The TDRSS Management Story

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NASA initiated the Tracking and Data Relay Satellite System (TDRSS) Program in 1973 to acquire a new capability for tracking and data acquisition from NASA spacecraft in low Earth orbit through the use of data relay satellites in geosynchronous orbit. The data relay satellites would relay communications first between user spacecraft and an Earth station in the continental U.S., then to and from the NASA mission control and data processing centers. A principal objective was to provide the almost continuous coverage of low-orbiting spacecraft (including the Space Shuttle and Spacelab), which is possible from a geosynchronous orbit, contrasted with the limited visibility of low-orbiting spacecraft provided by the network of ground stations then in use. Equally important was the need to meet requirements for the very high data rates (50 to 250 megabytes per second) which were being projected for Spacelab and the free-flyer, Earth-observation satellites.

In the intervening years, the TDRSS program evolved to become, from a program management and contract management viewpoint, one of the most complex and challenging programs in the NASA experience. Problems began with the approach taken in initiating and implementing the program and with programmatic actions stemming from that approach. Other problems were caused by delays in Shuttle launch availability, especially the extensive delay after the Inertial Upper Stage (IUS) rocket failure in 1983 and the loss of Tracking and Data Relay Satellite-2 (TDRS-2) in the 1986 Challenger tragedy. Nonetheless, problems were overcome through dedicated efforts of both the government and industry team members, and today, TDRSS stands as a success story. The space-based tracking and data acquisition network envisioned in the early 1970s is now in place and is performing well. NASA has received more data through the TDRSS than through all ground tracking and data systems worldwide since the initiation of space activities. The support provided to date to the Space Shuttle and Spacelab and to free-flying spacecraft in Earth orbit has fully confirmed the operational concepts which led to the initial approval of the program.

In this article, I will review the management history of this program, revisit the contractual and management problems encountered, and present an assessment of the experiences gained, to identify "lessons learned" which may be of benefit to NASA in the planning and management of programs of this nature in the future.

The Program Start

As early as the late 1960s, NASA realized that the ground network, even on an expanded and upgraded basis, could not meet the technological needs of the relatively near future. Data rates were increasing beyond the capacity of the network equipment and, moreover, the necessary geographical dispersion of the stations had limited coverage of spacecraft data transmissions to about 15 percent of the orbit for most low Earth orbital spacecraft. It would have been possible to upgrade the ground station equipment to overcome the data rate deficiency partially, but it would have been very costly to do so, and geographic expansion of the system was impracticable if not impossible. NASA was already experiencing political problems with certain ground stations located in foreign countries. Even with augmentation, the need for almost continuous coverage could not be realized.

If, on the other hand, NASA could develop a tracking and data network system in geosynchronous orbit, high data rate transmissions could be received in real-time and relayed directly into a single ground station for about 85 percent of the time from all low Earth orbiting spacecraft, thereby permitting most of the ground-based network to be phased down. The circumstances themselves led to the only practicable decision that NASA could make -- an in-orbit tracking and data acquisition network. This approach was supported by a number of conceptual design studies, both in-house and contracted, to determine the feasibility of such a system. By the mid-1970s when it was necessary to make the final decision, it was felt that the required technology was already in hand.

The NASA budget environment was unusually constrained at that time. The costs of developing the Shuttle was devouring a major share of the budget to the extent that it was difficult to maintain a balanced space research and applications program. The TDRSS program was first proposed to the Administrator as a conventional NASA-developed and implemented system. However, the Administrator was reluctant to commit the up-front funding which would have been required for such a program, feeling that the constrained NASA budget resources should instead be reserved for the Shuttle development and other space research and development programs. TDRSS was viewed more as an operational support system, and there were precedents for obtaining such services from the private sector, such as the NASA Communications Network (NASCOM) for communications support of NASA flight missions.

The Procurement Phase

In this environment, and after much discussion within NASA and with Congressional committees, the decision was made to acquire the TDRSS capability from the private sector under a long-term service arrangement rather than to pursue a NASA-developed and owned system. It was also felt that savings to NASA could result if the contractors were permitted to propose a shared-service system containing separate commercial communications capacity along with the required NASA communications capabilities. In either scenario, the contractor was to design, finance, and build the system to meet NASA performance specifications, and operate the system and provide services to NASA over a 10-year period, with no payments to be made to the contractor until acceptable services actually began. All this on a fixed-price contract basis! Such an arrangement would allow the project to proceed on a timely basis, and NASA could defer inclusion of funds in its annual budget until it came time to pay for the services, presumably after Shuttle development had been completed. Special legislation would be required to allow NASA to incur a liability in the absence of appropriated funds and so avoid violation of the Anti-deficiency Act. With the concurrence of the Congress, NASA planned to enter into this off-budget financing arrangement, even though it was totally alien to its normal mode of doing business.

As it evolved, however, the prospective contractors were not able to provide the multimillion dollar funding for the project from their corporate resources nor to obtain financing from the usual financial institutions. (Remember, this was before the days of "junk bonds.") It had been assumed that a 10-year NASA contract would be adequate security, but the financial institutions would not provide loans without a "full faith and credit" backing from the U.S. Government. NASA itself did not have authority to enter into such an agreement; it would have required a statement from the Attorney General's office. However, at that time, an alternate financing arrangement was suggested to NASA by a representative of the Federal Financing Bank (FFB), a component of the U.S. Treasury Department. Under this arrangement, construction loans would be provided directly to the contractor by the FFB, with NASA assuming the role of guarantor of the loans. This had the advantage to NASA of a lower interest rate on the loans than would have been obtainable through the commercial institutions, even with "full faith and credit" backing.

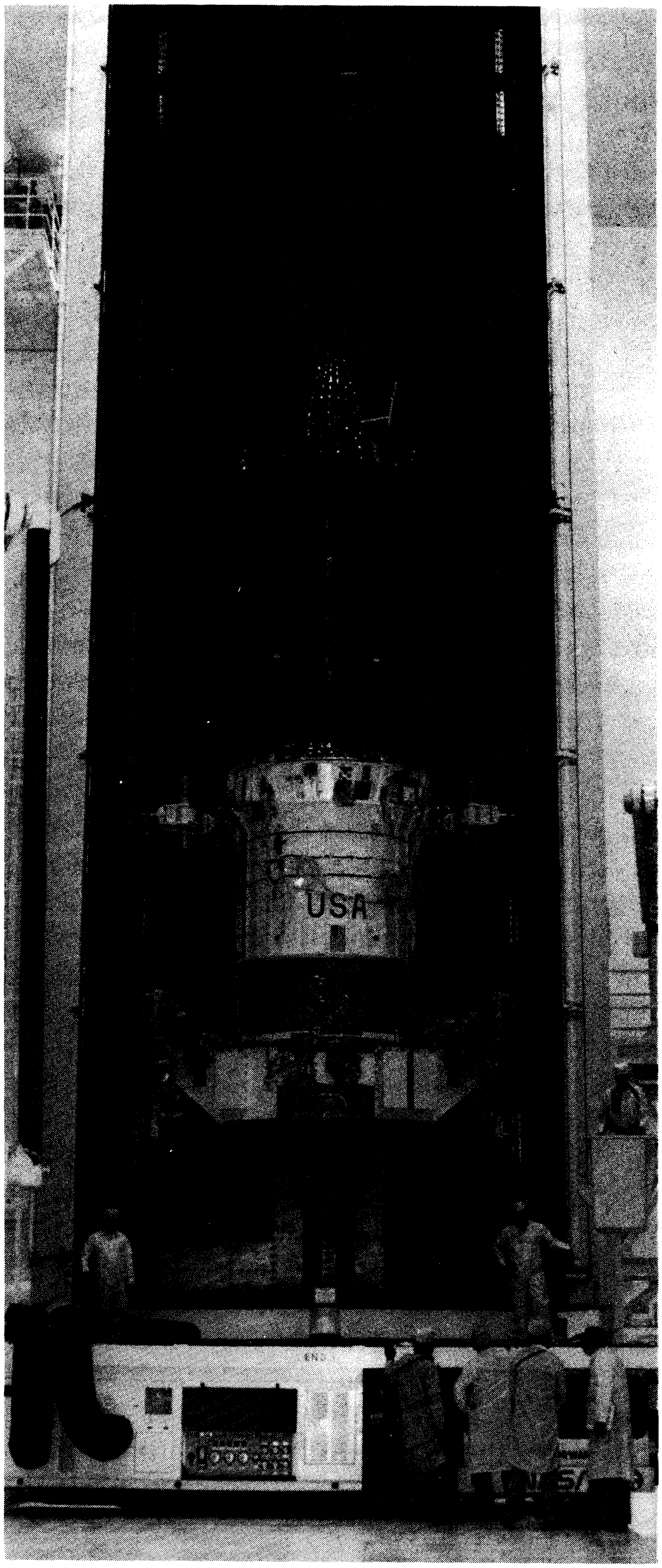
The Request for Proposal (RFP) entailed the development of a service and performance specification rather than a design specification. When services are acquired from the private sector, the performance parameters of an existing commercial system are already known. It then becomes a matter of determining if the commercial service will fulfill the government requirements. Here, however, it was necessary for NASA to specify in advance its own requirements as known or projected at the time for the planned 10-year service period, and really extending for 13 years ahead since it was expected that it would take about three years to design and build the system. As it turned out, some very important performance needs were not fully recognized at the time.

The RFP was issued in February 1975 for a two-phase procurement. After final proposals from two contractor teams were evaluated, the contract was awarded in December 1976 to Western Union Space Communications Company teamed with TRW and Harris Corporation, for development, implementation and operation of the TDRSS for 10 years of service to NASA. In addition, the space segment would have systems capabilities for Western Union's commercial satellite communication services, thus constituting a shared system in what was viewed as a joint venture with industry.

Problems and Their Solutions

The first major problems arose shortly after the project was under way. Potentially severe radio frequency interference, caused by high-power radio frequency energy bursts originating in eastern Europe, appeared to make full operation of the system questionable. The problem needed immediate correction. The RFP had specified performance criteria but had not cited the specifics of the radio frequency operating environment; NASA had, at this point, approved the contractor's proposed system design; and, most troublesome of all, it was a fixed-price contract.

Had this been the usual cost-plus-fixed-fee contract for a government-owned system, NASA would have been able to get involved in the immediate system redesign, issue a change order, and get the project moving with a minimum of loss of time and with some control over cost. In this "hands-off," leased-service mode, however, NASA was thrust into an engineering situation completely foreign to its culture. The project management office had been staffed at a minimal level considered appropriate for managing the service contract, but clearly not adequate for the in-depth technical design review and control of a conventional NASA space systems procurement. On the other side, Western Union, the prime contractor, with its orientation toward commercial communications services, had but little aerospace systems development experience or background; the subcontractor, TRW, had this experience and knowledge, but was not part of the NASA/contractor interface. Hindered by limited contractor access and precluded by the contract from giving technical direction, NASA became burdened with unseemly project delays and added expense. This was only the first of many circumstantial events that restricted NASA's ability to exercise technical management and control of the project.



Technicians transfer the Tracking and Data Relay Satellite and its Inertial Upper Stage, the primary cargo for STS-6, into the transport canister.

Other engineering changes, particularly in the ground station, resulted from new or changing operational requirements. Some of these came from the growing need for more stringent communications security provisions for the command and control systems. Usually, such changes to handle mission-unique requirements had to be made on the contractor's side of the system interface, a troublesome and usually costly process under a fixed-price contract.

The original contract contained provisions for penalties to the contractor for failure to meet specified levels of performance in the system. These were intended to promote a systems design with sufficient redundancy to assure reliable operations. However, the contract cost growth caused by engineering changes and repeated launch delays effectively eroded the penalty provisions to the point where the contractor would find it more cost-effective to skimp on redundancy and reliability and instead accept the risk of penalties for poor performance. In the ground station in particular, the contractor cut back significantly on the level of redundancy and even on the level of performance from the initial design proposal, contending that this system would still meet NASA's service specifications as given in the RFP. This type of situation led to many disagreements between NASA and the contractor, some of which had to be resolved by a change order and additional costs.

Since TDRSS was a leased-service type of procurement, it had not been subjected to the same type of end-to-end systems engineering analysis that would be normal in development of a NASA space mission support system, and the service and performance specifications expressed in the RFP did not bring forth a system design flexible enough to accommodate some of the changes in operational requirements.

Another major problem arose from the interdependency of the TDRSS Project with other projects. The original schedule for launching the first three TDRS spacecraft was based on using the Atlas-Centaur, followed by the Shuttle/Spinning Solid Upper Stage-Atlas (SSUS-A) combination. The SSUS-A was never actually produced, and instead, the Air Force's IUS was selected for the upper stage launch. However, both the Shuttle and the IUS suffered numerous delays. During the same period, additional user requirements were placed on the TDRS by the Shuttle and other programs that necessitated major engineering changes to the TDRSS data system. The repeated lengthy delays inflicted severe damage on the potential for commercial service envisioned by Western Union, because service date plans for commercial service could no longer be met.

At the same time, serious conflicting viewpoints arose between NASA and Western Union over many issues associated with the shared system: cost allocations, impact of engineering changes on schedules, priorities of NASA requirements versus commercial requirements, etc. The net result was that Western Union and NASA reached agreement in late 1982 for NASA to acquire rights to the complete transponder system, including the commercial capacity, bringing the joint venture to an end. This agreement also changed the fixed-price arrangement of the operations phase to a cost-plus-award-fee contract that would allow much more flexibility for NASA. The development and implementation phase remained fixed-price.

By the time of the first launch in April 1983, the project was more than three years behind schedule. TDRS-1 was launched on the Shuttle with an IUS developed by the Air Force. The IUS rocket motors failed to burn properly, however, and injected the TDRS into an elliptical orbit rather than into the desired geostationary orbit. Ironically, the fact that the spacecraft had been designed for dual government/commercial service saved the day. Using fuel ordinarily reserved for commercial purposes, a team of government and contractor personnel devised a series of maneuvers effected with one-pound thrusters over the next several months which placed the spacecraft into its proper orbit. By December 31, the TDRSS was declared to have begun providing services. TDRS-1 has performed well since that date, and has been joined in orbit recently by two more TDR satellites to establish an operational system.

The 'Lessons Learned' Workshop

With the publication of the Reagan Administration Space Policy in 1988, a renewed emphasis was placed on the desire to commercialize to the greatest extent certain new space project undertakings. High-level discussions between NASA officials and Administration policy-level representatives confirmed the intent of the Administration to move aggressively toward this manner of operation. Internal discussions ensued at NASA, and we began a serious review of upcoming programs to see what might be done to respond to this new initiative.

One aspect of this review focused on the joint venture between Western Union and NASA, and on the leased-services approach to involve the commercial sector in such a joint venture. As a result, I felt that it would be useful to revisit the TDRSS experience to see what lessons might be learned that would assist us in dealing with the commercialization program. To that end, I called together about 30 present and former NASA and industry people who were closely involved in the development and execution of the TDRSS project, to review its successes and its problems, and to identify "lessons learned." The major findings of the group follow.

LESSONS LEARNED

Shared Service Concept. *The concept of combining a commercial need with an established NASA need is valid, and may offer significant savings to the government through shared costs; however, the rights and operational utilization needs, availability, and privileges of each party must be clearly established in advance.*

The proportions of cost for the shared TDRSS space segment was approximately 20 percent for Western Union and 80 percent for NASA. Under proper conditions, such an arrangement could benefit both parties. In this case, however, serious conflict of interest problems arose over many elements of the program -- design changes, launch vehicle selections, and delays in the launch dates. It was a situation where the parties had different motivations: NASA was concerned with assuring the most effective performance for NASA missions, while Western Union was driven by the necessity to profit from communications services. That this set of circumstances eventually led to dissolution of the "partnership" does not diminish the possibility of shared service, but does focus on the need for totally clear understanding from the beginning. The priority of the government's service requirements must be clearly set forth at the outset if that service is critical to a government mission operation.

Leased-Service Concept. *A leased-service concept should be based on the use of available commercial services or existing system technology if service is mission-critical.*

There was much more development required for the design and implementation of this program than had been apparent in the beginning due, in great measure, to the changes in requirements after the contract was in place. The TDRS services were critical to NASA's mission. With the realization that major changes were required, NASA reacted by attempting to influence the design to ensure viability of the program purpose. The service-level specification, however, did not permit NASA to specify a design change; only a change in service requirements could be initiated under the contract. A very serious deficiency of this arrangement was NASA's inability to provide to the contractor specific experience in spacecraft and ground systems design, experience that could have benefited reliability and performance issues.

Interdependency with Government-provided Services. *The interdependency of government-provided services to the establishment of a shared-lease service should be avoided or minimized to avoid government impact to the enabling of the leased services.*

The original contract specified that the first three TDR satellites would be launched on Atlas-Centaurs, which were, of course, fully developed operational launch vehicles. The next three TDR satellites would go on the Shuttle/SSUS-A, later changed to the Shuttle/IUS, all of which were still under development at the time of the contract.

However, early in the contract, the spacecraft design was outgrowing the Atlas-Centaur load capability. Spacecraft weight reductions could be made only by unacceptable reductions in redundancy and other reliability provisions, and it soon became necessary to shift the first three TDR satellites to the Shuttle/IUS. The subsequent Shuttle and upper stage vehicle development delays made it impossible to maintain the program schedule, impacting the Western Union commercial communications as well as services to NASA. In agreeing to provide launch services, NASA had, in effect, become a subcontractor to its own prime contractor for TDRSS services. This complex interrelationship complicated the lines of responsibility, placed NASA directly in line to the success of Western Union's efforts, and led to conflicts of interest in questions of launch delay, scheduling, etc.

Fixed-price Contract for Developmental Work. *A fixed-price contract is not appropriate for development of a mission-critical support system where significant technology development may be required or where substantial changes to requirements may occur.*

The nature of the fixed-price contract made close technical direction very difficult. The contract specified certain services that were to be provided; therefore, NASA could not readily control the systems design or make changes to it. Technical direction, as traditionally practiced by NASA, was not possible.

In addition, the project management structure was inappropriate for what became a developmental program. The prime contractor, Western Union, had little background in the aerospace technology necessary for a successful project. Their subcontractors were TRW for systems integration and Harris Corporation for the ground station; Harris was also separately a subcontractor to TRW to provide the spacecraft antennas. The formal NASA-contractor interface could not function in the normal manner. This eventually led to an informal interface between NASA engineers and those of TRW and Harris, simply in the interest of keeping the project moving.

Government Control under Leased Service. *Under a leased-service arrangement, NASA must accept some loss of control over physical assets and accept risks of system outages or failures.*

Effective control of the TDRSS assets was in the hands of Western Union as owner of the system. Under such an arrangement, the only way that NASA could influence the design of the system and, in effect, the quality of services was by specifying service requirements, including penalty clauses to the contract for failure of the contractor to provide the required services. In this particular case, the penalty clauses were not fully effective, due to inflation and NASA-induced technical changes. When the original basis for the penalty clauses no longer existed, the contractor was relatively free to take actions that might reduce the level of service without incurring undue monetary risk.

Operational Interface. *In a fixed-price environment, establish the government/contractor operational interface at a point where changes in requirements affect only the government side, so far as possible.*

In developing the Request for Proposal for TDRSS, the prime effort was to define service capabilities that would meet the requirements of future NASA missions in low Earth orbit. The system was planned to have a broad envelope of capabilities that would handle the projected needs of the users over the 10-year service period without major changes to the system. However, unanticipated changes in requirements began to emerge soon after the contract was in place. Efforts were made to confine the impact of such changes to the NASA side of the interface, and thereby not perturb the fixed-price service contract. However, as this was often not practicable, contract modifications then had to be made, particularly in the ground system, which had significant cost as well as schedule impacts.

End-to-end Engineering and Operations Analysis. *In a leased-service approach to obtaining a mission support capability, it is just as essential initially to establish a comprehensive end-to-end systems engineering analysis and an operations and testing plan as would be done in a conventional NASA space system development program.*

Probably because of the view of TDRSS as a service procurement, there was not enough attention given initially to a systems engineering approach for the total end-to-end system -- the Network Control Center, the Project Operations Control Centers, etc., as well as the TDRSS. Operational concepts that would have correlated the designs and the requirements of all portions of the overall system were not developed until late in the game. The result was unnecessarily complex interfaces among elements of the overall system which might have been avoided by utilizing a systems engineering approach from the beginning; in that way, operational concepts would have been defined at an early stage.

Considerations for Prime Contractor. *The prime contractor must be one who has an extensive background in the business at hand.*

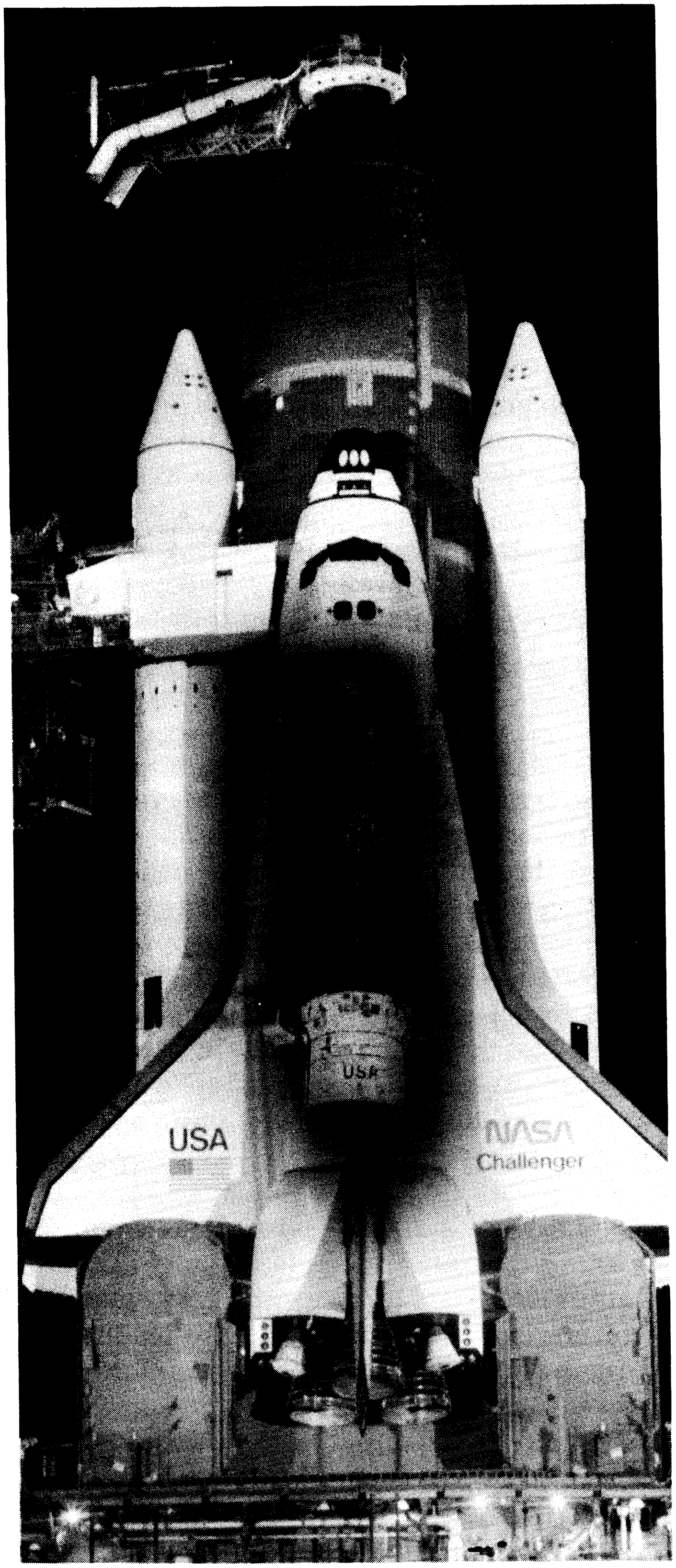
When the RFP was issued calling for a long-term service, there appeared to be a perception in the aerospace and communications industries that a communications carrier was the proper type of company for the effort. The initial proposals received by NASA were in that structure. It is quite possible that the initial demands for capital to finance the project led some to believe that only huge communications-oriented companies would be able to fund such a venture. Regardless of the motivation, the prime contractor's limited exposure to aerospace systems technology was not sufficient for sound technical management of the contract. NASA is more accustomed to dealing with aerospace firms in terms of system and subsystem design. As the technical problems in the system grew, NASA often tended to bypass the prime contractor and work directly with the subs to resolve the technical problems. Thus, de facto decisions were frequently made that had not flowed through the appropriate management channels.

Conclusion

The TDRSS leased-service approach was designed to involve the commercial sector (i.e., a contractor) in developing and implementing a new mission support capability for NASA. This approach used contractor funding, with costs to be amortized and reimbursed to the contractor over a 10-year operations period. Thus, NASA budget requirements for this capability would be deferred until the service was actually provided. As it turned out, the Federal Financing Bank became the source of funding, with NASA guaranteeing the repayment to the Bank. This was to NASA's advantage since the loans were obtained at a considerably lower interest rate than would have been otherwise available to the private contractor. Budget requirements for the system were deferred from the start of the contract in January 1977 until repayment to the Bank began in late 1983. From a management point of view, this arrangement was not a problem for NASA to administer.

Unfortunately, this all took place during a period of high inflation and unprecedented rises in interest rates -- from 7.5% planned to a peak of nearly 16%. These effects, coupled with the repeated delays in Shuttle and IUS availability, caused serious cost growth; almost half of the present total systems cost is in interest charges. However, the cost of these interest charges now appearing as NASA direct costs would not have appeared in the NASA budget had the project been funded in the conventional manner. Instead, the interest costs would have been included in the Treasury budget as part of the cost of financing government borrowing.

The TDRSS will end its sixth year of service on December 31, 1989. Even with only one satellite in operation from December 1983 until late 1988, the service provided was far superior to that provided by the network of ground stations. With the launch of the third satellite in March 1989, the system is now considered operational, and will service NASA's data acquisition requirements into the early phase of Space Station Freedom. In 1991, a replacement satellite will be launched to replace the first satellite in the system. At this point, NASA has achieved what it set out to do -- install an in-orbit tracking data acquisition system providing 85 percent coverage for all low Earth-orbiting spacecraft, leading to the closing of all but a few ground stations.



This double exposure by photographer Klaus Wilkins uses trick photography to cause the TRW Tracking Data and Relay System Satellite to appear to be inside the cargo bay of the orbiter Challenger at the Complex 39A launch site.

We are now approaching the next generation of TDRSS operations -- an advanced TDRSS that will meet the requirements of future missions in the late 1990s and on into the next century. This undertaking attests to the validity of the operational concepts that began nearly 20 years ago. It has been a challenge to reach this point, and we must now use some of the "lessons learned" through this experience to help us cope with the problems that we are sure to face in the development of this next generation of space network systems, as well as other government procurements.