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TRACCIA 10

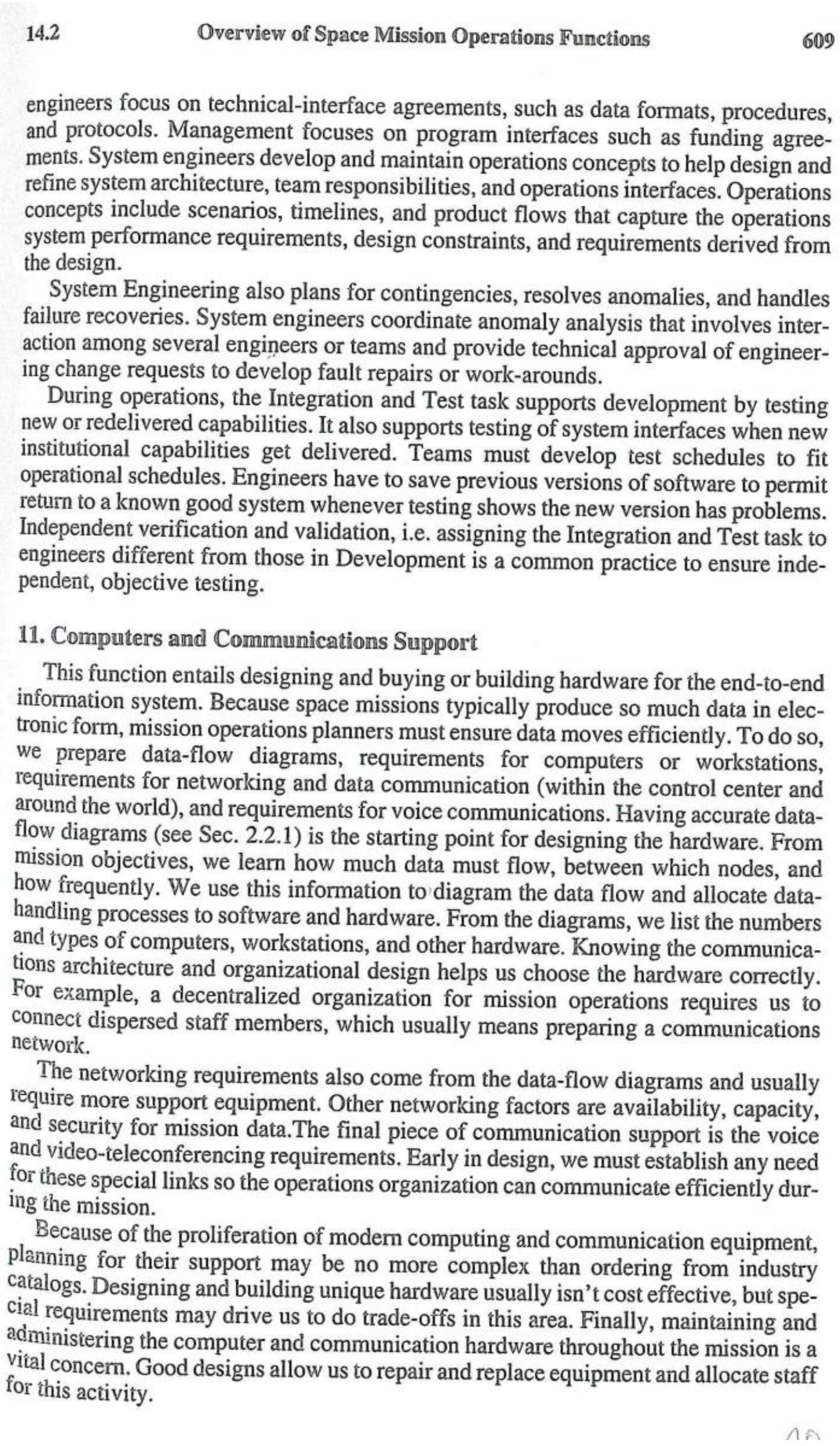
1) *ILLUSTRARE LE PROPRIE ATTIVITÀ/ESPERIENZE PROFESSIONALI.*
2) *DESCRIVERE COME VANNO TRATTATE LE MODIFICHE AI REQUISITI SCIENTIFICI E FUNZIONALI INDIVIDUATE IN FASE DI PROGETTAZIONE.*
3) *IL CANDIDATO DESCRIVA I PRINCIPALI STRUMENTI DI AUTOTUTELA A DISPOSIZIONE DELLA PUBBLICA AMMINISTRAZIONE (ANNULLAMENTO, REVOCA, SOSPENSIONE).*

Esercitazione:

4) *IL CANDIDATO REALIZZI IN WORD UN DOCUMENTO CHE SINTETIZZI LA SUA ISTRUZIONE E FORMAZIONE.*

Prova di Inglese:

5) LEGGERE E TRADURRE IL TESTO IN INGLESE SOTTOPOSTO DALLA COMMISSIONE.



engineers focus on technical-interface agreements, such as data formats, procedures, and protocols. Management focuses on program interfaces such as funding agreements. System engineers develop and maintain operations concepts to help design and refine system architecture, team responsibilities, and operations interfaces. Operations concepts include scenarios, timelines, and product flows that capture the operations system performance requirements, design constraints, and requirements derived from the design.

System Engineering also plans for contingencies, resolves anomalies, and handles failure recoveries. System engineers coordinate anomaly analysis that involves interaction among several engineers or teams and provide technical approval of engineering change requests to develop fault repairs or work-arounds.

During operations, the Integration and Test task supports development by testing new or redelivered capabilities. It also supports testing of system interfaces when new institutional capabilities get delivered. Teams must develop test schedules to fit operational schedules. Engineers have to save previous versions of software to permit return to a known good system whenever testing shows the new version has problems. Independent verification and validation, i.e. assigning the Integration and Test task to engineers different from those in Development is a common practice to ensure independent, objective testing.

11. Computers and Communications Support

This function entails designing and buying or building hardware for the end-to-end information system. Because space missions typically produce so much data in electronic form, mission operations planners must ensure data moves efficiently. To do so, we prepare data-flow diagrams, requirements for computers or workstations, requirements for networking and data communication (within the control center and around the world), and requirements for voice communications. Having accurate data-flow diagrams (see Sec. 2.2.1) is the starting point for designing the hardware. From mission objectives, we learn how much data must flow, between which nodes, and how frequently. We use this information to diagram the data flow and allocate data-handling processes to software and hardware. From the diagrams, we list the numbers and types of computers, workstations, and other hardware. Knowing the communications architecture and organizational design helps us choose the hardware correctly. For example, a decentralized organization for mission operations requires us to connect dispersed staff members, which usually means preparing a communications network.

The networking requirements also come from the data-flow diagrams and usually require more support equipment. Other networking factors are availability, capacity, and security for mission data.The final piece of communication support is the voice and video-teleconferencing requirements. Early in design, we must establish any need for these special links so the operations organization can communicate efficiently during the mission.

Because of the proliferation of modern computing and communication equipment, planning for their support may be no more complex than ordering from industry catalogs. Designing and building unique hardware usually isn't cost effective, but special requirements may drive us to do trade-offs in this area. Finally, maintaining and administering the computer and communication hardware throughout the mission is a vital concern. Good designs allow us to repair and replace equipment and allocate staff for this activity.

TRACCIA 6

1) *ILLUSTRARE LE PROPRIE ATTIVITÀ/ESPERIENZE PROFESSIONALI.*

2) *DESCRIVERE L'IMPORTANZA DEL CONTROLLO DI CONFIGURAZIONE DEI DOCUMENTI ED IL PROCESSO DI APPROVAZIONE DELLE MODIFICHE.*

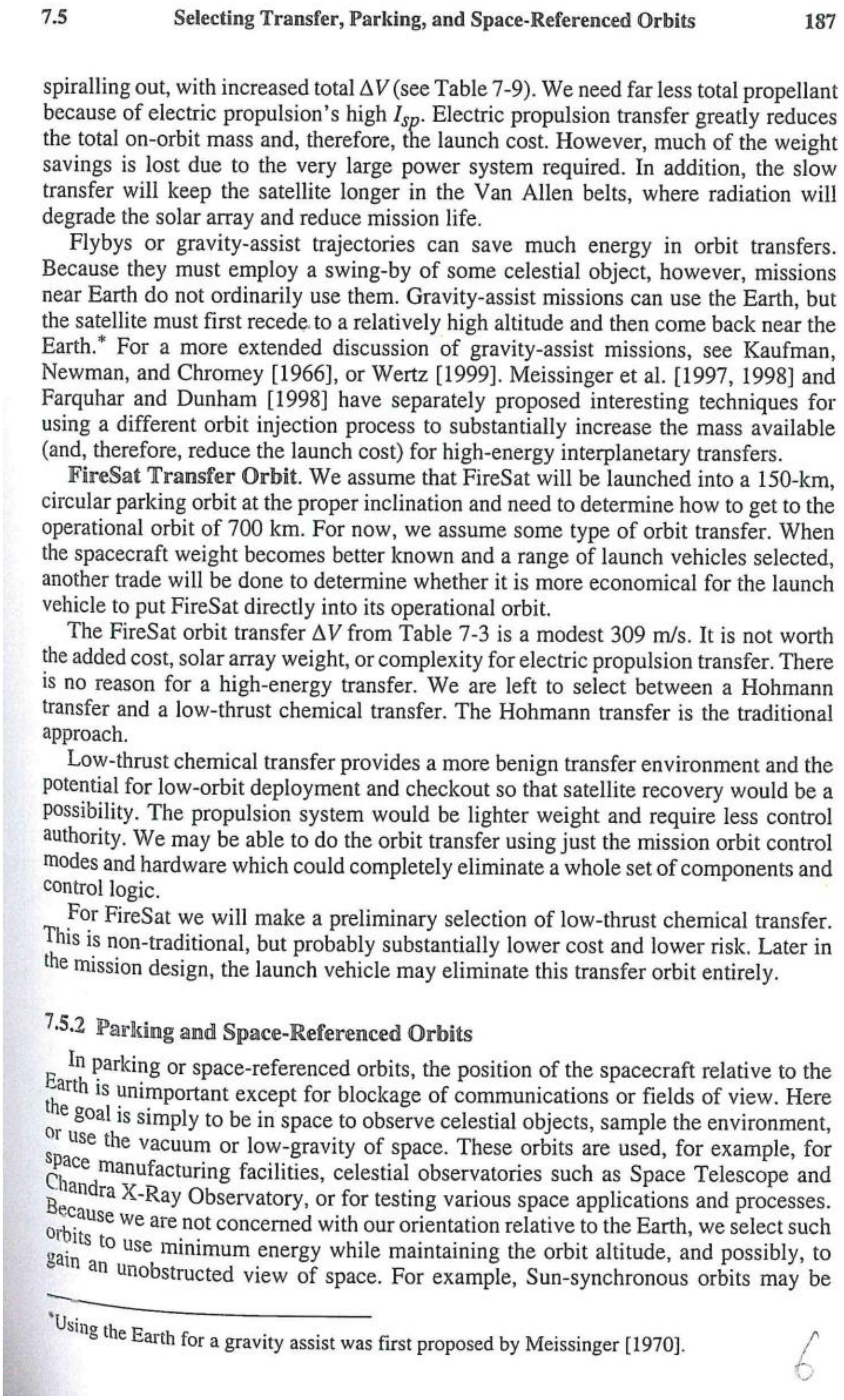
3) *QUALI SONO I REGOLAMENTI DI CUI LO STATUTO DALL'ASI PREVEDE L'AGENZIA DEBBA DOTARSI E LE LORO PRINCIPALI FINALITÀ.*

Esercitazione:

4) *IL CANDIDATO RAPPRESENTI IN EXCEL L'ANDAMENTO DI UNA FUNZIONE A SUA SCELTA.*

Prova di Inglese:

1) *LEGGERE E TRADURRE IL TESTO IN INGLESE SOTTOPOSTO DALLA COMMISSIONE.*



7.5 **Selecting Transfer, Parking, and Space-Referenced Orbits** 187

spiralling out, with increased total ΔV (see Table 7-9). We need far less total propellant because of electric propulsion's high I_{sp}. Electric propulsion transfer greatly reduces the total on-orbit mass and, therefore, the launch cost. However, much of the weight savings is lost due to the very large power system required. In addition, the slow transfer will keep the satellite longer in the Van Allen belts, where radiation will degrade the solar array and reduce mission life.

Flybys or gravity-assist trajectories can save much energy in orbit transfers. Because they must employ a swing-by of some celestial object, however, missions near Earth do not ordinarily use them. Gravity-assist missions can use the Earth, but the satellite must first recede to a relatively high altitude and then come back near the Earth.* For a more extended discussion of gravity-assist missions, see Kaufman, Newman, and Chromey [1966], or Wertz [1999]. Meissinger et al. [1997, 1998] and Farquhar and Dunham [1998] have separately proposed interesting techniques for using a different orbit injection process to substantially increase the mass available (and, therefore, reduce the launch cost) for high-energy interplanetary transfers.

FireSat Transfer Orbit. We assume that FireSat will be launched into a 150-km, circular parking orbit at the proper inclination and need to determine how to get to the operational orbit of 700 km. For now, we assume some type of orbit transfer. When the spacecraft weight becomes better known and a range of launch vehicles selected, another trade will be done to determine whether it is more economical for the launch vehicle to put FireSat directly into its operational orbit.

The FireSat orbit transfer ΔV from Table 7-3 is a modest 309 m/s. It is not worth the added cost, solar array weight, or complexity for electric propulsion transfer. There is no reason for a high-energy transfer. We are left to select between a Hohmann transfer and a low-thrust chemical transfer. The Hohmann transfer is the traditional approach.

Low-thrust chemical transfer provides a more benign transfer environment and the potential for low-orbit deployment and checkout so that satellite recovery would be a possibility. The propulsion system would be lighter weight and require less control authority. We may be able to do the orbit transfer using just the mission orbit control modes and hardware which could completely eliminate a whole set of components and control logic.

For FireSat we will make a preliminary selection of low-thrust chemical transfer. This is non-traditional, but probably substantially lower cost and lower risk. Later in the mission design, the launch vehicle may eliminate this transfer orbit entirely.

7.5.2 Parking and Space-Referenced Orbits

In parking or space-referenced orbits, the position of the spacecraft relative to the Earth is unimportant except for blockage of communications or fields of view. Here the goal is simply to be in space to observe celestial objects, sample the environment, or use the vacuum or low-gravity of space. These orbits are used, for example, for space manufacturing facilities, celestial observatories such as Space Telescope and Chandra X-Ray Observatory, or for testing various space applications and processes. Because we are not concerned with our orientation relative to the Earth, we select such orbits to use minimum energy while maintaining the orbit altitude, and possibly, to gain an unobstructed view of space. For example, Sun-synchronous orbits may be

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*Using the Earth for a gravity assist was first proposed by Meissinger [1970].

6

TRACCIA 4

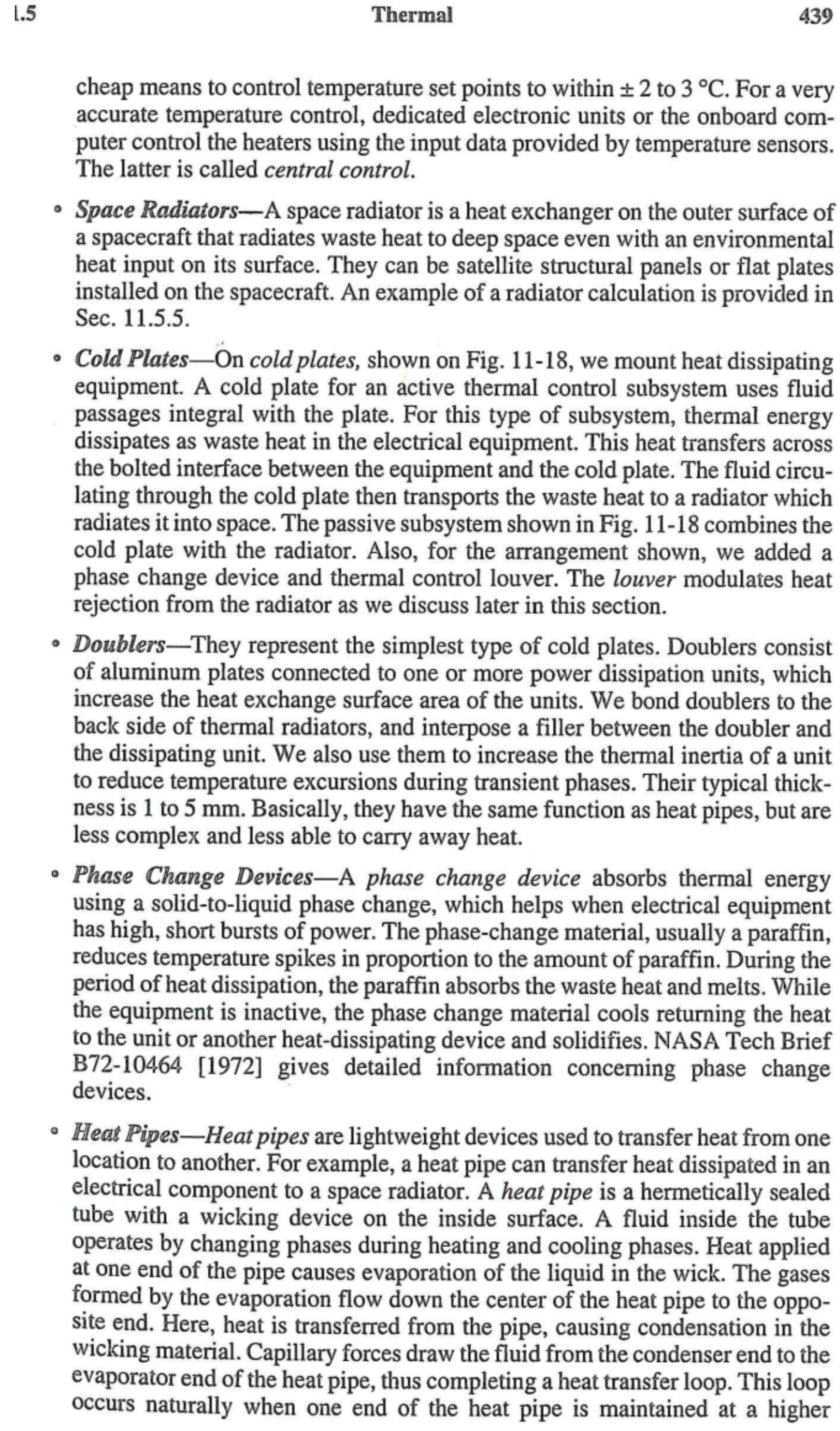
1) *ILLUSTRARE LE PROPRIE ATTIVITÀ/ESPERIENZE PROFESSIONALI.*
2) *DESCRIVERE BREVEMENTE L'UTILITÀ DEGLI STUDI A TERRA (MODELLISTICA E R&D) PER IL FUNZIONAMENTO DEI PAYLOAD SUI SATELLITI.*
3) *IL CANDIDATO DESCRIVA LA FIGURA DEL PRESIDENTE DELL'ASI AI SENSI DELLO STATUTO.*

Esercitazione:

4) *IL CANDIDATO REALIZZI IN POWER POINT UNA PRESENTAZIONE CHE SPIEGHI UN'EQUAZIONE DI SUA SCELTA.*

Prova di Inglese:

1) *LEGGERE E TRADURRE IL TESTO IN INGLESE SOTTOPOSTO DALLA COMMISSIONE.*



cheap means to control temperature set points to within ± 2 to 3 °C. For a very accurate temperature control, dedicated electronic units or the onboard computer control the heaters using the input data provided by temperature sensors. The latter is called *central control.*

- ***Space Radiators***—A space radiator is a heat exchanger on the outer surface of a spacecraft that radiates waste heat to deep space even with an environmental heat input on its surface. They can be satellite structural panels or flat plates installed on the spacecraft. An example of a radiator calculation is provided in Sec. 11.5.5.
- ***Cold Plates***—On *cold plates,* shown on Fig. 11-18, we mount heat dissipating equipment. A cold plate for an active thermal control subsystem uses fluid passages integral with the plate. For this type of subsystem, thermal energy dissipates as waste heat in the electrical equipment. This heat transfers across the bolted interface between the equipment and the cold plate. The fluid circulating through the cold plate then transports the waste heat to a radiator which radiates it into space. The passive subsystem shown in Fig. 11-18 combines the cold plate with the radiator. Also, for the arrangement shown, we added a phase change device and thermal control louver. The *louver* modulates heat rejection from the radiator as we discuss later in this section.
- ***Doublers***—They represent the simplest type of cold plates. Doublers consist of aluminum plates connected to one or more power dissipation units, which increase the heat exchange surface area of the units. We bond doublers to the back side of thermal radiators, and interpose a filler between the doubler and the dissipating unit. We also use them to increase the thermal inertia of a unit to reduce temperature excursions during transient phases. Their typical thickness is 1 to 5 mm. Basically, they have the same function as heat pipes, but are less complex and less able to carry away heat.
- ***Phase Change Devices***—A *phase change device* absorbs thermal energy using a solid-to-liquid phase change, which helps when electrical equipment has high, short bursts of power. The phase-change material, usually a paraffin, reduces temperature spikes in proportion to the amount of paraffin. During the period of heat dissipation, the paraffin absorbs the waste heat and melts. While the equipment is inactive, the phase change material cools returning the heat to the unit or another heat-dissipating device and solidifies. NASA Tech Brief B72-10464 [1972] gives detailed information concerning phase change devices.
- ***Heat Pipes***—*Heat pipes* are lightweight devices used to transfer heat from one location to another. For example, a heat pipe can transfer heat dissipated in an electrical component to a space radiator. A *heat pipe* is a hermetically sealed tube with a wicking device on the inside surface. A fluid inside the tube operates by changing phases during heating and cooling phases. Heat applied at one end of the pipe causes evaporation of the liquid in the wick. The gases formed by the evaporation flow down the center of the heat pipe to the opposite end. Here, heat is transferred from the pipe, causing condensation in the wicking material. Capillary forces draw the fluid from the condenser end to the evaporator end of the heat pipe, thus completing a heat transfer loop. This loop occurs naturally when one end of the heat pipe is maintained at a higher

TRACCIA 3

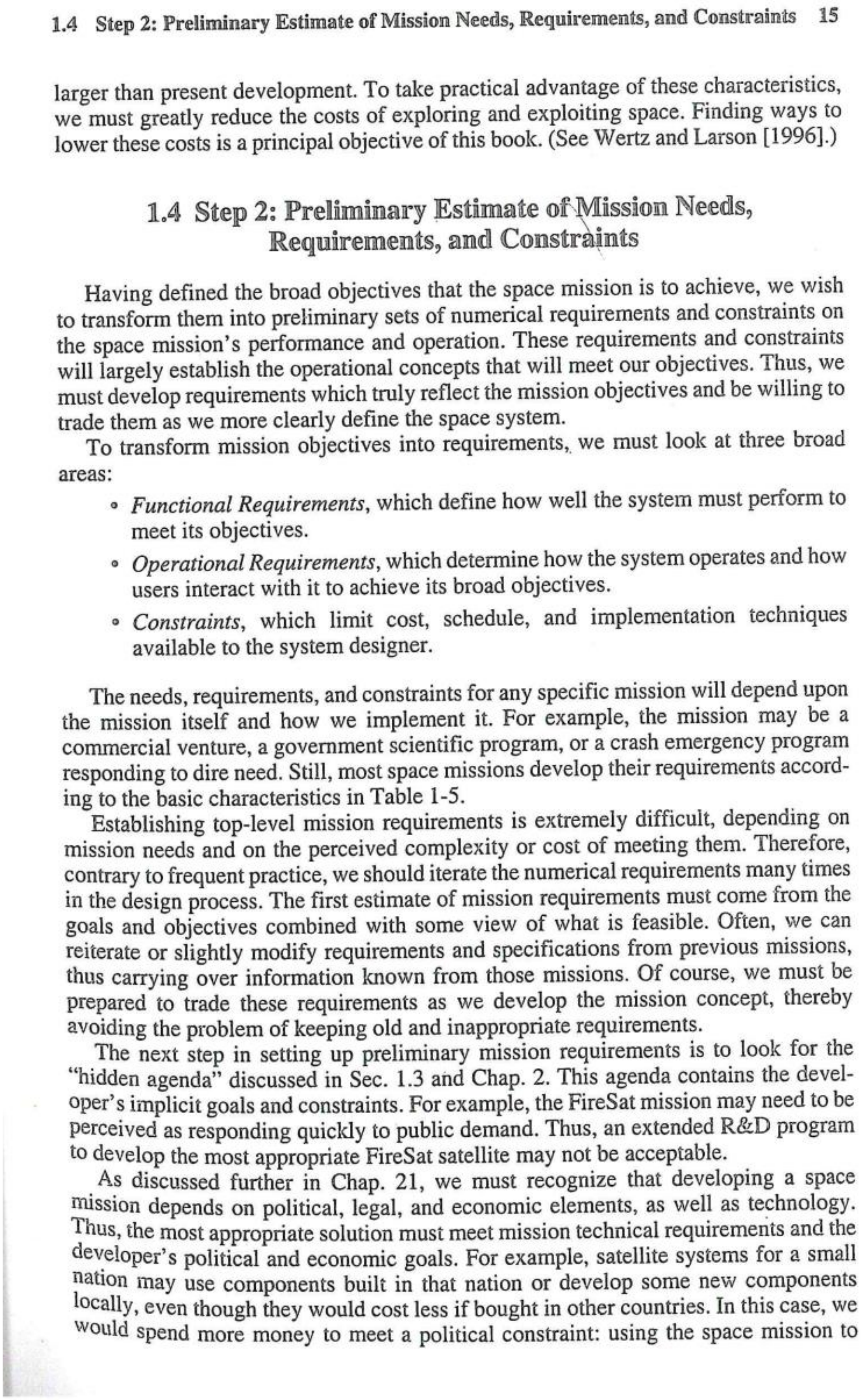
1) *ILLUSTRARE LE PROPRIE ATTIVITÀ/ESPERIENZE PROFESSIONALI.*
2) *LA PRESENZA DEI PRIVATI NELL'ESPLORAZIONE SPAZIALE CONTRIBUIRÀ AD AUMENTARE LE COMPETENZE E LE SFIDE TECNOLOGICHE DELL'INTERO SISTEMA "SPAZIO" O SI LIMITERÀ SOLO ALLA SPACE ECONOMY, CIOÈ AD UNA CRESCITA COMMERCIALE?*
3) *IN UN ENTE DI RICERCA IL CANDIDATO INDIVIDUI IL SOGGETTO O I SOGGETTI CHE SVOLGONO ATTIVITÀ DI GESTIONE E NE DESCRIVA I COMPITI.*

Esercitazione:

4) *IL CANDIDATO REALIZZI IN POWER POINT UNA PRESENTAZIONE CHE ILLUSTRI LA STRUTTURA DI UN PROGETTO DI SUA SCELTA.*

Prova di Inglese:

1) *LEGGERE E TRADURRE IL TESTO IN INGLESE SOTTOPOSTO DALLA COMMISSIONE.*



larger than present development. To take practical advantage of these characteristics, we must greatly reduce the costs of exploring and exploiting space. Finding ways to lower these costs is a principal objective of this book. (See Wertz and Larson [1996].)

1.4 Step 2: Preliminary Estimate of Mission Needs, Requirements, and Constraints

Having defined the broad objectives that the space mission is to achieve, we wish to transform them into preliminary sets of numerical requirements and constraints on the space mission's performance and operation. These requirements and constraints will largely establish the operational concepts that will meet our objectives. Thus, we must develop requirements which truly reflect the mission objectives and be willing to trade them as we more clearly define the space system.

To transform mission objectives into requirements, we must look at three broad areas:

- *Functional Requirements*, which define how well the system must perform to meet its objectives.
- *Operational Requirements*, which determine how the system operates and how users interact with it to achieve its broad objectives.
- *Constraints*, which limit cost, schedule, and implementation techniques available to the system designer.

The needs, requirements, and constraints for any specific mission will depend upon the mission itself and how we implement it. For example, the mission may be a commercial venture, a government scientific program, or a crash emergency program responding to dire need. Still, most space missions develop their requirements according to the basic characteristics in Table 1-5.

Establishing top-level mission requirements is extremely difficult, depending on mission needs and on the perceived complexity or cost of meeting them. Therefore, contrary to frequent practice, we should iterate the numerical requirements many times in the design process. The first estimate of mission requirements must come from the goals and objectives combined with some view of what is feasible. Often, we can reiterate or slightly modify requirements and specifications from previous missions, thus carrying over information known from those missions. Of course, we must be prepared to trade these requirements as we develop the mission concept, thereby avoiding the problem of keeping old and inappropriate requirements.

The next step in setting up preliminary mission requirements is to look for the "hidden agenda" discussed in Sec. 1.3 and Chap. 2. This agenda contains the developer's implicit goals and constraints. For example, the FireSat mission may need to be perceived as responding quickly to public demand. Thus, an extended R&D program to develop the most appropriate FireSat satellite may not be acceptable.

As discussed further in Chap. 21, we must recognize that developing a space mission depends on political, legal, and economic elements, as well as technology. Thus, the most appropriate solution must meet mission technical requirements and the developer's political and economic goals. For example, satellite systems for a small nation may use components built in that nation or develop some new components locally, even though they would cost less if bought in other countries. In this case, we would spend more money to meet a political constraint: using the space mission to

TRACCIA 7

1) *ILLUSTRARE LE PROPRIE ATTIVITÀ/ESPERIENZE PROFESSIONALI.*

2) *DESCRIVERE COME SI PROCEDE NEL MONITORAGGIO DELL'AVANZAMENTO DI UN PROGETTO E COME SI INTERVIENE UNA VOLTA INDIVIDUATO UN PERCORSO CRITICO.*

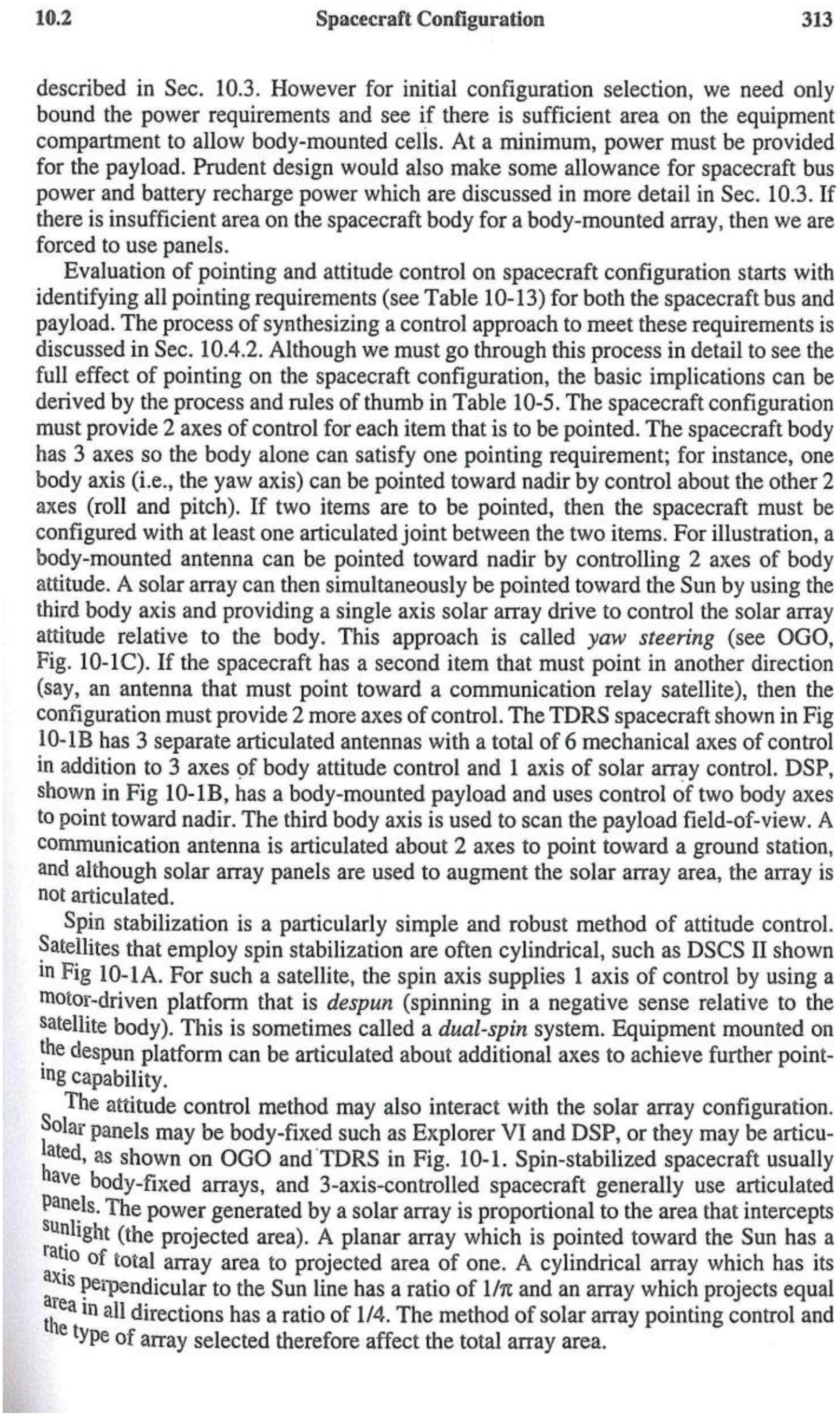
3) *IL RUOLO DEL RESPONSABILE DEL PROCEDIMENTO E NORMATIVA DI RIFERIMENTO.*

Esercitazione:

4) *IL CANDIDATO REALIZZI IN EXCEL UNA TABELLA DI NUMERI A SUA SCELTA E NE INDIVIDUI PER OGNI RIGA E COLONNA IL VALORE MASSIMO.*

Prova di Inglese:

5) *LEGGERE E TRADURRE IL TESTO IN INGLESE SOTTOPOSTO DALLA COMMISSIONE.*



described in Sec. 10.3. However for initial configuration selection, we need only bound the power requirements and see if there is sufficient area on the equipment compartment to allow body-mounted cells. At a minimum, power must be provided for the payload. Prudent design would also make some allowance for spacecraft bus power and battery recharge power which are discussed in more detail in Sec. 10.3. If there is insufficient area on the spacecraft body for a body-mounted array, then we are forced to use panels.

Evaluation of pointing and attitude control on spacecraft configuration starts with identifying all pointing requirements (see Table 10-13) for both the spacecraft bus and payload. The process of synthesizing a control approach to meet these requirements is discussed in Sec. 10.4.2. Although we must go through this process in detail to see the full effect of pointing on the spacecraft configuration, the basic implications can be derived by the process and rules of thumb in Table 10-5. The spacecraft configuration must provide 2 axes of control for each item that is to be pointed. The spacecraft body has 3 axes so the body alone can satisfy one pointing requirement; for instance, one body axis (i.e., the yaw axis) can be pointed toward nadir by control about the other 2 axes (roll and pitch). If two items are to be pointed, then the spacecraft must be configured with at least one articulated joint between the two items. For illustration, a body-mounted antenna can be pointed toward nadir by controlling 2 axes of body attitude. A solar array can then simultaneously be pointed toward the Sun by using the third body axis and providing a single axis solar array drive to control the solar array attitude relative to the body. This approach is called *yaw steering* (see OGO, Fig. 10-1C). If the spacecraft has a second item that must point in another direction (say, an antenna that must point toward a communication relay satellite), then the configuration must provide 2 more axes of control. The TDRS spacecraft shown in Fig 10-1B has 3 separate articulated antennas with a total of 6 mechanical axes of control in addition to 3 axes of body attitude control and 1 axis of solar array control. DSP, shown in Fig 10-1B, has a body-mounted payload and uses control of two body axes to point toward nadir. The third body axis is used to scan the payload field-of-view. A communication antenna is articulated about 2 axes to point toward a ground station, and although solar array panels are used to augment the solar array area, the array is not articulated.

Spin stabilization is a particularly simple and robust method of attitude control. Satellites that employ spin stabilization are often cylindrical, such as DSCS II shown in Fig 10-1A. For such a satellite, the spin axis supplies 1 axis of control by using a motor-driven platform that is *despun* (spinning in a negative sense relative to the satellite body). This is sometimes called a *dual-spin* system. Equipment mounted on the despun platform can be articulated about additional axes to achieve further pointing capability.

The attitude control method may also interact with the solar array configuration. Solar panels may be body-fixed such as Explorer VI and DSP, or they may be articulated, as shown on OGO and TDRS in Fig. 10-1. Spin-stabilized spacecraft usually have body-fixed arrays, and 3-axis-controlled spacecraft generally use articulated panels. The power generated by a solar array is proportional to the area that intercepts sunlight (the projected area). A planar array which is pointed toward the Sun has a ratio of total array area to projected area of one. A cylindrical array which has its axis perpendicular to the Sun line has a ratio of $1/\pi$ and an array which projects equal area in all directions has a ratio of 1/4. The method of solar array pointing control and the type of array selected therefore affect the total array area.

7

TRACCIA 9

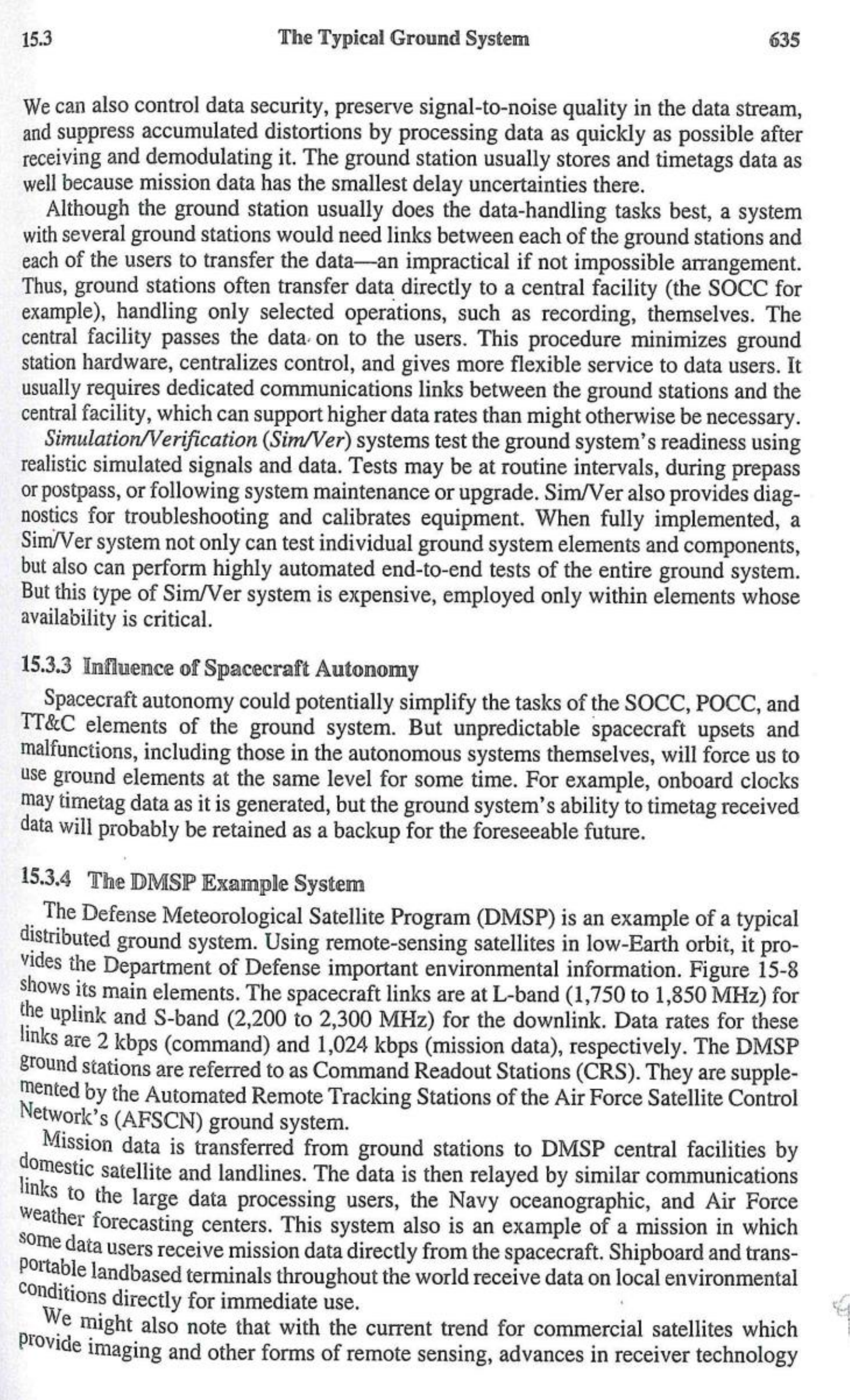
1) *ILLUSTRARE LE PROPRIE ATTIVITÀ/ESPERIENZE PROFESSIONALI.*
2) *DESCRIVERE I TEST NECESSARI PER LA QUALIFICA DI UN PAYLOAD SU UNA MISSIONE SPAZIALE, SOFFERMANDOSI SUI TEST TERMICI E MECCANICI.*
3) *IL CANDIDATO DESCRIVA IL DOVERE DI MOTIVAZIONE DEL PROVVEDIMENTO AMMINISTRATIVO.*

Esercitazione:

4) *IL CANDIDATO REALIZZI IN WORD UN DOCUMENTO CHE SINTETIZZI LA SUA ESPERIENZA LAVORATIVA.*

Prova di Inglese:

LEGGERE E TRADURRE IL TESTO IN INGLESE SOTTOPOSTO DALLA COMMISSIONE.



We can also control data security, preserve signal-to-noise quality in the data stream, and suppress accumulated distortions by processing data as quickly as possible after receiving and demodulating it. The ground station usually stores and timetags data as well because mission data has the smallest delay uncertainties there.

Although the ground station usually does the data-handling tasks best, a system with several ground stations would need links between each of the ground stations and each of the users to transfer the data—an impractical if not impossible arrangement. Thus, ground stations often transfer data directly to a central facility (the SOCC for example), handling only selected operations, such as recording, themselves. The central facility passes the data on to the users. This procedure minimizes ground station hardware, centralizes control, and gives more flexible service to data users. It usually requires dedicated communications links between the ground stations and the central facility, which can support higher data rates than might otherwise be necessary.

Simulation/Verification (*Sim/Ver*) systems test the ground system's readiness using realistic simulated signals and data. Tests may be at routine intervals, during prepass or postpass, or following system maintenance or upgrade. Sim/Ver also provides diagnostics for troubleshooting and calibrates equipment. When fully implemented, a Sim/Ver system not only can test individual ground system elements and components, but also can perform highly automated end-to-end tests of the entire ground system. But this type of Sim/Ver system is expensive, employed only within elements whose availability is critical.

15.3.3 Influence of Spacecraft Autonomy

Spacecraft autonomy could potentially simplify the tasks of the SOCC, POCC, and TT&C elements of the ground system. But unpredictable spacecraft upsets and malfunctions, including those in the autonomous systems themselves, will force us to use ground elements at the same level for some time. For example, onboard clocks may timetag data as it is generated, but the ground system's ability to timetag received data will probably be retained as a backup for the foreseeable future.

15.3.4 The DMSP Example System

The Defense Meteorological Satellite Program (DMSP) is an example of a typical distributed ground system. Using remote-sensing satellites in low-Earth orbit, it provides the Department of Defense important environmental information. Figure 15-8 shows its main elements. The spacecraft links are at L-band (1,750 to 1,850 MHz) for the uplink and S-band (2,200 to 2,300 MHz) for the downlink. Data rates for these links are 2 kbps (command) and 1,024 kbps (mission data), respectively. The DMSP ground stations are referred to as Command Readout Stations (CRS). They are supplemented by the Automated Remote Tracking Stations of the Air Force Satellite Control Network's (AFSCN) ground system.

Mission data is transferred from ground stations to DMSP central facilities by domestic satellite and landlines. The data is then relayed by similar communications links to the large data processing users, the Navy oceanographic, and Air Force weather forecasting centers. This system also is an example of a mission in which some data users receive mission data directly from the spacecraft. Shipboard and transportable landbased terminals throughout the world receive data on local environmental conditions directly for immediate use.

We might also note that with the current trend for commercial satellites which provide imaging and other forms of remote sensing, advances in receiver technology

TRACCIA 8

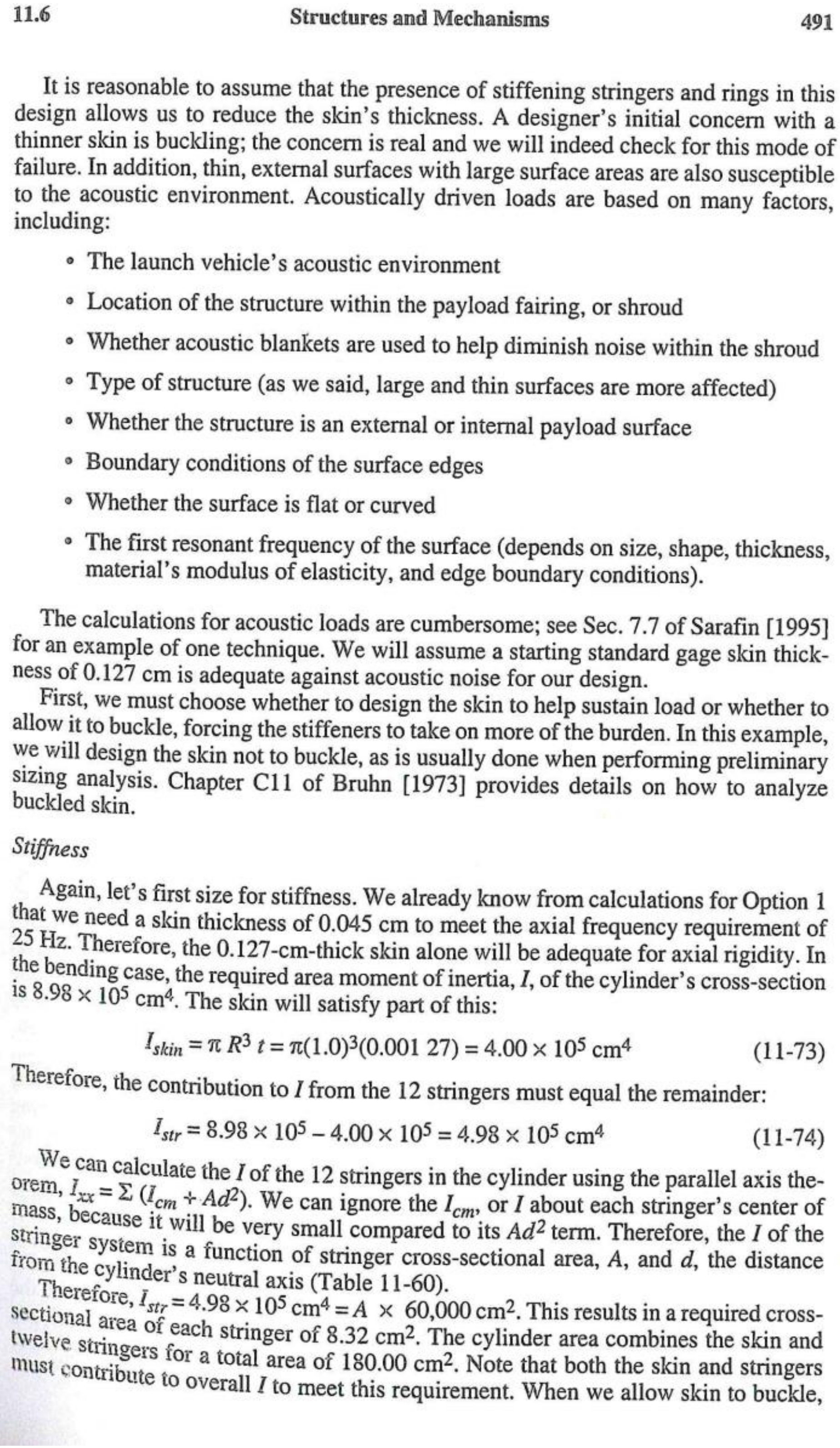
1) *ILLUSTRARE LE PROPRIE ATTIVITÀ/ESPERIENZE PROFESSIONALI.*
2) *DESCRIVERE LE PRINCIPALI CARATTERISTICHE DELL'AMBIENTE SPAZIALE EVIDENZIANDO LE CONSEGUENZE SULL'UOMO E SUI MATERIALI.*
3) *IL CANDIDATO DESCRIVA I VIZI DI NULLITÀ DEL PROVVEDIMENTO AMMINISTRATIVO AI SENSI DELLA LEGGE 241 DEL 1990.*

Esercitazione:

4) *IL CANDIDATO REALIZZI IN EXCEL UNA TABELLA DI DATI DI SUA SCELTA E POI NE COPI IL CONTENUTO TRASPOSTO IN UN NUOVO FOGLIO.*

Prova di Inglese:

5) LEGGERE E TRADURRE IL TESTO IN INGLESE SOTTOPOSTO DALLA COMMISSIONE.



It is reasonable to assume that the presence of stiffening stringers and rings in this design allows us to reduce the skin's thickness. A designer's initial concern with a thinner skin is buckling; the concern is real and we will indeed check for this mode of failure. In addition, thin, external surfaces with large surface areas are also susceptible to the acoustic environment. Acoustically driven loads are based on many factors, including:

- The launch vehicle's acoustic environment
- Location of the structure within the payload fairing, or shroud
- Whether acoustic blankets are used to help diminish noise within the shroud
- Type of structure (as we said, large and thin surfaces are more affected)
- Whether the structure is an external or internal payload surface
- Boundary conditions of the surface edges
- Whether the surface is flat or curved
- The first resonant frequency of the surface (depends on size, shape, thickness, material's modulus of elasticity, and edge boundary conditions).

The calculations for acoustic loads are cumbersome; see Sec. 7.7 of Sarafin [1995] for an example of one technique. We will assume a starting standard gage skin thickness of 0.127 cm is adequate against acoustic noise for our design.

First, we must choose whether to design the skin to help sustain load or whether to allow it to buckle, forcing the stiffeners to take on more of the burden. In this example, we will design the skin not to buckle, as is usually done when performing preliminary sizing analysis. Chapter C11 of Bruhn [1973] provides details on how to analyze buckled skin.

Stiffness

Again, let's first size for stiffness. We already know from calculations for Option 1 that we need a skin thickness of 0.045 cm to meet the axial frequency requirement of 25 Hz. Therefore, the 0.127-cm-thick skin alone will be adequate for axial rigidity. In the bending case, the required area moment of inertia, I, of the cylinder's cross-section is 8.98×10^5 cm^4. The skin will satisfy part of this:

$$I_{skin} = \pi R^3 t = \pi(1.0)^3(0.001\,27) = 4.00 \times 10^5 \text{ cm}^4 \tag{11-73}$$

Therefore, the contribution to I from the 12 stringers must equal the remainder:

$$I_{str} = 8.98 \times 10^5 - 4.00 \times 10^5 = 4.98 \times 10^5 \text{ cm}^4 \tag{11-74}$$

We can calculate the I of the 12 stringers in the cylinder using the parallel axis theorem, $I_{xx} = \Sigma\,(I_{cm} + Ad^2)$. We can ignore the I_{cm}, or I about each stringer's center of mass, because it will be very small compared to its Ad^2 term. Therefore, the I of the stringer system is a function of stringer cross-sectional area, A, and d, the distance from the cylinder's neutral axis (Table 11-60).

Therefore, $I_{str} = 4.98 \times 10^5 \text{ cm}^4 = A \times 60{,}000 \text{ cm}^2$. This results in a required cross-sectional area of each stringer of 8.32 cm^2. The cylinder area combines the skin and twelve stringers for a total area of 180.00 cm^2. Note that both the skin and stringers must contribute to overall I to meet this requirement. When we allow skin to buckle,