Appendix D

SYNOPSIS OF THE OTA WORKSHOP ON COST CONTAINMENT OF CIVILIAN SPACE INFRASTRUCTURE (CIVILIAN "SPACE STATION") ELEMENTS[1]

PREFACE

This appendix summarizes information presented at an OTA workshop on cost containment and cost minimization in NASA's projected civilian "space station" program. This program is expected to result in the Government's acquisition of elements of an overall in-space infrastructure support system. The 2-day workshop was held on October 18 and 19, 1983, and was attended by more than a dozen senior professional representatives from (non-NASA) high-technology Government organizations, Government-related aerospace industry organizations, and non-space industry organizations. Most of those attending were either former senior NASA professionals or had worked often on large NASA contracts. The views of invitees unable to attend are also contained in this appendix. A Glossary of Terms appears at the end of the document.

The workshop discussions were limited to a NASA program that would develop infrastructure elements without significant participation by foreign governments or the private sector in either funding or overall management. Such involvement would bring with it additional considerations that would have to be addressed early in the planning stages of the project in order to avoid serious, cost-increasing program changes.

Moreover, the workshop discussions assumed that NASA staffing for the project would remain at the minimum levels required to obtain the infrastructure at the earliest date and in the most cost-effective manner.

Workshop participants did not attempt to quantify, in either absolute or percentage terms, the estimates of possible cost reductions expected to result from using the management and technical approaches suggested here.

The first section summarizes the results of the 2 days of discussion; it is divided into the two areas on which the discussion centered: management considerations and technical considerations. A synthesis of the discussions in these two areas is presented in the next two sections. The last section is a set of tentative conclusions for the consideration of NASA and Congress.

Summary

Recent history indicates that only about one-third of the cost of acquiring a space system is directly related to hardware. Management, engineering, integration, test, software, documentation, and other acquisition support activities use up the remaining two-thirds. Although many ways that promise to cut costs in a civilian space infrastructure ("space station") program were discussed at the workshop, program philosophy and management were emphasized.

Some of the cost issues have already been recognized by NASA and may indeed be incorporated into NASA's current cost-control activities. These issues are nonetheless included here in order to bolster the argument that NASA will have to change the way it acquires high-technology space assets if acquisition unit costs are to be sharply reduced.

The major cost issues are summarized below:

COST-CONTAINMENT CONSIDERATIONS

- New **technology: In general, the cost of in-space infrastructure elements is directly related to the amount of new-technology research, development, test, and evaluation** (RDT&E) invested in the program. To minimize cost, NASA should adopt an approach that would minimize the amount of new technology necessary to meet performance objectives. Because NASA Centers have their own continuing agendas and tend to incorporate their own RDT&E interests into large, popular, long-term development programs, the extent of involvement of the Centers in the management of large space programs affects the cost of those programs.
- **Sufficient management authority:** NASA's current plan to designate a separate Associate Ad-

[1] Workshop conducted for OTA by Computer Sciences Corp.

ministrator for the program is both necessary and appropriate. The structure, responsibilities, and authorities of the management organization reporting to this Associate Administrator are also vital for controlling costs.

- **Careful definition:** An extensive definition phase (e.g., the present NASA Phase A/B) could help minimize costs by determining precisely what capabilities are required to meet specific objectives; technology development should be limited to those requirements.

These issues, discussed in terms of management and technical considerations, are summarized below.

MANAGEMENT CONSIDERATIONS

- **Centralized management:** A centralized, high-level NASA organization to manage development and procurement could lower cost by reducing layers of management, minimizing the number of organizational and design interfaces, and coordinating parallel development efforts. It could also simplify coordination of technical and management efforts.
- **System engineering and integration:** Strong system engineering and system integration efforts **(see** Glossary) both by contractors and by NASA could reduce the number of technical interfaces, allow most design conflicts to be resolved in-house, and help ensure that the overall system is engineered for optimal performance.
- **Bounded program:** Defining a bound, or end point, to the initial acquisition, including development, activities could contain costs by eliminating the possibility of prolonged RDT&E so as to reach an early initial operational capability (IOC).
- **Separation of NASA's general RDT&E costs from infrastructure acquisition costs:** The initial development should be based as much as possible on available technology. And only those RDT&E costs that directly contribute to development should be charged to this program.
- Development **of new cost models:** Current cost models will not provide accurate estimates of the funding needs of the future civilian "space station" program. These models were developed for efforts that had requirements fundamentally different from the needs of the proposed "space station. "

TECHNICAL AND PROCUREMENT CONSIDERATIONS

- **Current technology:** Based on the requirements defined to date for an operational civilian "space station, " extensive technological development does not appear to be necessary to obtain its necessary elements. Elements based on current technology would be less expensive to produce, with some exceptions would appear to have reasonable long-term operation and maintenance costs,** would permit later improvements, would not require as extensive a management effort, and would cost the taxpayer less,
- **Performance objectives requirements:** The strong Phase A/B effort that NASA currently performs is required. However, if NASA develops detailed design specifications and procures hardware on the basis of their use, contractors' initiatives to meet or better schedules and costs would be inhibited. Performance objectives (with specified minimums) based wherever possible on current technology would allow contractors to meet the program requirements in the most cost-effective and timely manner.
- **Contract incentives:** By specifying performance objectives that could be met with minimal advances in technology, NASA would encourage contractors to propose the most efficient cost and schedule approaches. Incentive contracts that both reward and penalize would help to ensure that these objectives are met.
- **Design issues:** Adopting standards, defining and maintaining simple" interfaces, replicating 'basic elements, and specifying common hardware would simplify design and development, reduce change-migration across the interfaces, and reduce the impact of nonrecurring costs.

Management Considerations

Both the management philosophy and practice under which any space program is conducted are usually dominant factors in determining the cost of the various program elements. Sound management practices must include cost avoidance, cost minimization, and cost containment. The following management practices should keep space system acquisition costs low:

- centralize the development program management organization and have it report directly to the NASA Associate Administrator;
- use proven industry contractors for acquiring the major program elements;
- set specific endpoints for the initial development phase; and
- develop and implement management practices that emphasize, and wherever possible reward, cost reduction and cost containment.

CENTRALIZED MANAGEMENT

A centralized organization to manage the acquisition program could reduce costs by concentrating the control and integration of all technical, cost, and scheduling activities. Clear lines of responsibility; centralized direction; strong control over budgets, funds, and technical decisions; and control over such factors as interface and communality would be enhanced under such an approach. Splitting program management among different NASA centers, as has sometimes been the practice in the past, could make it difficult to develop a fully integrated "space station." However, the centers should be used, as necessary, to provide specific expertise or technical support.

The management organization, which would be responsible for contracting for the various program elements, should be given a large measure of authority. The organization could be located at a Center in order to have access to technical and administrative support. Such an organization must have an experienced technical arm; to achieve that, expert personnel from NASA Centers could be assigned to the program management office.

This centralized approach would enable a program manager to more easily assess risks and make cost-reducing decisions, primarily because he or she would be freed from conflicting pressures from other parts of the organization. (This reasoning supports the argument that individual NASA Centers should not be given management control over elements of the program,) Under this approach the central program management team would have the best chance to evaluate costs, scheduling, and performance objectively, and to produce balanced emphases and decisions.

When a Center does manage the development of technology or hardware for the program, it should be on a subcontract basis from the program management office. It should have a specific development time and cost. Inasmuch as current technology would be used wherever feasible, long-term RDT&E programs at the NASA Centers would not burden the acquisition program with their associated costs and management demands. While new-technology RDT&E is an important continuing function of the NASA Centers, it should be funded separately unless it uniquely meets the performance or cost objectives of the space infrastructure program.

SYSTEM ENGINEERING AND INTEGRATION

In any complex system, each component or subsystem should be designed with the objective of enhancing the performance of the entire system. Thus, compromises must be made among the various subsystems so that the complete system—not just each component of it—performs as well as the technological state-of-the-art and the funds available for its acquisition will allow. This activity is known as system engineering. System integration is the term used to describe activities aimed at ensuring that the individual subsystems work together to create a well-functioning whole. Both of these concepts involve much more than just technical performance. In the case of NASA-procured systems, acquisition costs and operating and maintenance costs also should be important considerations. Usefulness to system users, such as simplicity of access, is another, and long life and easy evolution to the next step may be others. More detailed factors might include ease of flight preparation, in-orbit maintenance, and updating, for example.

Many past system engineering and integration efforts at NASA have emphasized the technical or mission performance. Certain changes that have occurred during the past 25 years of space effort should now allow NASA to broaden its view of system engineering and integration.

Until very recently, the civilian space program has been (it had to be) characterized as a very high-technology program that has had to bootstrap itself: that is, the technology often had to be developed during the same time interval that it would have to be incorporated into the spaceflight hardware. Thus, NASA's responsibility was not only to manage the aerospace contractors that build the mission hardware but also to establish both internal and external RDT&E capabilities to carry out the necessary parallel technology development. In discharging these dual roles, NASA, of necessity, has been intimately involved in design and development of the systems it was procuring. Indeed, doing so was the only practical way by which NASA could effectively communicate its requirements to its contractors. As a consequence of these circumstances, NASA has tended to concentrate on the hardware design and performance aspects of system engineering and integration—sometimes at the expense of cost containment.

Two factors present today should allow NASA to broaden its emphasis from hardware design considerations of system engineering and integration to other, equally important matters: 1) the relatively advanced state of the technology—especially that available for this program—and 2) the evolving sophistication of U.S. industrial capability. After 25 years of space technology development and operational experience in its use, essentially all of the technology is in hand to build a sophisticated, long-life, reasonably priced civilian "space station" for operation in LEO. Also, the aerospace industry has changed significantly. Part of NASA's original charter was to foster and enhance the space technology know-how of U.S. industry. To a considerable extent, NASA has achieved this objective: many senior personnel in industry have devoted their entire careers to space-related activities, and many have come to the industry from NASA–in various fashions NASA gave many of these and other individuals their professional "start."

Because of these factors, several cost-reduction possibilities now exist. Inasmuch as space systems should be built using current technology unless new technology would lower life-cycle costs, in many cases NASA should be able to specify the use of already existing hardware. Using this technology, together with current industry sophistication, should enable NASA to transfer more of the system engineering and integration associated with hardware design to industry, freeing NASA system engineers to concentrate on cost minimization and avoidance, operability, and other important matters. Of course, NASA must continue to ensure that all of the space infrastructure elements work together efficiently; that the major interfaces are defined, controlled, and integrated; and that the end use objectives are met. A NASA centralized project management organization would be responsible for these efforts. In particular, the organization could ensure that appropriate tradeoffs are made that result in reduced development and O&M costs.

BOUNDED ACQUISITION PROGRAM

NASA's present emphasis on the "evolutionary character" of the "space station" program, while embodying many good programmatic features, gives rise to a very real concern—that is, the pace at which initial elements of the integrated system become available for early operational use. Program delays often are associated with over-sophistication built in during the definition phase or with unrealistically stringent specifications. In addition, many engineers and scientists have a tendency to keep improving the design at all levels—improvements which also can result in delays in advancing to operational status.

This concern could be allayed by the very practical approach of establishing a program consisting of a bounded acquisition phase, including development, for the procurement, launch, in-orbit assembly, and acceptance of the infrastructure elements defined as providing initial IOC. The centralized program management office would carry out this phase. All other related or supporting activities would have separate budgets and would be subcontracted to other NASA offices after negotiation of performance specifications, costs, and schedules. Even the bounded program should have identified elements that could be eliminated or moved off-line in event of cost, schedule, or performance problems in order to meet the IOC date. This approach provides considerable flexibility should unforeseen program difficulties occur—as they almost always do.

The program's initial operational phase would be initiated on the IOC date, but the operational planning would be begun earlier by a parallel program organization. A well-thought-out transition plan to move from the acquisition to the operational phase should be developed as a part of Phase A/B and acted upon throughout the acquisition phase so that effective and comprehensive operating procedures exist at the outset of operations. Thus, the program organization needed to conduct the operational phase should be established by NASA during Phase B. This organization would work with the acquisition program office and with other operations organizations within NASA. In particular, it would become familiar with the operations of the Shuttle, Spacelab and other space infrastructure elements in order to gain experience in their use.

The two program organizations–acquisition and operations—should work together to obtain low life-cycle costs. Cost estimates should be keyed first to the two program phases and then to schedules, in order to foster sound decisionmaking regarding the program's ongoing budget. During the operations phase, the overall concept of a civilian "space station" should be reviewed periodically, in close concert with the private sector, to determine whether the Government should continue, expand, or reduce operations based on considerations of life-cycle costs and national benefits.

COST AWARENESS AND CONTROL

Establishing and maintaining cost awareness among aerospace engineering personnel in both Government and industry should be a major part of any program activity and should begin at the definition phase. At that phase, it is important that the definition be complete within the scope of the bounded program. This activity should include an estimate of costs of all elements of the work to be done. System designers should participate in this process and be responsible for any budget alterations assigned to them. Contractor costs and schedules must be realistic and contractors should be made aware of the need to estimate them accurately.

Cost awareness can be promoted through motivational programs. One useful approach involves contract incentive fees for cost, schedule, and performance. However, when this arrangement is used, the contractor must not be overly constrained in his problem-solving efforts. The incentive contract is a motivational technique that could be used effectively at all levels of the organization. It could be augmented at the lower levels by direct awards for cost-saving suggestions, underbudget performance, rapid problem-solving, and similar efforts that reduce the costs of a particular facet of the program.

Key to any effective cost control activity are accurate cost estimates. Estimates that are too low break down the cost control process. Estimates that are too high create a "vacuum" that will surely be filled. Moreover, cost models based on previous programs will not give satisfactory results for this program because those models use weight, volume, safety, and complexity factors that are significantly different. A quantitative analysis is needed to correct existing cost models. In the meantime, bottom-to-top estimates may prove instructive, particularly when applied to already existing technology or subsystems.

Life-cycle costing may dictate design decisions that are more costly initially but that provide savings over the long term. Program operating environments must also be considered for their effects on costs: designing for a fail-operational, as compared to a fail-safe, working environment is costly. The concept of acceptable risk, particularly human risk, as it affects costs should be analyzed anew, because the in-orbit "space station" operating environment is inherently much more tolerant of operating difficulties than has been the case in previous space programs. The ability to repair equipment and rescue personnel also should be taken into account.

Finally, to be effective, cost estimates, whether derived from cost models or otherwise, must assume a reasonably small development effort for solving unexpected problems. Additional funds should be set aside to handle such problems, but access to this money should be very carefully controlled.

Technical and Procurement Considerations

The kind of technology to be used, and the division of tasks between private contractors and NASA Centers during the acquisition process must be considered in order to achieve the lowest unit cost. The following factors should also be kept clearly in mind:

- The United States, the European Space Agency countries, Canada and other countries have already invested enormous amounts of money and effort to develop, test, and use sophisticated space technology.
- The aerospace industry has "come of age, " and now can be expected to exercise ingenuity in containing costs and meeting performance and time schedules without the detailed NASA management oversight required in the past.
- Conflicts of interest often exist between RDT&E-oriented NASA Centers and the system acquisition management office responsible for overall capability optimization, cost containment, and meeting of schedules.

USE OF CURRENT TECHNOLOGY

Together with various ground and space transportation infrastructure, appropriate in-space infrastructure should provide NASA and other users with cost-effective capabilities to pursue many important space-related objectives. It is quite appropriate that NASA consider the program in this larger context while making plans for its development. And, the character and magnitude of the NASA Centers' involvement in this planning activity must bean important part of this consideration.

The various NASA Centers are developing preliminary concepts for individual infrastructure elements and associated subsystems. These design concepts are technologically sophisticated and are being developed on an individual subsystem basis. It appears that these subsystems are to be packaged in modules that are as independent as possible from each other, and that the infrastructure central complex will bean aggregate of these modules.

Proceeding with the acquisition of such individual subsystems in this fashion could be evidence of inadequate system engineering capability, or inadequate management strength, or both. Both are needed to enforce those top-down tradeoffs and compromises necessary to ensure that the overall system—and not just the individual subsystems or modules—functions as well as possible, Experience has shown that early hesitation regarding system engineering can often result in increasing difficulty later in the enforcement of such compromises; measures taken to integrate subsystems that, by then, do not inherently fit together can be a very costly experience.

It appears that NASA may now be planning to employ a substantial amount of new and sophisticated technology in the program, and to have a parallel program for the development of this technology. it is very important that NASA first analyze, based on performance requirements and cost reduction/avoidance objectives alone, whether developing this new technology is necessary. In particular, it should seek sound professional advice from outside NASA in order to balance any internal tendency to favor new technology development. It must be repeated that, for the most part, a functional "space station" could be built using current technology. It could be cost effective in ad-

dressing important, long-term, civilian space program goals and objectives. And it should be designed so that it could be modified during its operating life as new, more cost-effective, technologies are developed "off-line."

INCENTIVE CONTRACTING VIA PERFORMANCE SPECIFICATIONS

To date, most NASA spaceflight activities have involved planning for and procuring hardware that has been at the leading edge of the technology. Accordingly, because it has had to issue detailed engineering specifications to contractors, NASA has been heavily involved in the technical aspects of such procurements. It is NASA's present intention to issue engineering specifications for procurement after the detailed definition is determined in a combined Phase A/B study. This process would tend to over-constrain potential private-sector contractors: the detailed design, budget, schedule, and expected performance would be predetermined. However, design changes are usually necessary to resolve unanticipated problems that occur as the design is developed. The need for such changes in turn may adversely affect the budget, schedule, and performance. Design changes have been the chief reason that spaceflight hardware has been so costly.

However, if the overall infrastructure was engineered first as a whole, then NASA could procure it on the basis of performance specifications rather than detailed engineering specifications. A detailed Phase A/B preparation would still be required, but its purpose should be to determine the performance objectives and minimum requirements of the overall infrastructure, and then of the specific elements, ensuring that all specifications are necessary and achievable. Such an approach provides contractors with incentives for achieving the performance objectives within cost and on schedule.

Specifying the desired performance, and providing contract incentives for achieving performance and for bettering costs and schedules, could minimize unit costs, Further, with negative incentives—i.e., penalties for failure to meet the costs and schedules–agreed-to unit costs could also be minimized. NASA should carefully define an acceptable incentive fee structure that relates to a predetermined level of risk acceptance for the program. Contractors would be responsible for any trade-offs to meet the performance specified. NASA's system engineering and integration role would be to define the areas where the elements meet and to ensure that the elements do in fact work together. This procedure is used by COMSAT to procure hardware for satellite communication systems from the aerospace industry, and has been highly successful and cost effective.

DESIGN ISSUES

For-profit companies understand the importance of good design practices in minimizing the cost of manufactured products. These practices include using standard components or subsystems when appropriate, minimizing and simplifying interfaces, and replicating basic elements as often as possible. It is expected that space hardware contractors will use such design practices if NASA encourages them to do so.

As noted earlier, however, NASA seemingly now plans to procure the infrastructure elements by means of detailed engineering specifications. Such a plan could prevent contractors, when the seemingly inevitable design changes crop up, from calling on the most cost-effective design options to remedy the problem.

Moreover, detailed design specifications are rarely developed with overall cost effectiveness in mind. Reflecting their past experience, NASA Centers often emphasize technical excellence and complete elimination of risks, even when the safety of people is not a concern, almost regardless of the costs.

But if performance specifications were written to require minimal use of new technology, design practices would not be an issue. Contractors could do what they do best—design cost-effective equipment that meets the Government's specified performance needs.

Acceptable risks should be assessed during NASA's Phase A/B definition to determine where performance specifications and, ultimately, design specifications could be relaxed to contain and minimize costs.

Conclusions

The primary conclusions of the OTA workshop follow.

CENTRALIZED MANAGEMENT OF INFRASTRUCTURE DEVELOPMENT

Effective and efficient management of the proposed program could be achieved by establishing an organization with a single point of authority and control at a high level within NASA. To ensure complete integration of all management interfaces, this organization should control all prime contractors directly and involve only those Centers necessary for the technical execution of the program. This central NASA management organization should be responsible for establishing performance specifications and for defining and managing interfaces between major elements. The prime contractors for these major elements should be fully responsible for the system engineering and integration of their respective elements.

MINIMIZATION OF THE USE OF NEW TECHNOLOGY

It is almost axiomatic that cost and risk will be minimized if the IOC infrastructure is built using proven, state-of-the-art technology to the extent feasible. Space technology has now developed to the point that future RDT&E and associated facilities should be funded separately from this program; they should not be dependent on justification by any one large space program for their inauguration or continuation. RDT&E performed at NASA Centers should be funded solely on the basis of need to support long-range space science, applications, or technology development. NASA should seek outside advice as to what new technology is needed in order to offset any possible in-house bias in favor of costly, and perhaps unnecessary, development.

PERFORMANCE SPECIFICATIONS AND INCENTIVE CONTRACTS

Significant cost savings could be realized if NASA were to procure major elements of the "space station" based on performance specifications, rather than on detailed design specifications, Contracting should include incentives and penalties based on performance objectives so that the contractors would be prompted to apply initiative and ingenuity in minimizing costs while meeting schedules and performance.

CONTRACTOR SYSTEM ENGINEERING AND INTEGRATION

If infrastructure elements were procured on the basis of incentive contracts defined by performance speci-" fications, design details would be the responsibility of the contractors, not NASA. By implication, contractors for major infrastructure elements would also perform the system engineering and integration for their elements. The centralized NASA program office would be responsible for defining, controlling, and integrating the interfaces.

FINITE, BOUNDED ACQUISITION PROGRAM

Costs could be contained if the program were planned as a finite, bounded acquisition program specifically designed to achieve an early IOC. The acquisition phase would include the procurement, launches, on-orbit construction, and acceptance testing of the flight systems. The later, separately managed, operations phase would then be initiated and reviewed periodically. The effect would be to bound all acquisition costs, including development costs, and to provide a fixed framework for operations planning,

RISK MANAGEMENT

With the program based, insofar as possible, upon proven current technology, operational risk could be examined rationally as a cost factor. Alternative approaches to quantifying risk acceptance should be explored; complete risk avoidance at any cost is not always required and is very costly.

Glossary of Terms

Available technology-space technology, including hardware, software, techniques, and capabilities that need no further development for inclusion as part of the infrastructure ("space station").

Bounded program–Predetermined end point of any research, development, test and **evaluation (RDT&E)** program, in terms of time and costs based on realistically achievable objectives.

Cost models–Formal methodologies for estimating the cost of planned future spacecraft subsystems/systems based on extrapolations of the cost of previously developed similar subsystems/systems, with appropriate weighting factors for differences in weight, volume, safety, complexity, past and/or anticipated cost increases, etc.

Components–The lowest level of decomposition of the parts that comprise a subsystem.

Configuration control–Formally established project control procedures for proposing and approving changes to a developing system by assessing the effects of possible changes on the other components/subsystems within the system, on the system performance, and on the interfaces with other systems.

Current technology-(See available technology.)

Design specifications- Detailed engineering specifications for the procurement and manufacture of elements of the infrastructure,

Definition phase–The initial phase of any proposed NASA high-technology development and/or acquisition program. (NASA proposes to spend more effort than usual on the definition phase of a space infrastructure—civilian "space station' '—program, corresponding to its more conventional Phases A and B so as to permit better estimates of infrastructure use, technology, and costs to be made, thereby enabling NASA to go directly into Phase C contracting following procurement funding approval.)

Elements–The highest level of decomposition of the modules, free flyers, platforms, and transportation vehicles that comprise any infrastructure.

Engineering specifications–(See design specifications.)

Incentive contracts-Contracts that reward the contractor for meeting or bettering performance, schedule and/or cost estimates while complying with all minimum specifications. Penalties are imposed for not meeting schedules, costs, or specifications.

Infrastructure-The totality of surface and in-space components, subsystems, modules, elements, and, perhaps, in-space human crew that are to be used to support various space activities efficiently and effectively. (See "Space Station.")

Interfaces-The point or points at which adjacent subsystems, systems, modules, or elements of any infrastructure come together in a structural, mechanical, electrical, or functional sense.

Life cycle cost–Total cost from start of concept through development, production, deployment, and operation throughout the useful life of the infrastructure. Includes all maintenance, operational, and peripheral costs.

New technology—Technology that either is nonexistent and must be developed or does not exist in fully usable form, and which must at least be changed and perhaps be developed further before it becomes "avail able." This implies that additional costs must be incurred to bring the technology to a useful stage.

Open-ended program–A program without a defined end point in time and/or cost and which, in many cases, tends to be self-perpetuating.

Performance requirements-Quantitatively stated functional requirements; they must precede engineering or design specifications.

Phases A, B, C, D–Fundamental elements of NASA's usual approach to the development and acquisition of large, high-technology systems:

Phase A–Study of conceptual design options and alternatives for accomplishing the desired objectives.

Phase B—Trade-offs to select one or more generally acceptable approaches as most cost effective. Usually provides first-order cost estimates based on past experience with analogous systems.

Phase C–Detailed design, which begins to provide information for a more accurate bottom-to-top cost estimate.

Phase D–Actual system development. Usually done on a cost basis, with an incentive fee; rarely procured at a fixed price. There is continuous management by NASA and, at times, negotiation regarding performance, costs and/or schedules.

(In phases A and B, suggestions regarding appropriate technologies are usually heavily influenced by NASA.)

RDT&E– Research, development, test, and evaluation (or engineering.)

Space Station–Infrastructure elements located in the Earth's space, perhaps containing a human crew, used to support space activities efficiently and effectively. (See "Infrastructure.")

System engineering-System design methodology that adjusts components and subsystems in order to achieve the best possible performance from the system as a whole in addressing specified objectives; system initial and life cycle cost is usually an important consideration; acquisition time can also be an important consideration.

System integration-The engineering necessary to ensure that all of the individual subsystems interface properly so that the complete system performs as it should.

Test bed (RDT&E)–A facility for simulating the environment and/or external interfaces so that systems and subsystems can be tested realistically.