

Most threads are oriented so that a bolt or nut, seen from above, is tightened (the item turned moves

6.5.2. BOLTS, STUDS AND SCREWS

Aircraft bolts are fabricated from cadmium- or zinc-plated corrosion-resistant steel, un-plated corrosion-resistant steel and anodized aluminum alloys. Most bolts used in aircraft structures are either general-purpose, AN bolts, or NAS internal-wrenching or close-tolerance bolts, or MS bolts. In certain cases, aircraft manufacturers make bolts of different dimensions or greater strength than the standard types. Such bolts are made for a particular application, and it is of extreme importance to use like bolts in replacement. Special bolts are usually identified by the letter "S" stamped on the head.

AN bolts come in three head styles - hex-head, clevis, and eyebolt (**Fig. 5-8**).

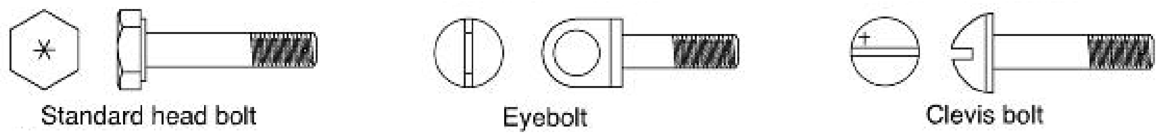


Figure 5-8. AN bolts

NAS bolts are available in hex-head, internal-wrenching, and countersunk head styles (**Fig. 5-9**).

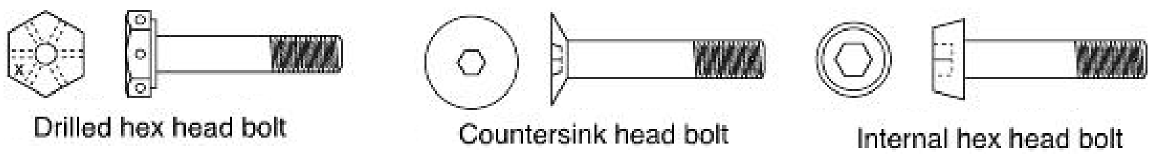


Figure 5-9. NAS bolts

MS bolts come in hex-head and internal-wrenching styles.

General-Purpose Bolts

The hex-head aircraft bolt (AN-3 through AN-20) is an all-purpose structural bolt used for general applications involving tension or shear loads where a light-drive fit is permissible (.006-inch clearance for a $^{5}/_{8}$-inch hole, and other sizes in proportion).

Alloy steel bolts smaller than No. 10-32 and aluminum alloy bolts smaller than $^{1}/_{4}$-inch diameter are not used in primary structures. Aluminum alloy bolts and nuts are not used where they will be repeatedly removed for purposes of maintenance and inspection. Aluminum alloy nuts may be used with cadmium-plated steel bolts loaded in shear on land airplanes, but are not used on seaplanes due to the increased possibility of dissimilar-metal corrosion.

The AN-73 drilled-head bolt is similar to the standard hex-bolt, but has a deeper head which is drilled to receive wire for safetying. The AN-3 and the AN-73 series bolts are interchangeable, for all practical purposes, from the standpoint of tension and shear strengths.

Lockbolt Numbering System

The numbering systems for the various types of lockbolts are explained as on **Fig. 5-17**.

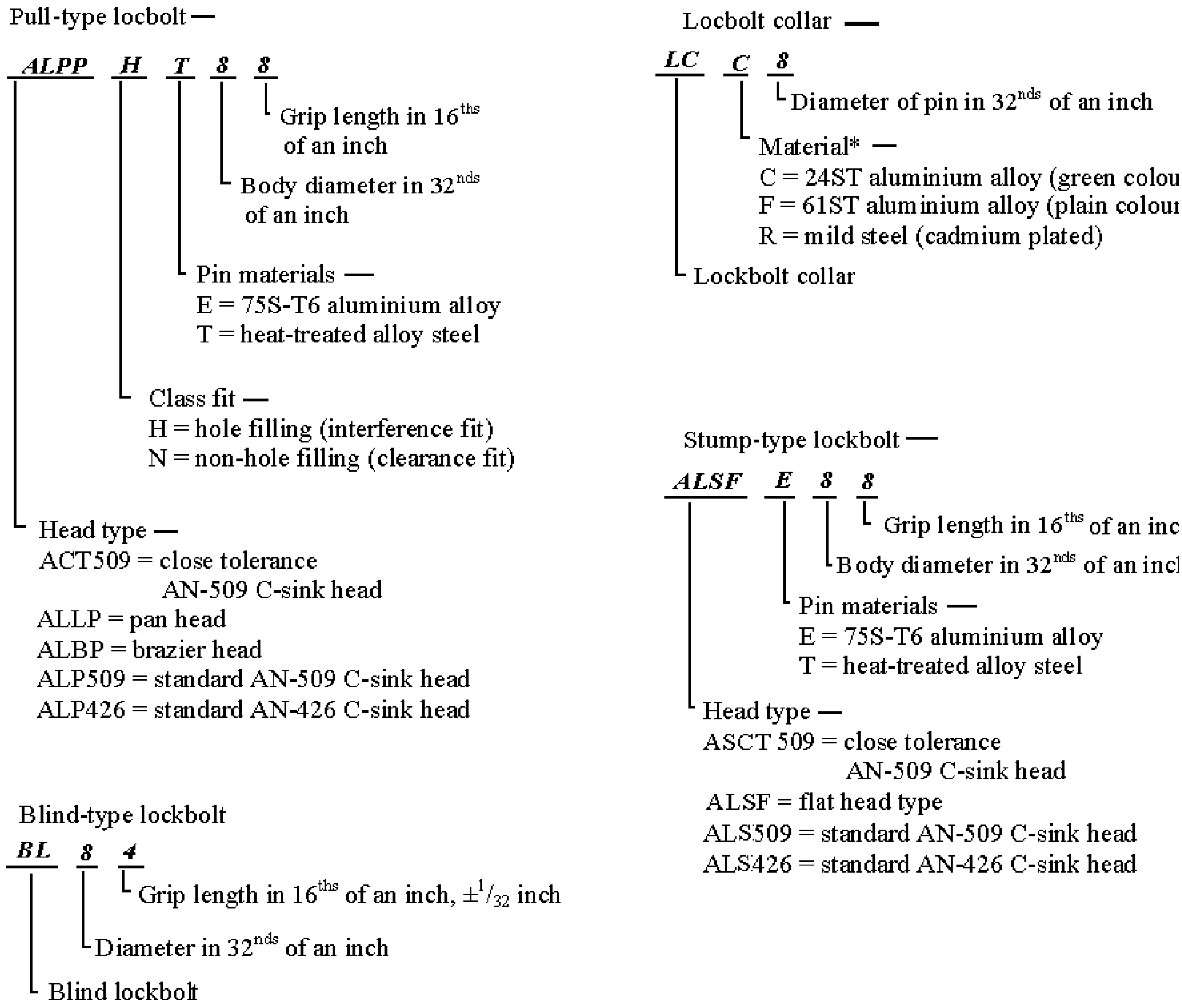


Figure 5-17. Lockbolt numbering systems

Aircraft Nuts

Aircraft nuts are made in a variety of shapes and sizes. They are made of cadmium-plated carbon steel, stainless steel, or anodized 2024T aluminum alloy, and may be obtained with either right- or left-hand threads. No identifying marking or lettering appears on nuts. They can be identified only by the characteristic metallic luster or color of the aluminum, brass, or the insert when the nut is of the self-locking type. They can be further identified by their construction.

Aircraft nuts can be divided into two general groups: Non-self-locking and self-locking nuts. Non-self-locking nuts are those that must be safetyied by external locking devices, such as cotter pins, safety wire, or locknuts. Self-locking nuts contain the locking feature as an integral part.

Boots Self-Locking Nut

The Boots self-locking nut is of one-piece, all-metal construction, designed to hold tight in spite of severe vibration. It (**Fig. 5-19**) has two sections and is essentially two nuts in one, a locking nut and a load-carrying nut. The two sections are connected with a spring which is an integral part of the nut. The spring keeps the locking and load-carrying sections such a distance apart that the two sets of threads are out-of-phase; that is, so spaced that a bolt which has been screwed through the load-carrying section must push the locking section outward against the force of the spring to engage the threads of the locking section properly.

Thus, the spring, through the medium of the locking section, exerts a constant locking force on the bolt in the same direction as a force that would tighten the nut. In this nut, the load-carrying section has the thread strength of a standard nut of comparable size, while the locking section presses against the threads of the bolt and locks the nut firmly in position. Only a wrench applied to the nut will loosen it. The nut can be removed and reused without impairing its efficiency.

Boots self-locking nuts are made with three different spring styles and in various shapes and sizes. The wing type, which is the most common, ranges in size for No. 6 up to $^{1}/_{4}$ inch, the Rol-top ranges from $^{1}/_{4}$ inch to $^{9}/_{16}$ inch, and the bellows type ranges in size from No. 8 up to $^{3}/_{8}$ inch. Wing-type nuts are made of anodized aluminum alloy, cadmium plated carbon steel, or stainless steel. The Rol-top nut is cadmium-plated steel, and the bellows type is made of aluminum alloy only.

Stainless Steel Self-Locking Nut

The stainless steel self-locking nut may be spun on and off with the fingers, as its locking action takes place only when the nut is seated against a solid surface and tightened. The nut consists of two parts (**Fig. 5-20**); a case with a beveled locking shoulder and key, and a threaded insert with a locking shoulder and slotted key way.

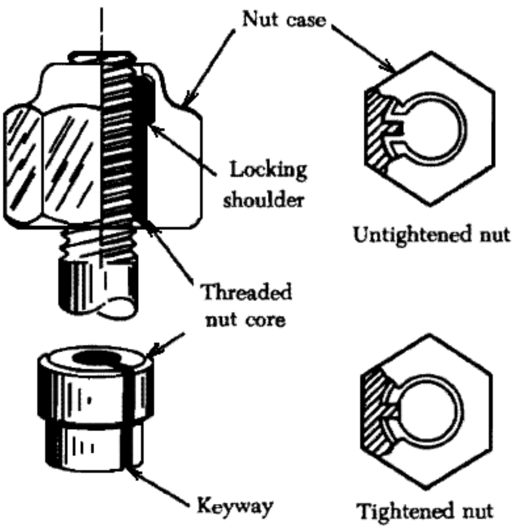


Figure 5-20. Stainless steel self-locking nut

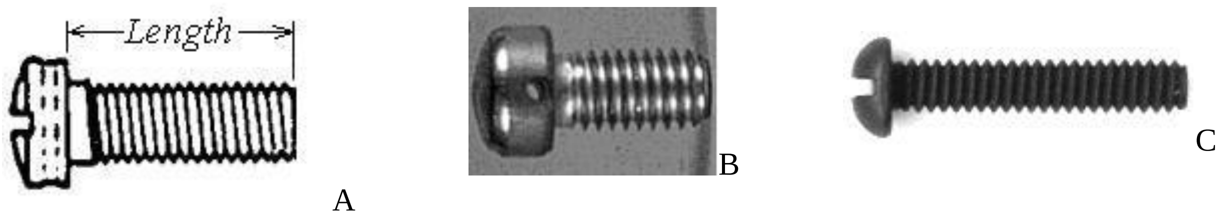


Figure 5-27. Machine screws: (A) AN500, (B) AN502, (C) AN515

The fillister-head screw, AN500 through AN503, is a general-purpose screw and is used as a cap-screw in light mechanisms. This could include attachments of cast aluminum parts such as gearbox cover plates.

The AN500 and AN501 screws (**Fig. 5-27A**) are available in low-carbon steel, corrosion-resistant steel, and brass. The AN500 has coarse threads while the AN501 has fine threads. They have no clearly defined grip length. Screws larger than No. 6 have a hole drilled through the head for safetying purposes.

The AN502 and AN503 (**Fig. 5-27B**) fillister-head screws are made of heat-treated alloy steel, have a small grip, and are available in fine and coarse threads. These screws are used as capscrews where great strength is required. The coarse-threaded screws are commonly used as capscrews in tapped aluminum alloy and magnesium castings because of the softness of the metal.

Machine Self-tapping Screws

Machine self-tapping screws are listed as AN504 and AN506 (**Fig. 5-28**).

Figure 5-28. Self-tapping screws: (A) AN530 round head, (B) AN504 and (C) AN506

The AN504 screw has a roundhead, and the AN506 is 82° countersunk. These screws are used for attaching removable parts, such as name-plates, to castings and parts in which the screw cuts its own threads.

AN530 and AN531 self-tapping sheet-metal screws, such as the Parker-Kalon Z-type sheet-metal screw, are blunt on the end. They are used in the temporary attachment of sheet metal for riveting, and in the permanent assembly of nonstructural assemblies. Self-tapping screws should not be used to replace standard screws, nuts, bolts, or rivets.

6.5.3 LOCKING DEVICES

Washers are one of the main locking devices used for securing threaded connections. Aircraft washers used in airframe repair are plain, lock, or special type washers.

Plain Washers

Plain washers (**Fig. 5-37**), both the AN960 and AN970, are used under hex nuts. They provide a smooth bearing surface and act as a shim in obtaining correct grip length for a bolt and nut assembly. They are used to adjust the position of castellated nuts in respect to drilled cotter pin holes in bolts. Plain washers should be used under lockwashers to prevent damage to the surface material.

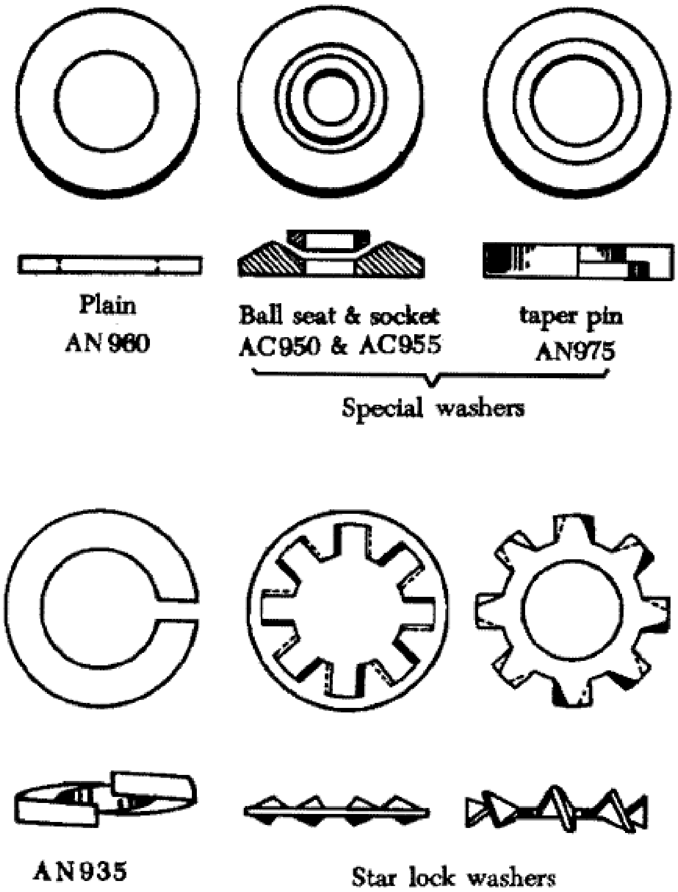


Figure 5-37. Various types of washers

Aluminium and aluminium alloy washers may be used under bolt heads or nuts on aluminium alloy or magnesium structures where corrosion caused by dissimilar metals is a factor. When used in this manner, any electric current flow will be between the washer and the steel bolt. However, it is common practice to use cadmium plated steel washer under a nut bearing directly against a structure as this washer which resist the cutting action of a nut better than an aluminium alloy washer.
The AN970 steel washer provides a greater bearing area than the AN960 washer and is used on wooden structures under both the head and the nut of a bolt to prevent crumbing the surface.

6.5.4 AIRCRAFT RIVETS

An aircraft, even though made of the best materials and strongest parts, would be of doubtful value unless those parts were firmly held together.

Several methods are used to hold metal parts together; they include riveting, bolting, brazing, and welding. The process used must produce a union that will be as strong as the parts that are joined.

Aluminium and its alloys are difficult to solder. To make a good union and a strong joint, aluminium parts can be welded, bolted, or riveted together. Riveting is satisfactory from the standpoint of strength and neatness, and is much easier to do than welding. It is the most common method used to fasten or join aluminium alloys in aircraft construction and repair.

A rivet is a metal pin used to hold two or more metal sheets, plates, or pieces of material together. A head is formed on one end when the rivet is manufactured. The shank of the rivet is placed through matched holes in two pieces of material, and the tip is then upset to form a second head to clamp the two pieces securely together. The second head formed either by hand or by pneumatic equipment, is called a "shop head". The shop head functions in the same manner as a nut on a bolt. In addition to their use for joining aircraft skin sections, rivets are also used for joining spar sections, for holding rib sections in place, for securing fittings to various parts of the aircraft, and for fastening innumerable bracing members and other parts together.

Two of the major types of rivets used in the aircraft are:

- The common ***solid-shank*** type, which must be driven using a bucking bar, and
- The ***special (blind) rivets***, which may be installed where it is impossible to use a bucking bar.

Solid-Shank Rivet Types

Solid-shank rivets are generally used in repair work. They are identified by the kind of material of which they are made, their head type, size of shank, and their temper condition. The designation of the solid-shank rivet head type, such as universal head, roundhead, flathead, countersunk head, and brazier head, depends on the cross sectional shape of the head (**Fig. 5-45**). The temper designation and strength are indicated by special markings on the head of the rivet.

The material used for the majority of aircraft solid-shank rivets is aluminium alloy. The strength and temper conditions of aluminium alloy rivets are identified by digits and letters similar to those adopted for the identification of strength and temper conditions of aluminium and aluminium alloy sheet stock. The 1100, 2017-T, 2024-T, 2117-T, and 5056 rivets are the five grades usually available.

The 1100 rivet, which is composed of 99.45% pure aluminium, is very soft. It is for riveting the softer aluminium alloys, such as 1100, 3003, and 5052, which are used for non-structural parts (all parts where strength is not a factor). The riveting of map cases is a good example of where a rivet of 1100 aluminium alloy may be used.

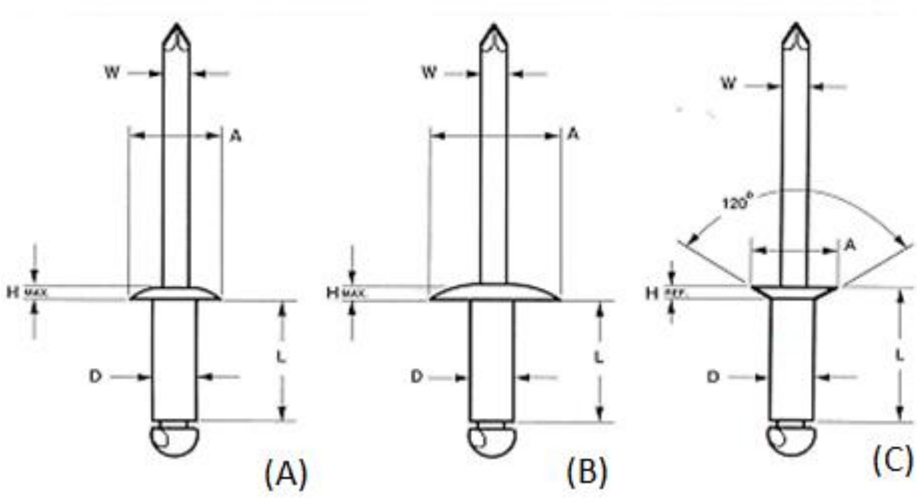


Figure 5-48. Special (blind) rivets: (A) – dome, (B) – Large Frank and (C) – countersunk head

Those designations on **Fig. 5-48** are:

A- head diameter;

D – body diameter;

H – head height;

L – rivet length;

W – mandrel diameter.

Part numbering for blind rivets is shown on **Fig. 5-49**.

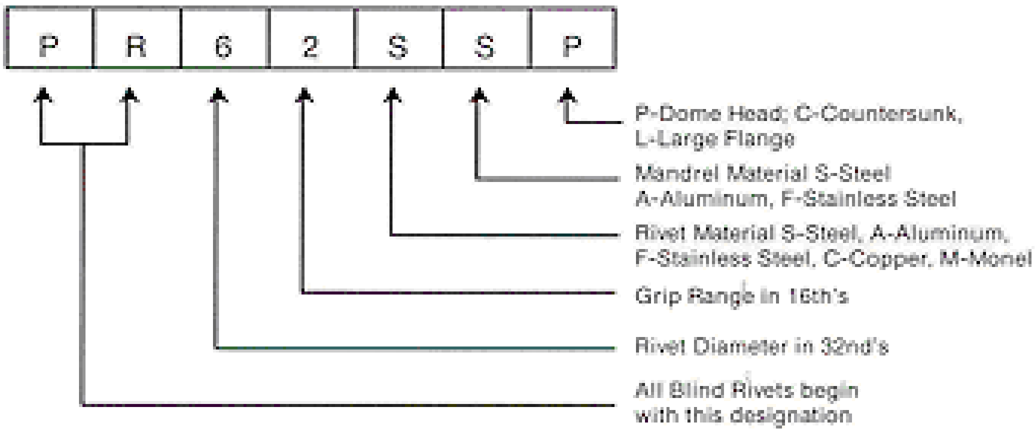


Figure 5-49. Special (blind) rivets part numbering

The designations on **Fig. 5-51** are:

A - Thickness of material (grip range);

B - $^{3}/_{64}$ - $^{1}/_{8}$-inch;

C - Total rivet shank length.

Pull-Thru Rivets

Pull-thru rivets are fabricated in two parts: A rivet head with a hollow shank or sleeve and a stem that extends through the hollow shank (**Fig. 6-52**).

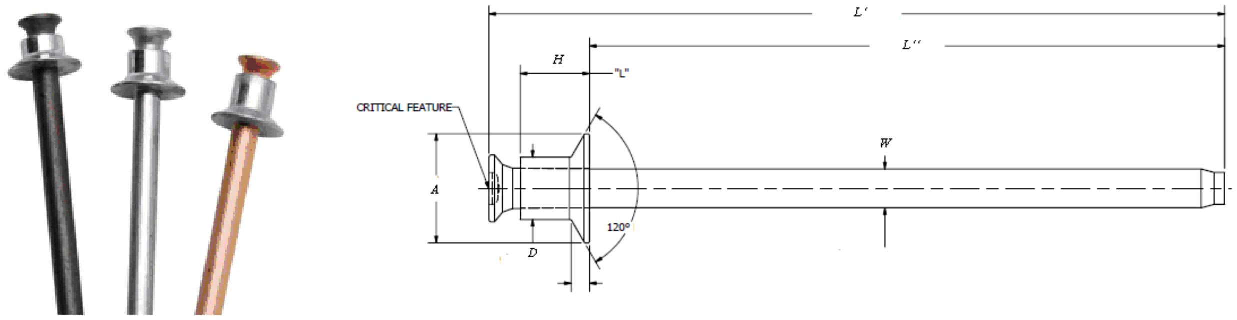


Figure 5-52. Pull-thru rivets

Several events, in their proper sequence (**Fig. 5-53**), occur when a pulling force is applied to the stem of the rivet:

1. The stem is pulled thru the rivet shank;
2. The mandrel portion of the stem forces the shank to expand forming the blind head and filling the hole.

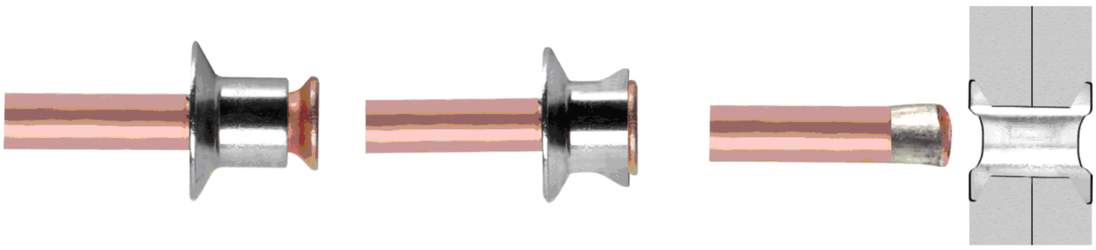


Figure 5-53. Pull-thru rivet setting sequence

Pull-thru rivets are fabricated in two common head styles:

1. Protruding head similar to the MS20470 or universal head, and
2. A 100° countersunk head.

6.6A PIPES AND UNIONS

The term "aircraft plumbing" refers not only to the hose, tubing, fittings, and connectors used in the aircraft, but also to the processes of forming and installing them.

Occasionally it may be necessary to repair or replace damaged aircraft plumbing lines. Very often the repair can be made simply by replacing the tubing. However, if replacements are not available, the needed parts may have to be fabricated. Replacement tubing should be of the same size and material as the original line.

Tubing is pressure tested prior to initial installation, and is designed to withstand several times the normal operating pressure to which it will be subjected. If a tube bursts or cracks, it is generally the result of excessive vibration, improper installation, or damage caused by collision with an object. All tubing failures should be carefully studied and the cause of the failure determined.

Plumbing Lines

Aircraft plumbing lines usually are made of metal tubing and fittings or of flexible hose. Metal tubing is widely used in aircraft for fuel, oil, coolant, oxygen, instrument, and hydraulic lines. Flexible hose is generally used with moving parts or where the hose is subject to considerable vibration.

Generally, aluminium alloy or corrosion-resistant steel tubing has replaced copper tubing. The high fatigue factor of copper tubing is the chief reason for its replacement. It becomes hard and brittle from vibration and finally breaks, however it may be restored to its soft annealed state by heating it red hot and quenching it in cold water. Cooling in air will result in a degree of softness but not equal to that obtained with the cold water quench. This annealing process must be accomplished if copper tubing is removed for any reason. Inspection of copper tubing for cracks, hardness, brittleness and general condition should be accomplished at regular intervals to preclude failure. The workability, resistance to corrosion, and lightweight of aluminium alloy are major factors in its adoption for aircraft plumbing.

In some special high-pressure (3 000 PSI) hydraulic installations, corrosion-resistant steel tubing, either annealed or $^1/_4$ hard, is used. Corrosion-resistant steel tubing does not have to be annealed for flaring or forming; in fact, the flared section is somewhat strengthened by the cold working and strain hardening during the flaring process. Its higher tensile strength permits the use of tubing with thinner walls; consequently the final installation weight is not much greater than that of the thicker-wall aluminium alloy tubing.

Identification of Materials

Before making repairs to any aircraft plumbing, it is important to make accurate identification of plumbing materials. Aluminium alloy or steel tubing can be identified readily by sight where it is used as the basic plumbing material. However, it is difficult to determine whether a material is carbon

6.6B PIPES AND UNIONS

Plumbing connectors, or fittings, attach one piece of tubing to another or to system units. There are four types:

1. Flared fitting;
2. Flare-less fitting;
3. Bead and clamp, and
4. Swaged.

The amount of pressure that the system carries is usually the deciding factor in selecting a connector. The beaded type of joint, which requires a bead and a section of hose and hose clamps, is used only in low or medium-pressure systems, such as vacuum and coolant systems. The flared, flareless, and swaged types may be used as connectors in all systems, regardless of the pressure.

Flared-Tube Fittings

A flared-tube fitting consists of a sleeve and a nut, as shown in **Fig. 6-6**. The nut fits over the sleeve and, when tightened, draws the sleeve and tubing flare tightly against a male fitting to form a seal. Tubing used with this type of fitting must be flared before installation.

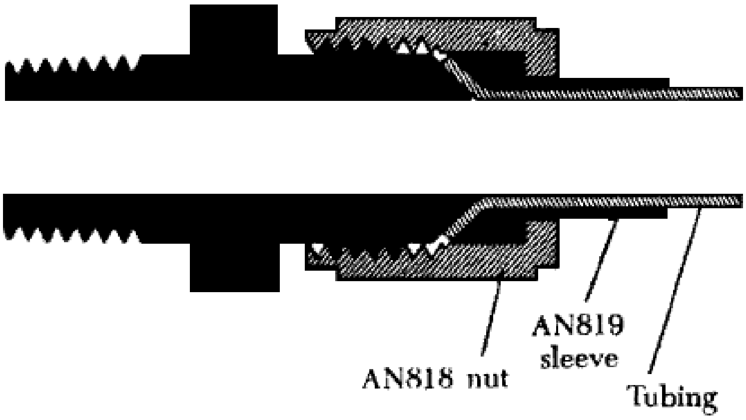


Figure 6-6. Flared-tube fitting

The male fitting has a cone-shaped surface with the same angle as the inside of the flare. The sleeve supports the tube so that vibration does not concentrate at the edge of the flare, and distributes the shearing action over a wider area for added strength.

It is important to be able to identify between AC and AN flared-tube fittings. The AN fitting has a shoulder between the end of the threads and the flare cone (**Fig. 6-7**). The AC fitting does not have this shoulder.

Other differences between the AC and AN fittings include the sleeve design, the AC sleeve being noticeably longer than the AN sleeve of the same size. Although certain flared-tube fittings are interchangeable, the pitch of the threads is different in most cases.

Quick-disconnect Couplings

Quick-disconnect couplings (**Fig. 6-15**) of the self-sealing type are used at various points in many fluid systems. The couplings are installed at locations where frequent uncoupling of the lines is required for inspection and maintenance.

Figure 6-15. Quick-disconnect couplings

Quick-disconnect couplings provide a means of quickly disconnecting a line without loss of fluid or entrance of air into the system. Each coupling assembly consists of two halves, held together by a union nut. Each half contains a valve that is held open when the coupling is connected, allowing fluid to flow through the coupling in either direction. When the coupling is disconnected, a spring in each half closes the valve, preventing the loss of fluid and entrance of air.

The union nut has a quick-lead thread which permits connecting or disconnecting the coupling by turning the nut. The amount the nut must be turned varies with different style couplings. One style requires a quarter turn of the union nut to lock or unlock the coupling while another style requires a full turn.

Some couplings require wrench tightening; others are connected and disconnected by hand. The design of some couplings is such that they must be safetied with safety wire. Others do not require lock wiring, the positive locking being assured by the teeth on the locking spring, which engage ratchet teeth on the union nut when the coupling is fully engaged. The lock spring automatically disengages when the union nut is unscrewed. Because of individual differences, all quick disconnects should be installed according to instructions in the aircraft maintenance manual.

6.7. SPRINGS

A spring is a flexible elastic object used to store mechanical energy. Springs are usually made out of hardened steel. Small springs can be wound from pre-hardened stock, while larger ones are made from annealed steel and hardened after fabrication. Some non-ferrous metals are also used including phosphor bronze for parts requiring corrosion resistance and beryllium copper for springs carrying electrical current (because of its low electrical resistance).

Simple non-coiled springs were used throughout human history. In the Bronze Age more sophisticated spring devices were used, this can be known from the spread of the tweezers in many cultures. The Greek engineer Ctesibius of Alexandria developed a method for making bronze with spring-like characteristics by producing an alloy of bronze with an increased proportion of tin, and then hardening it with hammering after it is cast. Coiled springs were introduced in the 15th century.

Types of springs

The most common types of spring are:

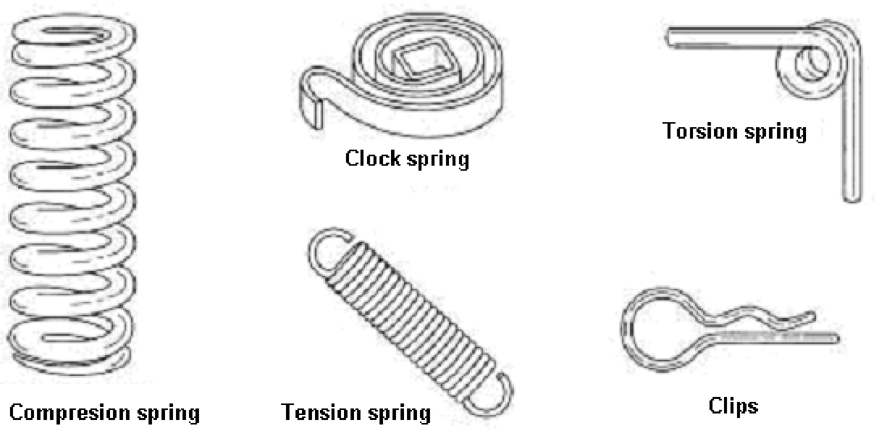


Figure 6.7.1. Examples of different types of springs

The coil spring or helical spring is a spring made by winding a wire around a cylinder and the conical spring both these are types of torsion spring, because the wire itself is twisted when the spring is compressed or stretched.

These are in turn of two types:

- *Tension springs* (**Fig. 7-1**) are designed to become longer under load. Their turns are normally touching in the unloaded position, and they have a hook, eye or some other means of attachment at each end.
- *Compression springs* (**Fig. 7-1**) are designed to become shorter when loaded. Their turns are not touching in the unloaded position, and they need no attachment points. A *volute* spring is a compression spring in the form of a cone so that under compaction the coils are not forced against each other, thus permitting longer travel.

6.8 BEARINGS

A **bearing** (**Fig. 8-1**) is a device to allow constrained relative motion between two or more parts, typically rotation or linear movement. Bearings may be classified broadly according to the motions they allow and according to their principle of operation as well as by the directions of applied loads they can handle.

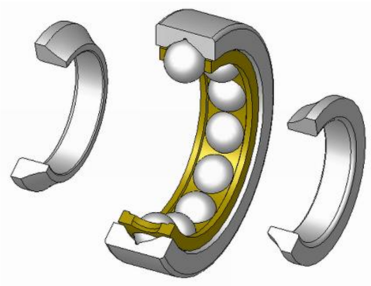


Figure 8-1. A cutaway example of a four-point contact ball bearing

Plain bearings use surfaces in rubbing contact, often with a lubricant such as oil or graphite. A plain bearing may or may not be a discrete device. It may be nothing more than the bearing surface of a hole with a shaft passing through it, or of a planar surface that bears another (in these cases, not a discrete device); or it may be a layer of bearing metal either fused to the substrate (semi-discrete) or in the form of a separable sleeve (discrete). With suitable lubrication, plain bearings often give entirely acceptable accuracy, life, and friction at minimal cost. Therefore, they are very widely used. However, there are many applications where a more suitable bearing can improve efficiency, accuracy, service intervals, reliability, and speed of operation, size, weight, and costs of purchasing and operating machinery.

Thus, there are many types of bearings, with varying shape, material, lubrication, principal of operation, and so on. For example, rolling-element bearings use spheres or drums rolling between the parts to reduce friction; reduced friction allows tighter tolerances and thus higher precision than a plain bearing and reduced wear extends the time over which the machine stays accurate. Plain bearings are commonly made of varying types of metal or plastic depending on the load, how corrosive or dirty the environment is, and so on. In addition, bearing friction and life may be altered dramatically by the type and application of lubricants. For example, a lubricant may improve bearing friction and life, but for food processing a bearing may be lubricated by an inferior food-safe lubricant to avoid food contamination; in other situations a bearing may be run without lubricant because continuous lubrication is not feasible, and lubricants attract dirt that damages the bearings.

6.9 TRANSMISSIONS

A gear is a rotating machine part having cut teeth, or cogs, which mesh with another toothed part in order to transmit torque. Two or more gears working in tandem are called a transmission and can produce a mechanical advantage through a gear ratio and thus may be considered a simple machine. Geared devices can change the speed, magnitude, and direction of a power source. The most common situation is for a gear to mesh with another gear; however a gear can also mesh a non-rotating toothed part, called a rack, thereby producing translation instead of rotation.

The gears in a transmission are analogous to the wheels in a pulley. An advantage of gears is that the teeth of a gear prevent slipping.

When two gears of unequal number of teeth are combined a mechanical advantage is produced, with both the rotational speeds and the torques of the two gears differing in a simple relationship.

In transmissions which offer multiple gear ratios, such as bicycles and cars, the term gear, as in first gear, refers to a gear ratio rather than an actual physical gear. The term is used to describe similar devices even when gear ratio is continuous rather than discrete, or when the device does not actually contain any gears, as in a continuously variable transmission.

Spur Gears

Spur gears or *straight-cut gears* are the simplest type of gear (**Fig. 9-1**). They consist of a cylinder or disk, and with the teeth projecting radially, and although they are not straight-sided in form, the edge of each tooth thus is straight and aligned parallel to the axis of rotation. These gears can be meshed together correctly only if they are fitted to parallel axles.

Figure 9-1. Spur gears or straight-cut gears

Helical Gear

Helical gears (**Fig. 9-2**) offer a refinement over spur gears. The leading edges of the teeth are not parallel to the axis of rotation, but are set at an angle. Since the gear is curved, this angling causes the tooth shape to be a segment of a helix. Helical gears can be meshed in a *parallel* or *crossed* orientations. The former refers to when the shafts are parallel to each other; this is the most common orientation. In the latter, the shafts are non-parallel.

Reduction Gear Boxes

Epicyclic Gear Box

The three basic components of the epicyclic gear (**Fig. 9-11**) are:

Sun	The central gear
Planet carrier	Holds one or more peripheral *planet* gears, of the same size, meshed with the sun gear
Annulus	An outer ring with inward-facing teeth that mesh with the planet gear or gears

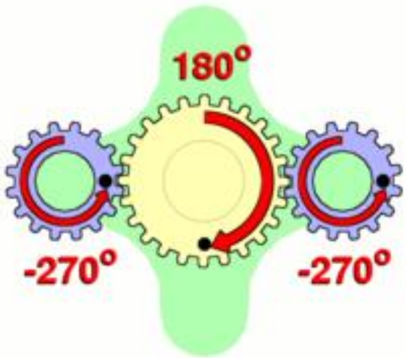


Figure 9-11. Epicyclic gear with stationary carrier (green)

In **Fig. 9-11**, the carrier (green) is held stationary while the sun gear (yellow) is used as input. The planet gears (blue) turn in a ratio determined by the number of teeth in each gear. Here, the ratio is $-{}^{24}/_{16}$, or $-{}^{3}/_{2}$; each planet gear turns at ${}^{3}/_{2}$ the rate of the sun gear, in the opposite direction.

In many epicyclic gearing systems, one of these three basic components is held stationary; one of the two remaining components is an *input*, providing power to the system, while the last component is an *output*, receiving power from the system. The ratio of input rotation to output rotation is dependent upon the number of teeth in each gear, and upon which component is held stationary.

In other systems, such as hybrid vehicle transmissions, two of the components are used as *inputs* with the third providing *output* relative to the two inputs.

One situation is when the planetary carrier is held stationary, and the sun gear is used as input. In this case, the planetary gears simply rotate about their own axes at a rate determined by the number of teeth in each gear. If the sun gear has *S* teeth, and each planet gear has *P* teeth, then the ratio is equal to $-{}^{S}/_{P}$. For instance, if the sun gear has 24 teeth, and each planet has 16 teeth, then the ratio is $-{}^{24}/_{16}$, or $-{}^{3}/_{2}$; this means that one clockwise turn of the sun gear produces 1.5 *counterclockwise* turns of the planet gears.

Vee-belts

Vee-belts (also known as V-belt or wedge rope) solved the slippage and alignment problem. It is the basic belt for power transmission. They provide the best combination of traction, speed of movement, load of the bearings, and long service life (**Fig. 9-13**).

Figure 9-13. V-belt or wedge rope

They are generally endless, and their general cross-section shape is trapezoidal. The "V" shape of the belt tracks in a mating groove in the pulley (or sheave), with the result that the belt cannot slip off. The belt also tends to wedge into the groove as the load increases — the greater the load, the greater the wedging action — improving torque transmission and making the V-belt an effective solution, needing less width and tension than flat belts. V-belts trump flat belts with their small center distances and high reduction ratios. The preferred center distance is larger than the largest pulley diameter, but less than three times the sum of both pulleys. Optimal speed range is $1\,000\text{–}7\,000\ {}^{ft}/_{min}$.

V-belts need larger pulleys for their larger thickness than flat belts. They can be supplied at various fixed lengths or as a segmented section, where the segments are linked (spliced) to form a belt of the required length. For high-power requirements, two or more V-belts can be joined side-by-side in an arrangement called a multi-V, running on matching multi-groove sheaves. The strength of these belts is obtained by reinforcements with fibers like steel, polyester or aramid (e.g. Twaron or Kevlar). This is known as a multiple-belt drive. When an endless belt does not fit the need, jointed and link V-belts may be employed. However they are weaker and only usable at speeds up to $4\,000\ {}^{ft}/_{min}$. A link V-belt is a number of rubberized fabric links held together by metal fasteners. They are length adjustable by disassembling and removing links when needed.

6.10 CONTROL CABLES

Cables are the most widely used linkage in primary flight control systems not only on small (**Fig. 10-1**) but on large aircrafts also. Cable-type linkage is also used in engine controls, emergency extension systems for the landing gear, and various other systems throughout the aircraft.

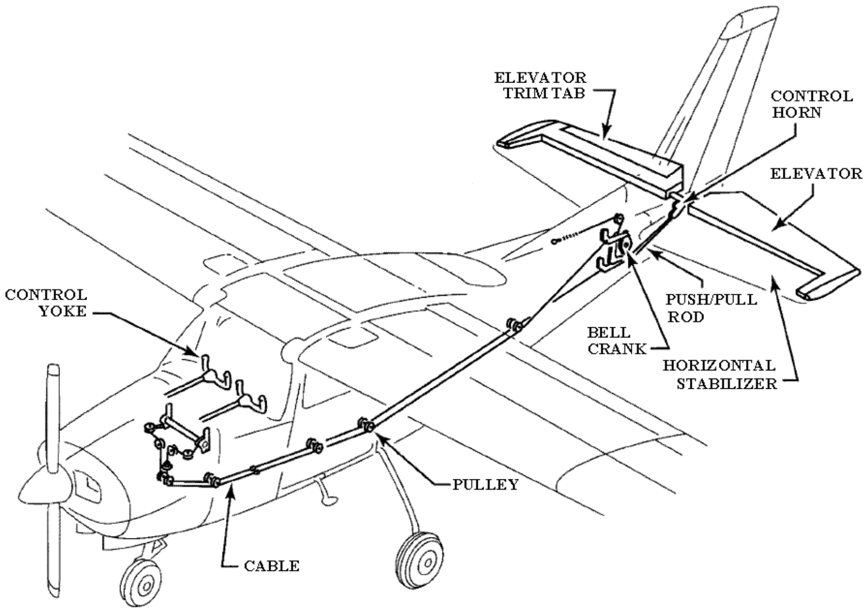


Figure 10-1. A typical small aircraft elevator-control system consists of cables and pulleys

Cable-type linkage has several advantages over the other types. It is strong and light in weight and its flexibility makes it easy to route through the aircraft. An aircraft cable has a high mechanical efficiency and can be set up without hack-lash, which is very important for precise control.

Cable linkage also has some disadvantages. Tension must be adjusted frequently due to stretching and temperature changes. Aircraft control cables are fabricated from carbon steel or stainless steel.

Cable Construction

The basic component of a cable is a wire. The diameter of the wire determines the total diameter of the cable. A number of wires are preformed into a helical or spiral shape and then formed into a strand. These preformed strands are laid around a straight centre strand to form a cable.

Cable designations are based on the number of strands (**Fig. 10-2**) and the number of wires in each strand for flexible cables.

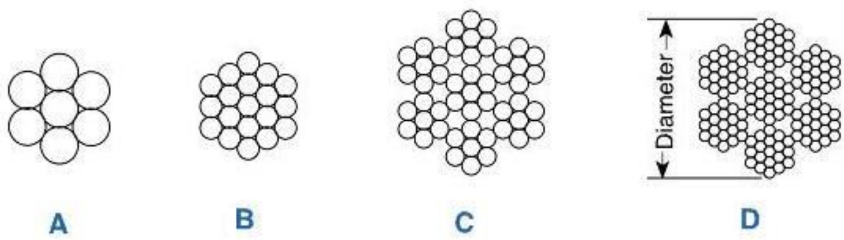


Figure 10-2. Control cable construction

6.11. ELECTRICAL CABLES AND CONNECTORS

The satisfactory performance of any modern aircraft depends to a very great degree on the continuing reliability of electrical systems and subsystems. Improperly or carelessly installed or maintained wiring can be a source of both immediate and potential danger. The continued proper performance of electrical systems depends upon the knowledge and technique of the mechanic who installs, inspects, and maintains the electrical wire and cable of the electrical systems.

Commonly a wire is described as a single solid conductor, or a stranded conductor covered with an insulating material (**Fig. 11-1**).

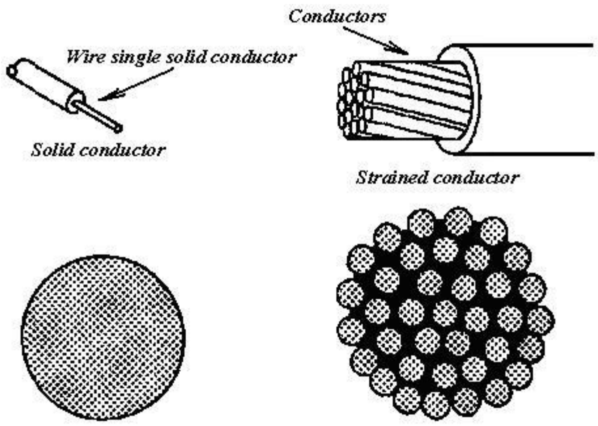


Figure 11.1. Two types of aircraft wire

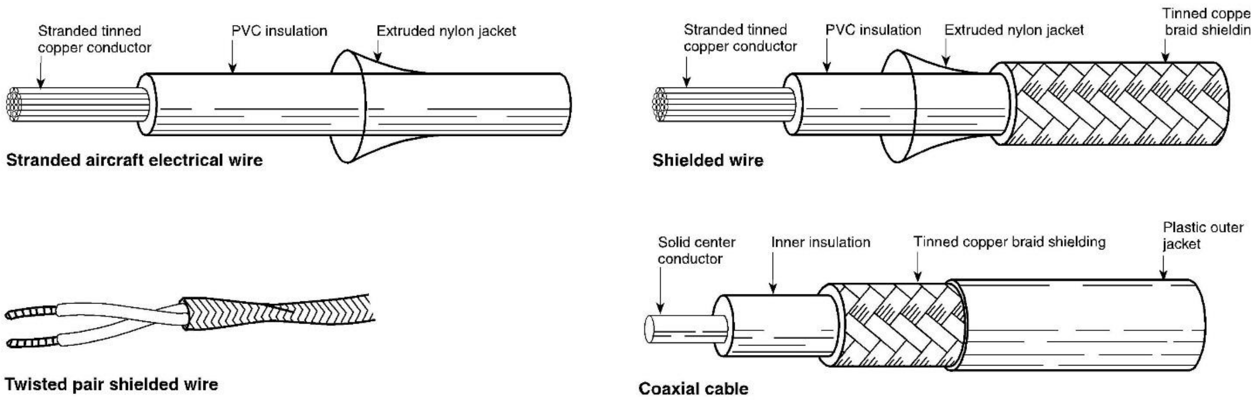


Figure 11-2. Types of aircraft electrical wire

The term “cable” or “wire” as used in aircraft electrical installations (**Fig. 11-2**) includes:

A - Two or more separately insulated conductors in the same jacket (multi-conductor cable);

B - Two or more separately insulated conductors twisted together (twisted pair);

C - One or more insulated conductors, covered with a metallic braided shield (shielded cable);

D - A single insulated centre conductor with a metallic braided outer conductor (radio frequency cable).

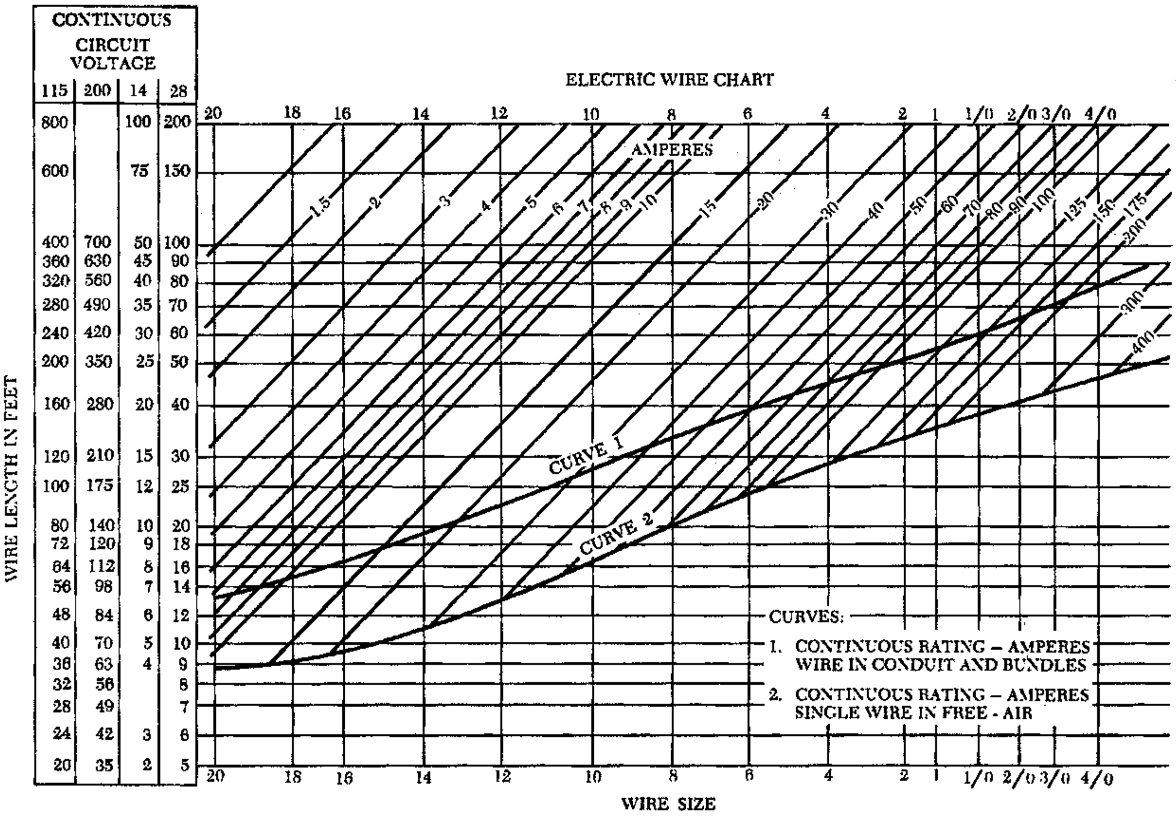


Figure 11-7. Conductor chart, continuous rating (Applicable to copper conductors)

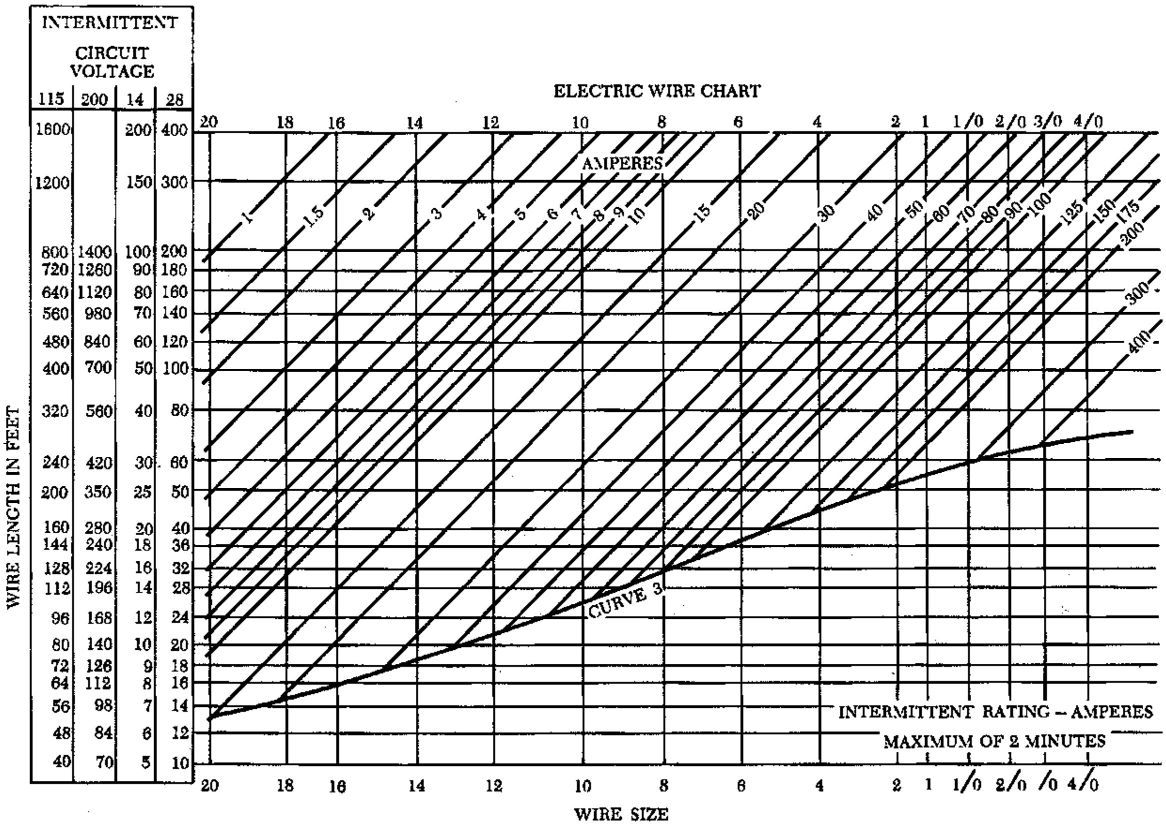


Figure 11-8. Conductor chart, intermittent rating (Applicable to copper conductors)

Figure 11-12. Segments of high-voltage cables

The cable system must prevent contact of the high-voltage conductor with other objects or persons, and must contain and control leakage current. Cable joints and terminals must be designed to control the high-voltage stress to prevent breakdown of the insulation. Often a high-voltage cable will have a metallic shield layer over the insulation, connected to earth ground and designed to equalize the dielectric stress on the insulation layer, and to prevent shock.

High voltage cables may be any length, with relatively short cables used in apparatus, longer cables run within buildings or as buried cables in an industrial plant or for power distribution, and the longest cables are often run as submarine cables under the ocean for power transmission.

Construction

Like in other, the structural elements of *HV-cables* have one or more conductors, insulation, and a protective jacket. *HV cables* differ from lower-voltage cables in that they have additional internal layers in the insulation jacket to control the electric field around the conductor (**Fig. 11-13**).

Figure 11-13. A cross-section through a 400 kV cable

Fig. 11-13 shows the stranded segmented copper conductor in the center, semiconducting and insulating layers, copper shield conductors, aluminum sheath and plastic outer jacket. For circuits operating at or above 2,000 volts between conductors, a conductive shield may surround each

Connectors are often plated with high-conductivity metals such as silver or gold. Due to the skin effect, the RF signal is only carried by the plating and does not penetrate to the connector body. Although silver oxidizes quickly, the silver oxide that is produced is still conductive. While this may pose a cosmetic issue, it does not degrade performance.

Solderless Terminals and Splices

Splicing of electrical cable should be kept to a minimum and avoided entirely in locations subject to extreme vibrations. Individual wires in a group or bundle can usually be spliced, provided the completed splice is located so that it can be inspected periodically. The splices should be staggered so that the bundle does not become excessively enlarged. Many types of aircraft splice connectors are available for splicing individual wires. Self-insulated splice connectors are usually preferred; however, a non-insulated splice connector can be used if the splice is covered with plastic sleeving secured at both ends. Solder splices may be used, but they are particularly brittle and not recommended.

Electric wires are terminated with solderless terminal lugs to permit easy and efficient connection to and disconnection from terminal blocks, bus bars, or other electrical equipment. Solderless splices join electric wires to form permanent continuous runs. Solderless terminal lugs and splices are made of copper or aluminium and are pre-insulated or uninsulated, depending on the desired application.

Terminal lugs are generally available in three types for use in different space conditions (**Fig. 11-17**).

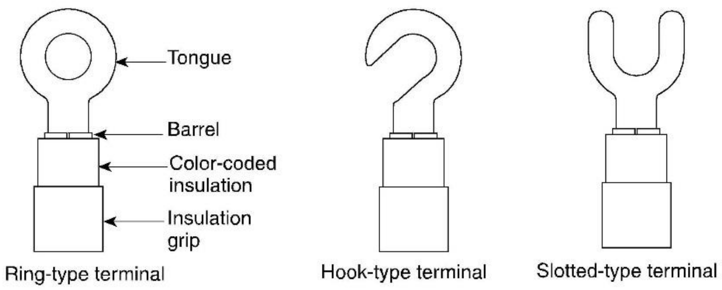


Figure 11-17. Terminal lug types

Terminal lugs are "crimped" (sometimes called "staked" or "swaged") to the wires by means of hand or power crimping tools. The terminals used in aircraft applications are of ring type to prevent effect of vibrations on contacts properties.

Copper Wire Terminals

Copper wires are terminated with solderless, pre-insulated straight copper terminal lugs. The insulation is part of the terminal lug and extends beyond its barrel so that it will cover a portion of the wire insulation, making the use of an insulation sleeve unnecessary (**Fig. 11-18**).

In addition, pre-insulated terminal lugs contain an insulation grip (a metal reinforcing sleeve) beneath connection by excluding moisture and air. The compound is retained inside the terminal lug barrel by a plastic or foil seal at the end of the barrel.

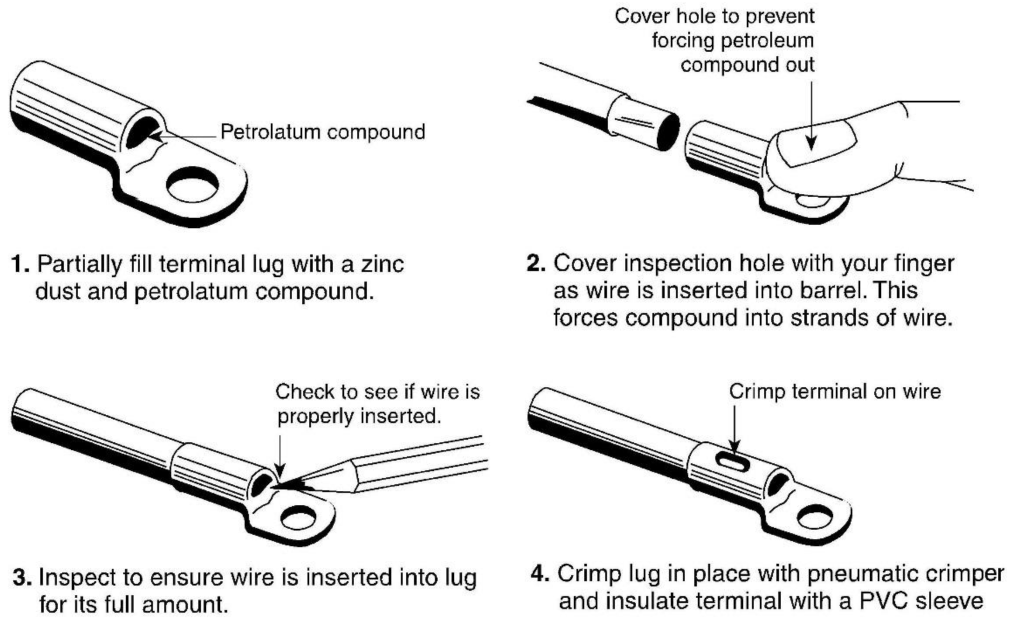


Figure 11-22. Installation of an aluminium terminal lug on a large aluminium wire

Connecting Terminal Lugs to Terminal Blocks

Terminal lugs should be installed on terminal blocks in such a manner that they are locked against movement in the direction of loosening (**Fig. 11-23**).

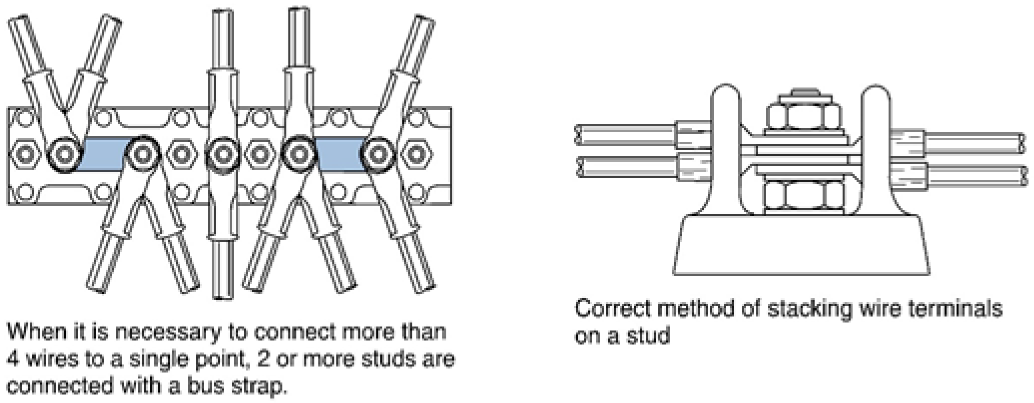


Figure 11-23. Connecting terminals to terminal block

Terminal blocks are normally supplied with studs secured in place by a plain washer, an external tooth lock washer, and a nut. In connecting terminals, a recommended practice is to place copper terminal lugs directly on top of the nut, followed with a plain washer and elastic stop nut, or with a plain washer, split steel lock washer and plain nut.

Aluminium terminal lugs should be placed over a plated brass plain washer, followed with another plated brass plain washer, split steel lock washer, and plain nut or elastic stop nut. The plated brass washer should have a diameter equal to the tongue width of the aluminium terminal lug. Consult the

Contact Insertion and Extraction

Modern connectors are manufactured with locking mechanism built into the insert which accept a whole range of contact sizes. There are two types of locking mechanism, FRONT and REAR release (**Fig. 11-29**); both systems use a similar mechanism but the tools used are not interchangeable between the two types.

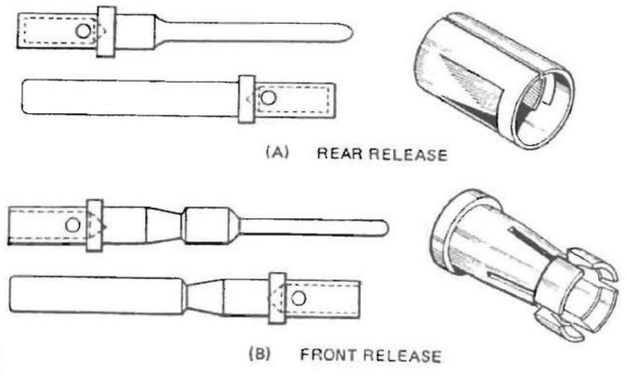


Figure 11-29. Rear and front contact release arrangement

Tool selection is critical and tooling information for both insertion and extraction tools can be found in Maintenance Manual.

Pin Removal

There are two basic types of contact retention used in plug and socket connectors, one with the contacts being released for removal from the rear of the contact insert and the other from the front. Each system requires the use of different types of insertion/extraction tools, therefore. It is essential that the correct procedures and tools are used for a particular type of plug or socket.

Rear Release

The appropriate extraction tool should be positioned over the cable connected to the contact to be removed (**Fig. 11-29**).

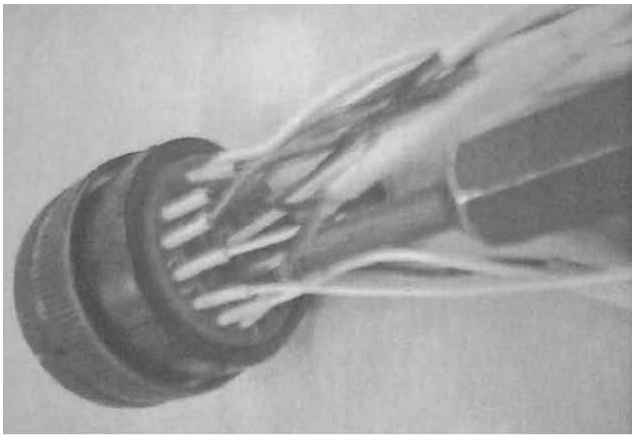


Figure 11-29. Rear-release pin removal