Conceptual Design of an Ultra-Resistant and Futuristic Propulsion System

1. General Objective

To create a propulsion system that combines mechanical strength, thermal efficiency, and the advanced properties of metallic materials obtained through rolling and advanced manufacturing processes. The design must be robust enough to withstand high pressures, temperatures, and dynamic forces, designed for highly demanding aerospace or industrial applications.

2. Materials and Processes Used

Main material: Titanium alloy reinforced with boron carbide and graphene nanoparticles for high strength and low weight.

Initial Processing:
Hot rolling to form basic parts (cylinders, discs, and tubes).
Shape rolling to create complex and aerodynamic structural shapes (e.g., nozzles, housings, and internal supports).
Cold rolling for parts requiring high dimensional precision and surface finish (seals, contact surfaces).
Heat treatments to optimize the microstructure (hardening, annealing, and aging).
Laser welding with atmosphere control to join critical components, avoiding embrittlement.
Aluminum nitride-based ceramic coatings for protection against corrosion and thermal wear.

3. Main Components of the Propulsion System
Combustion chamber and nozzle:
Manufactured using shape-rolling technology from reinforced alloy to withstand high pressures and temperatures.
Variable cross-section design for efficient gas flow control and maximum thrust.
Shaft and rotor:
Constructed with shape-rolled tubes and bars, optimized for torque transmission and high-speed rotation.
Central shaft machined using cold rolling technology for tight tolerances and reduced friction.

Integrated cooling system:
Internal ducts manufactured with shape-rolled tubes for coolant circulation.
Thermal coatings to minimize losses and maintain structural integrity.
Structural supports:
Shape-rolled I-beams for maximum rigidity and minimum weight.
Integrated with reinforcement rings obtained through ring rolling to distribute radial loads.

4. Future Innovations
Integration of embedded sensors in critical areas, with microchannels for real-time thermal and vibration monitoring. Modular structure to allow rapid maintenance and part replacement, with couplings precisely designed through relief rolling.

Advanced aerodynamic optimization through CFD simulations and post-machining to reduce turbulence losses and improve efficiency. A lubrication and adaptive tensioning system that adjusts pressure in real time to minimize wear, based on integrated electronic control systems.

5. Manufacturing Process Summary
Selection and mixing of special alloys. Continuous casting and melting to form ingots.
Hot rolling for initial forming of basic parts.
Shape rolling for specific shapes (nozzles, rings, supports).
Cold rolling for parts with critical tolerances (shaft, seals).
Heat treatments to optimize strength and ductility.
Assembly with laser welding and dimensional control.
Application of thermal and protective coatings.
Integration of sensors and electronic systems.
Non-destructive testing and final calibration.

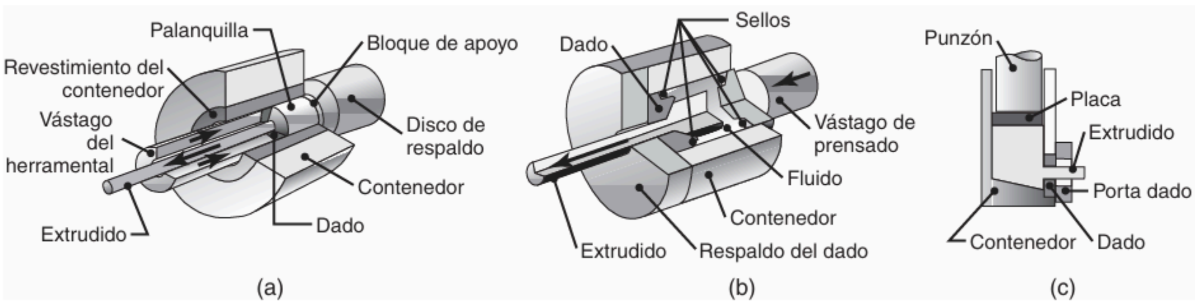


FIGURA 15.3 Tipos de extrusión: *(a)* indirecta, *(b)* hidrostática; *(c)* lateral.

All these models will be designed in Python with a better Pycharm development environment, electronic designs or small processors and sensors will be made with Microblaze and VHDL bases along with the documentation to insert the sensors, or the approach inside the ship or satellite of the solar parker or similar.

There are three basic types of extrusion. In the most common process (known as direct or forward extrusion), a billet is placed in a chamber (container) and forced through a die opening by hydraulic actuation of a piston (press rod or punch), as shown in Figure 15.1. The die opening can be round or have various shapes, depending on the desired extruded shape. The function of the support or dummy block is to protect the tip of the press rod, especially in hot extrusion. Other types of extrusion include indirect, hydrostatic, and impact. In indirect extrusion (also known as inverted or retro extrusion), the die moves toward the extruded billet (Figure 15.3a). In hydrostatic extrusion (Fig. 15.3b), the billet has a smaller diameter than the chamber (which is filled with a fluid), and pressure is transmitted to the billet by means of a piston. Unlike direct extrusion, there is no friction to overcome on the walls of the container because the billet is stationary relative to the chamber. A less common type of extrusion is lateral (or side) extrusion.

15.2 El

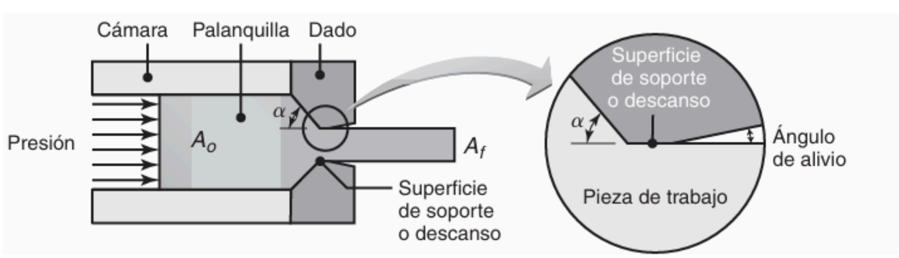


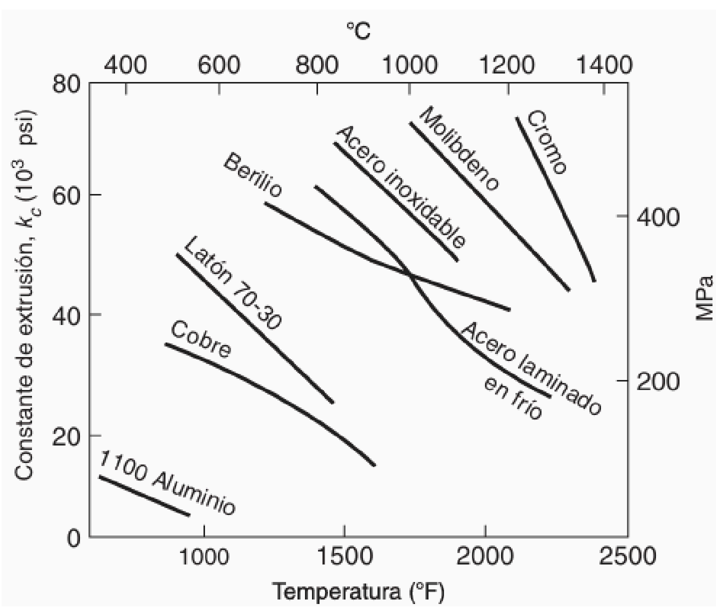
FIGURA 15.4 Variables del proceso en extrusión directa. Todos, el ángulo del dado, la reducción en la sección transversal, la velocidad de extrusión, la temperatura de la palanquilla y la lubricación, afectan la presión de la extrusión.

Process variables in direct extrusion. All of these variables—die angle, cross-sectional area reduction, extrusion speed, billet temperature, and lubrication—affect extrusion pressure.
Billet temperature, ram travel speed, and the type of lubricant used.

Extrusion force. The force required for extrusion depends on (a) the strength of the billet material, (b) the extrusion ratio, (c) the friction between the billet and the chamber and die surfaces, and (d) process variables such as billet temperature and extrusion speed. The extrusion force (F) can be estimated from the formula:

F = Aok lnaAo Afb
Chromium
Molybdenum
Stainless Steel

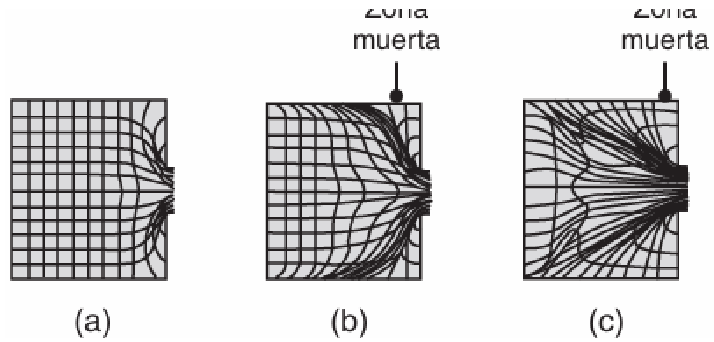
where k is the extrusion constant (determined experimentally), and Ao and Af are the areas of the billet and extrudate, respectively. Thus, the value of k in equation 15.1 is a measure of the strength of the extruded material and the friction conditions. Values of k for various metals for a range of extrusion temperatures are given in the next figure:



The extrusion force is calculated using Equation 15.1, where the extrusion constant (k) is obtained from Figure 15.5. For this material, k = 12.522 psi (250 MPa) at the given extrusion temperature.
Therefore, 35,000
F = 12.522 p135,0002 lncp12.522
p11.022
*d = 1.26 * 106 lb= 630 tons = 5.5 MN*

Metal Flow in Extrusion. The metal flow pattern in extrusion, as in other forming processes, is important because of its influence on the quality and mechanical properties of the extruded product. This pattern is determined based on the basic principle that energy is minimized in any of the aforementioned processes.

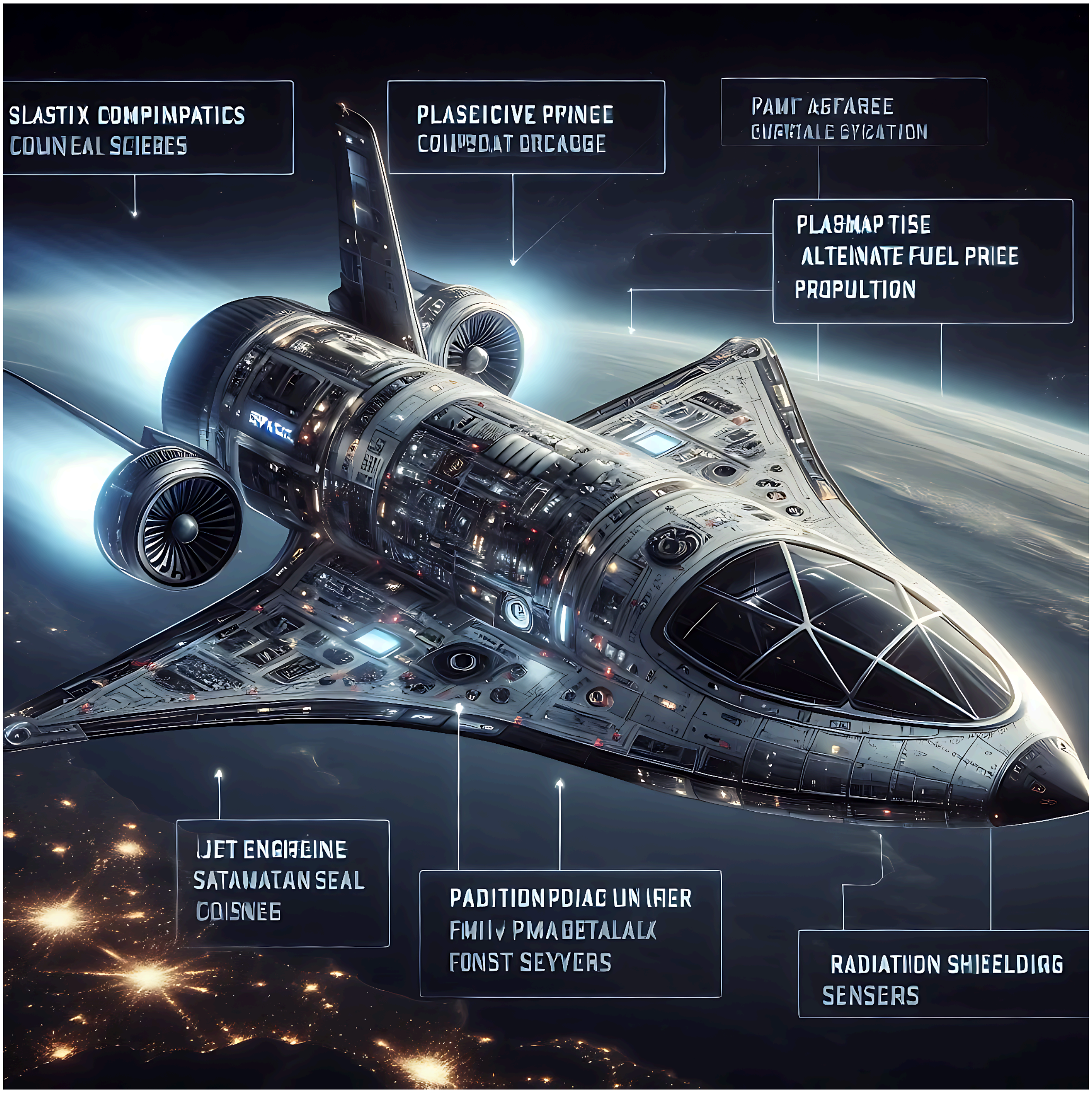
The material flows longitudinally, very similar to the flow of an incompressible fluid in a channel; therefore, extruded products have an elongated grain structure (preferred orientation). Section 15.5 describes how improper metal flow can produce various defects in the extruded product during extrusion. A common technique for investigating the flow pattern is to section the round billet longitudinally in half and then score one face with a square grid pattern. The two halves are placed together inside the chamber and extruded. They are then separated and studied individually. Figure 15.6 shows the common flow patterns obtained using this technique for direct extrusion with straight dies (90° die angle). The flow pattern is a function of several variables, including friction. The conditions under which these flow patterns occur are described in the legend for Figure 15.6. Note the dead metal zones in Figures 15.6b and c, where the metal is essentially stationary at the corners. This situation is similar to the stagnation of fluid flow in channels with acute angles or turns.



Process parameters. Because of their high ductility, wrought aluminum, copper, magnesium and their alloys, common steels, and stainless steels are extruded relatively easily into various shapes. Other metals (such as titanium and refractory metals) can also be extruded, but only with some difficulty and considerable die wear. In practice, extrusion ratios (R) typically range from 10 to 100. They can be higher in special applications (400 for softer nonferrous metals) or lower for less ductile materials, although the ratio must be at least 4 to plastically deform the material throughout the entire mass of the workpiece. It is common for extruded products to be less than 7.5 m (25 ft) in length due to the difficulty of handling larger sizes, but they can be as long as 30 m (100 ft). Ram speeds vary up to 0.5 m/s (100 ft/min).
In general, lower speeds are preferable for aluminum, magnesium, and copper, with higher speeds for steels, titanium, and refractory alloys. Dimensional tolerances in extrusion are typically in the range of 0.25–2.5 mm (0.01–0.1 in) and increase with increasing cross-sectional area.

In TP systems using a gas generator cycle, a small portion of the overall propellant is used by the gas generator. It operates at lower flame temperatures and different mixture ratios than the thrust chamber; this causes a slight change to the overall mixture ratio on the propellants flowing from the tanks, as shown later in Eqs. (11–3) and (11–5). 3. In a rocket propulsion system with thrust vector control (TVC), such as a swiveling thrust chamber or nozzle, the thrust vector may rotate by a few degrees; this causes a slight decrease in the axial thrust that reduces the vehicle velocity increment in item 1. The extra propellant needed to compensate for this small velocity reduction is determined from mission requirements and TVCduty cycles. It could amount to between 0.1 and 4% of the total propellant depending on the average angle of the thrust vector. Thrust vector control systems In some engines with cryogenic propellants, a small portion of propellant is vaporized and then used to pressurize its own tank. A heat exchanger is used to heat liquid oxygen (LOX) from the pump discharge and pressurize the oxygen tank. This method is used in the hydrogen and oxygen tanks of several space vehicles. Auxiliary rocket engines that provide for trajectory corrections, station keeping, maneuvers,or attitude control normally have a series of small restartable thrusters (see Chapter 4). Propellants for these auxiliary thrusters have to be included in the propellant budget when they are supplied from the same feed system and tanks as the larger rocket engine. Depending on the mission, the duty cycle, and the propulsion system concept, auxiliary propulsion systems may consume a significant portion of the budgeted propellants. Anyresidual propellant that clings to tank walls or remains trapped in valves, pipes, injector passages, or cooling passages is unavailable for producing thrust. It can typically amount to between 0.5 and 2% of the total propellant load. All unused residual propellants increase the final vehicle mass at thrust termination and slightly reduce the final vehicle velocity. 7. A loading uncertainty always exists due to variations in tank volume or changes in propellant density or liquid level in the tank. This typically amounts to 0.25 to

0.75% of the total propellant. It depends, in part, on the accuracy of the method of measuring the propellant mass during loading (weighing the vehicle, flow meters, level gauges, etc.). 8. Off-nominal rocket performance refers to manufacturing variations on the of hardwarefromoneenginetoanother(such as slightly different pressure losses in cooling jackets, in injectors and valves, or somewhat different pump characteristics); these cause slight changes in combustion behavior, mixture ratio, and/or specific impulse. When there are such variations in mixture ratio, one of the two liquid propellants

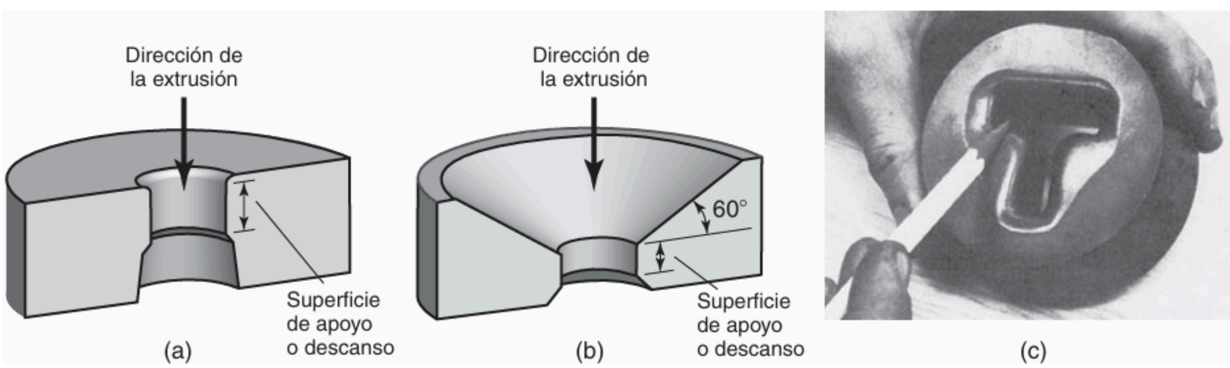


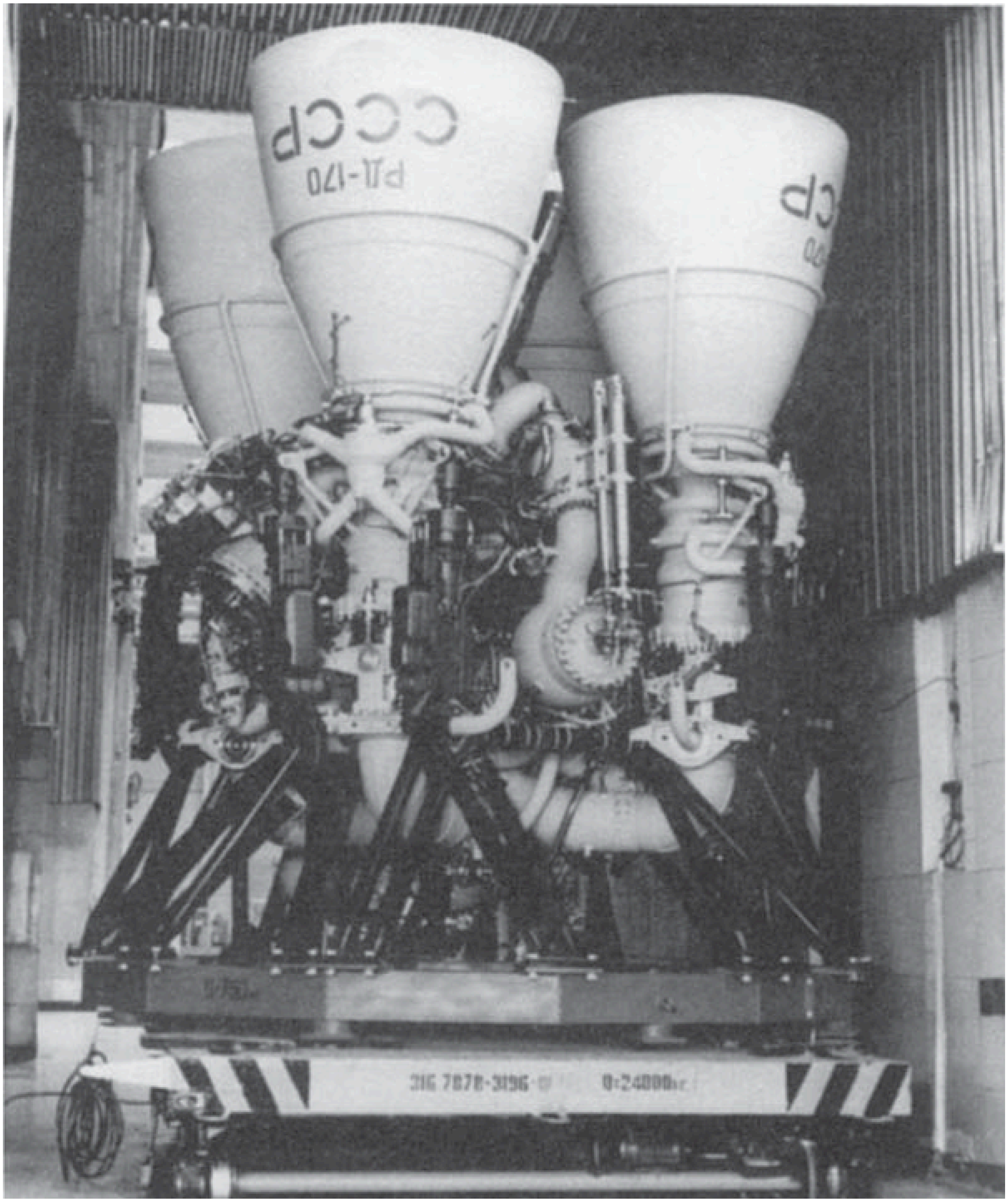
Die and die design. Die design requires considerable experience, as can be seen from Figure 15.7. Angle dies (cutting dies) are used in the extrusion of nonferrous metals, particularly aluminum. Angle dies develop dead metal zones, which in turn form a "die angle" (see Figures 15.6b and c) along which the material flows in the deformation area.

These zones produce extrudates with bright finishes due to the burnishing that occurs as the material flows over the surface of the "die angle."

The pipe is extruded from a solid or hollow billet. Typically, wall thickness is limited to 1 mm (0.040 in) for aluminum, 3 mm (0.125 in) for carbon steels, and 5 mm (0.20 in) for stainless steels.
When solid billets are used, the ram is equipped with a mandrel that drills a hole in the billet. Billets with a pre-drilled hole can also be extruded this way. Due to friction and the severity of deformation, thin-walled extrudates are more difficult to produce than thick-walled ones.
Hollow cross-sections (Fig. 15.8a) can be extruded using welding chamber methods and using various dies known as spider dies, bull's-eye dies, and bridge dies.

Operational factors, such as filling more propellant than needed into a tank or incorrectly adjusting regulators or control valves and can also include changes in flight acceleration from the nominal value, may result in additional propellant requirements. For an engine that has been carefully calibrated and tested, this factor can remain small, usually between 0.1 and 1.0%. 10. When using cryogenic propellants, an allowance for evaporation and for engine cooling down has to be included. This represents the extra propellant mass that is allowed to evaporate (and vented overboard while the vehicle is waiting to be launched) and that is fed through the engine to lower its temperature just before start. It is common practice to replace the evaporated propellant by feeding fresh cryogenic propellant into the tank; this process is called “topping off” and it occurs just before launch. If there are significant time delays between tapping off and launch, additional cryogenic propellant will evaporate, so there is often some uncertainty about the precise amount of propellant in the tanks at launch.





ENGINE DESIGN CONCEPT

Approaches, methods, and resources for designing rocket engines vary depending on organizational philosophy, engine type, and the degree of innovation required.

1. FULLY NEW ENGINE DESIGN
A completely new engine, with novel components and manufacturing methods, often offers the highest performance but is the most expensive and time-consuming option. High development cost is driven by extensive testing requirements — components, full engines, and various flight conditions — to ensure reliability and flight readiness. This path is rare today due to technological maturity.

2. PARTLY NOVEL DESIGN
Most common today is the use of partially new designs with modified or new key components integrated into proven frameworks. These designs balance innovation and risk, minimizing testing due to familiarity with core systems.

3. UPRATED ENGINE DESIGN
An uprated version of a proven engine adds performance by increasing thrust, burn time, propellant flow, and chamber pressure. This often results in increased inert mass due to reinforced structures.

ENGINE DESIGN PROCESS
Design begins by defining engine requirements derived from mission constraints and vehicle design. These include thrust levels, duration, restart capabilities, placement, and operational environments. Choices on propellants, mixture ratios, cooling, ignition, and chamber configurations are made early.

Coordination with systems engineering, customers, and vendors is essential during preliminary and final design stages. One early decision is feed system selection:

- PRESSURIZED FEED SYSTEM
  • Simpler and more reliable
  • Used for low-thrust missions (< 4.5 kN, < 2 min)
  • High-pressure systems yield compact chambers, but heavy tanks
  • Favored for reaction control thrusters and short-duration burns

- PUMP-FED SYSTEM
  • Suitable for high-thrust, long-duration missions
  • Higher chamber pressure (3.5 to 24.1 MPa)
  • Better performance and lighter propellant tanks
  • Increased engine complexity and cost
  • Requires more testing to validate reliability

DESIGN TRADE-OFFS
Design teams must evaluate thrust-to-weight, component layout, inert mass, thermal cooling, vector control, combustion stability, stress, vibration, and safety. Initial sketches and component sizing are followed by performance predictions, structural analysis, and layout optimizations.

Each configuration must balance compactness, weight distribution, performance, and reliability. These evaluations are supported by trade studies, expert input, and iterative testing to refine the engine configuration.

ENGINE DESIGN CONCEPT (EXTENDED WITH MATERIALS AND STRUCTURAL CONSIDERATIONS)

Approaches, methods, and resources for designing rocket engines vary depending on organizational philosophy, engine type, materials technology, and the degree of innovation required.

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1. FULLY NEW ENGINE DESIGN

A completely new engine with novel components, manufacturing methods, and advanced materials (metals and composites) offers the highest performance but entails the highest cost and risk.

Materials Role:

- Nickel-based superalloys (e.g., Inconel 718, Hastelloy X) are commonly selected for turbine blades, combustion chambers, and injector heads due to their high strength at elevated temperatures (up to ~1100 °C).
- Ceramic Matrix Composites (CMCs) are being explored for nozzles and hot structures, reducing cooling needs due to their low thermal conductivity.
- Additive manufacturing enables the integration of lattice structures and topology-optimized titanium components, lowering mass while maintaining strength.
- In early concepts, composite overwrapped pressure vessels (COPVs) with carbon fiber are used for high-pressure helium or oxygen tanks to reduce mass compared to traditional monolithic titanium tanks.

This design path often involves experimental manufacturing and materials characterization (creep, fatigue, oxidation resistance) under relevant thermal and dynamic loads.

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2. PARTLY NOVEL DESIGN

This hybrid approach combines proven engine cycles with modified hardware (e.g., injectors, turbopumps) or updated material systems. It achieves a balance between innovation and development cost.

Materials Innovation:

- Switching from aluminum-lithium alloys to carbon fiber composites in tank structures cuts inert mass and improves volumetric efficiency.
- Use of friction stir welded aluminum alloys (like 2195) for cryogenic tanks, combining manufacturability with strength and compatibility with LOX and LH_2.
- Composite nozzle skirts can be used to extend nozzles with low thermal conductivity materials (e.g., carbon-phenolic) to maximize expansion ratio without significant weight penalties.

Thermal and vibration analysis is critical to verify that new materials do not adversely affect fatigue life or structural integrity when integrated into existing designs.

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3. UPRATED ENGINE DESIGN

An uprated version boosts performance by increasing thrust, burn time, or chamber pressure. This increases structural loading and heat flux, necessitating reinforced materials and thermal protection strategies.

Structural Response to Materials:

- Increased pressure requires thicker walls or stronger alloys (e.g., switching from 6061-T6 to maraging steel or titanium) for chambers and manifolds.
- The nozzle's cooling system may shift from regenerative cooling to ablative or transpiration-cooled composites if chamber pressures increase significantly.
- Reinforced mounts and gimbal actuators often employ high-strength stainless steels (17-4PH or 15-5PH) or Ti-6Al-4V alloys to maintain stiffness and fatigue resistance.

The mass gain from stronger materials must be justified by the thrust increase, often through detailed trade-off and FEA analysis.

ENGINE DESIGN PROCESS

The process begins by defining mission constraints and vehicle integration requirements. These affect material selection early, especially when designing for launch environments involving:

- Acoustic loads
- Thermal cycling
- Cryogenic storage
- Oxidizing or corrosive environments (e.g., LOX-rich hot gases)

FEED SYSTEM CHOICES AND MATERIAL CONSTRAINTS

PRESSURIZED FEED SYSTEM

• Tanks must withstand very high pressures (15–35 MPa). Materials used:

- Titanium alloys for high-pressure, low-weight tanks.
- COPVs with carbon/epoxy or carbon/PEEK for mass efficiency, but with strict fracture control.
  • Simpler valve manifolds made from 316L stainless steel or monel, offering good corrosion resistance.

PUMP-FED SYSTEM

• Turbopumps see extreme mechanical and thermal loads. Materials include:

- Mar-M247 or Rene 41 superalloys in turbine rotors.
- Ti-6Al-4V or aluminum 7075 in pump housing and impellers.
- Cooled copper alloys (e.g., CuCrZr) in combustion chambers for efficient heat transfer.

These systems require close cooperation with materials engineers to predict creep, fatigue, and oxidation in high-cycle turbomachinery.