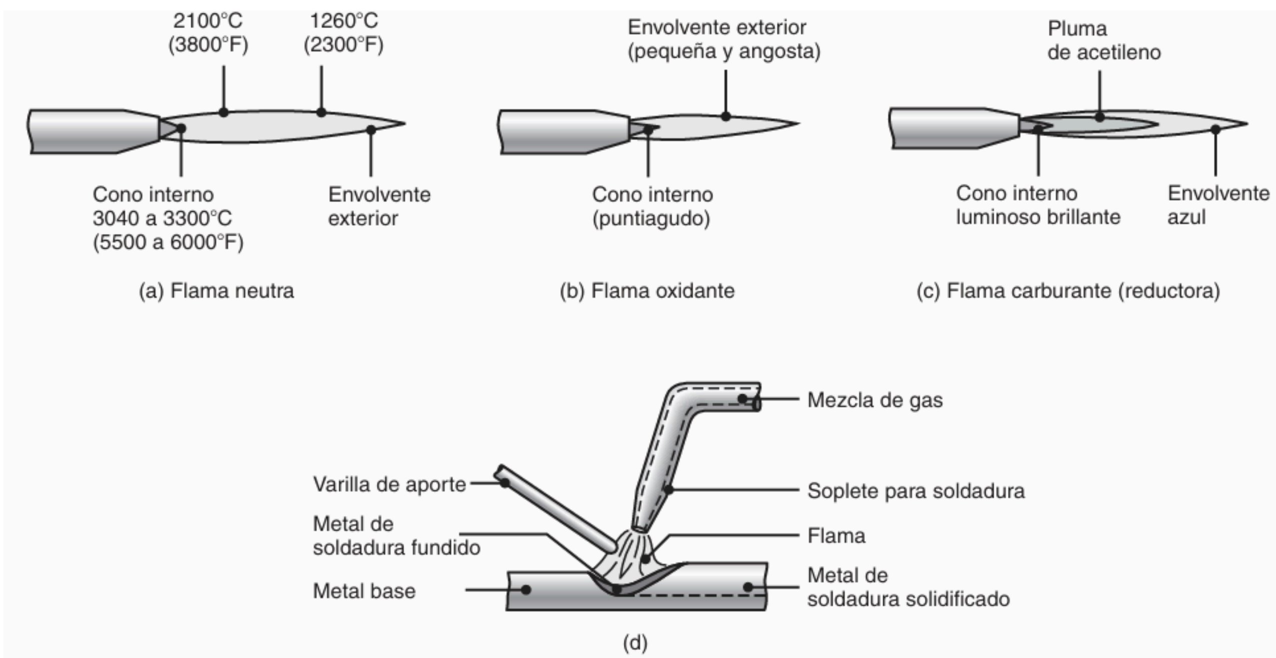
Structure of composites(metals) and assembly of spacecraft and propulsion systems

“Intro: We're going to fit the pieces and metals together to build a spacecraft, taking into account compounds like carbon and the conditions of a supposed black hole whose gravity isn't lethal, so that in the future we can take advantage of the conditions of gravity and its anomalies and understand how to manipulate these conditions in space systems and nuclear plasma propulsion. Cool, huh?”

Material properties The selection of an appropriate material for an application requires knowledge of the advantage to be gained from each property of the material and where each limitation must be recognized. Selection criteria can encompass the following:

1. • specific strength, • specific stiffness, • stress corrosion resistance, • fracture and fatigue resistance, • thermal expansion coefficient and conductivity, • ease of manufacture.



Oxygen-fuel welding (OFW) is a general term used to describe any welding process that uses a fuel gas combined with oxygen to produce a flame. This is the heat source used to melt the metals in the joint. The most common gas welding process uses acetylene; this process is known as oxyacetylene welding (OAW) and is commonly used in structural sheet metal fabrication, automotive bodywork, and various repair work. The OAW process was developed in the early 20th century and uses the heat generated by the combustion of gaseous acetylene (C2H2) mixed with oxygen. The heat is generated through a pair of chemical reactions. The primary combustion process, which takes place in the inner cone of the flame

This process of assembly involves the following reaction:
This reaction dissociates acetylene, forming carbon monoxide and hydrogen, producing almost one-third of the heat generated in the flame. The secondary combustion process is: This reaction consists of the subsequent burning of hydrogen and carbon monoxide, which produces almost two-thirds of the total heat. Note that the reaction also produces water vapor. The temperatures developed in the flame can reach 3300 °C (6000 °F).

2CO+H2+1.5O2¡2CO2+H2O+heat
C2H2+O2¡2CO+H2+heat

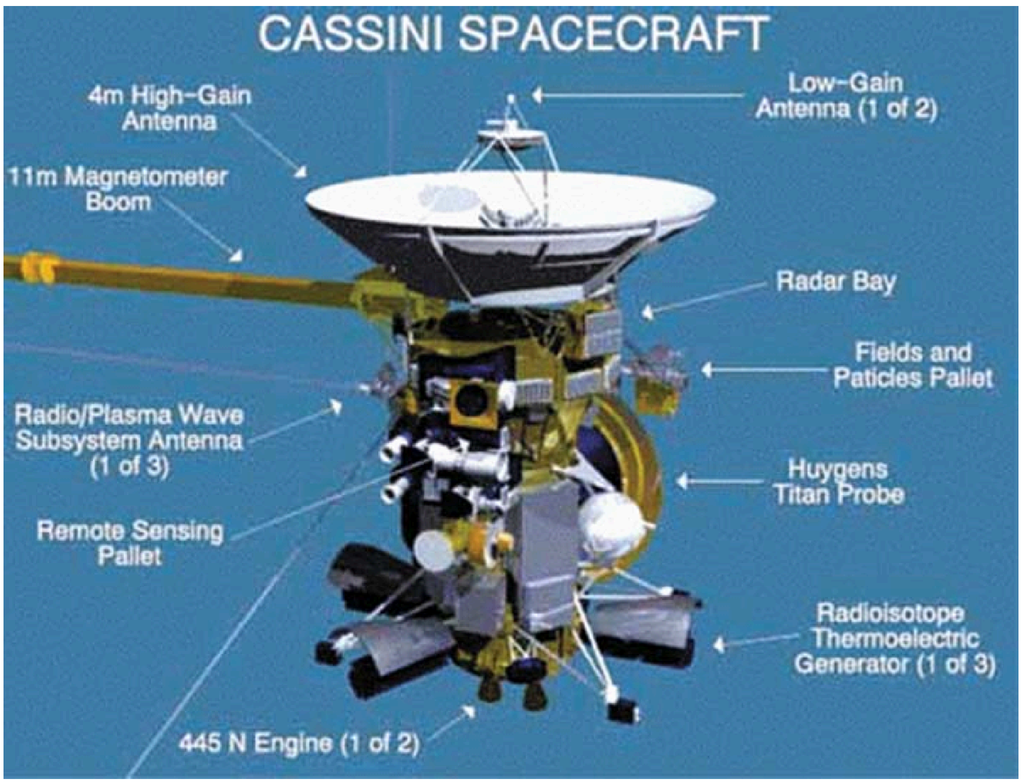
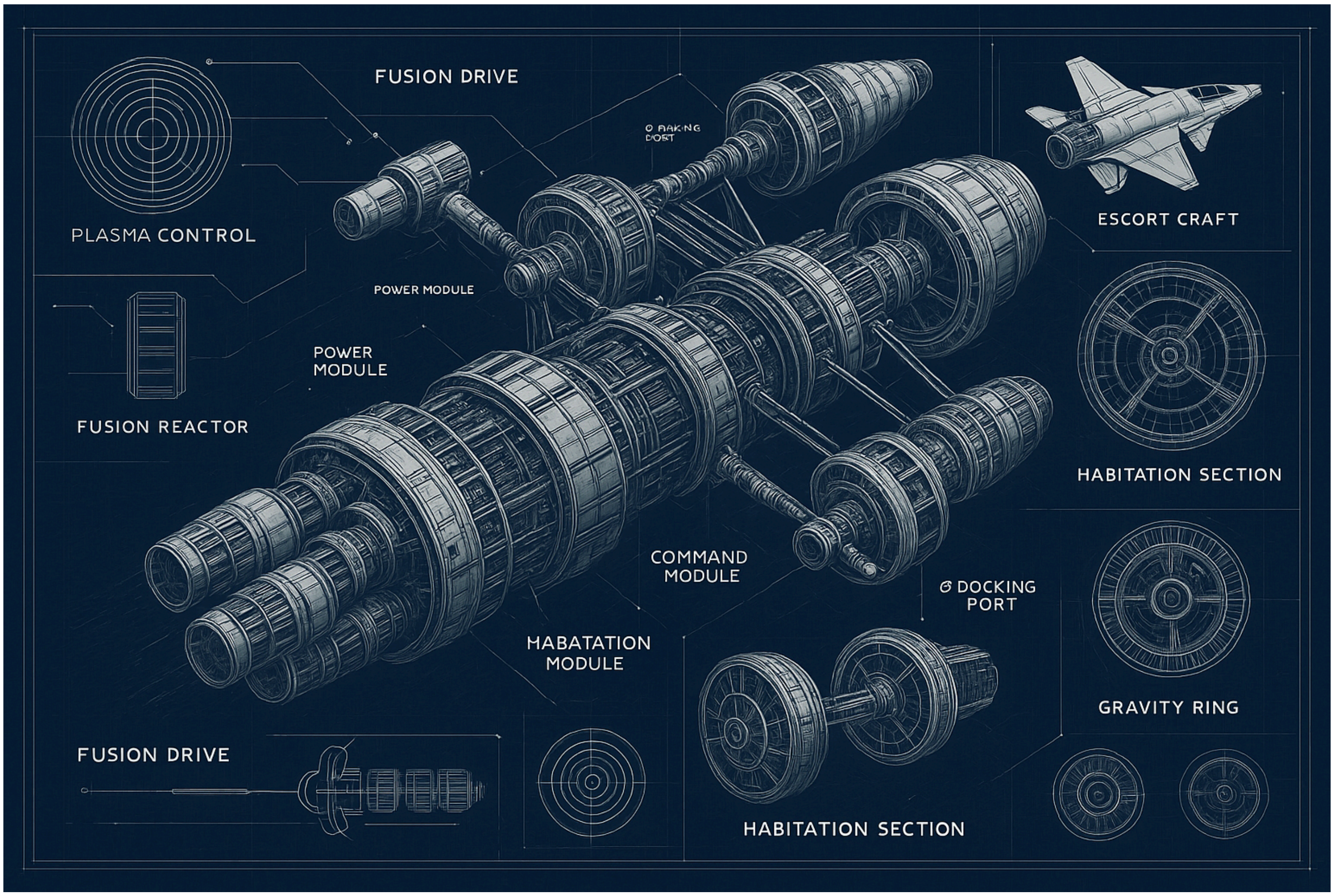
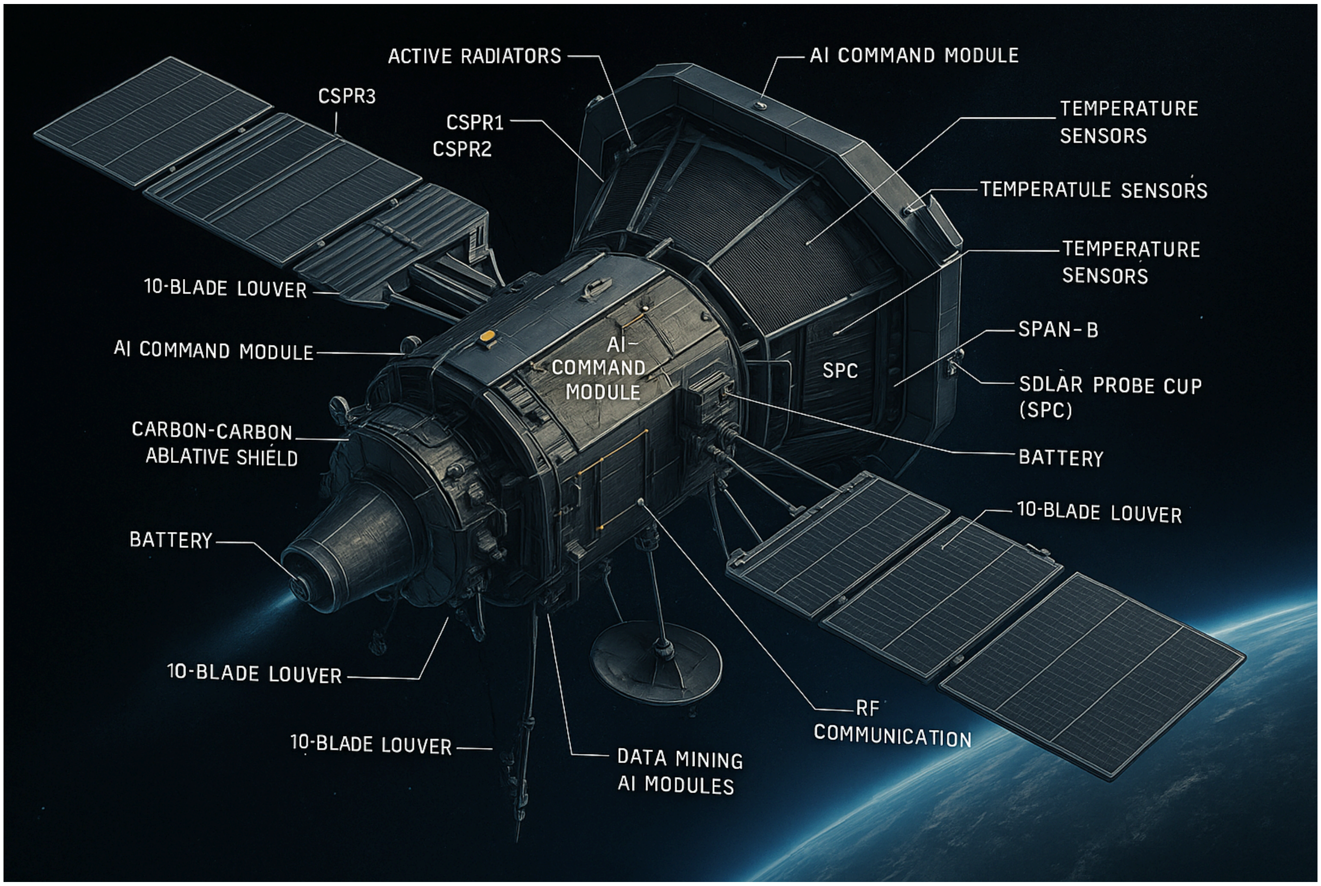


Figure 2. Cassini Spacecraft in Cruise Configuration.

Stress corrosion resistance Stress corrosion cracking (SCC) can develop in a terrestrial environment containing a corrosive medium and moisture when materials are subject to sustained tensile loading, particularly in the short transverse grain direction. Tensile loading conditions can exist even when in storage, due to weight, residual stress or joint assembly preload. The potential effect is a failure occurring at stress levels below values normally considered safe for the material. An ESA design guideline [3] points out that the corrosive environment need not be severe, and failed parts may not show visible evidence of corrosion. Small joints made using this process may consist of a single weld bead; deep V-groove welds are completed in several steps. It is important to clean the surface of each bead before depositing a second layer to ensure joint strength and avoid defects (see section 30.9). Wire brushes, whether manual or electric, can be used for this purpose. Oxygen-fuel gas welding equipment basically consists of a torch connected by hoses to high-pressure gas cylinders equipped with gauges and regulators (Fig. 30.2c). Safety equipment (such as sunglasses, face shields, gloves, and protective clothing) is essential. Correct connection of the hoses to the cylinders is an important safety factor. Oxygen and acetylene cylinders have different threads, so the hoses cannot be connected to the wrong cylinders. The low cost of the equipment is an attractive aspect of oxyfuel gas welding. Although mechanized, this welding operation is essentially manual and therefore slow. However, it has the advantages of being portable, versatile, and economical for simple jobs and small quantities.

Gas-pressure welding. In this method, two-component welding begins by heating the interface with a torch, typically using an oxyacetylene gas mixture (Fig. 30.3a). When the interface begins to melt, the torch is withdrawn, and a force is applied to press the two components together (Fig. 30.3b) and maintained until the interface solidifies.





Flame Types. An important factor in oxyacetylene welding is the ratio of acetylene to oxygen in the gas mixture. At a ratio of 1:1 (i.e., when there is no excess oxygen), a neutral flame is considered to be produced. With a higher oxygen supply, it can be harmful (particularly to steels) because it oxidizes metals. For this reason, a flame with excess oxygen is known as an oxidizing flame and is only desirable for welding copper and its alloys, where a thin protective layer of slag (oxide compounds) forms on the molten metal. If oxygen is insufficient to produce full combustion, the flame is called a reducing flame (with excess acetylene) or a carburizing flame. The temperature of a reducing flame is lower, making it suitable for applications requiring little heat, such as brazing, soldering, and flame-hardening operations.

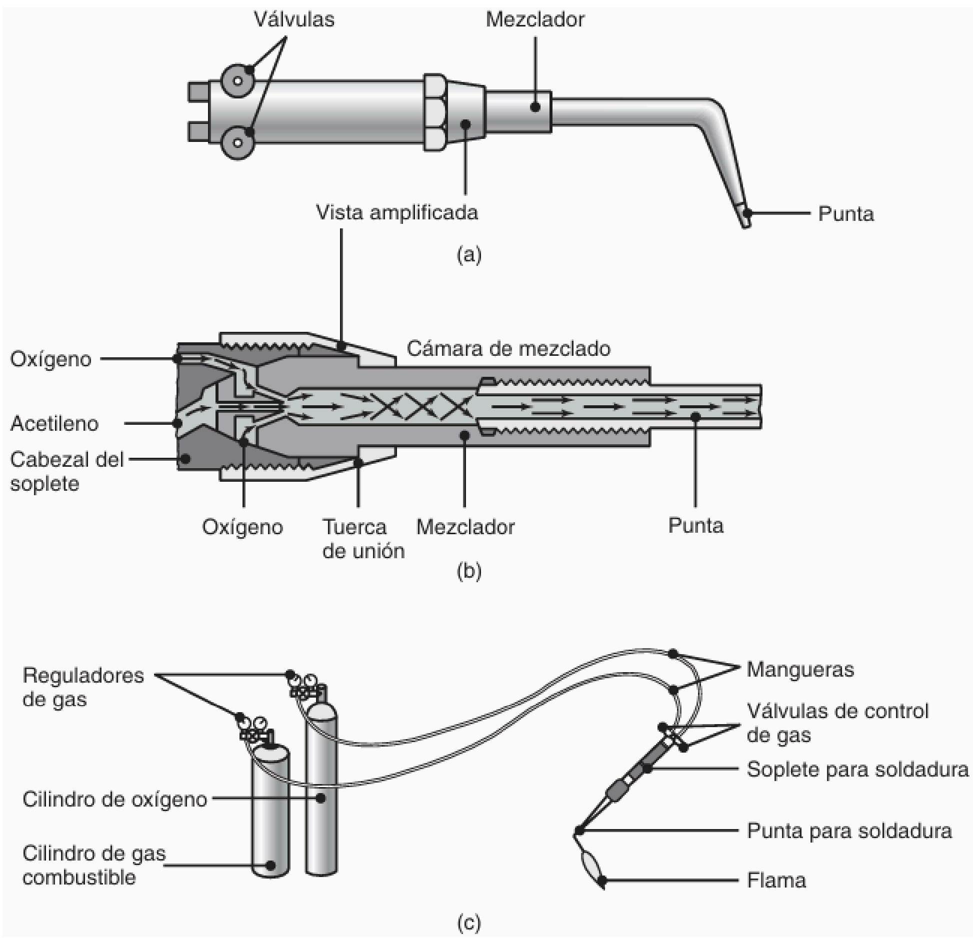
Other gases (such as hydrogen and methylacetylene propadiene) can also be used in oxygen-fuel gas welding. However, the temperatures obtained with them are low, which is why they are used for welding (a) metals with low melting points (such as lead) and (b) thin, small parts. The flame with pure hydrogen is colorless, making it difficult to adjust visually.

Filler metals. Filler metals are used to provide additional material to the welding zone during the operation. They are available as filler rods or wire (Fig. 30.1d) and may be bare or flux-coated. The purpose of flux is to retard oxidation of the surfaces of the parts being welded, generating a gaseous shield around the weld zone. The flux also helps dissolve and remove oxides and other substances from the weld zone, thus contributing to the formation of a stronger joint. The slag that forms (composites of oxides, fluxes, and coated electrode materials) protects the molten metal mixture from oxidation as it cools.

Welding Practice and Equipment. Oxygen-fuel gas welding can be used on most ferrous and nonferrous materials, for almost any workpiece thickness, but the relatively low heat output limits this process to thicknesses less than 6 mm (0.25 in). The basic steps can be summarized as follows:

1. Prepare the ends to be joined, secure them, and hold them in their proper position using vises and stands.
2. Open the acetylene valve and ignite the gas at the torch tip. Open the oxygen valve and adjust the flame for the particular operation (Fig. 30.2).

3. Hold the torch at about 45° to the plane of the workpiece, with the inner flame close to it and the filler rod at about 30° to 40°. 4. Touch the joint with the filler rod and monitor its movement along the joint by observing its melting and filling rates.



(a) Gas tungsten arc welding process, formerly known as TIG (tungsten inert gas) welding. (b) Equipment for gas tungsten arc welding operations.

External gas shielding is required to prevent oxidation of the weld zone. Direct current (DC) is commonly used, and its polarity (i.e., the direction of current flow) is important. Its selection depends on factors such as the type of electrode, the metals being welded, and the depth and width of the weld zone.
In direct polarity, also called direct current electrode negative (DCEN), the workpiece is positive (anode) and the electrode negative (cathode). It typically produces narrow, deep welds (Fig. 30.5a). In reverse polarity, also known as direct current electrode positive (DC),

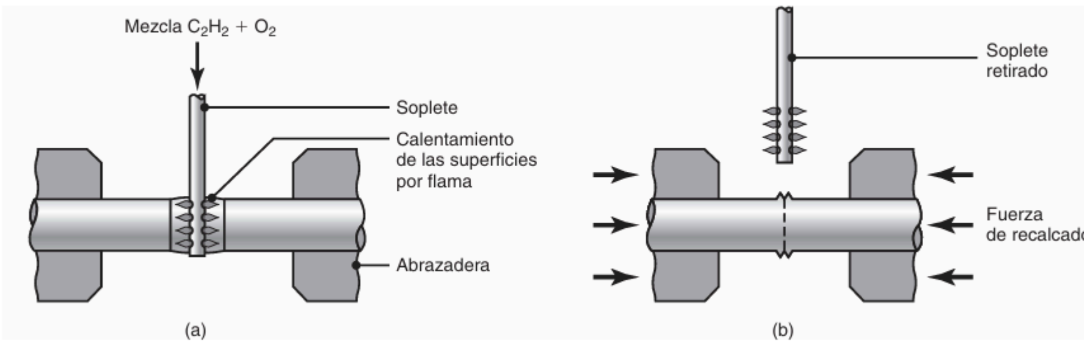
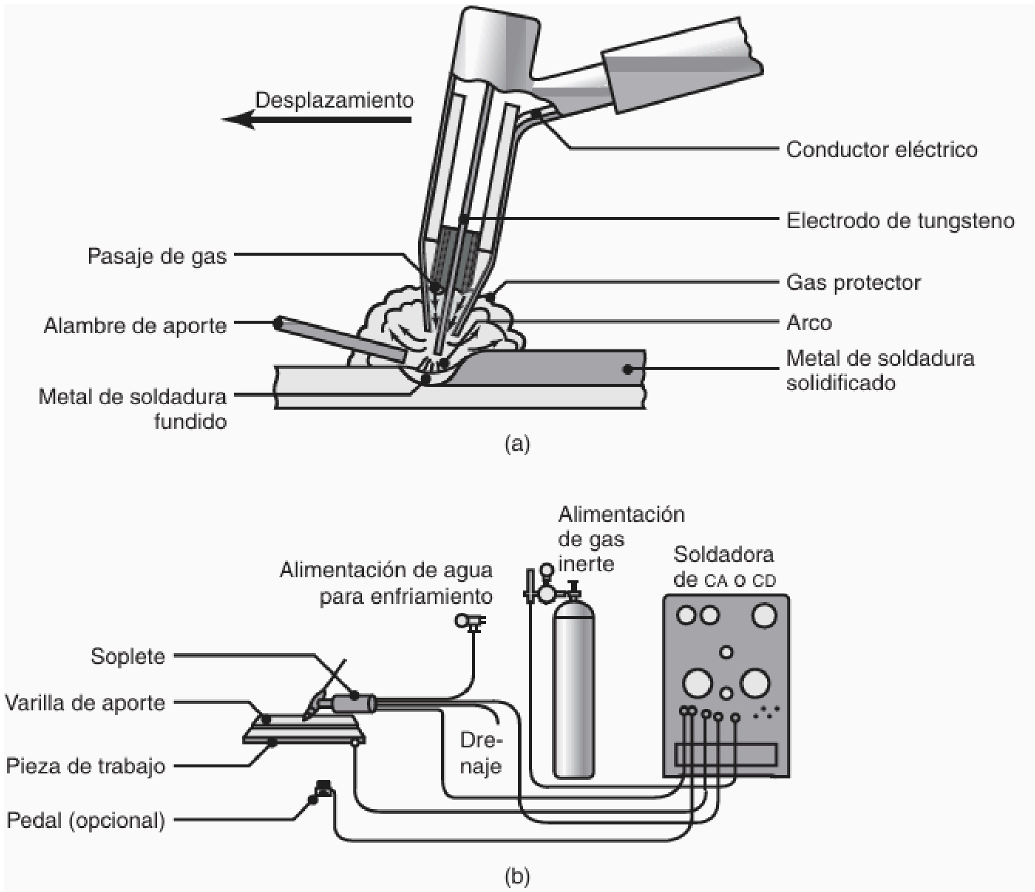


FIGURA 30.3 Esquema del proceso de soldadura por gas de presión: *(a)* antes, y *(b)* después. Obsérvese la formación de la proyección en la unión, que se recorta después.



METALS

MATERIAL SELECTION

Sample Materials Properties

Caution: There is considerable variation in material properties according to conditions (ageing, temper, form, and structure orientation). Consult manufacturers' data.

Material Type	Density (kg/m³)	Young's Modulus E (GPa)	Yield Strength f (MPa)
Aluminium Alloy			
6061-T6	2700	68	276
7075-T6	2800	71	503

Magnesium Alloy			
A231B	1700	45	220
ZK60A-T5 Extrn	1700	45	234
Titanium Alloys			
Ti-6Al-4V	4400	110	825
(Solution Treated & Aged)	1035	42	690
Beryllium Alloys			
S65A	2000	304	207
Hot Pressed Sheet			
Low Fracture Toughness SR200E	345		
Ferrous Alloys			
INVAR	150	275/415	1.66
Stainless Steel			
AM350 (SCT850)	7700	200	1034
304L Annealed	7800	193	170
Composites			
KEVLAR 490°	1380	76	1379
(Aramid Fiber)	1380	5.5	29.6
Graphite Epoxy Sheets	1620	282	586

Other material properties such as **thermal expansion, fracture toughness, fatigue strength**,
and **selection criteria** depend on environmental and operational conditions.

Consult detailed reference sources for **application-specific variations**.

Electronics:

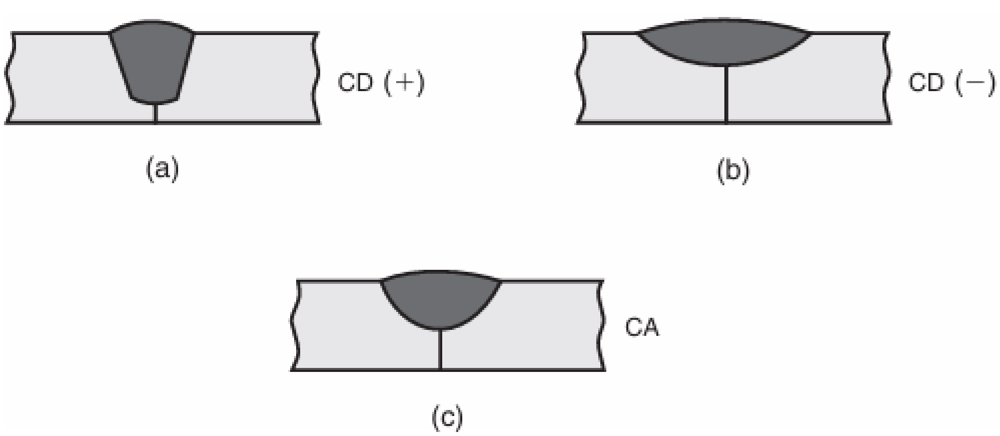
TABLE II
Contents of Orbiter Electronics Bays

Bay #	Assemblies Within Bay
Bay 1	Attitude control computers, sun sensor electronics

Bay 2	Power distribution
Bay 3	Power subsystem remote engineering units, Power control, shunt regulator, pyro
Bay 4	Science calibration, magnetometer, and radio & Plasma wave electronics
Bay 5	Radio system amplifiers
Bay 6	Transponders, command detectors, ultra-stable Oscillator electronics, telemetry control units
Bay 7	Radio frequency instrument electronics
Bay 8	Command and data subsystem electronics
Bay 9	Solid state recorders, backdoor ALF injection Loader
Bay 10	Reaction wheel electronics
Bay 11	Remote sensing pallet, remote engineering units, Radar electronics
Bay 12	Imaging science electronics, accelerometer Penthouse additional radar electronics

Precautions In Design And Material Selection Include:

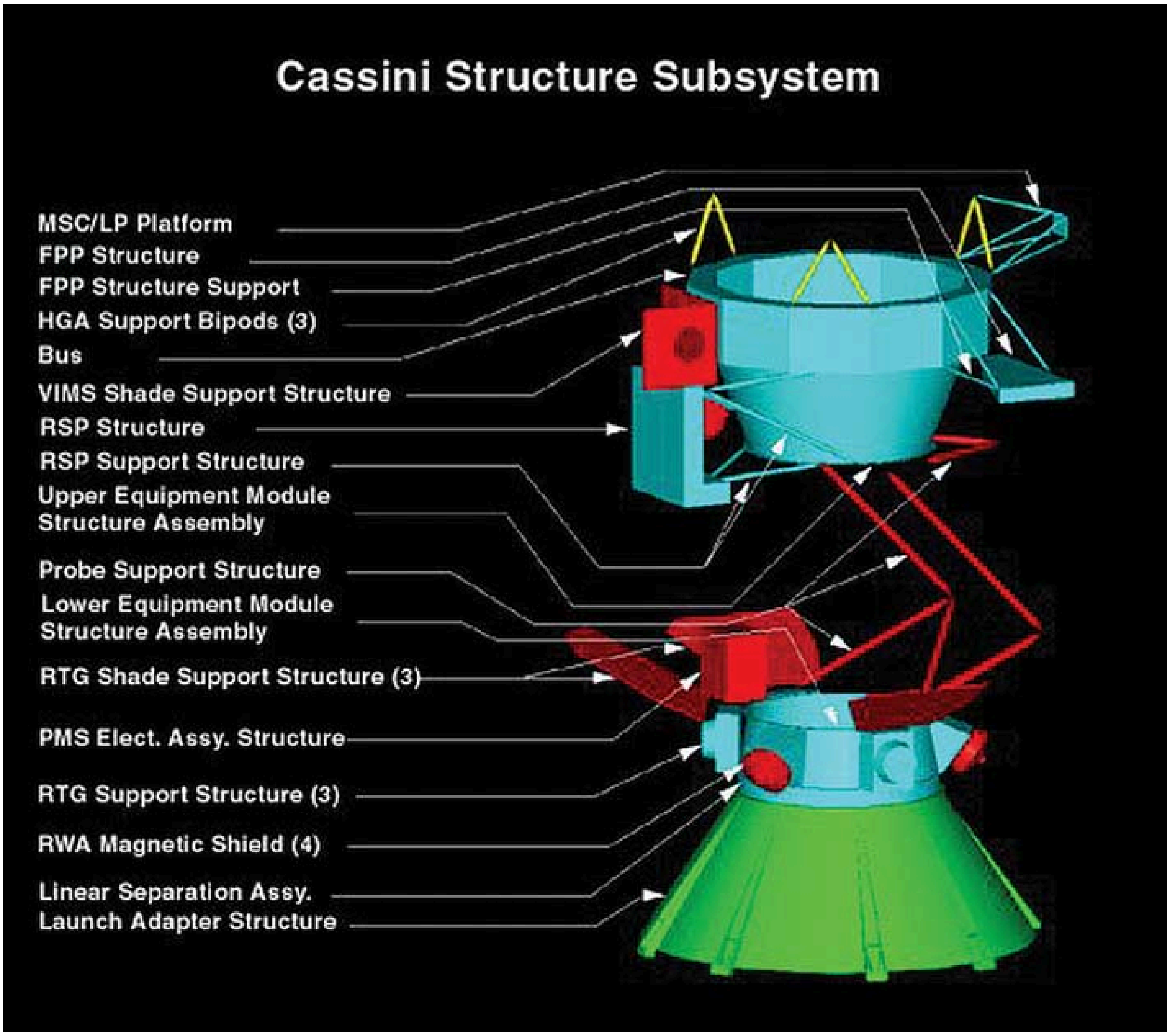
- choosing alloys lesssusceptibletoSCC,
- minimizing sustained tensile stress, particularly in the short transverse grain direction,
- specifyingtheneedforcloseinspectionofareasofstressconcentrationandwelds,
- heat-treatingcomponentstoremoveresidualstressesduetomanufacturingprocesses,
- avoiding material combinations,which promote galvanic corrosion,
- avoiding exposure to atmospheric conditions,which can induce corrosion.

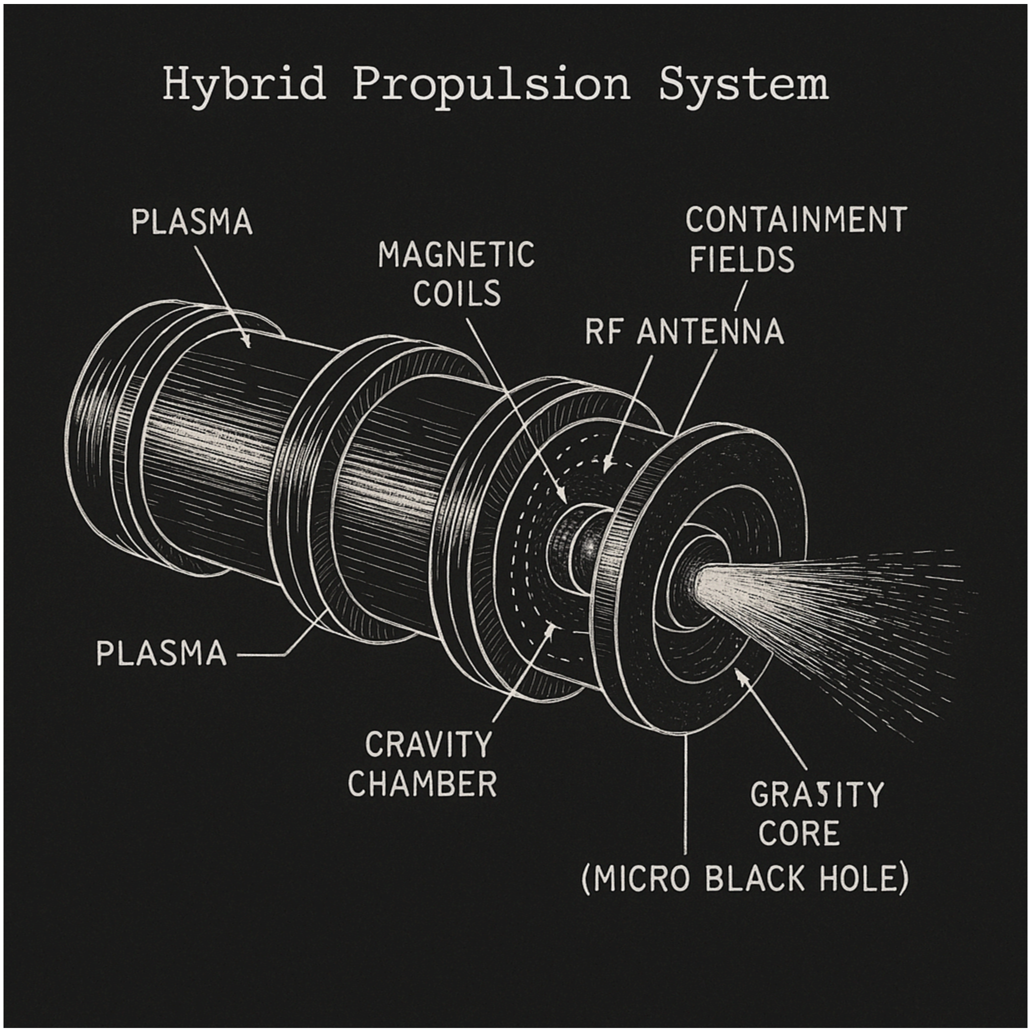


The electronics bus is constructed of aluminum. The top of the electronics bus is covered by an electrically conductive cap to create a Faraday cage. The magnetometer boom (see Figure 2) is mounted to the top of the electronics bus. It is the same design used on the Galileo spacecraft. After the last Earth

flyby it was deployed from a canister to its full length of 10.5 m. The boom is constructed of 3 fiberglass longerons and supporting cross members and has a triangular cross section. The boom is home to inboard and outboard magnetometer sensors. The inboard sensor is located about half way out the boom. The upper shell structure (USS) connects the bottom of the electronics bus to the propulsion module. It is a conic section of aluminum to which the following assemblies are mounted: remote sensing pallet, the CDA instrument, an articulated reaction wheel assembly, the RPWS antenna assembly, the MIMI INCA and electronics, the ultra stable oscillator, and the probe support electronics.Gas tungsten arc welding. In gas tungsten arc welding (GTAW), formerly known as TIG (tungsten inert gas) welding, the filler metal is supplied by a filler wire (Fig. 30.4a). Because the tungsten electrode is not consumed in this operation, a constant and stable arc gap is maintained at a constant current level. The filler metals are similar to those being welded, and no flux is used. The shielding gas is usually argon or helium, or a mixture of the two. GTAW welding can be performed without filler metals, for example, in the welding of precision-fit joints. Depending on the metals being welded, the power source can be DC at 200 A or AC at 500 A (Fig. 30.4b). Alternating current is generally preferred for aluminum and magnesium because it has a cleaning action that removes oxides and improves weld quality. Thorium or zirconium can be used in tungsten electrodes to improve their electron emission characteristics. The required power ranges from 8 to 20 kW. Contamination of the tungsten electrode with molten metal can be a significant problem, especially in critical applications, where it can cause discontinuities in the weld. Therefore, contact of the electrode with the molten metal mixture should be avoided. The GTAW process is used for a wide variety of metals and applications, particularly aluminum, magnesium, titanium, and refractory metals. It is especially suitable for thin metals. The cost of inert gas makes this process more expensive than shielded metal arc welding (SMAW), but it produces very high-quality welds and surface finishes. It is used in several critical applications, in a wide range of workpiece thicknesses and shapes. The equipment is portable. Plasma arc welding. In plasma arc welding (PAW), developed in the 1960s, a concentrated arc of plasma is produced and directed toward the weld area. The arc is stable and reaches temperatures of up to 33,000°C (60,000°F). A plasma is a hot, ionized gas made up of nearly equal amounts of electrons and positive ions. The plasma is initiated between the tungsten electrode and the orifice by a low-current pilot arc. Unlike other processes, the plasma arc is concentrated because it passes through a relatively small orifice. Operating currents are typically less than 100 A, but can be higher in special applications. When a filler metal is used, the arc is fed, as is done in GTAW. The arc and the welding area are protected by an external protective ring, and gases such as argon, helium, or mixtures of these are used.
There are two methods for plasma arc welding:

• In the transferred arc method (Fig. 30.6a), the workpiece is part of an electrical circuit. The arc is transferred from the electrode to the workpiece; hence the term "transferred."


Cassini Structure Subsystem
MSC/LP Platform
FPP Structure
FPP Structure Support
HGA Support Bipods (3)
Bus
VIMS Shade Support Structure
RSP Structure
RSP Support Structure
Upper Equipment Module
Structure Assembly
Probe Support Structure
Lower Equipment Module
Structure Assembly
RTG Shade Support Structure (3)
PMS Elect. Assy. Structure
RTG Support Structure (3)
RWA Magnetic Shield (4)
Linear Separation Assy.
Launch Adapter Structure



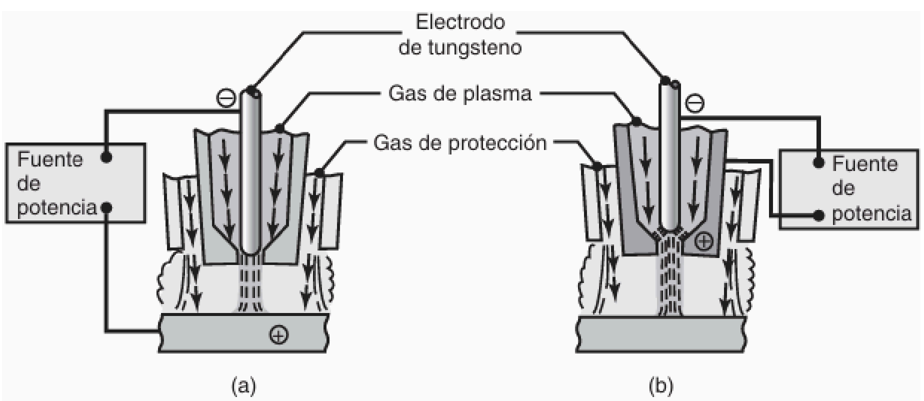
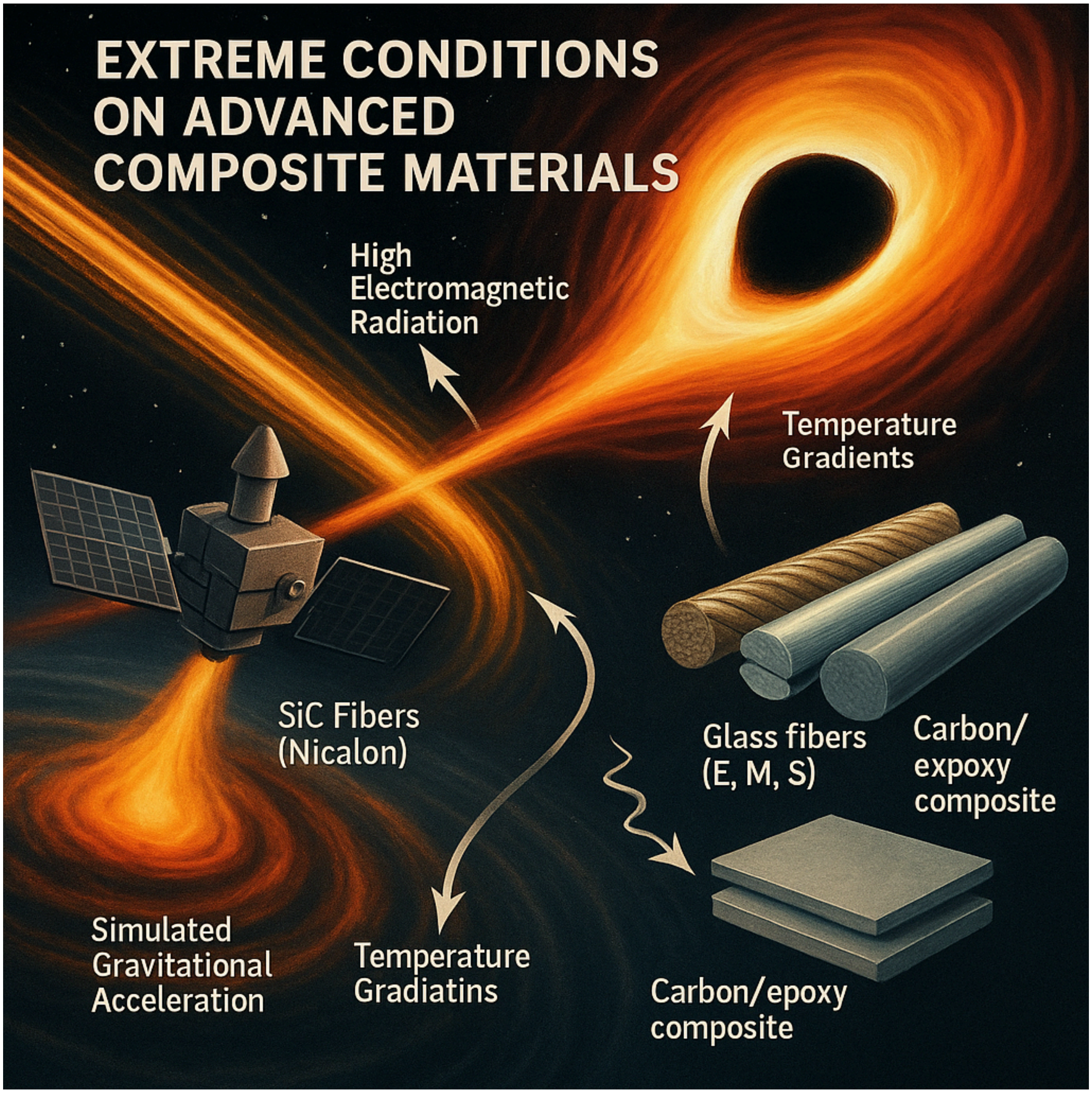


FIGURA 30.6 Dos tipos de procesos de soldadura por arco de plasma: *(a)* transferido, y *(b)* no transferido. Por medio de este proceso se pueden efectuar soldaduras profundas y estrechas a altas velocidades de soldado.



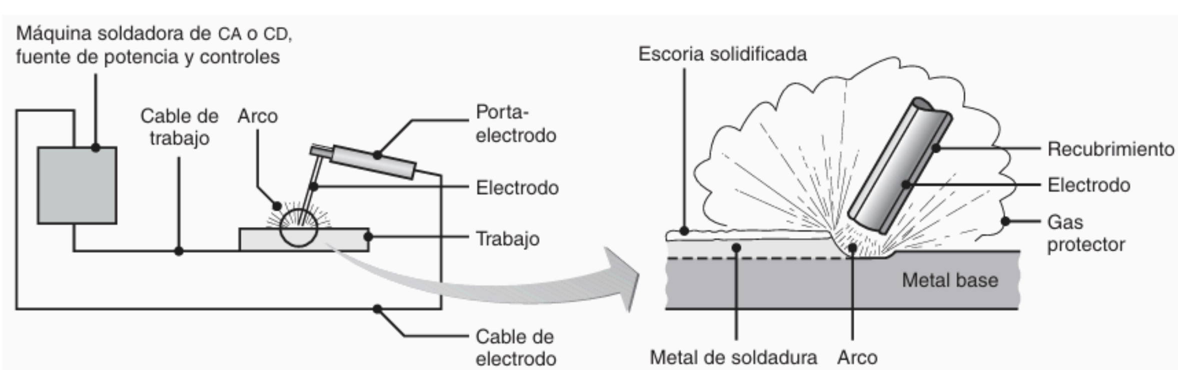
Sublimation/erosion Normally the sublimation of metals does not pose any major problems in the space environment, although for thin films the rate at which their thickness decreases may be significant.Erosion Yatomicoxygen, particularly in respect of polymeric materials in LEO, can be an important factor in material selection [4, 5]. This is a subject of investigation and research, in view of the possible long-term problems which could ensue in the25-year life of a space station, for example.

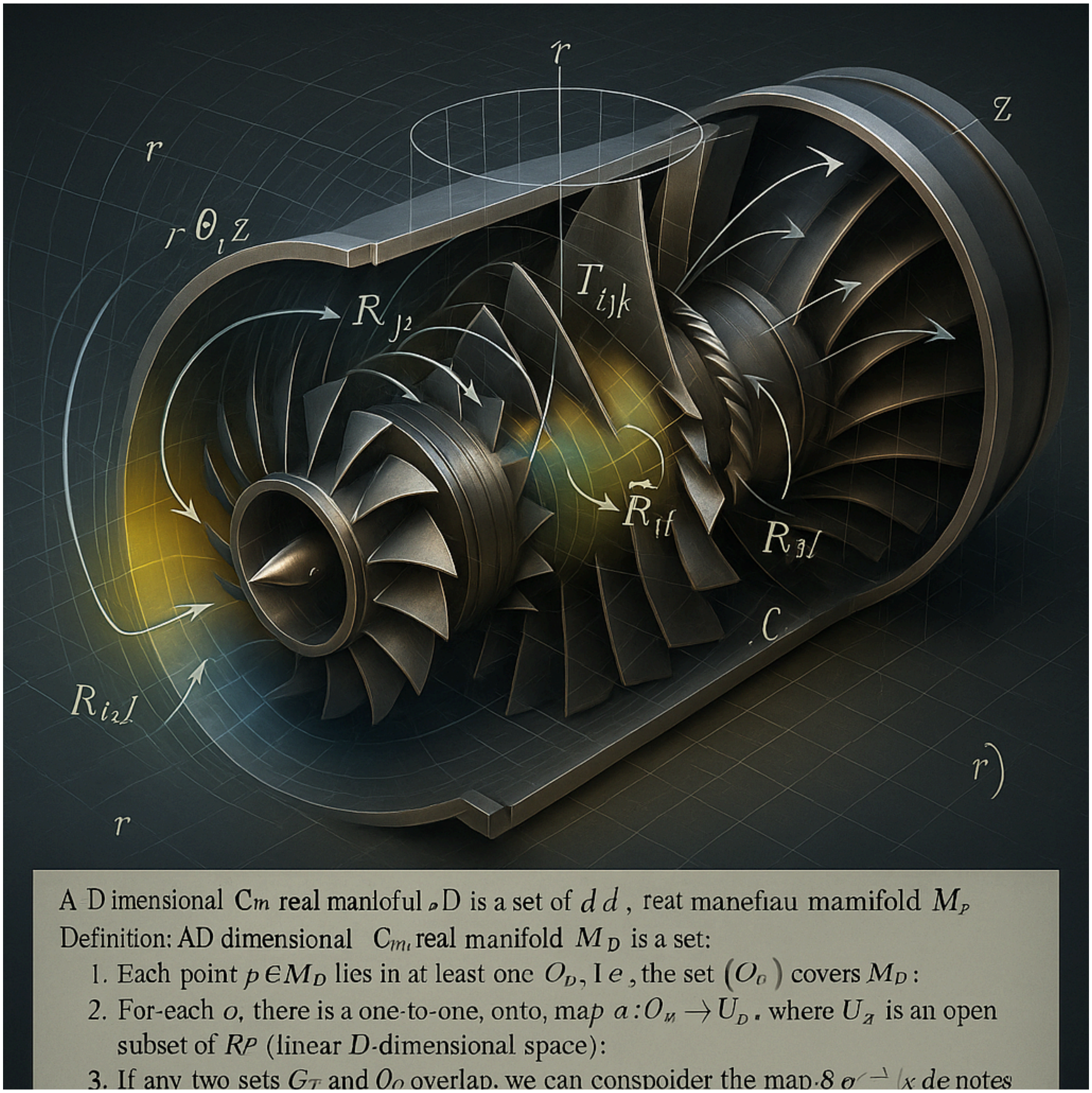
Atomic hydrogen welding. In atomic hydrogen welding (AHW), an arc is generated between two tungsten electrodes in a protective atmosphere of hydrogen. The arc remains independent of the workpiece or parts being welded. Normally, hydrogen gas is diatomic (H2), but when temperatures exceed 6000°C (11,000°F) near the arc, it decomposes into its atomic form, simultaneously absorbing a large amount of heat from the arc. When the hydrogen strikes a relatively cool surface (i.e., the welding zone), it recombines back into its diatomic form and rapidly releases the stored heat. In AHW, the energy can be easily varied by changing the distance between the arc current and the workpiece surface. This process has been replaced by shielded metal arc welding, primarily due to the availability of inexpensive inert gases. Shielded Metal Arc Welding

Shielded metal arc welding (SMAW) is one of the oldest, simplest, and most versatile joining processes. Today, approximately 50% of all welding in industry and maintenance is performed using this process. The electric arc is generated by touching the workpiece with the tip of a coated electrode and quickly withdrawing it far enough to maintain the arc (Fig. 30.7a). The electrodes are shaped like a long, thin rod (hence the process also called stick welding) that is held in the hand. The heat generated melts a portion of the electrode tip, its coating, and the base metal in the immediate arc zone. The molten metal consists of a mixture of the base metal (of the workpiece), the electrode metal, and the electrode coating substances; this mixture forms the weld when solidified. The electrode coating deoxidizes the weld area and creates a gas shield that protects it from ambient oxygen.
A bare electrode end is attached to one terminal of the power source, while the other terminal is connected to the work being welded (Fig. 30.7b). The current, which can be direct or alternating current, is typically 50 to 300 A.
DC is preferred for welding sheet metal because the arc it produces is stable.
Generally, power requirements are less than 10 kW.

The SMAW process has the advantage of being relatively simple and versatile, and requiring a smaller variety of electrodes. The equipment consists of a power source, power cables, and an electrode holder.

The SMAW process is often used in general construction, shipyards, pipelines, and maintenance work. It is very useful in remote areas, where an internal combustion engine generator can be used as a power source. This process is best suited for workpieces 3 to 19 mm (0.12 to 0.75 in) thick, although this range can be easily extended if operators are skilled and employ multiple-pass techniques (Fig. 30.8).
With the multiple-pass method, slag must be cleaned after each weld bead; if not completely removed, the solidified slag can cause severe corrosion in the weld area and lead to weld failure. It also prevents the weld layers from fusing together and thus compromises their strength. Before applying a new weld, the slag must be completely removed, either by wire brushing or chiseling. Consequently, both labor and material costs are high.

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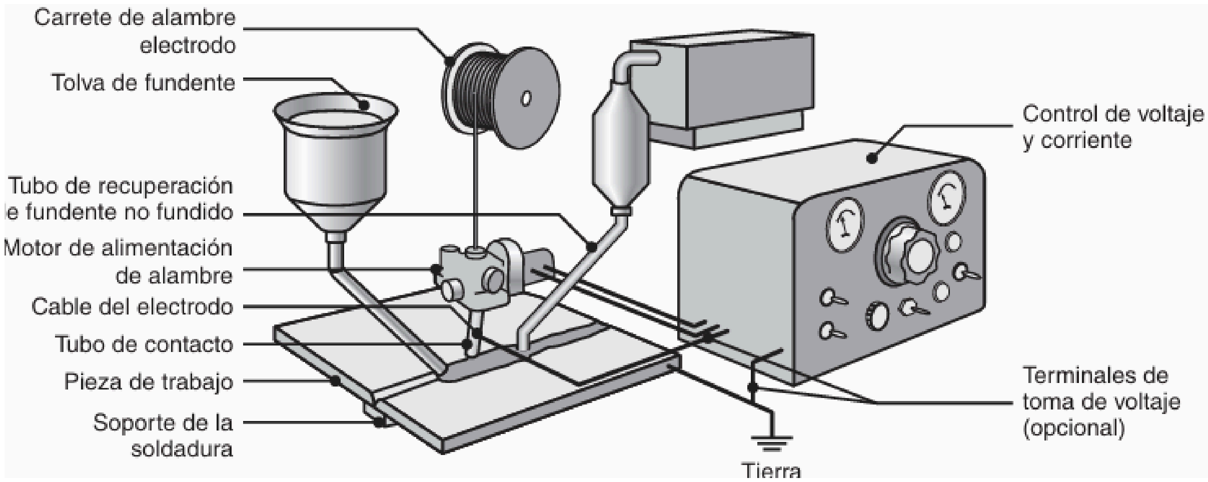
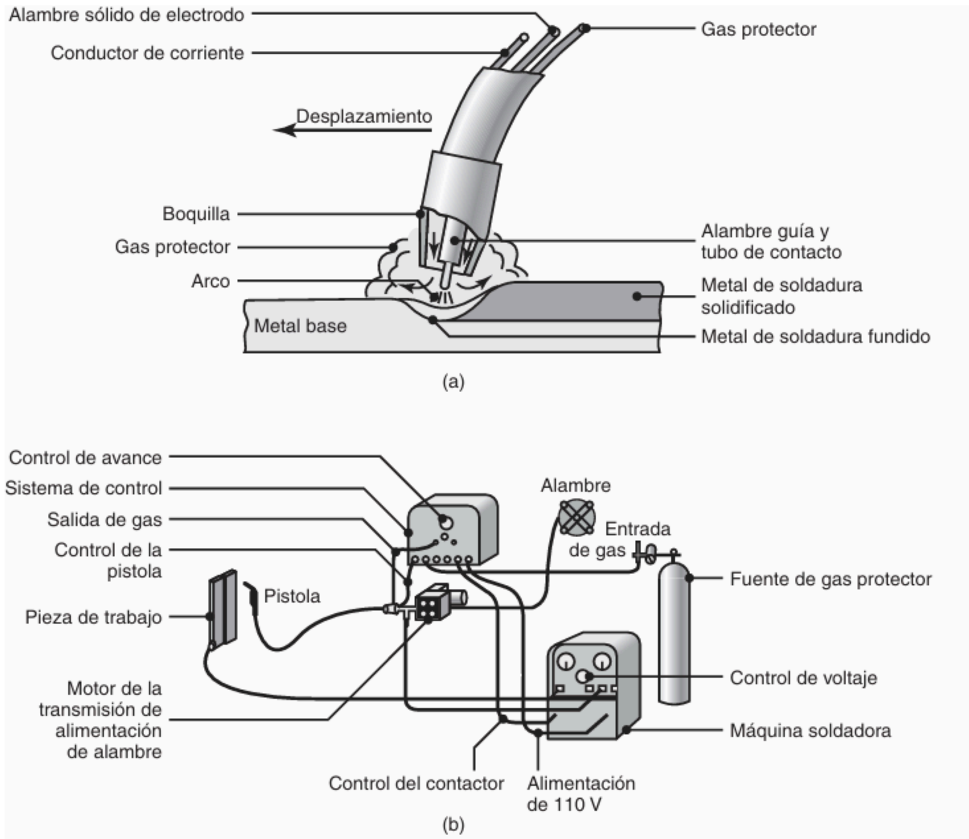
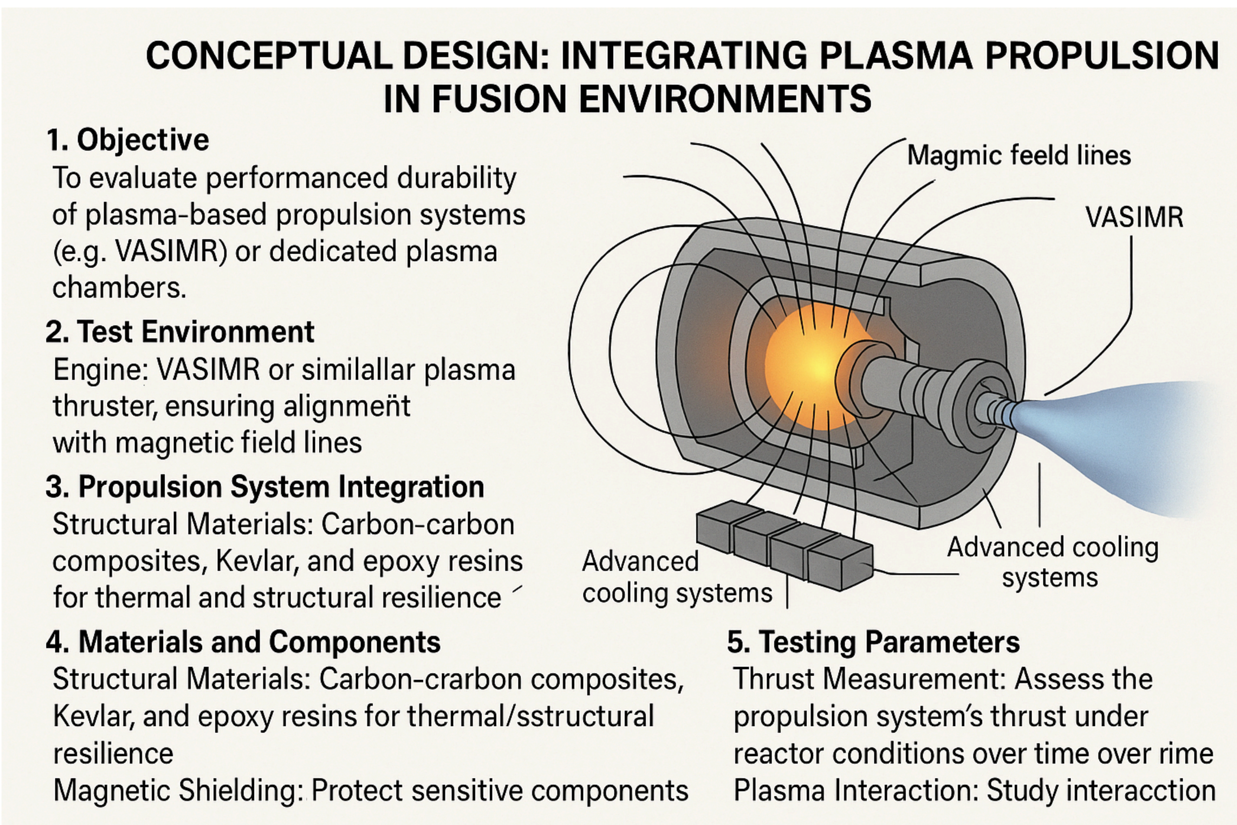
A D imensional Cm real manloful D is a set of d d , reat manefiau mamifold M
Definition: AD dimensional Cm real manifold M D is a set:
1. Each point p ∈M D lies in at least one O D, I e , the set (O) covers M D :
2. For-each o, there is a one-to-one, onto, map a : O → U D . where U is an open
subset of R (linear D-dimensional space):
3. If any two sets G and O overlap, we can conspoider the map

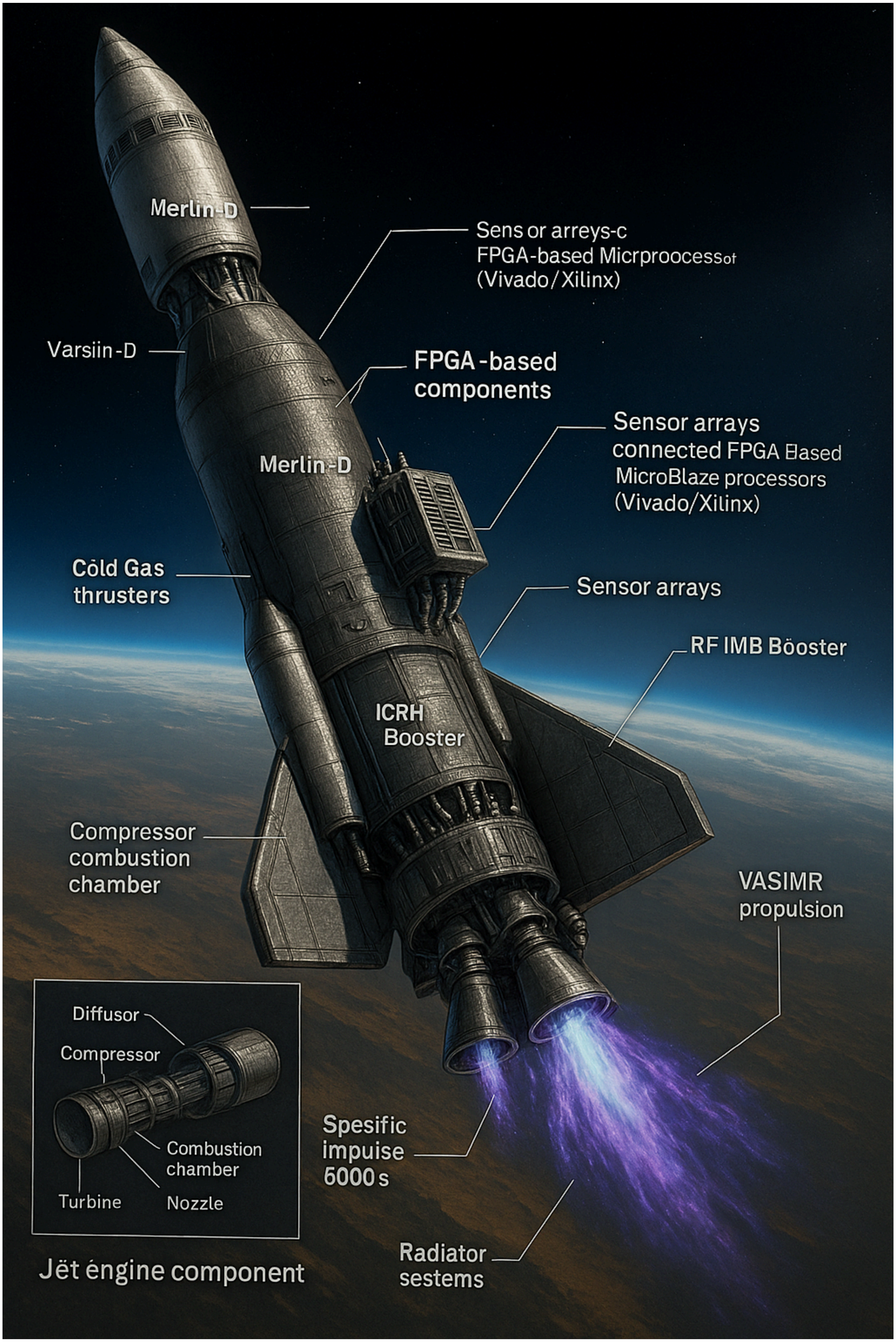


The consumable electrode is a roll of bare round wire measuring 1.5 mm to 10 mm in diameter; it is fed automatically through a tube (welding gun). Typically, electrical currents range from 300 to 2000 A. Power sources are connected to standard single-phase or three-phase lines with voltages up to 440 V. Because the flux is fed by gravity, the SAW process is limited primarily to welding in a flat or horizontal position with a backing piece. Circular welds can be made on tubes and cylinders, provided they are rotated during the process. As shown in Figure 30.9, unused flux can be recovered, treated, and reused. This automated process is used to weld various carbon and alloy steels, as well as stainless steels, in sheets or plates, at speeds up to 5 m/min (16 ft/min). The weld quality is very high, with good toughness, ductility, and uniform properties. The SAW process allows for very high welding productivity because it deposits four to 10 times the amount of filler metal per hour compared to the SMAW process. Typical applications include the welding of thick plates for ships and pressure vessels. Advanced materials The aerospace industry has driven the development of numerous advanced materials in the search for more mass efficient structures. In most cases cost is a significant factor since, particularly in the space sector, designs are very low volume/high quality applications. Many materials developments now fail to reach maturity simply on the grounds of economics. There are exceptions where the need for a technical solution is paramount. A good example is high stability ceramic optical bench material. A wide range of materials with developed characteristics is discussed in useful detail with a commentary on fabrication, jointing and applications in [6, 7]. These materials can generally be grouped as follows: • Polymer composites Continuous fibre reinforcements: Carbon Aramid Glass Matrix: Epoxy Polyimide Bismaleimide Thermoplastic: Carbon in polyether ether ketone (PEEK) Aramide-based (PEI) • Advanced metal matrix and ceramic materials Magnesium alloys and their composites Aluminium alloys and their composites Titanium alloys and their composites Super alloys and their composites Intermetallic materials Refractory materials Beryllium Ceramic matrix composites Glass and glass-ceramic matrix composites Carbon-carbon matrix composites



Metals Ferrous alloys have numerous applications in which their properties of high strength, corrosion resistance and toughness are required. Austenitic stainless steels are used for propulsion and cryogenic systems due to their excellent low temperature toughness. Other alloys are used in optical and precision structures where properties can be selected to match expansion criteria in a dynamic thermal environment. Susceptibility to hydrogen embrittlement is a potential hazard for ferrous alloys, particularly where they have been treated in plating solutions. The result is similar to SCC. The corrective treatment is a severe bake-out within a limited time period—observing of course that the materials are not affected. Some types of stainless steel and invar are magnetic. This can be a problem when a spacecraft carries electromagnetic sensors. Fibre reinforced composites Advantage can be taken of the high strength offered along the fibre. In a single ply of unidirectional fibres, the ply strength and stiffness in the fibre direction is about 60% of the fibre strength and stiffness due to the presence of the relatively low strength and stiffness resin. In the other two orthogonal directions, strength and stiffness is limited to the properties of the matrix resin. A multi-ply laminate can be built by adding unidirectional plies aligned at an angle to the first. A laminate can be created with structural properties tailored to the application. The high unidirectional strength and stiffness, such as is quoted in Table 8.1 will be reduced in any one direction by approximately the ratio of the number of plies in that direction to the number of plies in the complete laminate. Methods for the analysis of individual ply stresses, and failure prediction of a laminate have been developed [9, 10]. Computer programs are commercially available from agencies such as ESA, which enable much quicker analysis, particularly where optimization is required. Carbon epoxy materials are used quite extensively in fabrication by hand lay up of unidirectional or woven plies to produce flat or curved panels often of honeycomb sandwich construction. Large deployable antenna reflectors use the combination of high stiffness, lightweight and low coefficient of expansion (to hold shape under temperature extremes) to particular advantage. Composite materials (metal matrix) The limiting factors of an epoxy matrix can be substantially overcome by employing high strength fibres in a diffusion bonded metal matrix. Although this technology may represent the ultimate direction for ‘designed’ materials, current costs are high and care is required with non-destructive testing (NDT). Some materials suffer from low yield strength or elongation to failure, which is an indication of brittleness, notch sensitivity and poor fatigue strength. However, applications are emerging, one particular example being lightweight mirrors and optical benches [11]. In general, a clear rule to be borne in mind is to choose materials (or their close equivalents) that appear in the ESA handbooks [6, 7] or American standards [12, 13]. This gives all of the design and approval data necessary, and the confidence that no non-compliances will be discovered later in a programme when any required material qualification testing is completed. When this is not possible, national defence specifications should be used for guidance. In all cases, material tractability, including treatment history from billet/raw material to finished product, is one of the quality assurance records to be maintained. 8.3.3 Section properties Hollow or reduced section members such as tubes and ‘I’ beams give much better mass efficiency than solid bars. Panel deformations such as corrugations can give greatly increased stiffness and resistance to buckling compared with flat sections. It is the art of the design engineer to use materials most efficiently in this way when considering all of the duties required of a section.




Merlin-D
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Cold Gas
thrusters
Sensor arrays
RF IMB Booster
ICRH
Booster
Compressor
combustion
chamber
VASIMR
propulsion
Diffusor
Compressor
Combustion
chamber
Turbine
Nozzle
Spesific
impulse
6000 s
Jet engine component
Radiator
sestems

Metal Forging for Carbon and Alloy Construction

2. In globular transfer welding, gases rich in carbon dioxide are used, and the molten metal globules are propelled by the **electrical arc transfer forces**, which cause significant splatter.

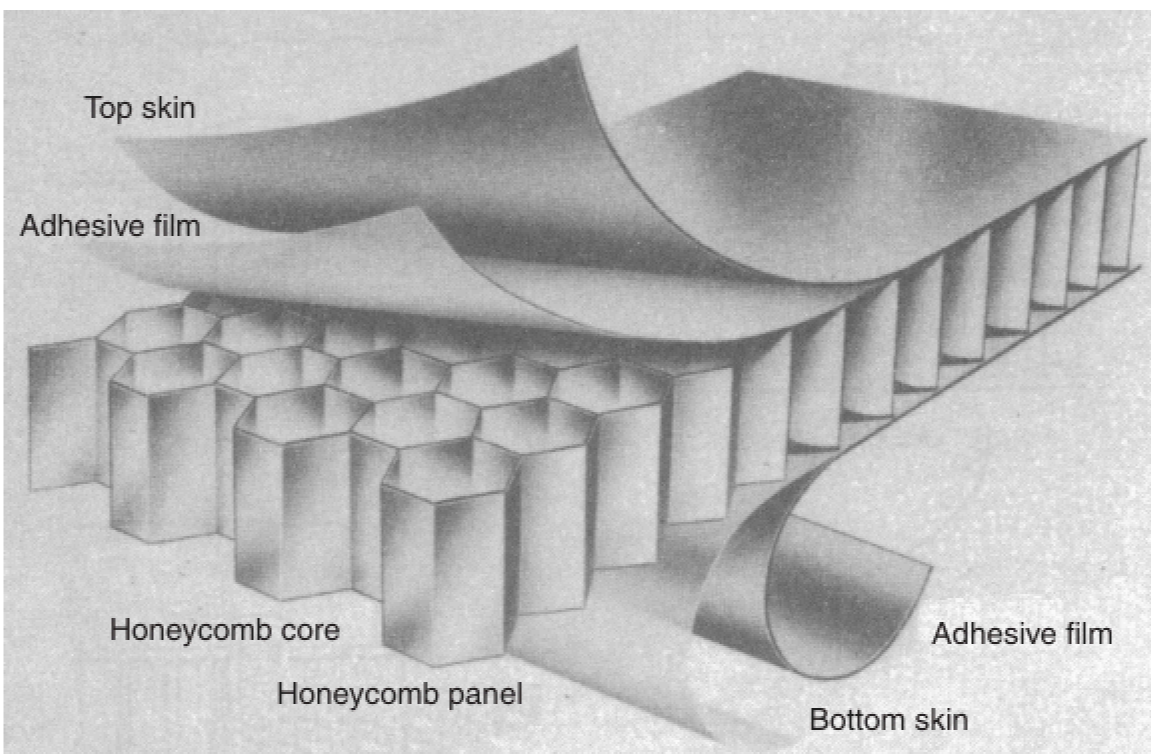
- High current levels are applied, allowing **greater weld penetration** and **higher speed** compared to spray transfer.
- This method is commonly used to **join heavier metal components**.

3. In short-circuit transfer, metal is deposited in the form of **individual droplets** (more than **50 per second**) when the **electrode tip touches the molten weld pool**, creating a short circuit.

- **Low current and voltage settings** are used.
- Carbon dioxide-rich shielding gases and **small-diameter wire electrodes** are preferred.
- The power required is approximately **2 kW**.

The temperatures generated in **Gas Metal Arc Welding (GMAW)** are relatively **low**. Consequently, this method is **only suitable for thin sheets and sections** under **6 mm (0.25 inches)**, as otherwise **incomplete fusion** may occur.

This process is **easy to use** and is widely **applied to thin sections of ferrous metals**. **Pulsed arc systems** are typically used for **thin parts of both ferrous and non-ferrous metals**.



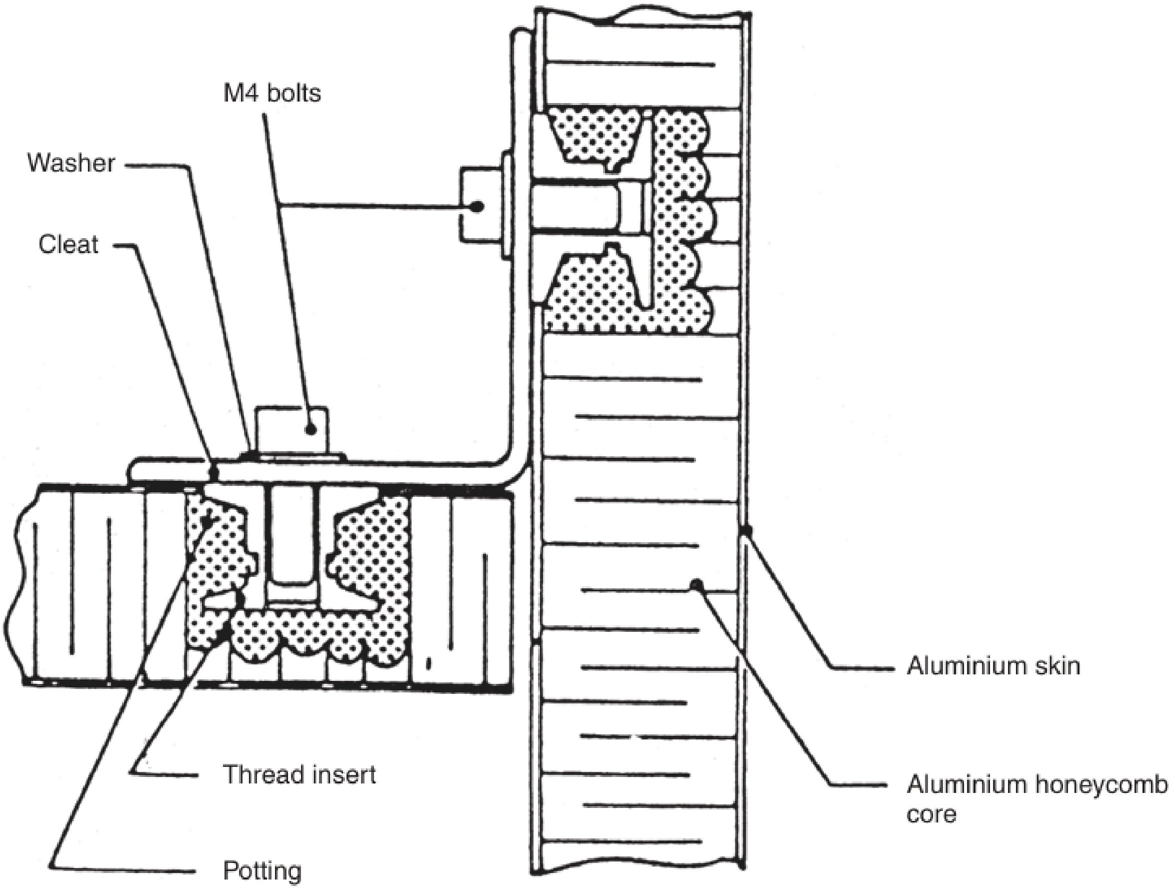


Figure 8.7 Inserts and panel cleat joints. (Reproduced by permission of EADS Astrium Ltd.)

Flux-Cored Arc Welding

The flux-cored arc welding (FCAW) process, shown in Fig. 30.11, is similar to gas metal arc welding, except that the electrode is tubular and filled with flux (hence the term flux-cored). Flux-cored electrodes produce a more stable arc and improved mechanical properties of the weld metal, as well as improving the weld contour. The flux in these electrodes is much more flexible than the fragile coating used in SMAW electrodes, so they can be supplied in long, coiled lengths. The electrodes generally have small diameters, from 0.5 mm to 4 mm (0.020 to 0.15 in), and the power required is about 20 kW. There are also electrodes with a cored core and self-shielding, which do not require external gas shielding because they contain fluxes that release gases and protect the welding area from the atmosphere. Small-diameter electrodes have made welding thinner materials with this process not only possible, but often preferable. These electrodes also allow for relatively easy welding of parts in different positions, and the flux chemical composition allows for the welding of many metals. The arc welding process (FCAW) combines the versatility of SMAW with the continuous and automatic electrode feeding characteristic of GMAW. It is economical and versatile, and is therefore used for welding a variety of joints, especially steels, stainless steels, and nickel alloys. The faster metal deposition rate of the FCAW process (compared to

GMAW) has allowed its application to join sections of all thicknesses. The use of tubular electrodes with very small diameters has expanded the application of this process to workpieces with smaller cross-sections.

Ultimate design for rockets:

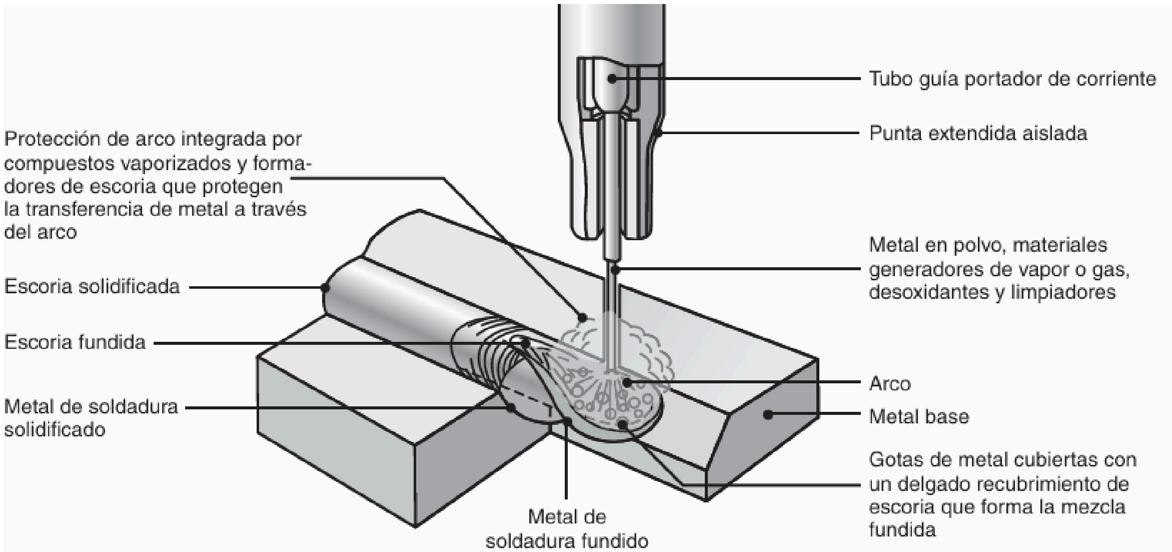


FIGURA 30.11 Esquema del proceso de soldadura por arco con núcleo de fundente. Esta operación es similar a la soldadura por arco metálico y gas, mostrada en la figura 30.10.

Covered Mild Steel Electrode Designation

The prefix **"E"** indicates an electrode for arc welding.

The first two digits in four-digit numbers and the first three digits in five-digit numbers
represent the **minimum tensile strength**:

E60XX → 60,000 psi minimum tensile strength
E70XX → 70,000 psi minimum tensile strength
E110XX → 110,000 psi minimum tensile strength

The **second-to-last digit** indicates the **position**:

EXX1X → All positions
EXX2X → Flat position and horizontal fillets

The **last two digits** indicate the type of **coating and current type** to be used.

The **suffix** (Example: EXXXX-A1) represents the **approximate alloy composition**
in the weld deposit:

A1 → 0.5% Mo
B1 → 0.5% Cr, 0.5% Mo
B2 → 1.25% Cr, 0.5% Mo

```
B3  → 2.25% Cr, 1% Mo
B4  → 2% Cr, 0.5% Mo
B5  → 0.5% Cr, 1% Mo
C1  → 2.5% Ni
C2  → 3.25% Ni
C3  → 1% Ni, 0.35% Mo, 0.15% Cr
D1, D2 → 0.25–0.45% Mo, 1.75% Mn
G   → 0.5% min Ni, 0.3% min Cr, 0.2% min Mo, 0.1% min V, 1% min Mn

These designations help in selecting **appropriate electrodes** based on mechanical properties,
weld composition, and **specific application requirements**.
```

Electrode coatings. Electrodes are coated with clay materials that include silicate binders and powdered materials such as oxides, carbonates, fluorides, metal alloys, and cellulose (cotton cellulose and sawdust). The coating (which is brittle and participates in complex interactions during welding) has the following basic functions:

• Stabilize the arc.
• Generate gases that act as shields against the surrounding atmosphere; these gases include carbon dioxide and water vapor (as well as carbon monoxide and hydrogen in small amounts).
• Control the rate at which the electrode melts.
• Act as a flux to protect the weld from the formation of oxides, nitrides, and other inclusions and to protect the molten weld pool (with the resulting slag).
• Add alloying elements to the weld zone to improve the joint properties; These elements include deoxidizers, to prevent the weld from becoming brittle.

to determine load distributions internal to a structure with multiple load paths; • to predict spacecraft overall natural frequencies;

• to predict the level of spacecraft response to low frequency vibration;

• to be used by the launch vehicle contractor to determine the mission-specific maximum loads, accelerations and deflections and thereby determine sine test input level reductions (notching); and

• to apportion stiffness and corresponding strength requirements to sub-structured appendages.

Electron Beam Welding
In electron beam welding (EBW), developed in the 1960s, heat is generated by a thin beam of high-speed electrons. The kinetic energy of the electrons is converted into heat as they strike the workpiece. This process requires special equipment to focus the electron beam onto the workpiece, usually in a vacuum. The greater the vacuum, the greater the beam penetration and the greater the depth-to-width ratio; hence, the methods are called EBW-HV (for high vacuum) and EBW-MV (for medium vacuum). Some materials can be welded using EBW-NV (non-vacuum).

Nearly all metals can be welded using EBW, and the workpiece thickness can vary from thin sheet to plate. The intense energy can also produce holes in the workpiece (keyhole technique; Section 30.3). Generally, no gas, shielding flux, or filler metal is required. Electron gun capacities can reach up to 100 kW. This process is capable of producing high-quality welds with nearly parallel sides that are deep and narrow and have small heat-affected zones (see section 30.9). Depth-to-width ratios range from 10 to 30. Weld sizes made using EBW are much smaller than those made using conventional processes. Using automation and servo controls, parameters can be precisely controlled at welding speeds up to 12 m/min (40 ft/min). The Laser beam welding (LBW) uses a high-power laser beam as a heat source to produce a fusion weld. Because the beam can be concentrated into a very small area, it has high energy density and deep penetration capabilities. It can be precisely directed, shaped, and focused onto the workpiece. Consequently, this process is particularly suitable for welding deep, narrow joints (Fig. 30.14), with typical depth-to-width ratios between 4 and 10. Welding of transmission components is the most widespread application in the automotive industry, while welding of thin parts is used for electronic components, among many other applications. The laser beam can be generated in pulses (in milliseconds) for applications (such as spot welding of thin materials) with power outputs up to 100 kW. Continuous laser systems of several kW are used for deep welds in thick sections. Laser beam welding processes produce good quality welds.

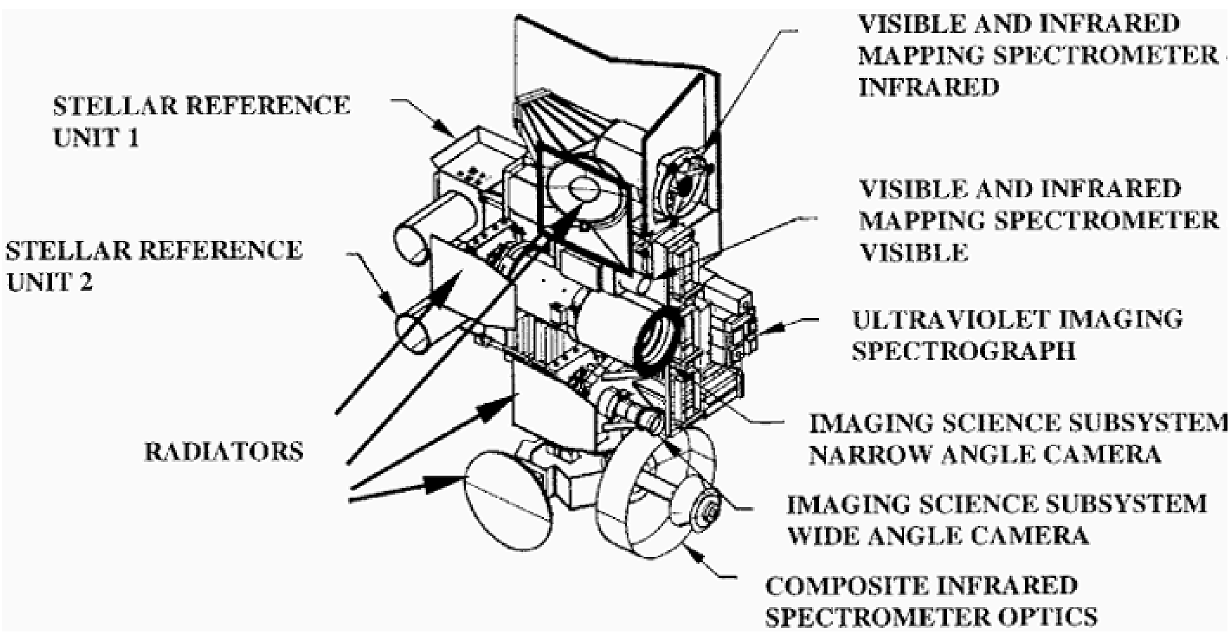


Figure 5. Remote Sensing Pallet with Instruments.

Oxygen-fuel cutting. Oxygen-fuel cutting (OFC), or oxy fuel cutting, is similar to oxygen-fuel welding, but in this case the heat source is used to remove a thin area from a metal plate. The remote sensing pallet (RSP) shown in Figure 5 and fields and particles pal let (FPP) shown in Figure 6 are two aluminum structures attached to the USS that support science instruments. The RSP supports the ISS NAC, ISS WAC, VIMS, CIRS,UVIS,and two stellar reference units. The fields and particles pallet supports the INMS, the CAPS, MIMI CHEMS,and MIMI LEMMS. The propulsion module subsystem (PMS) shown in Figure 7 attaches to the bot of theUSS.Theprimary structure is a cylindrical, semi-monocoque, aluminum shell. Housed within this shell are 2 tanks for bipropellants. Attached to the outside of the shell are a helium tank, spherical monopropellant tank, four thruster booms, two main engines, two pressurant control components assemblies, two propellant isolation components assemblies, and an electronics bay.

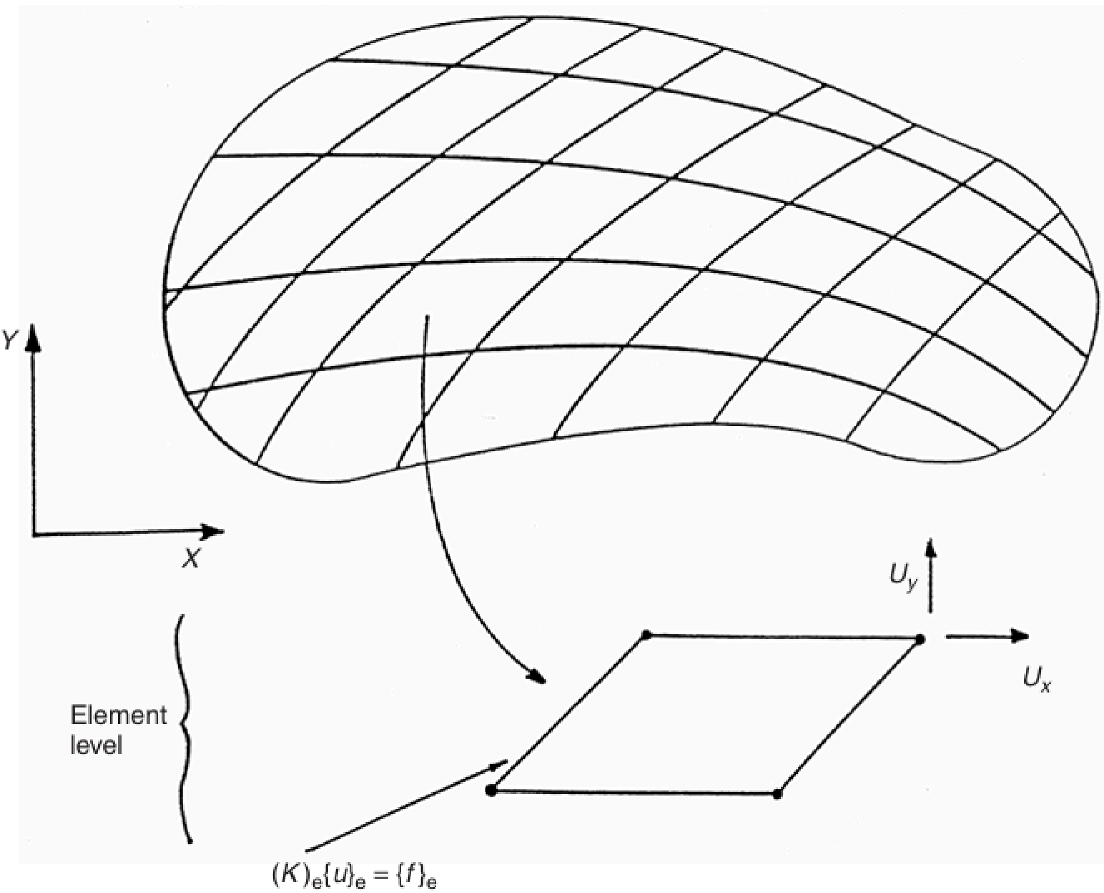
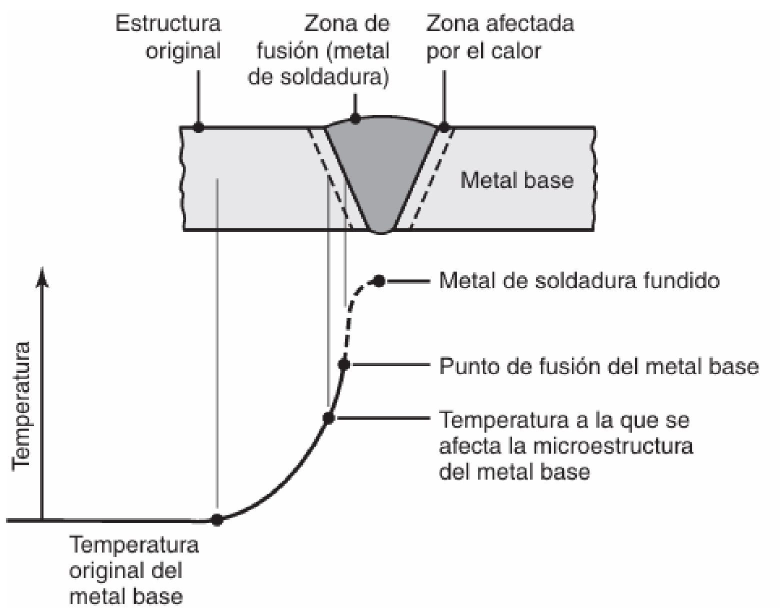


Figure 8.8 Finite element modelled area

The maximum thickness that can be cut using OFC depends primarily on the gases used. With oxyacetylene, the maximum thickness is almost 300 mm (12 in); with an oxyhydrogen torch, it is about 600 mm (24 in). Cutting kerf widths range from about 1.5 mm to 10 mm (0.06 to 0.4 in), with reasonably good tolerance control. The flame leaves drag lines on the cut surface (Fig. 30.16b), producing a rougher surface than those obtained by processes such as sawing, punching, or other operations using mechanical cutting tools. In OFC, distortion caused by uneven temperature distribution can be a serious problem. Although it has long been used in reclamation and repair work, oxyfuel gas cutting can also be used in manufacturing. Torches can be guided in various trajectories manually, mechanically, or by automatic machines with programmable controllers and robots. Underwater cutting is performed with specially designed torches that create a blanket of compressed air between the flame and the surrounding water. Arc cutting. Arc cutting processes are based on the same principles as arc welding. They can cut various materials at high speeds, but, like welding, they also leave a heat-affected zone that must be considered, particularly in critical applications.

In carbon arc cutting in air (CAC-A), a carbon electrode is used, and the molten metal is blown with a jet of air at high velocity. Thus, the metal being cut does not oxidize. This process is particularly used for grooving and beveling (removing metal from the surface). However, it is noisy, and the molten metal can be thrown long distances, posing safety hazards. Plasma arc cutting (PAC) produces the highest temperatures. It is used for fast cutting of non-ferrous metal plates and stainless steel. Its productivity is higher than that of gaseous oxygen-fuel processes.

1. Base metal.
2. Heat-affected zone.
3. Weld metal.



The example of the generators (RTG), 3 reaction wheels (RWA), low gain antenna #2 (LGA2), and a deployable and retractable cover for the main engines. The Spacecraft structural coordinate system origin is on the spacecraft centerline in the plane defined by the interface between the electronics bus and the upper equipment module. The +X axis points radially outward in the direction of the stellar reference units' boresights (which is perpendicular to the remote sensing boresights). The +Y axis points in the direction of the magnetometer boom. The +Zaxis points down toward the main rocket engines.
Heat-affected zone. The heat-affected zone (HAZ) is within the base metal itself. It has a different microstructure than the base metal before welding because it has been temporarily subjected to elevated temperatures during welding. Portions of the base metal that are far enough away from the heat source do not undergo any structural change during welding because they are subjected to a much lower temperature.
The properties and microstructure of the HAZ depend on (a) the rate of heat supply and cooling, and (b) the temperature to which this zone was raised.

In addition to metallurgical factors (such as the original grain size and orientation, and the degree of prior cold working), physical properties (including the specific heat and thermal conductivity of metals) also affect the size and characteristics of this zone.
The strength and hardness of the heat-affected zone (Fig. 30.18d) depend in part on how the original strength and hardness of the base metal developed before welding. As indicated in Chapters 2 and 4, these could have been developed by (a) cold working; (b) solid-solution strengthening; (c) precipitation hardening; or (d) various heat treatments.

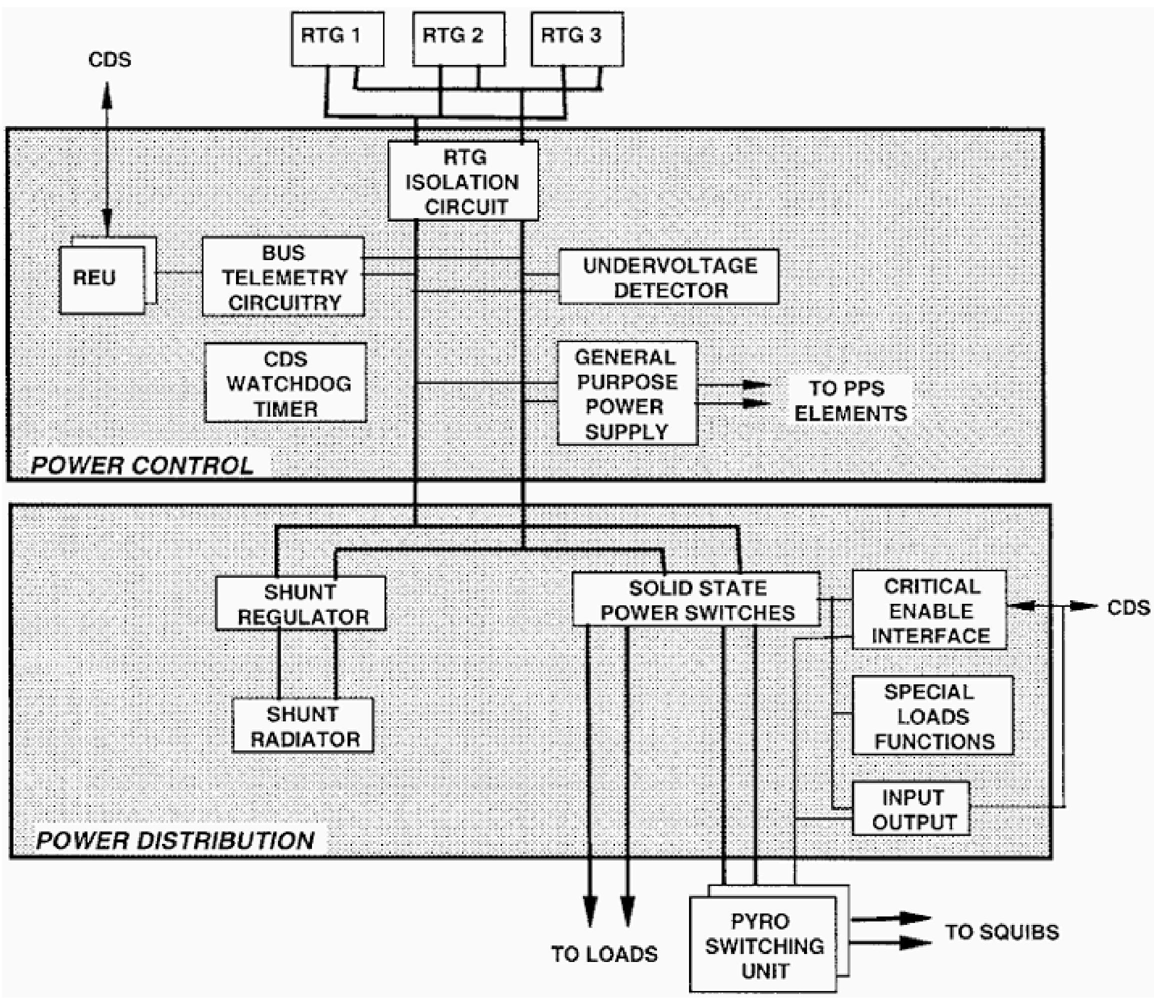


Figure 8. Power and Pyrotechnics Subsystem.

Grain structure in (a) a deep weld, and (b) a shallow weld. Note that the grains in the solidified weld metal are perpendicular to their interface with the base metal. (c) Weld bead on a cold-rolled nickel strip, produced by laser beam. (d) Microhardness (HV) profile across a weld bead.

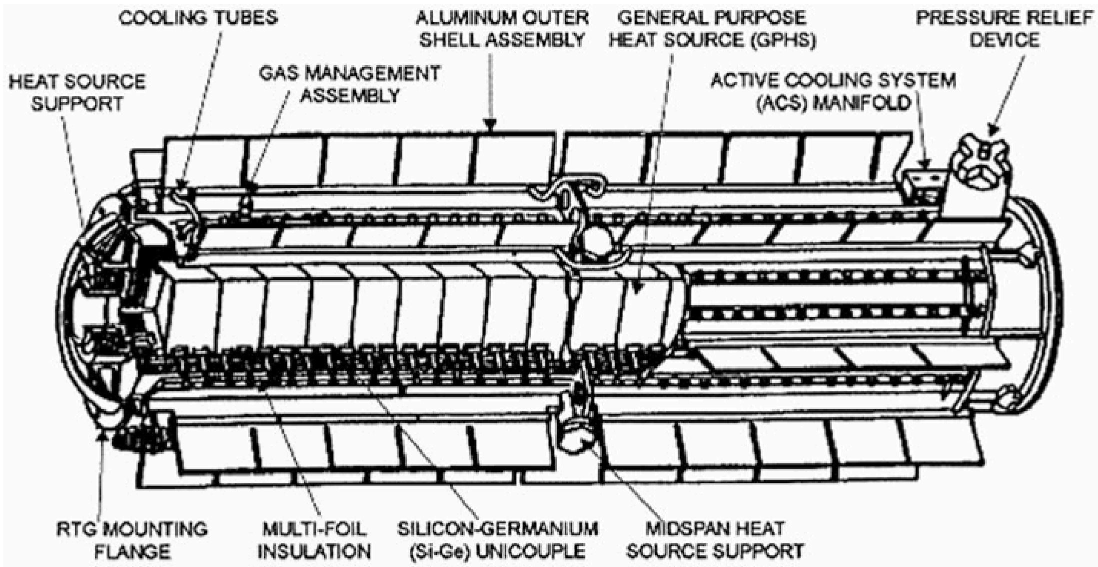
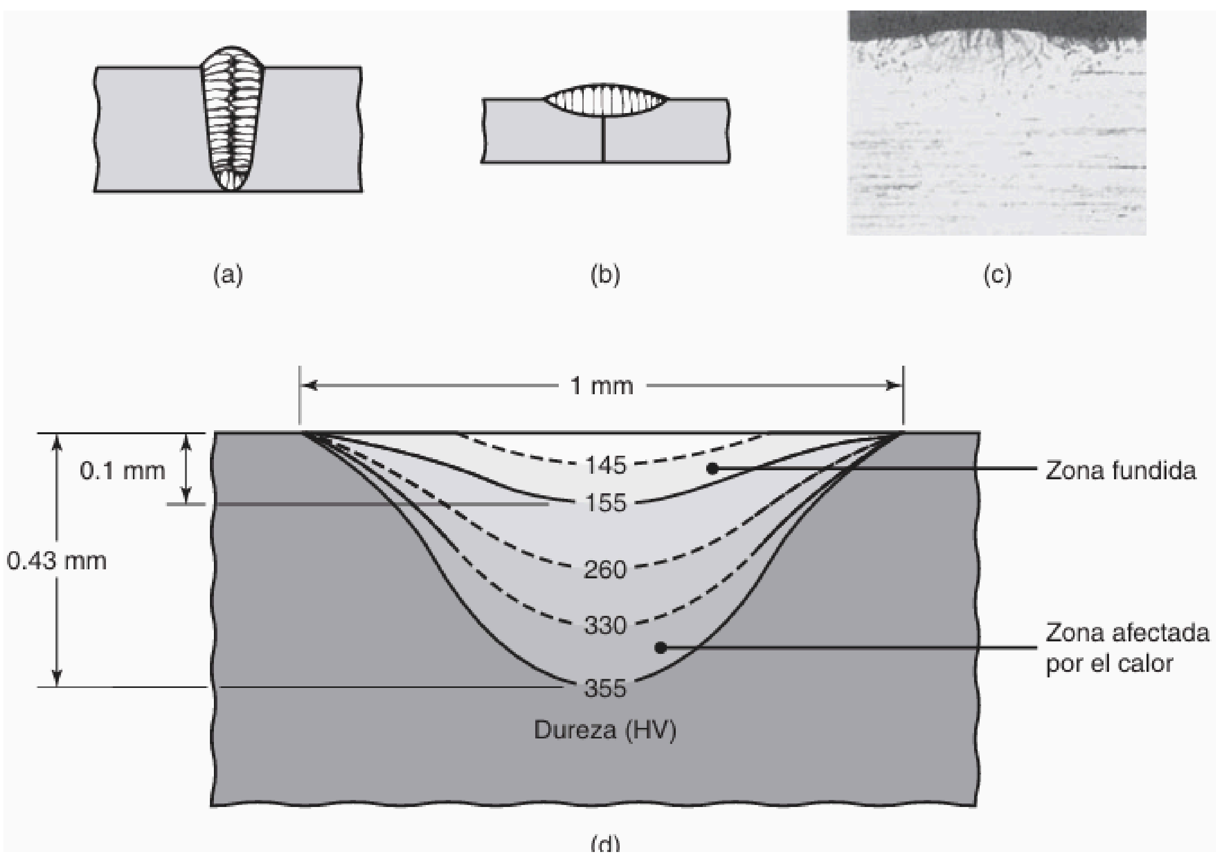


Figure 9. Radioisotope Thermoelectric Generator.



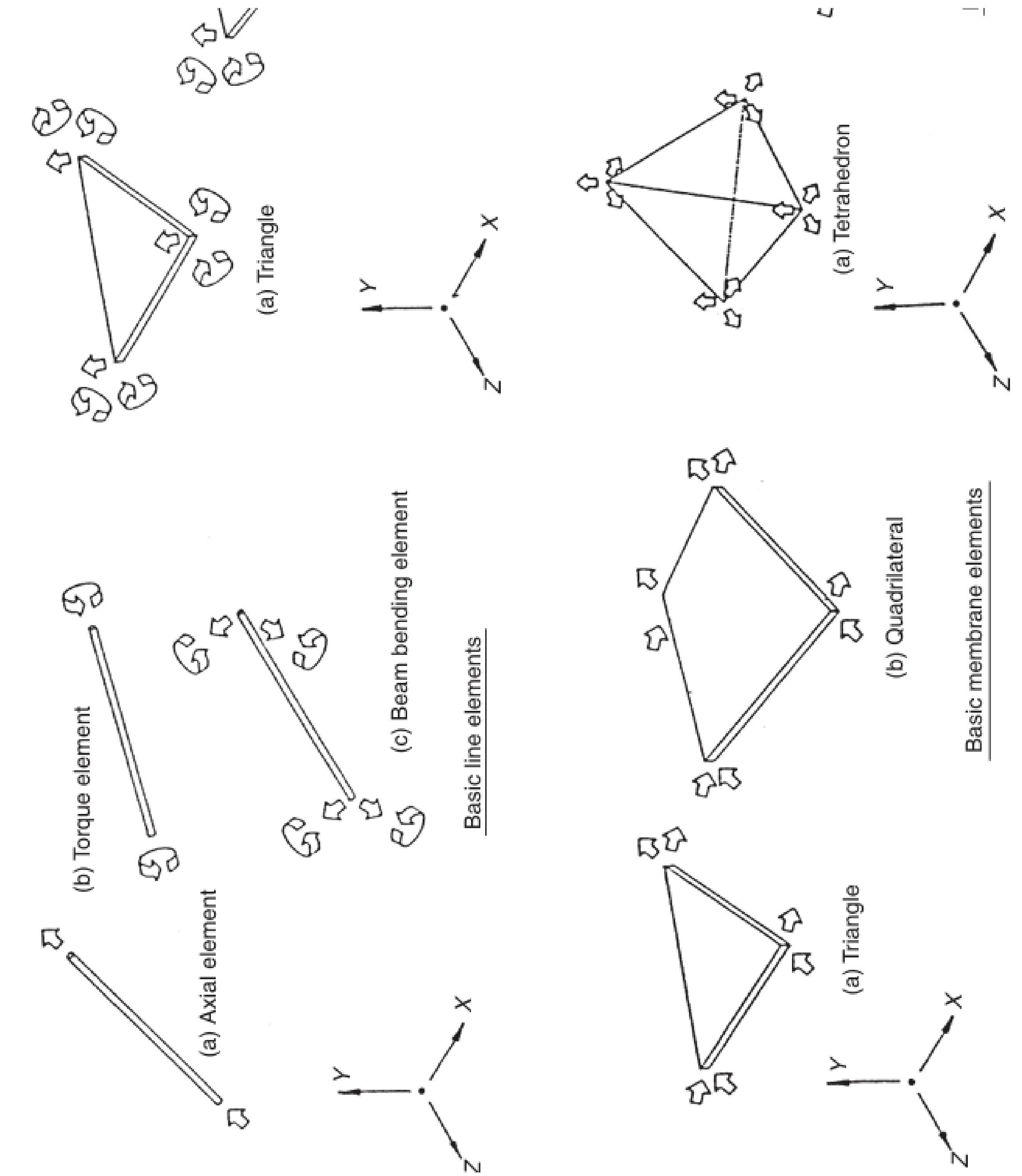


Figure 8.9 Standard finite elements for modelling

Weld Quality

As a result of the history of thermal cycles and the microstructural changes that occur, a weld can develop various discontinuities. These can also be caused by improper or careless application of welding techniques or by poor operator training. This section describes the important discontinuities that affect weld quality.

Porosity. Porosity in welds is caused by:

- Gases released during fusion of the welded area, but which are trapped during solidification.
- Chemical reactions during welding.
- Contaminants.

Most welded joints contain some porosity, which usually appears as spheres or elongated cavities (see also section 10.6.1). The distribution of porosity in the weld zone can be random or concentrated in a certain region.

Porosity in welds can be reduced through the following practices:

- Proper selection of electrodes and filler metals.
- Improved welding techniques, such as preheating the welding area or increasing the heat delivery rate.
- Proper cleaning, in addition to preventing contaminants from entering the welding zone.
- Reducing welding speeds to allow time for gas to escape.

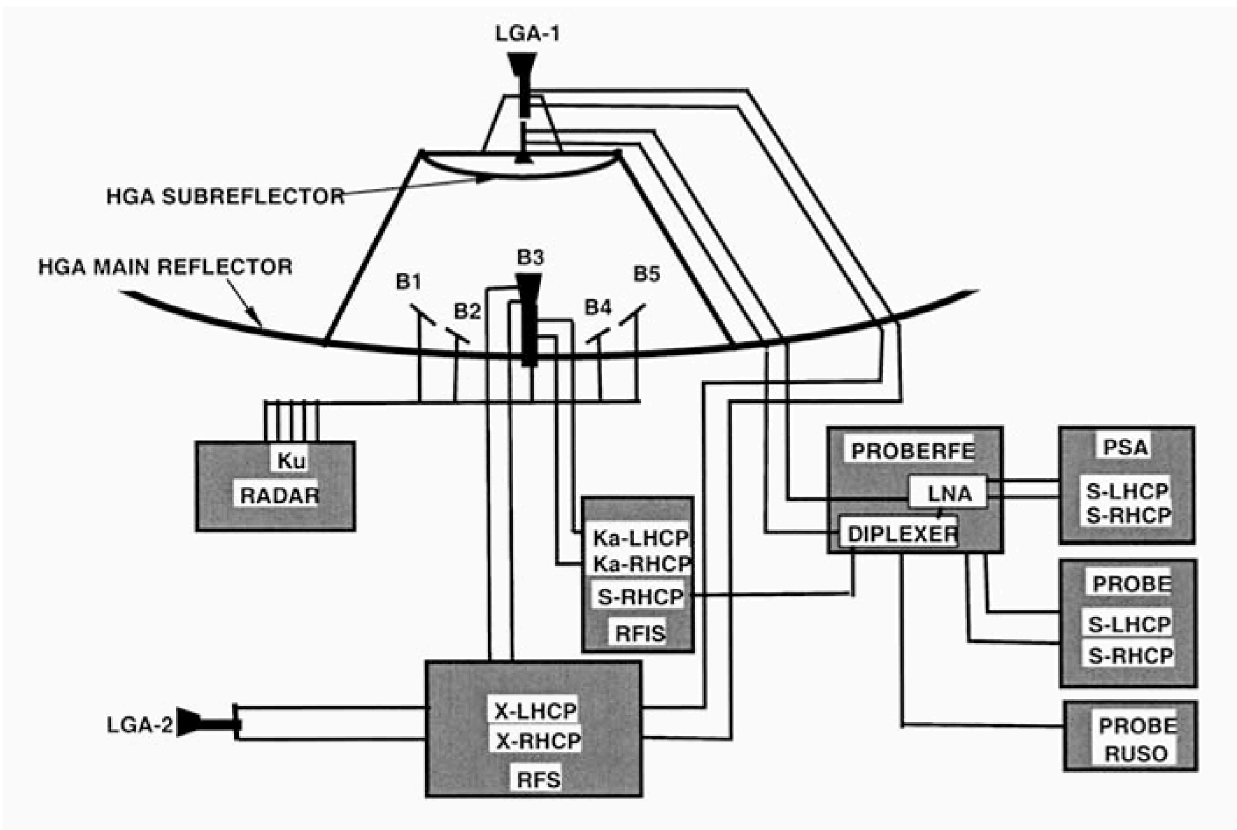
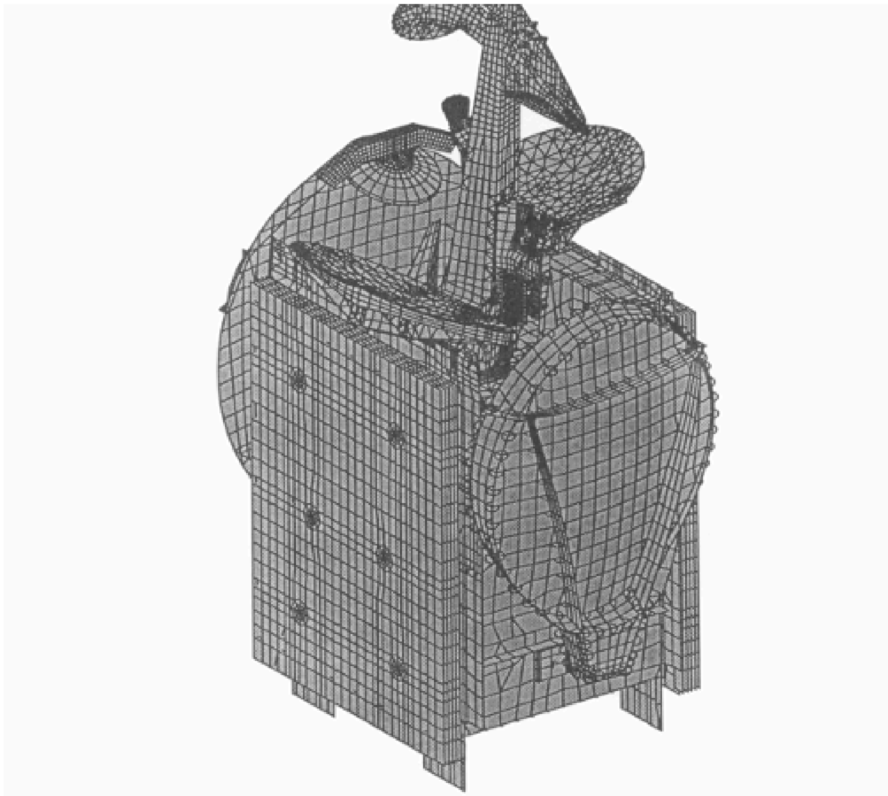


Figure 10. Antenna System.

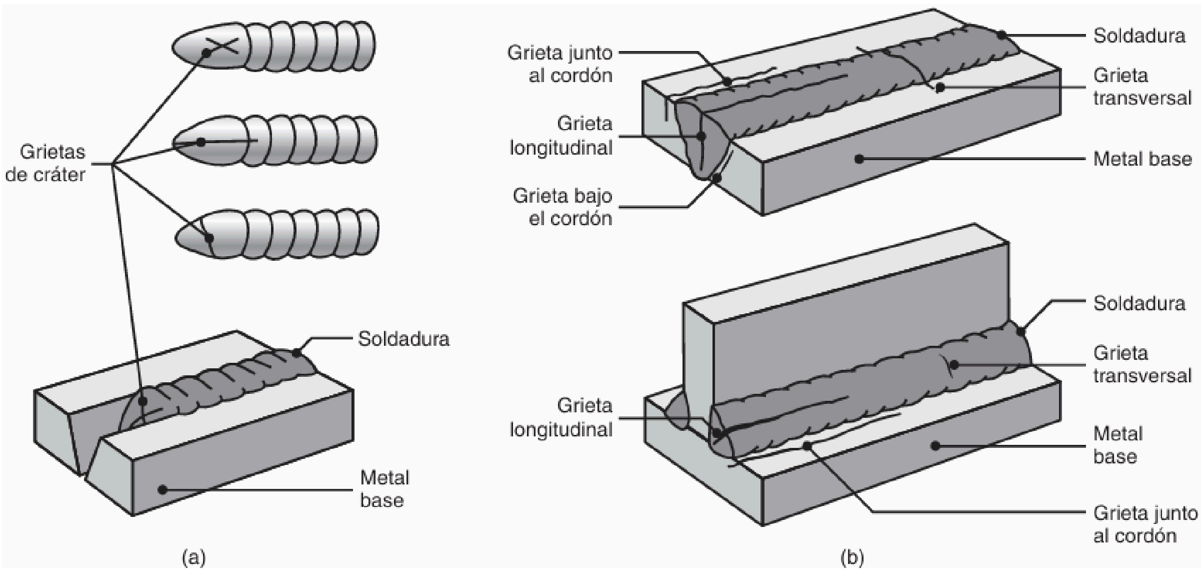


8 Super elements	Degrees of freedom
−X reflector	7145
−X feed	13867
+X reflector	7782
+X feed	13819
−Y solar array	21121
+Y solar array	21121
Top floor antenna	58387
Platform	32498
Total	175740

Element types	
24671	quad 4
7114	tria 3
9371	bar
6936	elas
348	hexa
33302	grids

Incomplete fusion and penetration. Incomplete fusion (lack of fusion) produces poor weld beads, as shown in Figure 30.19. A better weld bead can be obtained by using the following practices:
• Raising the temperature of the base metal.
• Cleaning the weld area before welding.
• Modifying the joint design and changing the type of electrode used.
• Providing sufficient shielding gas.
Incomplete penetration occurs when the depth of the welded joint is insufficient. Penetration can be improved by using the following practices:
• Increasing the heat input.
• Reducing the travel speed during welding.
• Modifying the joint design.
• Ensuring that the surfaces to be joined mate properly.

Weld profile. The weld profile is important not only for its effects on the strength and appearance of the weld, but also because it indicates incomplete fusion or the presence of slag inclusions in multilayer welds.
• Incomplete filling occurs when the joint is not filled with the appropriate amount of weld metal.



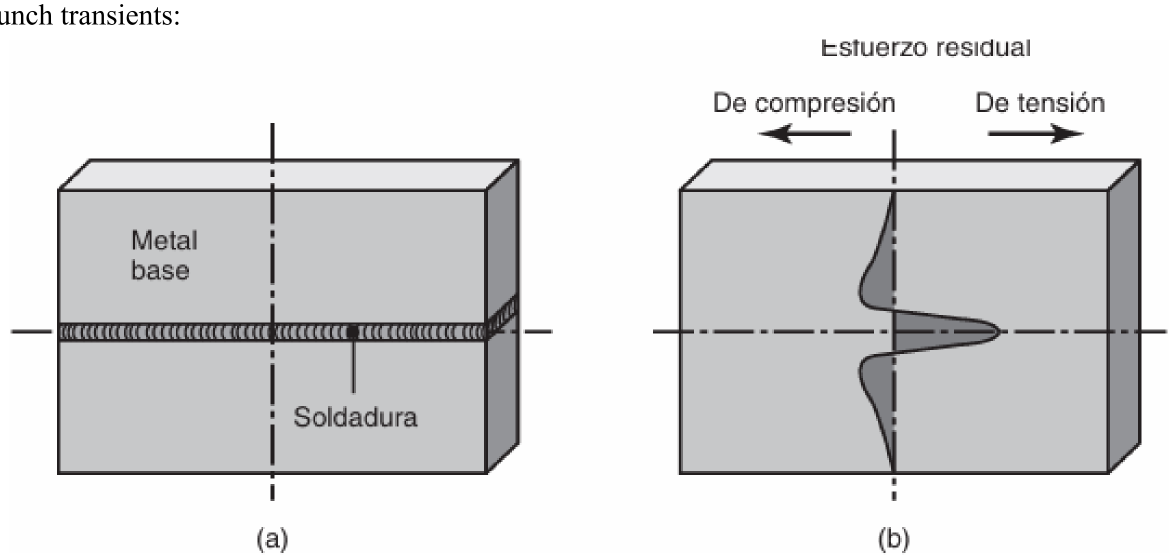
Temperature gradients that cause thermal stresses in the weld zone.
• Variations in the composition of the weld zone that cause different contraction rates during cooling.
• Grain boundary embrittlement (section 1.4), caused by the segregation of elements such as sulfur toward the grain boundaries, and movement of the solid-liquid boundary as the weld metal begins to solidify.
• Hydrogen embrittlement (section 2.10.2).
• Failure of the weld metal to contract during cooling (Fig. 30.22). This is similar to shrinkage cracks in castings (Fig. 10.12) and is related to excessive restraint of the workpiece during the welding operation.
Cracks are also classified as hot cracks, which occur when the joint is still at elevated temperature, and cold cracks, which develop after the weld metal has solidified.
The basic measures to prevent weld cracks are as follows:
• Modify the joint design to minimize stresses resulting from shrinkage during cooling.
• Change the parameters, procedures, and sequence of the welding operation.
• Preheat the components to be welded.
• Avoid rapid cooling of the welded components.

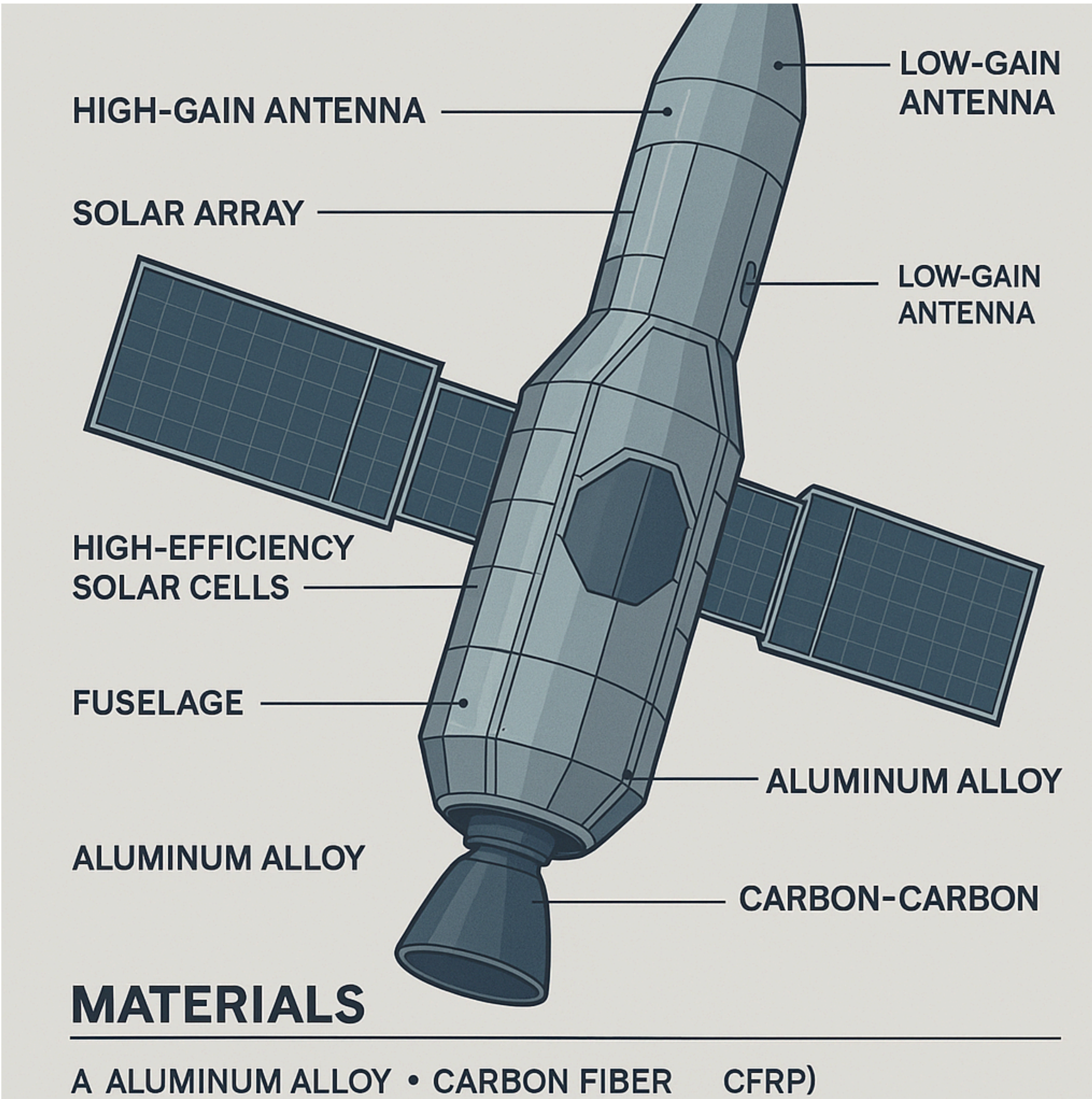
When welding such components, gaps may develop due to the contraction of the restrained components of the structure during cooling. These gaps can be avoided by providing for member shrinkage or by modifying the joint design to allow the weld bead to penetrate deeper into the weaker component. Surface damage. During welding, some metal may spatter and deposit as small droplets on adjacent surfaces. In arc welding processes, the electrode may inadvertently touch the parts being welded at locations other than the weld zone (arc flash). Such surface discontinuities may be objectionable for reasons of appearance or for subsequent use of the welded part. If severe, these discontinuities will adversely affect the properties of the welded structure, especially in notch-sensitive metals. To avoid surface damage, it is important to use appropriate welding techniques and procedures.

Residual stresses. Due to localized heating and cooling during welding, the expansion and contraction of the welded area causes residual stresses in the workpiece (see also section 2.11), which can cause the following defects:

- Distortion, warping, and buckling of welded parts (Fig. 30.23).
- Stress-corrosion cracking (Section 2.10.2).
- Subsequent distortion, if a portion of the welded structure is subsequently removed, by machining or sawing, for example.
- Reduction in the fatigue life of the welded structure.

Sine vibration The sine vibration environment for Ariane 5 is given in Table 8.3. It is a relatively simply defined envelope of all of the many complex low frequency transient vibrations that may occur during launch. For a qualification sine vibration test, a spacecraft in launch configuration is attached to a large 'shaker' which starts vibrating at 5Hz. The frequency of the vibration is increased at a rate of 2 octaves (doublings) per minute. In one minute the frequency increases from 5Hz, through 10 to 20Hz. This continues until 100Hz is reached when the test stops. Any lightweight spacecraft will have resonant frequencies in this range which can cause responses in the spacecraft 20 or more times the specified input. If these responses are in excess of the predicted launch transient responses, the defined test input may be reduced, or notched at critical response frequencies by agreement with the launcher agency. Such an agreement requires demonstration by the spacecraft-and-launcher coupled loads transient analysis that the reduced response within the spacecraft in the notched sine test is still greater than that to be expected from launch transients:

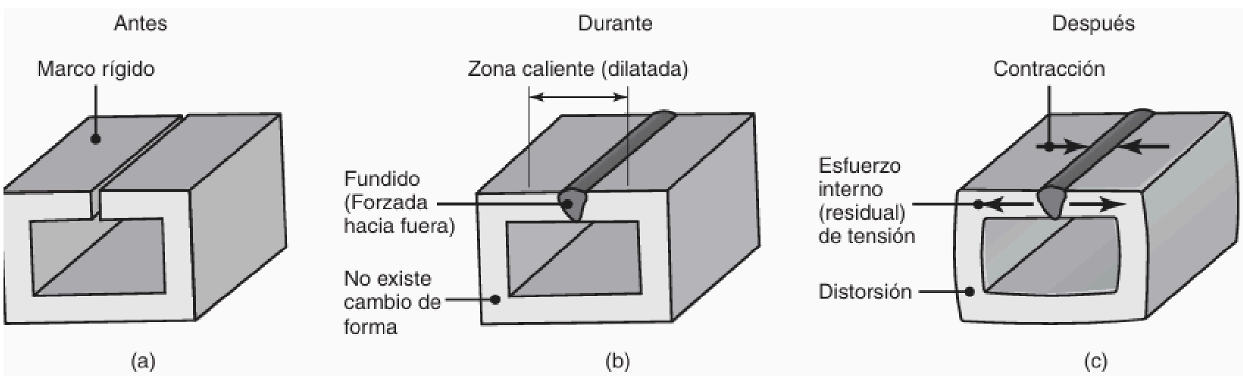




For reference, Figure 30.24 better describes the type and distribution of residual stresses in welds. When two plates are welded, a long, narrow area is subjected to elevated temperatures, while the remaining plates remain essentially at room temperature. Once welding is completed, and time passes, the heat from the weld zone dissipates laterally within the plates while the weld area cools. The plates then begin to expand longitudinally, while the welded length begins to contract (Fig. 30.23b). If the plate is not restrained, it warps, as shown in Figure 30.23a. However, if the plate is not allowed to warp, it develops residual stresses that are normally distributed as shown in Figure 30.24b. Note that the magnitude of the compressive residual stresses in the plates decreases to zero.

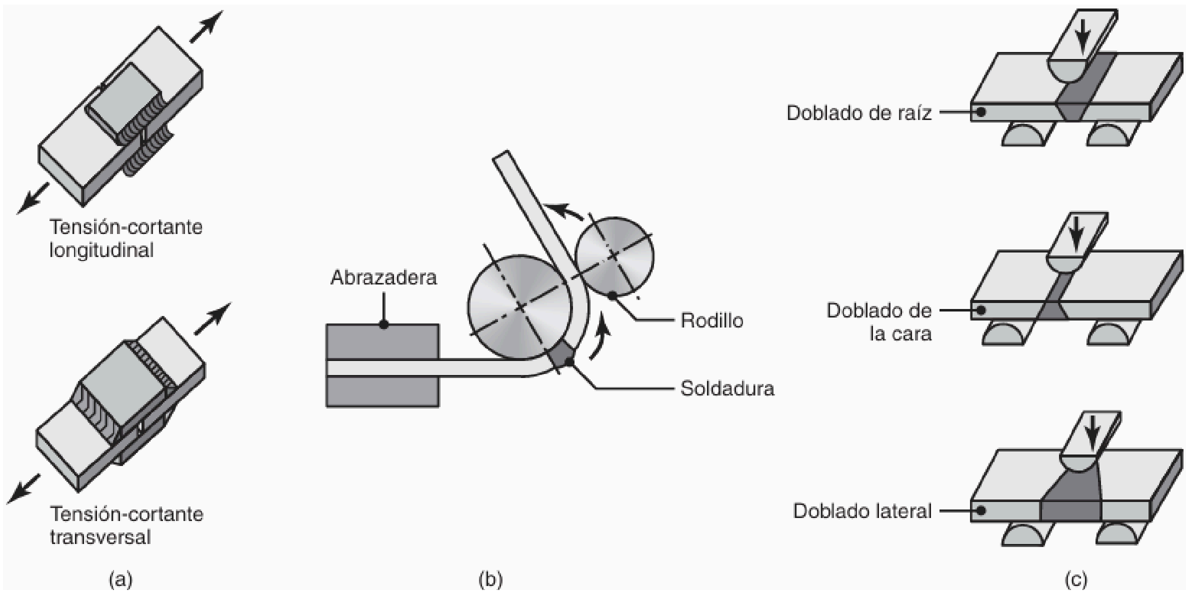
TABLE 8.3
Sine Vibration Environment for Ariane 5

Sine Frequency Range (Hz)	Qualification	Protoflight	Acceptance
Longitudinal 2–5	12.4mm	12.4mm	9.9mm
Longitudinal 5–50	1.25g	1.25g	1g
Longitudinal 50–100	1g	1g	0.8g
Lateral 2–5	9.9mm	9.9mm	8.0mm
Lateral 5–25	1g	1g	0.8g
Lateral 25–100	0.8g	0.8g	0.6g
Sweep Rate	2 oct./min	4 oct./min	4 oct./min



Stress Relief in Welds. Problems caused by residual stresses (such as distortion, buckling, and cracking) can be reduced by preheating the base metal or the parts to be welded. Preheating reduces distortion by reducing the cooling rate and the level of thermal stresses (by lowering the elastic modulus). This technique also reduces shrinkage and potential cracking of the joint. For optimal results, preheating temperatures and cooling rates must be carefully controlled to maintain acceptable strength and toughness in the welded structure. Workpieces can be heated in a variety of ways, including (a) in a furnace; (b) electrically (resistance or induction); or (c) using radiant lamps or hot air blast for thin parts. The temperature and time required for stress relief depend on the type of material and the magnitude of the residual stresses developed. Other stress relief methods include shot peening, peening, or rolling the weld bead area. These techniques induce compressive residual stresses, which, in turn, reduce or eliminate tensile residual stresses in the weld. In the case of multilayer welds, the first and last layers should not be shot peened to protect them from possible damage caused by the shot peening itself. Residual stresses can also be relieved or reduced by slightly plastically deforming the structure. For example, this technique can be used in pressure vessels manufactured by welding, by internally pressurizing them (subjecting them to a proof stress). To reduce the possibility of sudden fracture under high internal pressure, the weld must be properly welded and free of notches or discontinuities, which could act as stress concentration points.

so que cae provee la energía.

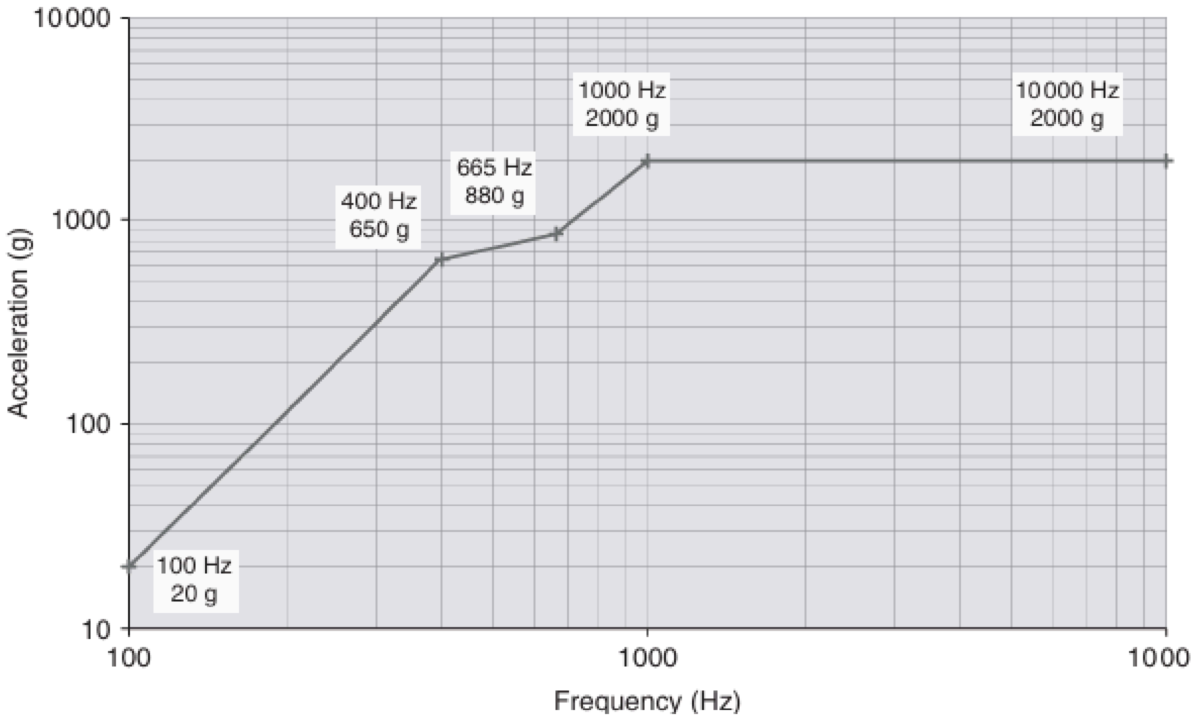


Equipment Random Vibration Spectrum
From Spacecraft Acoustic Testing

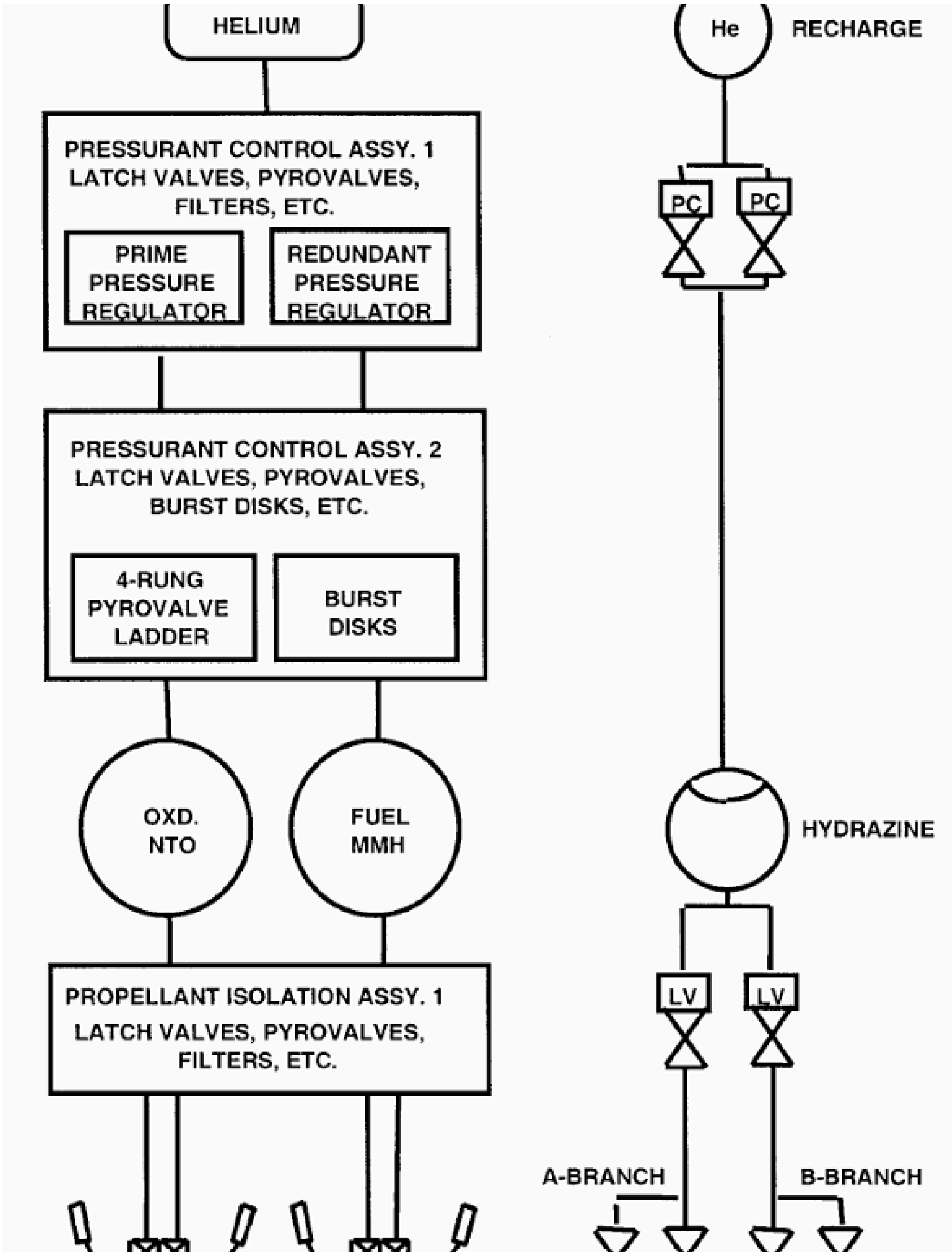
(Duration: 1 min for Protoflight Testing, 2 min for Qualification Testing)

Frequency (Hz)	Level
20–150	+6 dB/oct.
150–1000	0.25 g^2/Hz (18.7 g RMS)
1000–2000	−6 dB/oct.

ANALYSIS 8.4



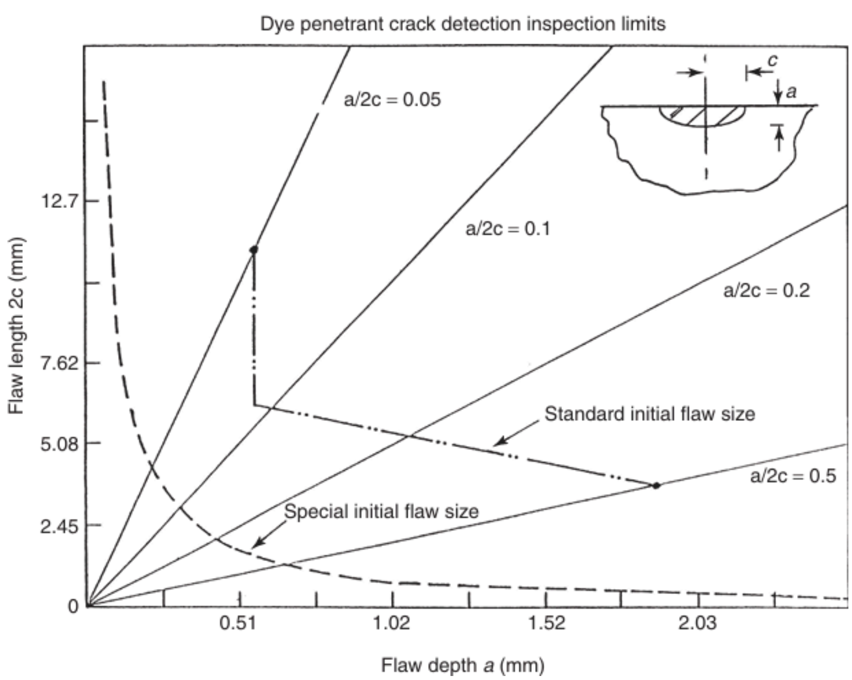
On-station loads are of a much smaller magnitude than launch cases but they can be equally demanding on structure design. Structural transmission of micro-vibration from sources, such as momentum wheel bearing rumble or thruster firing, to sensitive equipment such as lasers or telescopes may be of critical concern. Large appendages, such as antenna reflectors or solar array panels, may have a very low natural frequency when deployed. A minimum deployed natural frequency between 0.5–2Hz is often required to avoid attitude control instability. Although a very low frequency, this requirement may be difficult to meet. Consequently it may be critical in the design of the deployed appendage interface and local backing structure. Items such as strut tubes and honeycomb core cells, when manufactured in atmospheric pressure, could become inadvertent pressure vessels in the vacuum of space. They must be vented, or if venting is not practicable, designed as a pressure vessel. All non-metallic materials must be space-qualified, primarily with respect to out-gassing under sunlight in vacuum. The release of volatiles is doubly undesirable, since they may degrade the performance of the residual material and may redeposit on adjacent sensitive equipment.



Physical Properties of Matrix Materials and Reinforcements 3.2.1.1 Reinforcements of Metal Matrix Composites The reinforcement is an important constituent part of metal matrix composite materials. The introduction of reinforcements can obviously improve the strength, modulus, heat resistance, and wear resistance properties of the metal matrixes. Therefore, the properties of metal matrix composites are closely related to the selected reinforcements. The reinforcements of metal matrix composites should have the following basic features [17, 18]. 1) The reinforcements should have excellent chemical stability. During the high-temperature preparation process and the application process, the structures and properties of the reinforcements will not show any obvious changes or degeneration. The reinforcements must have good chemical compatibility with the matrix materials, so no serious interface reactions that would damage the combination of the interfaces will occur. 2) The reinforcements and the matrix materials should have good wetting properties. Alternatively, after surface treatment, the reinforcements will have a good wetting state with the matrix materials to ensure a good compounding.

AACS Sensor Parameters

Parameter	Value
Field of View	15 deg × 15 deg
SRU-Based Attitude Knowledge	Sensitivity
Stars in Catalog (in AFC)	5.6 Mv stars
SSA Field of View	60 deg × 60 deg
SSA Range	0.6 to 10.06 AU
SSA-Based Attitude Knowledge	26 mrad (2 axis)
IRU Type	Hemispherical resonating
IRU Drift Rate	<1 deg h^{-1}
IRU Drift Rate Stability	<0.06 deg h^{-1} (8h period)
IRU Resolution	0.25 microrad
IRU Full Performance Range	<2 deg s^{-1}
IRU Degraded Performance Range	<15 deg s^{-1}
ACC Range	>±1.12 g
ACC Resolution	0.002 g



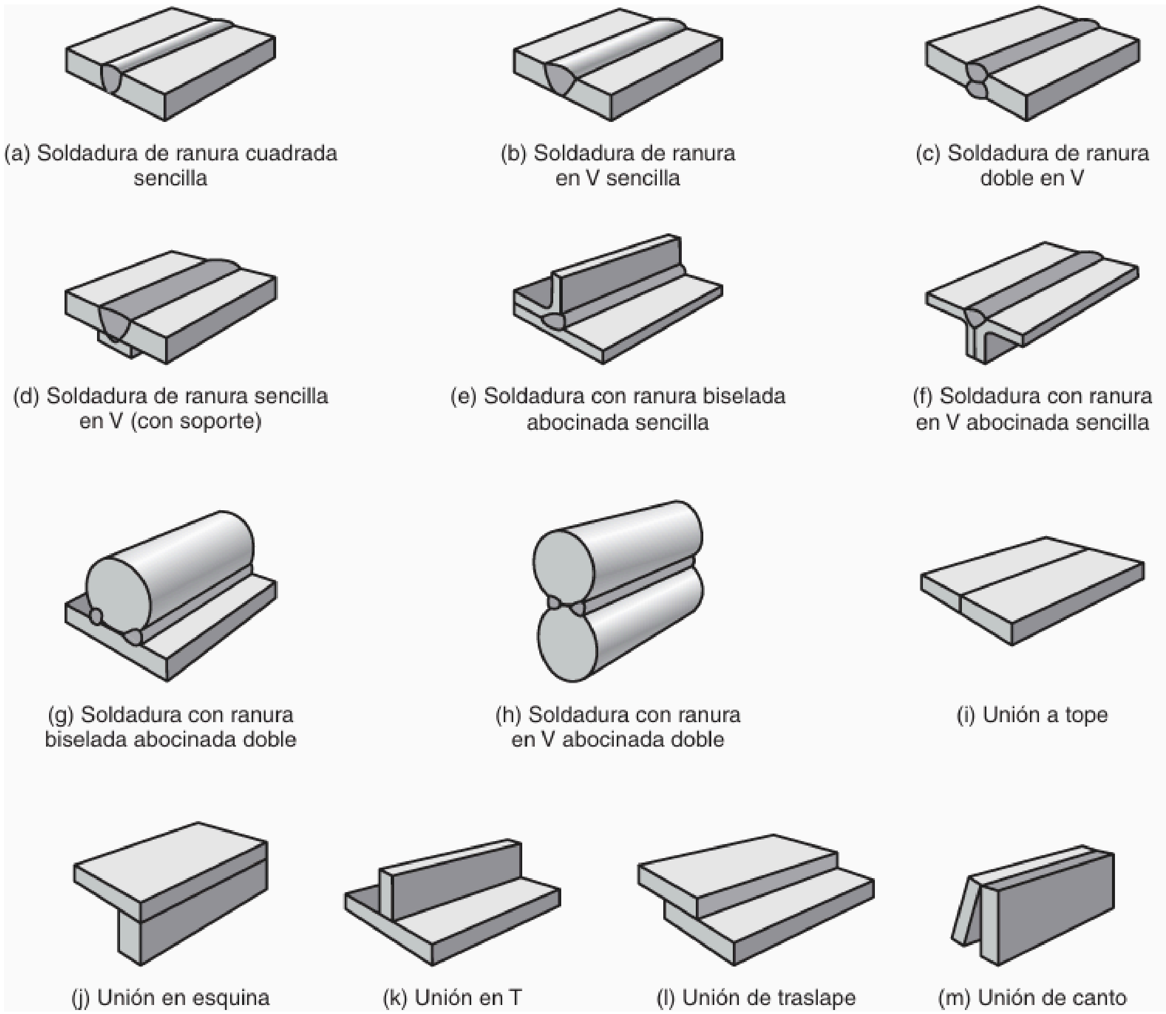


FIGURA 30.27 Ejemplos de uniones soldadas y su terminología.

Process Selection. In addition to the process characteristics, capabilities, and material considerations described so far, the selection of a welded joint and the appropriate welding process include the following considerations:

• The configuration of the parts or structure to be joined, the joint design, the thickness and size of the components, and the number of joints required.
• The methods used to manufacture the components to be joined.
• The type of materials involved, which may be metallic or nonmetallic.
• The location, access, and ease of joining.
• The application and service requirements, such as the type of loading, the stresses generated, and the environment.
• The effects of distortion, warping, and discoloration on appearance and service.
• The costs involved in edge preparation, joining, and subsequent processing (including machining, grinding, and finishing operations).
• The cost of the equipment, materials, labor, and skills required, as well as the joining operation