CHAPTER 17

SELECTION OF ROCKET PROPULSION SYSTEMS

With few exceptions, design problems have several possible engineering solutions from which to select. In this chapter we discuss in general terms the process of selecting propulsion systems for a given mission. Three specific aspects are covered in some detail:

1. A comparison of the merits and disadvantages of liquid propellant rocket engines with solid propellant rocket motors.
2. Some key factors used in evaluating particular propulsion systems and selecting from several competing candidate rocket propulsion systems.
3. The interfaces between the propulsion system and the flight vehicle and/or the overall system.

A propulsion system is really a subsystem of a flight vehicle. The vehicle, in turn, can be part of an overall system. An example of an overall system would be a communications network with ground stations, computers, transmitters, and several satellites; each satellite is a flight vehicle and has an attitude-control propulsion system with specific propulsion requirements. The length of time in orbit is a system parameter that affects the satellite size and the total impulse requirement of its propulsion system.

Subsystems of a vehicle system (such as the structure, power supply, propulsion, guidance, control, communications, ground support, or thermal control) often pose conflicting requirements. *Only through careful analyses and system engineering studies is it possible to find compromises that allow all subsystems to operate satisfactorily and be in harmony with each other.* The subject of engineering design has advanced considerably in recent times and general references such as Ref. 17–1 should be consulted for details. Other works address the design of space systems (e.g., Refs. 17–2, 17–3) and the design of liquid propellant engines (e.g., Ref. 17–4).

All mission (overall system), vehicle, and propulsion system *requirements* can be related to either performance, cost, or reliability. For a given mission, one of these criteria is usually more important than the other two. There is a strong interdependence between the three levels of requirements and the three categories of criteria mentioned above. Some of the characteristics of the propulsion system (which is usually a second-tier subsystem) can have a strong influence on the vehicle and vice versa. An improvement in the propulsion performance, for example, can have a direct influence on the vehicle size, overall system cost, or life (which can be translated into reliability and cost).

17.1. SELECTION PROCESS

The selection process is a part of the overall design effort for the vehicle system and its rocket propulsion system. The selection is based on a *series of criteria*, which are based on the requirements and which will be used to evaluate and compare alternate propulsion systems. This process for determining the most suitable rocket propulsion system depends on the application, the ability to express many of the characteristics of the propulsion systems quantitatively, the amount of applicable data that are available, the experience of those responsible for making the selection, and the available time and resources to examine the alternate propulsion systems. What is described here is one somewhat idealized selection process as depicted in Fig. 17–1, but there are alternate sequences and other ways to do this job.

All propulsion selections start with a definition of the overall system and its mission. The mission's objectives, payload, flight regime, trajectory options, launch scenarios, probability of mission success, and other requirements have to be defined, usually by the organization responsible for the overall system. Next, the vehicle has to be defined in conformance with the stated flight application. Only then can the propulsion system requirements be derived for the specific mission and/or vehicle. For example, from the mission requirements it is possible to determine the required mass fraction, the minimum specific impulse, and the approximate total propellant mass, as shown in Chapter 4. Furthermore, this can include propulsion parameters such as thrust–time profile, propellant mass fraction, allowable volume or envelope, typical pulsing duty cycle, ambient temperature limits, thrust vector control needs, vehicle interfaces, likely number of units to be built, prior applicable experience, time schedule requirements, and cost limits.

Since the total vehicle's performance, flight control, operation, or maintenance are usually critically dependent on the performance, control, operation, or maintenance of the rocket propulsion system (and vice versa), the process will usually go through several iterations in defining both the vehicle and propulsion requirements, which are then documented. This iterative process

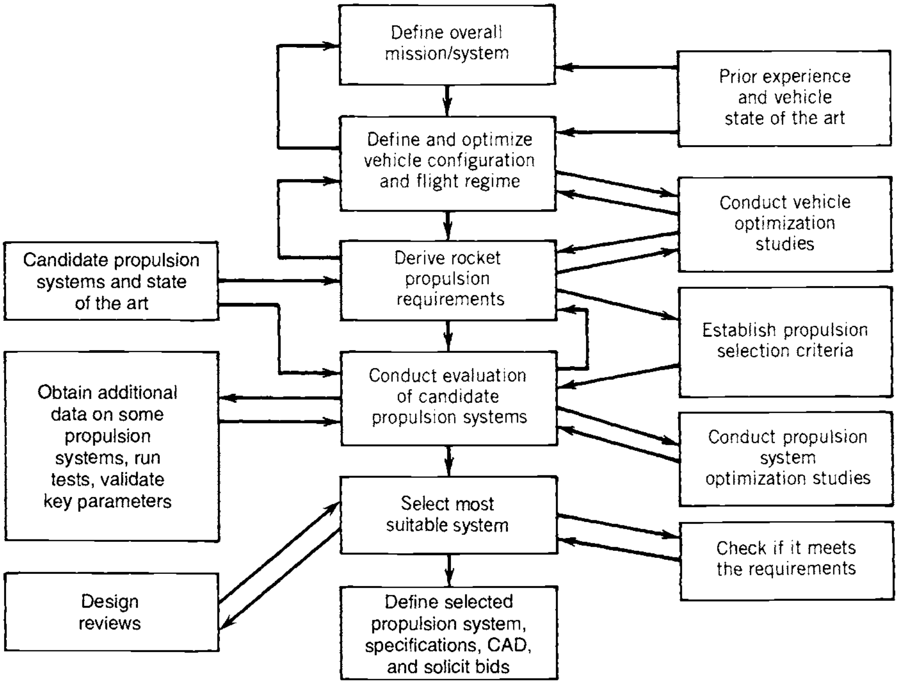

FIGURE 17–1. Idealized process for selecting propulsion systems.

involves both the system organization (or the vehicle/system contractor) and one or more propulsion organizations (or rocket propulsion contractors). Documentation can take many forms; electronic computers have expanded their capability to network, record, and retrieve documents.

A number of competing candidate systems are usually evaluated. They may be proposed by different rocket propulsion organizations, perhaps on the basis of modifications of some existing rocket propulsion system, or may include some novel technology, or may be new types of systems specifically configured to fit the vehicle or mission needs. In making these evaluations it will be necessary to compare several candidate propulsion systems with each other and to rank-order them (in accordance with the selection criteria) on how well they meet each requirement. This requires analysis of each candidate system and also, often, some additional testing. For example, statistical analyses of the functions, failure modes, and safety factors of all key components can lead to quantitative reliability estimates. For some criteria, such as safety or prior related experience, it may not be possible to compare candidate systems quantitatively but only somewhat subjectively.

Various rocket parameters for a particular mission need to be optimized. Trade-off studies are used to determine the number of thrust chambers, engines or motors, optimum chamber pressure, best packaging of the propulsion system(s), optimum mixture ratio, optimum number of stages in a multistage vehicle, best trajectory, optimum nozzle area ratio, number of nozzles, TVC (thrust vector control) concept, optimum propellant mixture ratio or solid propellant formulation, and so on. These trade-off studies are usually aimed at achieving the highest performance, highest reliability, or lowest cost for a given vehicle and mission. Some of these optimizations are needed early in the process to establish propulsion criteria, and some are needed in evaluating competing candidate propulsion systems.

Early in the selection process a tentative recommendation is usually made as to whether the propulsion system should be a solid propellant motor, a liquid propellant engine, an electrical propulsion system, or some other type. Each type has its own regime of thrust, specific impulse, thrust-to-weight ratio (acceleration), or likely duration, as shown in Table 2–1 and Fig. 2–5; these factors are listed for several chemical rocket engines and several types of non-chemical engines. Liquid engines and solid motors are covered in Chapters 6 to 14, hybrids in Chapter 15.

If an existing vehicle is to be upgraded or modified, its propulsion system is usually also improved or modified (e.g., higher thrust, more total impulse, or faster thrust vector control). While there might still be some trade-off studies and optimization of the propulsion parameters that can be modified, one normally does not consider an entirely different propulsion system as is done in an entirely new vehicle or mission. Also, it is rare that an identical rocket propulsion system is selected for two different applications; usually, some design changes and interface modifications are necessary to adapt an existing rocket propulsion system to another application. Proven existing and qualified propulsion systems, that fit the desired requirements, usually have an advantage in cost and reliability.

Electric propulsion systems have a set of unique applications with low thrusts, low accelerations, trajectories exclusively in space, high specific impulse, long operating times, and generally a relatively massive power supply system. They perform well in certain space transfer and orbit maintenance missions. With more electric propulsion systems flying than ever before, the choice of proven electric propulsion thruster types is becoming larger. These systems, together with design approaches, are described in Chapter 19 and Ref. 17–3.

When a chemical rocket is deemed most suitable for a particular application, the selection has to be made between a liquid propellant engine, a solid propellant motor, or a hybrid propulsion system. Some of the major advantages and disadvantages of liquid propellant engines and solid propellant motors are given in Tables 17–1 to 17–4. These lists are general in nature; some items can be controversial, and a number are restricted to particular applications. Items from this list can be transformed into evaluation criteria. For a specific mission, the relevant items on these lists would be rank-ordered in accordance with their relative importance. A quantification of many of the items would be

TABLE 17–1. Solid Propellant Rocket Advantages

Simple design (few or no moving parts).
Easy to operate (little preflight checkout).
Ready to operate quickly.
Will not leak, spill, or slosh.
Sometimes less overall weight for low total impulse application.
Can be throttled or stopped and restarted (a few times) if preprogrammed.
Can provide TVC, but at increased complexity.
Can be stored for 5 to 25 years.
Usually, higher overall density; this allows a more compact package, a smaller vehicle (less drag).
Some propellants have nontoxic, clean exhaust gases, but at a performance penalty.
Some grain and case designs can be used with several nozzles.
Thrust termination devices permit control over total impulse.
Ablation and gasification of insulator, nozzle, and liner materials contribute to mass flow and thus to total impulse.
Some tactical missile motors have been produced in large quantities (over 200,000 per year).
Can be designed for recovery, refurbishing, and reuse (Space Shuttle solid rocket motor).

TABLE 17–2. Liquid Propellant Rocket Advantages

Usually highest specific impulse; for a fixed propellant mass, this increases the vehicle velocity increment and the attainable mission velocity.
Can be randomly throttled and randomly stopped and restarted; can be efficiently pulsed (some small thrust sizes over 250,000 times). Thrust–time profile can be randomly controlled; this allows a reproducible flight trajectory.
Cutoff impulse can be controllable wth thrust termination device (better control of vehicle terminal velocity).
Can be largely checked out just prior to operation. Can be tested at full thrust on ground or launch pad prior to flight.
Can be designed for reuse after field services and checkout.
Thrust chamber (or some part of the vehicle) can be cooled and made lightweight.
Storable liquid propellants have been kept in vehicle for more than 20 years and engine can be ready to operate quickly.
With pumped propulsion feed systems and large total impulse, the inert propulsion system mass (including tanks) can be very low (thin tank walls and low tank pressure), allowing a high propellant mass fraction.
Most propellants have nontoxic exhaust, which is environmentally acceptable.
Same propellant feed system can supply several thrust chambers in different parts of the vehicle.
Can modify operating conditions during firing to prevent some failures that would otherwise result in the loss of the mission or vehicle.
Can provide component redundancy (e.g., dual check valves or extra thrust chamber) to enhance reliability.
With multiple engines, can design for operation with one or more shutoff (engine out capability).
The geometry of low-pressure tanks can be designed to fit most vehicles' space constraints (i.e., mounted inside wing or nose cone).
The placement of propellant tanks within the vehicle can minimize the travel of the center of gravity during powered flight. This enhances the vehicle's flight stability and reduces control forces.
Plume radiation and smoke are usually low.

TABLE 17–3. Solid Propellant Rocket Disadvantages

Explosion and fire potential is larger; failure can be catastrophic; most cannot accept bullet impact or being dropped onto a hard surface.
Many require environmental permit and safety features for transport on public conveyances.
Under certain conditions some propellants and grains can detonate.
Cumulative grain damage occurs through temperature cycling or rough handling; this limits the useful life.
If designed for reuse, it requires extensive factory rework and new propellants.
Requires an ignition system.
Each restart requires a separate ignition system and additional insulation—in practice, one or two restarts.
Exhaust gases are usually toxic for composite propellants containing ammonium perchlorate.
Some propellants or propellant ingredients can deteriorate (self-decompose) in storage.
Most solid propellant plumes cause more radio frequency attenuation than liquid propellant plumes.
Only some motors can be stopped at random, but motor becomes disabled (not reusable).
Once ignited, cannot change predetermined thrust or duration. A moving pintle design with a variety throat area will allow random thrust changes, but experience is limited.
If propellant contains more than a few percent particulate carbon, aluminum, or other metal, the exhaust will be smoky and the plume radiation will be intense.
Integrity of grain (cracks, unbonded areas) is difficult to determine in the field.
Thrust and operating duration will vary with initial ambient grain temperature and cannot be easily controlled. Thus the flight path, velocity, altitude, and range of a motor will vary with the grain temperature.
Large boosters take a few seconds to start.
Thermal insulation is required in almost all rocket motors.
Cannot be tested prior to use.
Needs a safety provision to prevent inadvertent ignition, which would lead to an unplanned motor firing. Can cause a disaster.

TABLE 17–4. Liquid Propellant Rocket Disadvantages

Relatively complex design, more parts or components, more things to go wrong.
Cryogenic propellants cannot be stored for long periods except when tanks are well insulated and escaping vapors are recondensed. Propellant loading occurs at the launch stand and requires cryogenic propellant storage facilities.
Spills or leaks of several propellants can be hazardous, corrosive, toxic, and cause fires, but this can be minimized with gelled propellants.
More overall weight for most short-duration, low-total-impulse applications (low propellant mass fraction).
Nonhypergolic propellants require an ignition system.
Tanks need to be pressurized by a separate pressurization subsystem. This can require high-pressure inert gas storage (2000 to 10,000 psi) for long periods of time.
More difficult to control combustion instability.
Bullet impact will cause leaks, sometimes a fire, but usually no detonations; gelled propellants can minimize or eliminate these hazards.
A few propellants (e.g., red fuming nitric acid) give toxic vapors or fumes.
Usually requires more volume due to lower average propellant density and the relatively inefficient packaging of engine components.
If vehicle breaks up and fuel and oxidizer are intimately mixed, it is possible (but not likely) for an explosive mixture to be created.
Sloshing in tank can cause a flight stability problem, but it can be minimized with baffles.
If tank outlet is uncovered, aspirated gas can cause combustion interruption or combustion vibration.
Smoky exhaust (soot) plume can occur with some hydrocarbon fuels.
Needs special design provisions for start in zero gravity.
With cryogenic liquid propellants there is a start delay caused by the time needed to cool the system flow passage hardware to cryogenic temperatures.
Life of cooled large thrust chambers may be limited to perhaps 100 or more starts.
High-thrust unit requires several seconds to start.

needed. These tables apply to generic rocket propulsion systems; they do not cover systems that use liquid–solid propellant combinations.

A favorite student question has been: Which are better, solid or liquid propellant rockets? A clear statement of strongly favoring one or the other can only be made when referring to a specific set of flight vehicle missions. Today, solid propellant motors seem to be preferred for tactical missiles (air-to-air, air-to-surface, surface-to-air, or short-range surface-to-surface) and ballistic missiles (long- and short-range surface-to-surface) because instant readiness, compactness, and their lack of spills or leaks of hazardous liquids are important criteria for these applications. Liquid propellant engines seem to be preferred for space-launched main propulsion units and upper stages, because of their higher specific impulse, relatively clean exhaust gases, and random throttling capability. They are favored for post-boost control systems and attitude control systems, because of their random multiple pulsing capability with precise cutoff impulse, and for pulsed axial and lateral thrust propulsion on hit-to-kill defensive missiles. However, there are always some exceptions to these preferences.

When selecting the rocket propulsion system for a major new multiyear high-cost project, considerable time and effort are spent in evaluation and in developing rational methods for quantitative comparison. In part this is in response to government policy as well as international competition. Multiple studies are done by competing system organizations and competing rocket propulsion organizations; formal reviews are used to assist in considering all the factors, quantitatively comparing important criteria, and arriving at a proper selection.

17.2. CRITERIA FOR SELECTION

Many criteria used in selecting a particular rocket propulsion system are peculiar to the particular mission or vehicle application. However, some of these selection factors apply to a number of applications, such as those listed in Table 17–5. Again, this list is incomplete and not all the criteria in this table apply to every application. The table can be used as a checklist to see that none of the criteria listed here are omitted.

Here are some examples of important criteria in a few specific applications. For a spacecraft that contains optical instruments (e.g., telescope, horizon seeker, star tracker, or infrared radiation seeker) the exhaust plume must be free of possible contaminants that may deposit or condense on photovoltaic cells, radiators, optical windows, mirrors, or lenses and degrade their performance, and free of particulates that could scatter sunlight into the instrument aperture, which could cause erroneous signals. Conventional composite solid propellants and pulsing storable bipropellants are usually not satisfactory, but cold or heated clean gas jets (H_2, Ar, N_2, etc.) and monopropellant hydrazine reaction gases are usually acceptable. Another example is an emphasis on smokeless propellant exhaust plumes, so as to make visual detection of a smoke or vapor trail very difficult. This applies particularly to tactical missile applications. Only a few solid propellants and several liquid propellants would be truly smokeless and free of a vapor trail under all weather conditions.

Several selection criteria may be in conflict with each other. For example, some propellants with a very high specific impulse are more likely to experience combustion instabilities. In liquid propellant systems, where the oxidizer tank is pressurized by a solid propellant gas generator and where the fuel-rich hot gases are separated by a thin flexible diaphragm from the oxidizer liquid, there is a trade-off between a very compact system and the potential for a damaging system failure (fire, possible explosion, and malfunction of system) if the diaphragm leaks or tears. In electric propulsion, high specific impulse is usually accompanied by heavy power generating and conditioning equipment.

Actual selection will depend on the balancing of the various selection factors in accordance with their importance, benefits, or potential impact on the system, and on quantifying as many of these selection factors as possible through analysis, extrapolation of prior experience/data, cost estimates, weights, and/or separate tests. Design philosophies such as the *Taguchi methodology* and *TQM* (total quality management) can be inferred (Refs. 17–1 and 17–2). Layouts, weight estimates, center-of-gravity analyses, vendor cost estimates, preliminary stress or thermal analysis, and other preliminary design efforts are usually necessary to put numerical values on some of the selection parameters. A comparative examination of the interfaces of alternate propulsion systems is also a part of the process. Some propulsion requirements are incompatible with each other and a compromise has to be made. For example, the monitoring of extra sensors can prevent the occurrence of certain types of failure and thus enhance the propulsion system reliability, yet the extra sensors and control components contribute to the system complexity and their possible failures will reduce the overall reliability. The selection process may also include feedback when the stated propulsion requirements cannot be met or do not make sense, and this can lead to a revision of the initial mission requirements or definition.

Once the cost, performance, and reliability drivers have been identified and quantified, the selection of the best propulsion system for a specified mission proceeds. The final propulsion requirement may come as a result of several iterations and will usually be documented, for example in a *propulsion requirement specification*. A substantial number of records is required (such as engine or motor acceptance documents, CAD (computer-aided design) images, parts lists, inspection records, laboratory test data, etc.). There are many specifications associated with design and manufacturing as well as with vendors, models, and so on. There must also be a disciplined procedure for approving and making design and manufacturing changes. This now becomes the starting point for the design and development of the propulsion system.

TABLE 17.5. Typical Criteria Used in the Selection of a Particular Rocket Propulsion System

Mission Definition

Purpose, function, and final objective of the mission of an overall system are well defined and their implications well understood. There is an expressed need for the mission, and the benefits are evident. The mission requirements are well defined. The payload, flight regime, vehicle, launch environment, and operating conditions are established. The risks, as perceived, appear acceptable. The project implementing the mission must have political, economic, and institutional support with assured funding. The propulsion system requirements, which are derived from mission definition, must be reasonable and must result in a viable propulsion system.

Affordability (Cost)

Life cycle costs are low. They are the sum of R&D costs, production costs, facility costs, operating costs, and decommissioning costs, from inception to the retirement of the system (see Ref. 17–5). Benefits of achieving the mission should appear to justify costs. Investment in new facilities should be low. Few, if any, components should require expensive materials. For commercial applications, such as communications satellites, the return on investment must look attractive. No need to hire new, inexperienced personnel, who need to be trained and are more likely to make expensive errors.

System Performance

The propulsion system is designed to optimize vehicle and system performance, using the most appropriate and proven technology. Inert mass is reduced to a practical minimum, using improved materials and better understanding of loads and stresses. Residual (unused) propellant is minimal. Propellants have the highest practical specific impulse without undue hazards, without excessive inert propulsion system mass, and with simple loading, storing, and handling (the specific impulse of the propulsion system is defined in Section 2.1 and is further discussed in Section 19.1). Thrust–time profiles and number of restarts must be selected to optimize the vehicle mission. Vehicles must operate with adequate performance for all the possible conditions (pulsing, throttling, temperature excursions, etc.). Vehicles should be storable over a specified lifetime. Will meet or exceed operational life. Performance parameters (e.g., chamber pressure, ignition time, or nozzle area ratio) should be near optimum for the selected mission. Vehicle should have adequate TVC. Plume characteristics are satisfactory.

Survivability (Safety)

All hazards are well understood and known in detail. If failure occurs, the risk of personnel injury, damage to equipment, facilities, or the environment is minimal. Certain mishaps or failures will result in a change in the operating condition or the safe shutdown of the propulsion system. Applicable safety standards must be obeyed. Inadvertent energy input to the propulsion system (e.g., bullet impact, external fire) should not result in a detonation. The probability for any such drastic failures should be very low. Safety monitoring and inspections must have proven effective in identifying and preventing a significant share of possible incipient failures (see Ref. 17–6). Adequate safety factors must be included in the design. Spilled liquid propellants should cause no undue hazards. All systems and procedures must conform to the safety standards. Launch test range has accepted the system as being safe enough to launch.

Reliability

Statistical analyses of test results indicate a satisfactory high-reliability level. Technical risks, manufacturing risks, and failure risks are very low, well understood, and the impact on the overall system is known. There are few complex components. Adequate storage and operating life of components (including propellants) have been demonstrated. Proven ability to check out major part of propulsion system prior to use or launch. If certain likely failures occur, the system must shut down safely. Redundancy of key components should be provided, where effective. High probability that all propulsion functions must be performed within the desired tolerances. Risk of combustion vibration or mechanical vibration should be minimal.

TABLE 17–5 (*Continued*)

Controllability
Thrust buildup and decay are within specified limits. Combustion process is stable. The time responses to control or command signals are within acceptable tolerances. Controls need to be foolproof and not inadvertently create a hazardous condition. Thrust vector control response must be satisfactory. Mixture ratio control must assure nearly simultaneous emptying of the fuel and oxidizer tanks. Thrust from and duration of afterburning should be negligible. Accurate thrust termination feature must allow selection of final velocity of flight. Changing to an alternate mission profile should be feasible. Liquid propellant sloshing and pipe oscillations need to be adequately controlled. In a zero-gravity environment, a propellant tank should be essentially fully emptied.

Maintainability
Simple servicing, foolproof adjustments, easy parts replacement, and fast, reliable diagnosis of internal failures or problems. Minimal hazard to service personnel. There must be easy access to all components that need to be checked, inspected, or replaced. Trained maintenance personnel are available. Good access to items which need maintenance.

Geometric Constraints
Propulsion system fits into vehicle, can meet available volume, specified length, or vehicle diameter. There is usually an advantage for the propulsion system that has the smallest volume or the highest average density. If the travel of the center of gravity has to be controlled, as is necessary in some missions, the propulsion system that can do so with minimum weight and complexity will be preferred.

Prior Related Experience
There is a favorable history and valid, available, relevant data of similar propulsion systems supporting the practicality of the technologies, manufacturability, performance, and reliability. Experience and data validating computer simulation programs are available. Experienced, skilled personnel are available.

Operability
Simple to operate. Validated operating manuals exist. Procedures for loading propellants, arming the power supply, launching, igniter checkout, and so on, must be simple. If applicable, a reliable automatic status monitoring and check-out system should be available. Crew training needs to be minimal. Should be able to ship the loaded vehicle on public roads or railroads without need for environmental permits and without the need for a decontamination unit and crew to accompany the shipment. Supply of spare parts must be assured. Should be able to operate under certain emergency and overload conditions.

Producibility
Easy to manufacture, inspect, and assemble. All key manufacturing processes are well understood. All materials are well characterized, critical material properties are well known, and the system can be readily inspected. Proven vendors for key components have been qualified. Uses standard manufacturing machinery and relatively simple tooling. Hardware quality and propellant properties must be repeatable. Scrap should be minimal. Designs must make good use of standard materials, parts, common fasteners, and off-the-shelf components. There should be maximum use of existing manufacturing facilities and equipment. Excellent reproducibility, i.e., minimal operational variation between identical propulsion units. Validated specifications should be available for major manufacturing processes, inspection, parts fabrication, and assembly.

Schedule
The overall mission can be accomplished on a time schedule that allows the system benefits to be realized. R&D, qualification, flight testing, and/or initial operating capability are completed on a preplanned schedule. No unforeseen delays. Critical materials and qualified suppliers must be readily available.

TABLE 17–5 *(Continued)*

Environmental Acceptability
No unacceptable damage to personnel, equipment, or the surrounding countryside. No toxic species in the exhaust plume. No serious damage (e.g., corrosion) due to propellant spills or escaping vapors. Noise in communities close to a test or launch site should remain within tolerable levels. Minimal risk of exposure to cancer-causing chemicals. Hazards must be sufficiently low, so that issues on environmental impact statements are not contentious and approvals by environmental authorities become routine. There should be compliance with applicable laws and regulations. No unfavorable effects from currents generated by an electromagnetic pulse, static electricity, or electromagnetic radiation.

Reusability
Some applications (e.g., Shuttle main engine, Shuttle solid rocket booster, or aircraft rocket-assisted altitude boost) require a reusable rocket engine. The number of flights, serviceability, and the total cumulative firing time then become key requirements that will need to be demonstrated. Fatigue failure and cumulative thermal stress cycles can be critical in some of the system components. The critical components have been properly identified; methods, instruments, and equipment exist for careful check-out and inspection after a flight or test (e.g., certain leak tests, inspections for cracks, bearing clearances, etc.). Replacement and/or repair of unsatisfactory parts should be readily possible. Number of firings before disassembly should be large, and time interval between overhauls should be long.

Other Criteria
Radio signal attenuation by exhaust plume to be low. A complete propulsion system, loaded with propellants and pressurizing fluids, can be storable for a required number of years without deterioration or subsequent performance decrease. Interface problems are minimal. Provisions for safe packaging and shipment are available. The system includes features that allow decommissioning (such as to deorbit a spent satellite) or disposal (such as the safe removal and disposal of over-age propellant from a refurbishable rocket motor).

17.3. INTERFACES

In Section 2 of this chapter the interfaces between the propulsion system and the vehicle and/or overall system were identified as some of the criteria to be considered in the selection of a propulsion system. A few rocket propulsion systems are easy to integrate and interface with the vehicles. Furthermore, these interfaces are an important aspect of a disciplined design and development effort. Table 17–6 gives a partial listing of typical interfaces that have been considered in the propulsion system selection, design, and development. It too may be a useful checklist. The interfaces assure system functionality and compatibility between the propulsion system and the vehicle with its other subsystems under all likely operating conditions and mission options. Usually, an interface document or specification is prepared and it is useful to designers, operating personnel, or maintenance people.

Besides cold gas systems, a simple solid propellant rocket motor has the fewest and the least complex set of interfaces. A monopropellant liquid rocket engine also has relatively few and simple interfaces. A solid propellant motor with TVC and a thrust termination capability has additional interfaces, compared to a simple motor. Bipropellant rocket engines are more complex and the

TABLE 17–6. Typical Interfaces between Rocket Propulsion Systems and Flight Vehicle

Interface Category	Typical Detailed Interfaces
Structural	Interface (geometry/location/fastening mechanism) for mounting propulsion system
	Restraints on masses, moments of inertia, or the location of the center of gravity
	Type and degree of damping to minimize vibrations
	Attachment of vehicle components to propulsion system structure, such as wings, electrical components, TVC, or skirts
	Loads (aerodynamic, acceleration, vibrations, thrust, sloshing, dynamic interactions) from vehicle to propulsion system, and vice versa
	Dimensional changes due to loads and/or heating and means for allowing expansions or deflections to occur without overstress
	Interactions from vibration excitation
Mechanical	Interfaces for electric connectors; for pneumatic, hydraulic, propellant pipe connections
	Volume/space available and geometric interference with other subsystems
	Access for assembly, part replacement, inspection, maintenance, repair
	Lifting or handling devices, and lifting attachment locations
	Measurement and adjustment of alignment of fixed nozzles
	Matching of thrust levels when two or more units are fired simultaneously
	Sealing or other closure devices to minimize air breathing and moisture condensation in vented tanks, cases, nozzles, porous insulation, or open pipes
Power	Source and availability of power (usually electric, but sometimes hydraulic or pneumatic) and their connection interfaces
	Identification of all users of power (solenoids, instruments, TVC, igniter, sensors) and their duty cycles. Power distribution to the various users
	Conversion of power to needed voltages, dc/ac, frequencies, or power level
	Electric grounding connections of rocket motors, certain electric equipment or pyrotechnic devices, to minimize voltage buildup and prevent electrostatic discharges
	Shielding of sensitive wires and/or high-voltage components
	Telemetry and radio communications interface

TABLE 17–6 (*Continued*)

Interface Category	Typical Detailed Interfaces
	Heaters (e.g., to keep hydrazine from freezing or to prevent ice formation and accumulation with cryogenic propellants)
	Interfaces with antennas, wiring, sensors, and electronic packages located in the propulsion section of the vehicle
	Thermal management of heat generated in electric components
Propellants	Sharing of propellants between two or more propulsion systems (main thrust chambers and attitude control thrusters)
	Control of sloshing to prevent center of gravity (CG) excursions or to prevent gas from entering the liquid propellant tank outlet
	Design of solid propellant grain or liquid propellant tanks to limit CG travel
	Loading/unloading provisions for liquid propellants
	Access for X-ray inspection of grain for cracks or unbonded areas, while installed
	Access to visually inspect grain cavity for cracks
	Access to inspect cleanliness of tanks, pipes, valves
	Connection of drain pipes for turbopump seal leakage
Vehicle flight control and communications	Command signals (start/stop/throttle, etc.) interface
	Feedback signals (monitoring the status of the propulsion system, e.g., valve positions, thrust level, remaining propellant, pump speed, pressures, temperatures); telemetering devices
	Range safety destruct system
	Attitude control: command actuation in pitch, yaw, or roll; feedback of TVC angle position and slew rate, duty cycle, safety limits
	Division of control logic, computer capability, or data processing and databases between propulsion system controller, vehicle controller, test stand controller, or ground-based computer/controller system
	Number and type of fault detection devices and their connection methods
Thermal	Heat from rocket gas/exhaust plume or aerodynamic airflow will not overheat critical exposed components
	Transfer of heat between propulsion system and the vehicle
	Provisions for venting cryogenic propellant tanks overboard
	Radiators for heat rejection
	Interfaces for cooling, if any

TABLE 17–6. (*Continued*)

Interface Category	Typical Detailed Interfaces
Plume	Radiative and convective heating of vehicle by plume
	Impingement (forces and heating) of plume from attitude control nozzle with vehicle components
	Noise effects on equipment and surrounding areas
	Contamination or condensation of plume species on vehicle or payload parts, such as solar panels, optical components of instruments, or radiation surfaces
	Attenuation of radio signals
Safety	Condition monitoring and sensing of potential imminent failure and automatic remedial actions to prevent or remedy impending failure (e.g., reduce thrust or shut off one of several redundant propulsion systems)
	Arming and disarming of igniter. Access to safe & arm device
	Safe disposal of hazardous liquid propellant leaking through pump shaft seal, valve stem seal, or vented from tanks
	Designed to avoid electrostatic buildup and discharge
Ground support equipment	Interface with standby power system
	Interfaces with heating/cooling devices on ground at launch or test site
	Supply and loading method for liquid propellant, pressurizing gases, and other fluids. Also, interface with method for unloading these
	Electromechanical checkout
	Interface with ground systems for flushing, cleaning, drying the tanks and piping
	Transportation vehicles/boxes/vehicle erection devices
	Lifting devices and handling equipment
	Interface with fire extinguishing equipment on ground

number and difficulty of interfaces increase if they have a turbopump feed system, throttling features, TVC, or pulsing capability. In electric propulsion systems the number and complexity of interfaces is highest for an electrostatic thruster with pulsing capability, when compared to electrothermal systems. More complex electrical propulsion systems generally give higher values of specific impulse. If the mission includes the recovery and reuse of the propulsion system or a manned vehicle (where the crew can monitor and override the propulsion system commands), this will introduce additional interfaces, safety features, and requirements.

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