Chapter XI

Spacelab: International Cooperation in Orbit

Spacelab, one of Marshall's longest and most successful programs, is a Shuttle-based habitat that allows scientists to work in shirt-sleeves. Spacelab enabled NASA to accomplish several objectives. Commissioned in the aftermath of the 1972 decision to forego development of a large Space Station, Spacelab provided the Agency an interim means to conduct the types of space science experiments suited for a Space Station. Developed by European interests, Spacelab allowed the Agency to fulfill a mandate to foster international cooperation. With Congress pressing NASA to privatize, Spacelab gave the Agency a means by which American businesses and universities could conduct space science at a relatively modest cost.

The program also perfectly suited Marshall's needs. Any new start was welcome in the post-Apollo era, and Spacelab helped revitalize the Center. Spacelab also offered new opportunities, allowing the Center to pursue its goal of diversification into space science, systems integration, and orbital operations. By moving into new areas, Marshall created new alliances with scientists and engineers, and became the NASA installation with the greatest experience in international space ventures.

Sortie Can and the Spacelab Concept

Spacelab emerged from NASA's scramble to find successors to Apollo between 1969 and 1971. NASA planners had discussed transporting modules to space for some time, and had incorporated the concept into early Space Station studies in the late 1960s. In 1969, Associate Administrator for Manned Space Flight George Mueller proposed that NASA construct a semi-permanent Space Station by the mid-1970s by assembling a series of modules, each with its own function.[1] Marshall and Houston's Manned Spacecraft Center (MSC) planned for such modules in their early Space Station studies.

Over the course of the next three years, the plan for Spacelab emerged. Three key developments define Spacelab's early history: the assignment of Lead Center responsibility to Marshall; the decision to continue the module concept as a part of the Shuttle program after the deferral of a large Space Station; and the agreement to build Spacelab with the Europeans.

Marshall's designation as Lead Center for a manned module for space science seemed unlikely in 1969, when Huntsville still had a reputation as principally a propulsion center. That Marshall won the assignment owed both to efforts at Headquarters to divide tasks equitably between its major manned Space Centers and to aggressive efforts at the Center to obtain new business. Mueller was Marshall's most forceful advocate at Headquarters in the immediate aftermath of Apollo, and when discussing prospects for launching a Space Station by the mid-1970s, he suggested that Marshall would likely become the Lead Center if the project won approval.[2] When Houston became Lead Center for the Shuttle, Marshall was in line for compensation, and Spacelab offered some solace.

But compensatory awards alone would not have been enough had Marshall not demonstrated the capacity to manage such a program. *Skylab*, a program similar in many respects to Spacelab, provided just such a demonstration. Moreover, Marshall's expertise in propulsion gave the Center experience that could be applied to the laboratory. "It was in fact a pressurized structure," explained Marshall Spacelab Program Manager Thomas J. (Jack) Lee, and the Center's work with propellant tanks gave it knowledge about the operation of pressurized systems. Marshall knew "how to design, develop, qualify and have the in-house expertise to ensure that a pressurized structure in orbit was sound. In other words we had that technical capability. I think that's the reason that we got it."[3]

Concurrently the new Program Development Directorate began to seek more work for the Center, and payload development, management, and operations offered a fruitful new field. "We'd been into payloads even before we became a part of NASA," remembered William Lucas. "We began searching and looking in the field. What is there that needs to be done that we at Marshall can do? Where do we have the talents? What do our talents match?"[4]

O.C. Jean was one of those in Program Development who believed that payloads might offer the answer to Lucas's question. "Marshall Space Flight

Center needed an activity that would sustain its base without being slave to a development project," Jean recalled. Jean headed a group that included Bill Sneed and Bob Marshall. "We worked that problem for three months and came up with a recommendation of what Marshall should do." Their recommendations included work in payloads and development of a Marshall operations Center. Spacelab enabled the Center to pursue both goals.[5]

Pressure from another source pushed the Center in the same direction. Ernst Stuhlinger, the Center's associate director for science, advocated a Marshall specialty in payloads. He reported that scientists from around the country wanted to work with NASA, and expressed "a considerable willingness . . . to discuss space projects, and to develop plans for participation." The opportunity suited Marshall's needs and experience. "We did have a science component that was small but significant, and they had had an interest in payloads," Lucas continued. "Utilizing the science component of the Center . . . supported by the science community and universities" would allow Marshall to begin developing payloads. "We did not compete for small payloads. We thought that our expertise would lend itself to large systems."[6]

Program Development initiated a payload planning study that examined possible concepts for the Shuttle. On one level, the goal was to establish criteria for categorizing experiments by weight, size, mission duration, and orbital requirements in order to determine payload groupings and vehicle assignments. But Program Development also sought to ensure that Marshall would have a continuing role in payload management. A 1971 internal report established goals that would place Marshall in control of Shuttle payloads from inception through operational supervision:

- Establish MSFC's role in the *development* and *operation* [emphasis in original] of Shuttle payloads such as: RAM [Research Applications Module], Tug, and Space Station.
- Develop an operational concept for Shuttle utilization that establishes MSFC as the Center that:
  - Plans the mission
  - Aids and coordinates the experiment P.I.'s [Principal Investigators]
  - Has hard mock-up facilities to verify systems compatibility to actual flight hardware
  - Trains the P.I.'s that will make the flights
  - Recycles mission hardware

Thus while the primary goal was to establish policies for payload planning, Program Development wanted Marshall at the focus of that activity; the document twice emphasized that *"The concept must put MSFC between the Shuttle and the experiment P.I."* (emphasis in original).[7]

During 1971 it became clear that budget constraints would prevent NASA from developing both, Space Station and the Space Shuttle. As the Nixon Administration and NASA moved toward deferring Station and developing the Shuttle, the module concept offered a means to use the Shuttle cargo bay to house an orbiting laboratory. Although Shuttle flights would be of short duration, Research and Applications Modules (RAM), as they were now called, might provide opportunity for space science investigations in the years before a Space Station. NASA envisioned short-duration Shuttle flights, or sortie missions, employing RAMs for experimental work in astronomy, materials science, and manufacturing in space.

The Agency expected to develop manufacturing techniques for projects in crystal growth, metallurgical and glass processes, biological preparations, and physical and chemical processes in fluids. The Shuttle could accommodate a variety of payloads, but increasingly NASA began to focus on a pressurized payload carrier called the sortie can, which Headquarters considered "the least expensive and simplest member of the family of research and applications modules."[8]

In September 1971, Headquarters asked Marshall to conduct a design study of the Sortie Can. NASA envisioned the Sortie Can as a bare-bones pressurized module, and as a possible candidate for in-house development and manufacture. The Sortie Can would be suitable for short-duration missions of five to seven days, and could be extended from the Shuttle bay to enhance viewing capabilities for astronomy or Earth observations. Headquarters suggested Ames Research Center's high altitude test program as a model. Ames had used a converted Convair 990 for a variety of experiments, short lead-time between selection and flight, and an opportunity for investigators to assume direct responsibility for their experiments—all goals for the Sortie Can.[9] Marshall's assignment was comprehensive: the Center would have to design the module and develop plans for manufacture, test and inspection, and funding. At the time, NASA conceived Sortie Lab as an in-house project since the Agency could not expect additional funds for the coming fiscal year.[10] A small in-house team in the Preliminary Design Office worked from September 1971 to January 1972, when it recommended that the Sortie Can should be a cylinder 15 feet in diameter and 25 feet long. The study had substantial impact on the evolution of Spacelab design—it was "perhaps the most important" of the early studies, according to Douglas Lord, NASA's Spacelab director in Washington.[11]

By late 1971 the Program Development strategy for Marshall to move into manned science payloads began to bear fruit. The Sortie Can was but one of several payload studies assigned to the Center, and when NASA divided the $10.5 million allocated for experiment definition, nearly $7 million went to Huntsville. During the next several months, the Center conducted payload studies of many possible Shuttle cargoes, including the Sortie Can and other more complex RAMs, the High Energy Astronomical Observatory (HEAO), and an orbit-to-orbit vehicle called the Space Tug. Marshall moved into the forefront of NASA payload planning, conducting in-house studies while contractors worked on parallel investigations.[12] The Center's Sortie Can studies examined ways to use off-the-shelf laboratory equipment and investigated guidelines for temperature, acoustic, and pressure environments.[13]

Since NASA traditionally assigned development responsibility to the Center that managed definition studies, the payload studies carried with them the potential for substantial prolonged projects. With so much at stake, other Centers vied for a share, and Marshall once again found itself competing with Houston. Internal rivalries became endemic during the era of scarce resources that characterized NASA's post-Apollo years. Intercenter disputes were intense during the program definition phase when the Agency divided responsibilities; working relationships improved after Headquarters assigned tasks. But even after Headquarters divided the pie, competition continued in areas where responsibility was not clearly defined.

"I am sure that MSC will not be happy about their portion," Program Development Director James T. Murphy told Center Director Eberhard Rees after learning of Marshall's allocation for payload studies.[14] Similarly Rees worried that Houston might capitalize on its position as Shuttle Lead Center to seize other Shuttle-related programs. Coincident with early Space Station studies, Marshall developed a Concept Verification Test (CVT) project designed to use simulators to evaluate space activities proposed during station definition studies.[15] Rees worried his Space Station team was missing an opportunity to use CVT to support early Shuttle payloads. "If we don't change this attitude drastically," he cautioned, "we will find ourselves pretty soon out in the cold and MSC does the Sortie Can."[16]

Early in 1972, Headquarters directed Marshall to prepare for the Sortie Can definition phase, acknowledging the Center's work on the Sortie Can, RAM, and concept verification as "the hard core of our manned payload opportunities utilizing the Shuttle."[17] In April the Center established a Sortie Can Task Team headed by Fred Vruels of Program Development.[18]

A hazily defined area that opened an arena for Center rivalry was the question of which Center should work with customers who wanted to fly experiments on the Shuttle. With Marshall assuming responsibility for payloads and payload carriers, and Houston serving as Lead Center for the Shuttle orbiter, someone had to satisfy user demands and minimize impact on the Shuttle. Rees, following the strategy of always keeping the Center between the Shuttle and experimenters, suggested that since Marshall already had contact with the user community, it should coordinate. Users would "see" the Sortie Can or the tug, not the orbiter. MSC Director Chris Kraft countered that "the Shuttle/payloads interface is fundamental to the Shuttle development task," and insisted that Houston should reconcile user requests through an MSC Payloads Coordination Office.[19]

"Houston at that time seemed to want to control every interface with the Shuttle," recalled Lucas. "Ultimately it came out to be the logical thing that if Marshall's going to control the Spacelab, they need to control the people directly and then meet the interface with the Shuttle. You don't need to speak to someone in Houston to speak to your customer. . . . The logic is that as long as the Spacelab meets the established interface with the Shuttle, then why should the people responsible for Spacelab go through Shuttle management to get to Spacelab? That's the way it turned out to be. I like to think logic prevailed."[20]

The disagreement over user coordination was typical of the intercenter disputes that arose as Marshall diversified. The Center guarded its flanks to prevent other Centers from closing potential avenues of expansion. When MSC opposed initiation of a Shuttle Payload Data Bank study that would have enhanced Marshall's interface with Shuttle payload customers, Murphy acknowledged that "the objections to this study stem from the fact that MSFC has been posturing itself to play a key role in the Shuttle payloads business, and other

Centers are viewing MSFC's growing payload activities with some concern."[21] Rees also worried that Houston might encroach on Marshall's other emerging specializations. "I have been having a certain feeling for quite some time that MSC wants to wedge themselves into the Shuttle Payload business," he told his technical deputy, Lucas, in the fall of 1972. Rees believed that Houston would "try anything to get on the Payload and Tug Bandwagon," and cautioned that "we should be constantly aware of this tendency of MSC and fight it wherever we can."[22]

International Partnership

NASA had since its inception wanted international partners, an imperative that became more pressing after the 1969 Space Task Group included such a recommendation in its report.[23] NASA's tight budget made international participation more attractive. European interest in a cooperative venture also increased in the early 1970s. The European Launch Development Organization (ELDO) and the European Space Research Organization (ESRO)—already engaged in negotiations that would lead to the formation of an all-encompassing European Space Agency (ESA) in 1975—both explored the possibility of a joint venture with the Americans. By 1971, when it became clear that NASA's next major project would be the Shuttle, Europe's options narrowed to development of a specific part of the Shuttle (such as the payload doors), the Space Tug, or the Sortie Can.[24]

The European consortium spent $20 million on studies of the three alternatives, and in the process began working with Marshall.[25] During 1971 and 1972, ELDO conducted design studies of the tug under Marshall supervision. By February 1972, ELDO informed Marshall representatives that the Europeans were very interested in developing the Tug.[26]

Space Tug was "a natural" for Marshall, Lucas recalled, since it entailed a propulsion system and a Shuttle interface. In addition to its work with ELDO, the Center monitored Tug studies by American contractors McDonnell Douglas and North American Rockwell. Other NASA Centers and the Department of Defense helped develop design and interface requirements.[27]

Department of Defense participation doomed the hope that Space Tug might be an international program even before budget pressure forced NASA to abandon the concept. In June 1972 the Agency decided that the Europeans would not develop the Tug. "There was no way that was going to happen, not from NASA's standpoint but from the military's standpoint," explained Lucas. "That Tug was to serve both NASA's interest and the military's payload interests. The military certainly would not have been willing to have a foreign entity that they had no control over to be in the loop as far as their payloads were concerned."[28]

NASA also decided not to accept European participation in the development of the Shuttle. One assessment suggested that the Europeans lacked the organization, experience, knowledge, and laboratory depth needed to make much of a contribution to the Shuttle.[29] The Agency worried about dependence on foreign sources for critical items, and feared that it would lose more than it could gain.[30] The only alternative remaining for international participation was the Sortie Can, which Lucas said went to the Europeans as "sort of a consolation prize."[31] The Sortie Can required less advanced technology, and if it lagged in schedule or ran over budget, it would not affect the Shuttle.[32]

The Europeans hesitated to participate in development of the Sortie Can, however—and for good reason. Many Europeans questioned whether they had much to gain with Sortie Lab. Douglas Lord, who as director of NASA's Space Station Task Force negotiated with ESRO regarding participation on the Sortie Can, acknowledged NASA's advantages. "We are dealing with a potential supplier who is seriously considering investing $250 million of his own funds in the development of a spacecraft to be used primarily by the U.S.," Lord told Marshall. "This is not a typical joint venture since the direct benefits are heavily in our direction."[33]

NASA pressed the Europeans for a decision by September 1972, requesting a "start-to-completion" agreement.[34] The Europeans were not in a strong position to bargain, and would later admit that in 1972 they lacked confidence in their capabilities and believed they needed American assistance to establish their own manned program. Political scientist John Logsdon concluded that at least some of the Europeans were "willing to pursue cooperation on almost any terms, no matter how one-sided."[35] The Europeans could not be pushed into a hasty accord, however, and deliberations dragged past NASA's September target.

While the Agency conducted negotiations with the Europeans, Marshall continued its in-house definition studies of the research and applications carrier, which now bore the more elegant name "Sortie Lab." Lee succeeded Jack Trott as Phase B director of the Marshall task team. "I had a small staff of people in PD [Program Deployment], and then I drew on the whole of the engineering capability of the Center to put down the details of the design," Lee remembered. The in-house work preserved NASA's options in case the Europeans decided not to join. "We were pretty far along on the completion of that Phase B," Lee explained, "so that we could either try to build it in-house or go to contracting out."[36]

Center management followed the European negotiations with interest, since Headquarters told them that Marshall should expect a substantial role if the Europeans decided to participate. Rees told Program Development to begin planning Marshall's managerial approach if the Europeans accepted, since project management would be "somewhat different from our usual Phase C/D project management with American contractors."[37]

Marshall's role in the development of the Sortie Lab could not be defined until the Europeans decided whether to participate. The logjam began to break late in 1972 when the Europeans approved involvement by ESRO member states. At a European Space Conference in November, ministers removed obstacles blocking member nations from contributing to Phase B studies and endorsed formation of a single European space organization to supersede ESRO and ELDO.[38] In January ESRO voted to work on the lab. During the next four months, representatives of ESRO and NASA worked out the details that led to a Memorandum of Understanding. The Europeans agreed to develop a pressurized manned laboratory and an unpressurized instrument platform, or pallet. ESRO accepted responsibility for the "definition, design, development, manufacturing, qualification, acceptance testing and delivery" of an engineering model and a flight unit to NASA. They also agreed to provide ground support equipment and engineering support through the first two flights. ESRO agreed to deliver the flight unit one year before the first Shuttle flight, then scheduled for 1979. NASA would operate the lab and purchase additional units from the Europeans if needed, but the agreement did not guarantee additional purchases.[39]

Marshall's role evolved during the international conferences leading to the formal agreement. Headquarters insisted on "strong centralized management and coordination of all activities related to the Sortie Lab" under direction of an

Agency-level Sortie Lab Task Force. NASA Associate Administrator Dale Myers assured Rees that Marshall would be Lead Center, however, and directed the Headquarters task force to develop a plan for the eventual transfer of authority to a Marshall task team.[40]

The Center laid the groundwork for its assumption of Lead Center responsibilities. The Center reviewed the European Phase A Sortie Lab studies, and considered the results "reasonable." But reviewers lamented that the Europeans lacked understanding of orbiter interfaces and space limitations, and applied requirements so rigidly as to cause "extreme penalties on cost, weight, power, and other design factors." Marshall's reviewers determined to "prevent a similar happening during their Phase B."[41]

As in concurrent Shuttle development, cost became a major factor in Sortie Lab planning. The Europeans insisted on an escape clause that would allow them to back out if costs exceeded $300 million.[42] Lucas, technical deputy to new Marshall Center Director Rocco Petrone, advised that the Sortie Lab would have to be kept simple "to provide the greatest cost advantage," and directed Program Development to "maintain this cost consideration as a primary design driver."[43]

Selection of Marshall as Lead Center enabled the Center to resolve differences with the Johnson Space Center (JSC) over management of Sortie Lab. Huntsville requested JSC assistance on its Phase B studies, and the two Centers divided other responsibilities in meetings in the spring of 1973. Marshall would provide technical support to the Europeans related to the design and definition of the lab; Houston would provide interfaces for the lab with the Shuttle and direct overall safety, crew training and requirements, and mission operations.[44]

Marshall's efforts to define its Lead Center responsibilities for Sortie Lab provoked renewed concern in NASA over the larger issue of payloads. Late in 1972 Headquarters directed that the long-delayed Shuttle System Payload Data Study proceed, a decision that Marshall welcomed as "another step forward in enhancing MSFC's Shuttle Payload activities."[45] Marshall's role in payload management grew in the months that followed. Headquarters gave Marshall responsibility to integrate NASA's payload requirements, but also established a Payload Requirements Board staffed by representatives from Payload Program offices.[46] Even these assignments left questions unanswered and lines of authority hazy. Deputy Administrator George Low worried that the "the question of how Shuttle payloads will be handled and assigned within NASA is so important to the future of the Agency that it is not possible to address some of the lesser goals and objectives until it is resolved." He directed establishment of an Agencywide team under former Langley Deputy Director Charles J. Donlan to examine the distribution of payload responsibilities.[47]

By this time, however, Marshall's central role in payload development was well established, and in fact NASA augmented the Center's responsibilities a week after commissioning the Donlan study. Not only was Marshall to continue its current studies, but it would update the Shuttle payload model, conduct payload and mission planning, and develop payload accommodations for the Shuttle, Sortie Lab, and Tug based on comments from users.[48] Marshall's payload duties remained undiminished when the Donlan group submitted its report the following spring.[49]

Months of international negotiations culminated on September 24 in a formal ceremony in Washington when NASA Administrator James C. Fletcher and Dr. Alexander Hocker, Director General of ESRO, signed a Memorandum of Understanding. The accord established a Joint Spacelab Working Group (JSLWG)—soon dubbed "Jizzlewig""—to coordinate NASA and ESRO. With American and European program heads serving as co-chairs, the group could resolve technical and managerial issues, exchange information, and identify potential problems. Finally, Fletcher announced that the Sortie Lab would now be called "Spacelab," the name preferred by the Europeans.[50]

Building Spacelab

With the formalities of an international accord complete, Marshall assumed its role as Lead Center. The Center changed its internal management of Spacelab, moving it out of Program Development to a new Spacelab Program Office in December with Lee as manager.[51] Lee's first major task was to represent NASA during the European competition to select a prime contractor for Spacelab Phase C/D design and development. ESRO tried to achieve equity on its projects by seeking geographic distribution of contracts based on the financial participation of its member states. In the case of Spacelab, West Germany's 54.1-percent contribution placed it far ahead of second place Italy's 18-percent participation, virtually assuring that the prime contractor would be a German company. The leading contenders were two consortia: Messerschmitt-Bölkow-Blohm (MBB) of Munich, and ERNO of Bremen, a VFW-Fokker subsidiary. So close was the competition that the evaluation team refused to choose; an adjudication committee selected ERNO based on its management, technical concept, and design.[52]

Before the contract could be awarded, a serious problem emerged. When NASA Administrator Fletcher met with Dr. Hocker, he learned that both the MBB and ERNO proposals were overweight and would undercut payload capability. When Fletcher learned about the discrepancy, he insisted that the proposals were unacceptable, and that differences would have to be resolved before proceeding. Lee worried about holding the agreement together. “It is not black, but I have no idea how bright it will be,” he reported as he anticipated another round of meetings. “We need to satisfy all parties concerned.”[53]

Fletcher’s reaction hit ESRO like a “bombshell,” according to Lord. The new trans-Atlantic partnership entered its first crisis.[54] The European press criticized NASA. Typical was a Dutch newspaper that complained that NASA’s action “took both ERNO and MBB completely by surprise.” The paper blamed NASA for rejecting the design proposals “on the very moment that the Dutch space organization ESRO/ESTEC in Noordwijk wanted to place a contract with the European industry.”[55] Lee helped to diffuse the tension, meeting with his counterpart Heinz Stoewer and ESRO Director General Roy Gibson and encouraging them to explain that the weight issue reflected a joint NASA/ESRO concern. Stoewer concurred, but ESRO insisted that the problem was less serious than NASA claimed, surely not so critical as to invalidate the award to ERNO.[56]

John F. Yardley, the new NASA associate administrator for Manned Space Flight, flew to Europe to help resolve the dispute. NASA and ESRO agreed to reduce weight and to develop different categories so that weights could vary from mission to mission. Fletcher and Hocker agreed that the issue was not so weighty as to force abandonment of the selection of ERNO as prime contractor. On 5 June, ESRO awarded the Bremen consortium a six-year, $226 million contract.[57]

The weight controversy demonstrated the fragility of NASA’s relationship with the Europeans. In a legal sense, NASA and ESRO were partners; state agreements sanctioned the Memorandum of Understanding, and diplomats on both sides of the Atlantic celebrated the Spacelab agreement as symbolic of an international partnership. "It was very much, by necessity, a partnership relationship," Lucas insisted. "Europeans were very sensitive about that. They were supplying most of the money so you couldn't think of it as a contractor."

But in many ways NASA—and Marshall as Lead Center—found themselves acting as if ESRO was a contractor. Lucas acknowledged the dual nature of Marshall's position, explaining that the Center had to "act like we had a contractor but not let them know that. In other words, we had to give them a lot of guidance, but we had to do it in a discrete way rather than like you would work with a contractor here. . . . It's just much less direct than the contract relationship."[58]

Lee, who bore the major responsibility for Marshall's contact with the Europeans, told Lucas in 1978 that ESA "resents being treated like a contractor."[59] Lee understood ESA's concern, and years later he explained that the Europeans "made it very clear that ESA was not a contractor of NASA. We honored that. It was difficult sometimes because I found myself being the judge on the imposition of certain requirements." Lee tried to avoid dictating NASA specifications and requiring ESRO to impose them on the contractor; he sought instead to give basic requirements, inform Stoewer of the criteria that would be used to judge "whether what we were going to fly was acceptable," and allow ESRO to make major development decisions about how to proceed. Lee's approach applied what would later be called performance specifications. "I saw it better to let them have the flexibility of working against performance specification," he explained, "instead of me having to have to follow along with all the detailed specs."[60]

The weight controversy, although resolved amicably, exposed the potential for problems in this unusual relationship. And after resolution, anticipating a joint NASA and ESRO discipline-by-discipline review to ensure that ERNO's proposal matched the requirements stipulated by the NASA–ESRO agreement, Lee commented that the review would "allow a more thorough penetration on our part."[61] It was the language of a contracting officer, and although Lee did not specify whether he meant penetration of the partner or the partner's contractor, it was clear that the relationship was indeed unconventional.

The multinational character of ESRO also complicated relations with the Europeans. "Not only were we dealing with a different culture, but we were dealing with ten different cultures," Lucas recounted.[62] "Communication made it more difficult," according to Lee. Problems were not only cultural, but institutional. Lee believed that the program might have been completed sooner had it not been for the difficulties in getting agreements between ESRO's member states. "I suspect that we waited on them more than they waited on us," he said. Congress did not interfere with the relatively inexpensive Spacelab program, but ESRO operated under "more of a parliamentary process so quite often we would have to wait for a year. Ministers don't meet, and you don't call them together to deal with it."[63]

Selection of the prime contractor signified an important milestone. As the project moved into development, Marshall's role and Lee's responsibilities changed. "My role then became a little bit different. We weren't doing in-house design any more," Lee recalled. "We were more focused on what we considered a program function." Lord assumed NASA's Level 1 responsibilities at Headquarters in Washington; Lee's duties as program manager placed him at Level 2. ESRO established its development Center at the European Space Technology Center (ESTEC) at Noordwijk in the Netherlands. Lee and Stoewer, his European counterpart, met frequently and arranged for exchanges of information, means of monitoring progress, and program coordination.[64]

Marshall's relations with Houston also tested its diplomatic skills. Lucas tried for nine months to get Houston to assign an individual as "a single point of contact with authority to represent JSC on all Spacelab technical and programmatic matters." At one point he became so exasperated with Houston's failure to cooperate that he wrote on the margins of a note: "Don't want to call again. Just file as a reminder of how JSC cooperates with us."[65] Finally JSC appointed Glynn Lunney, who had been working on the Apollo-Soyuz Test Project.[66]

The liaison with Houston was critical since the two Centers had to coordinate interfaces for two projects, Shuttle and Spacelab, that were both in development; changes in one inevitably affected the other. "Spacelab ended up costing quite a bit more than the Europeans originally thought, partially because the Shuttle kept changing," according to Marshall's Stanley Reinartz. "And if you're trying to do two things in parallel, it can run up the bill, particularly if you're trying to do one thing in this country and one thing in another."[67] Both programs had to learn how to adjust. "On the front end, you sort of had the instinct that everything wasn't defined, but yet on the other hand you didn't know what it all was until you got in and started handling it," Lunney recalled. "The Marshall and ESA people would go back to the Spacelab project and get definitive [data and] we would go back to the orbiter and Shuttle program." Gradually a system evolved; by developing a series of interface control documents (ICDs), Houston and Marshall were able to coordinate the simultaneous development of the Shuttle and Spacelab.[68] With Lunney serving as liaison, coordination between Houston and Marshall improved.[69] Center rivalry diminished, James Kingsbury explained, as everyone in NASA worked hard "to show one front to ESA."[70]

Planning Spacelab Missions

While Marshall's program office coordinated Spacelab development, the Center's payload activities became more focused. Marshall's payload studies through the spring of 1974 concentrated on developing candidate payloads based on research at the Center and proposals submitted by users.[71] The Donlan committee report of April 1974 recommended establishing a Headquarters office with supporting activities at Marshall for payload planning and at Houston for flight planning and mission assignments. The committee also recommended that the Marshall Center handle integration and payload flight control for multipurpose Spacelab flights. Marshall would assemble and check out payloads for early Spacelab flights, then relinquish this duty to KSC. JSC would be in charge of Spacelab subsystems during flight as part of its Shuttle operations management.[72]

Marshall's Program Development office was at the Center of NASA's payload planning activities, taking a leading role on panels examining payload profiles for the first six Shuttle flights and for Spacelab. The Center chaired a NASA committee charged with defining payload requirements in light of Shuttle and Spacelab hardware design. Headquarters assigned Marshall responsibility for planning the first Spacelab mission, and the Center continued to work on a broader profile of the first 20 Shuttle missions.[73]

To coordinate its payload activities Marshall established a Payload Planning Office under Jean.[74] "O.C. Jean impressed me as a manager," remembered David Jex, who worked for him. "One philosophy that he espoused that always stayed with me was it doesn't matter who gets the credit as long as the work gets done."[75] In June 1975, Marshall shifted planning for the first Spacelab flight from Program Development to Jean's office.

Headquarters assigned Marshall management of payloads for the first three Spacelab missions, including responsibility to plan, develop, integrate and operate the payloads.[76] In one sense the assignment was a logical extension of the Center's development of Spacelab, particularly since the first two missions would verify Spacelab systems. NASA Chief Scientist John E. Naugle commented that "Introduction of another Center into the Shuttle/Spacelab/NASA/ESA operation would have converted a very complex barely manageable problem into a completely unmanageable one."[77] But the assignment also signaled the maturity of the Center's diversification into payloads, and gave Marshall the opportunity to broaden its experience in space science and operations.

While the principal task of the first two missions was to evaluate Spacelab systems, NASA believed there would be enough space, resources, and time available to conduct additional space science experiments. Marshall intended to incorporate several disciplines and experiments from European and American investigators to demonstrate the range of Spacelab capabilities for research.

The Marshall Center's payload work opened scores of opportunities, but like other diversification projects of the 1970s it also placed Marshall in competition with other Centers. Goddard Space Flight Center (GSFC) worried that Marshall's work in space science payloads might infringe on its specialties. Johnson Space Center found reason for concern in Marshall's involvement in operations, payload specialist selection and training, and life sciences.

Spacelab gave Marshall a chance to broaden the operations experience it acquired during *Skylab*, and although JSC preferred to manage all Shuttle-related operations, it accepted a role for Marshall. Early Spacelab missions required a dual structure for operations; JSC would have responsibility for the orbiter, Marshall for Spacelab payloads. Marshall's mission management team would work out of a Payload Operations Control Center (POCC) located in Building 30 at JSC, while orbiter operations would be conducted from Houston's Mission Control. In the POCC, Marshall's team could work side by side with ESA representatives and principal investigators whose experiments were aboard the orbiting laboratory.[78]

Although Houston accepted a Marshall role in operations, it was less conciliatory in relinquishing its monopoly over astronauts. Spacelab introduced a new category of astronauts, the payload specialists. Their selection process was different from that of traditional astronauts, and therein lay the basis for Houston's objections. An Investigators Working Group (IWG) comprised of the principal investigator (or chief scientist) for each experiment on the mission selected scientists or engineers as payload specialists. Not only would Marshall have influence in the selection process by virtue of its role in payload integration, but the Center would provide mission-specific training in Marshall's Payload Crew Training Complex (PCTC), thereby infringing on Houston territory (of astronaut training).[79] Houston Center Director Kraft objected vigorously to this process, arguing that Spacelab payload specialists ought to be "selected from the present corps of mission specialists residing in Houston" since they were suited by training, experience, and involvement in Spacelab design and development.[80]

Kraft's proposal made no headway against an approach already accepted by Headquarters, and Marshall relished its victory. "Dr. Kraft is going to fight the payload specialist philosophy that NASA has developed and we are implementing on Missions 1, 2, and 3," Jean informed Lucas. "His whole supremacy collapses if a non-JSC man flies in space. I believe we have the whip and can do the driving."[81]

More important was Marshall's expansion of its involvement in space science. Marshall and its predecessor organization, the Army Ballistic Missile Agency (ABMA), had long worked with outside scientists, but Spacelab offered the Center opportunity to expand this activity. In planning for Spacelab 1, for example, the Center selected experiments in 1976, and the following year brought all chosen principal investigators to Marshall to form the Investigators Working Group.[82] Spacelab also afforded a chance for Marshall to develop its own experiments and to attract scientists to work at the Center.

When Marshall began developing payloads in life sciences, eyebrows raised at JSC and Ames. Marshall had begun investigations in life sciences as part of its early payload studies, but the other Centers saw this as their prerogative, and Marshall "got our arms broken," in the words of the Marshall Center's John Hilchey. Marshall found ways to remain active in life sciences nonetheless, concentrating on non-human subjects and accommodating Ames and JSC experiments in ways that enabled Center Director Lucas to justify the Center's work to Headquarters. Hilchey remembered that "Lucas would say to Herm Gierow, 'Hey Herm, how's that life science's program going?' The standard answer was, 'Dr. Lucas, we don't have a life sciences program; we have a payloads program of Space Station accommodations for payloads; and that's what we're doing, and life sciences is just one of the disciplines we deal with.' Lucas would just grin at him."[83]

A Troubled Partnership

More troubling than Center rivalry were emerging problems with ESA, for NASA was becoming more concerned about the performance of its European partner. The peculiar relationship between NASA and ESA led to unexpected difficulties. Marshall often learned of emerging problems before NASA Headquarters through on-site visits. In one such report—on the Spacelab thermal control systems in 1975—the Center learned how internal communications deficiencies, poor systems integration, customary exclusion of working level people from meetings, lack of experience, and limited facilities caused delays. Subcontractor Aeritalia, for example, had come to rely on McDonnell Douglas engineers, and had to replace them with Italian engineers, none of whom had spacecraft experience. Marshall's Kingsbury worried that similar shortcomings were "widespread in all subsystems."[84]

Such difficulties had serious implications, leading to delays, misunderstandings, and uncertainties. It was difficult to implement changes, in part because ESA's contractors operated under the assumption that systems were defined at the time of the proposal, and that they were to "design to cost." Unless contracts were completely definitive, contractors disclaimed responsibility. ESA thus found itself in the unusual position of having to persuade its contractors to make changes. Contractors, operating under fixed price contracts and working with limited engineering manpower, were seldom receptive.[85]

Although many of ESA's problems were the sorts of difficulties that customarily occur in large development programs, the Europeans became increasingly sensitive to NASA supervision. "The Europeans are a proud group. They didn't want us telling them how to do something," explained Kingsbury, whose contact with Spacelab came because of his position as head of Marshall's Science and Engineering Directorate. "When we would go and say to them, 'What you're doing isn't going to work,' they would say, 'Thank you very much,' and do it anyway. Then they would never tell us it didn't work. The next thing we knew they'd changed to something else. Of course we knew what happened to it. We had to get them around to a system that would work and that we could live with by trying not to offend them by telling them what they were doing was crazy. Engineers are not by their very nature very tactful people usually. We had some people who tried very, very hard to be tactful. We had some who couldn't stand it any more and lost all tact."[86]

In part problems arose because of the number of people working on Spacelab for each Agency. Marshall had 180 of its own people and 115 support contractor employees assigned to Spacelab in FY 1975.[87] Lee assigned 6 percent of them to monitoring ESRO, and 14 percent to assisting ESRO. The other 80 percent were divided equally between those assigned to systems engineering and the development of NASA-provided software and equipment, and those engaged in operations planning and experiment integration. In contrast, ESRO had only 80 people assigned to Spacelab, and Headquarters worried that either Marshall had too many on the project or ESRO had too few. Lee defended his manpower as the minimum required and expected to increase by about one-third over the next two years.[88] Some NASA administrators worried about the imbalance, and particularly about assigning too many NASA personnel to posts in Europe. "This approach might even be . . . harmful if it appears that NASA is 'taking over' the program," suggested one internal NASA assessment.[89] On the other hand, NASA's concern about the sensitivities of its European partner obscured a basic issue; as Marshall's Lowell Zoller, who was on duty in Europe, suggested, "ESA is facing about a 40 percent increase in manpower requirements to get the job done."[90]

NASA knew of European sensitivity to excessive penetration, but the Agency believed that ESA needed both managerial and technical advice. NASA approached ESA General Director Roy Gibson, criticizing project management and offering a "combined technical/management advisory package." Gibson admitted problems, but said he "would prefer by far not to accept an offer of NASA advisory support" below the program management level.[91] The two agencies negotiated an arrangement under which 12 NASA technical experts and 3 management advisers took assignments at ESTEC and ERNO. Although the Americans initially wanted a dual reporting system in which its experts would be responsible to both ESA and NASA chains of command, they agreed to an arrangement in which the individuals would be integrated into ESA's organization and have no responsibility for implementing NASA's requirements.[92]

ESA had its own reasons for dissatisfaction. As time passed, it became clear that Europe was going to get less than expected from Spacelab. Although the 1972 Memorandum of Understanding required delivery of only one Spacelab, the Europeans had anticipated selling NASA perhaps as many as four additional units. After all, NASA's 1973 plan for Shuttle utilization required six Spacelabs (and seven orbiters), and as recently as December 1974, NASA had projected flying as many as 25 Spacelab missions per year. A year and a half later Shuttle development lagged, and it was apparent that there would not be such high levels of use. Now NASA would commit only to one Spacelab with an option on a second. Many Europeans believed that too much money was going to Spacelab. As ESA's budget declined, less money was available for European utilization after completion, and there seemed to be little ESA could do to prevent the initiative from slipping to the Americans.[93]

By the summer of 1976, it was clear that the Spacelab program was in trouble. So concerned was NASA about both schedule slippage and ultimate performance capabilities of the European program that it took steps to initiate studies at Marshall and JSC for ways to back up ESA's work.[94]

Although the Europeans were reluctant to acknowledge the depth of their difficulties, Marshall representatives in Europe observed serious shortcomings. Zoller noticed "striking similarities" between the difficulties Marshall had experienced with the Shuttle main engine a few years earlier and the Spacelab problems. "Neither ESA or ERNO have very efficient management systems," he observed, "and the top management on both sides spends an inordinate amount of time fighting over fee and image." He worried that ERNO management was "concentrated at the top," and that ESA was "basically a one-man show," leaving inexperienced subordinates like Stoewer so cautious that they would postpone "sticky" issues until after key reviews. Another sign of excessive caution was a tendency to overdesign rather than analyze requirements that were peculiar to certain payloads or missions. Zoller nonetheless believed that both ESA and contractor were competent, but that "the biggest detriment to the program is the mistrust that is so evident among all the contractors and ESA."[95]

Spacelab began to experience the cost and schedule problems familiar to most post-Apollo space programs. Zoller cautioned Marshall about the emerging dilemma before the Europeans were willing to acknowledge it. “The technical baseline is not clear, and therefore the schedule and cost are up in the air,” he warned. “Needless to say, ESA doesn’t readily admit to the full implications of the programmatic problems.”[96] By the end of the year, even ESA was ready to address the crisis.

Costs were particularly problematic because of ESA’s multinational funding arrangements. ESA members participating in Spacelab understood the volatile nature of funding Big Science projects, and had agreed to support a 20-percent overrun. If costs exceeded 120 percent of initial support commitments, however, member states would be allowed to withdraw. As early as February 1975, ESRO began suggesting delays, descoping, or split deliveries after its contractor submitted funding requests in excess of the Agency’s budget.[97] By November 1976, ESA’s cost projections had already exceeded 100 percent. “We have always been very much afraid of being forced to exceed the 120 percent,” reported Michel Bignier, who was soon to take Stoewer’s place as Lee’s ESA counterpart. Bignier also lamented that “a certain number of systems are now behind schedule and . . . it will be difficult to catch up completely.” He suggested simplifications that might reduce delays and costs.[98]

The problems plaguing Spacelab strained the international partnership. NASA believed it had no alternative but to apply pressure. ESA, perturbed by its limited ability to compel changes from its contractors, fearful that budget overruns might lead to withdrawal of member states, and disappointed by diminishing returns from its large investment, reluctantly succumbed. By the mid-1970s, the NASA–ESA relationship was at best an unequal partnership. R.N. Lindley, one of NASA’s representatives in Paris at the time, observed that “Far too many people, on both sides of the Atlantic (and I have been one of them) have looked upon this relationship as one which places ESA almost into the role of a contractor to NASA (with a no-cost plus no-fee contract).”[99]

Cost reductions and schedule adjustments dominated meetings in the months that followed. ESA proposed a “comprehensive overhaul of the management of the project” and a “descoping.”[100] The Europeans suggested revisions in the schedule of equipment to be delivered, including the deletion of some equipment requirements, and offered to replace key personnel. They agreed to appoint a task force to review contractor management, and to include NASA representation.[101] Bignier took over as Program Director for Spacelab, and he conceded the need for "very tough Program Management, which is not exactly the image presented by Heinz Stoewer."[102]

Technical Challenges

Development of Spacelab continued while the Europeans and Americans established management for the program. The basic configuration was now set. Spacelab would have two elements: a pressurized chamber in which scientists could work in a shirt-sleeve environment, and an unpressurized pallet, or platform, for instruments requiring direct exposure to space. Modular design allowed for flexibility. The habitation module would have two segments—a core segment and an experiment segment. The core segment would contain basic support equipment and several cubic yards of experiment racks; the experiment segment would be devoted entirely to experiments. Up to five U-shaped pallet modules could be added, allowing for a variety of arrangements depending on the mission. When pallets would be flown without the core segment, supporting equipment would be protected in a small pressurized temperature-controlled chamber called an "igloo." Experimenters could also arrange modular experiment racks to suit a particular flight, and integrating experiments for the early flights would be Marshall's responsibility.

As Lead Center, Marshall had duties in addition to its supervision of the Spacelab module development. In order to ensure proper weight distribution aboard Shuttle, Spacelab would nest toward the rear of the orbiter's cargo bay, so Marshall would have to devise a crew tunnel from the orbiter flight deck to the laboratory. Much of the program's complexity centered around Spacelab's subsystems, which included structure, environmental control, electrical power, command and data management, and payload support equipment.[103] In addition to monitoring these subsystems, Marshall also bore responsibility for development of an instrument to provide precise alignment of experiment instruments.

Of the technical challenges involved in Spacelab development, the instrument pointing system (IPS) posed the most obstacles. Solar physics and astronomy experiments required a system that could align large instruments with pinpoint accuracy and stabilize them for long periods. It was "new and different and proposed requirements that we hadn't done before," Lee recalled in describing the IPS as the "most difficult" of all Spacelab projects.[104] Indeed the IPS was extraordinarily complex, requiring drive motor systems for movement in three axes, mechanisms to secure the gimbals for loading and unloading experiments, an optical sensing system for alignment in relation to stars and the Sun, a system for directional control and stabilization, support structures, a clamping system to secure the delicate instrument during ascent, and a means of temperature control—all of which had to ensure precise accuracy and stability. Lord concurred with Lee that "in terms of technical complexity, organizational responsibilities, schedule difficulties, and cost escalation," the IPS was the most challenging part of Spacelab.[105]

Perhaps no Spacelab subsystem demonstrates as well as IPS how Marshall carried out its Lead Center responsibilities, since the Center's presence was apparent throughout development of that system. Marshall's previous experience with the Apollo Telescope Mount and *Skylab* gave the Center unmatched experience in instrument pointing systems for manned space flight, and the Europeans turned first to Marshall for guidance.[106]

ESRO, its hands tied by tight budgets, proceeded with a single development approach, an imaginative concept called the inside-out gimbal that differed from conventional ring gimbals. That same principle had been used for gyro-stabilized platforms on recent rockets, such as the Saturn V, in contrast to older systems that used ring gimbals. Marshall had no objections to the method, but its approach differed from that of the Europeans. ESRO sought to satisfy the requirements set forth in the Spacelab Memorandum of Understanding and its requirements document, while Marshall wanted to satisfy the broader demands of experimenters. By early 1975 Lee worried that "no one IPS design will satisfy all the users' pointing requirements."[107] Lord conceded that "it was very difficult to get designers to agree on a statement of specifications."[108]

Marshall launched a "total effort" on the IPS, monitoring ESRO progress, briefing customers on IPS capabilities and limitations, and examining alternative approaches for a small IPS under study at Marshall and Goddard. Finally ESA, hemmed in by rising costs, suggested less restrictive specifications, and then abandoned the inside-out gimbal approach altogether in favor of a less expensive alternative. Marshall developed simulations to test the new ESA proposals, and in March 1976 NASA concurred with the Marshall recommendation to proceed to Phase C/D development in spite of the resulting schedule slippage.[109]

NASA hoped to have IPS ready for the second Spacelab mission, but development through the end of the decade was plagued by continuing cost, schedule, and technological problems that prompted contention between NASA and its European partner. NASA maintained that ESA was failing to provide adequate documentation, and ESA complained that NASA was continuing to develop competitive IPS systems. In 1977 ESA suggested removing the system from its Spacelab program in order to find another means of development.[110] ESA frustration boiled over in 1978, when member states refused to approve additional funding for IPS.[111] Increased load requirements rendered earlier specifications insufficient, and forced IPS contractor Dornier to make modifications and slip the schedule. Both ESA and NASA complained of a lack of cooperation from Dornier, and suspicions rose that the company was trying to use legitimate redesign demands resulting from load changes to hide other problems.[112]

Reviews conducted by ESA and Marshall in 1979 and 1980 raised questions as to whether the IPS as currently designed would meet requirements. Technical, management, and safety concerns dominated review reports. In April 1981 Dornier submitted a proposal for a redesigned IPS, and NASA accepted the proposal in July. ESA restructured its IPS contract, and Marshall assigned Gene Compton as a full-time liaison at Dornier. Although the redesigned IPS also encountered development difficulties, they were less onerous than those of the late 1970s. ESA delivered the first flight unit in November 1984, and delays elsewhere in the Shuttle program made it possible for the IPS to fly on Spacelab 2 as originally intended.[113]

Challenging as they were, the technical problems posed by the instrument pointing system were restricted to a single subsystem, and development of other subsystems and the Spacelab modules proceeded apace. In March 1977 Marshall awarded a systems analysis and integration contract to McDonnell Douglas Technical Services Company (MDTSC). The most significant Spacelab contract to go to an American company, it called for systems engineering, experiment integration, software development, and the design, development and fabrication of most of the Spacelab hardware under Marshall's purview, including the crew transfer tunnel.

Marshall also continued its monitoring of ESA's progress in Spacelab development. Beginning in 1974, Marshall conducted a series of periodic reviews of all major Spacelab subsystems. Reviews served first set baseline requirements, then monitored design modifications. At each step, these sessions helped to bring both technical and managerial problems to the attention of Marshall and NASA management, and to ensure that Spacelab-Shuttle interfaces were protected. Marshall also participated in reviews conducted by ESA's contractors. The most important step in the long review process was the Spacelab critical design review (CDR), initiated by ESA and NASA in March 1978 and completed in December. The CDR was particularly important for the Americans, since it was their last opportunity to make major changes in Spacelab design.[114]

Even after completion of the CDR, a final technical problem interrupted preparations for the first Spacelab mission. Weight status reports early in 1979 indicated that each of the first three Spacelab missions exceeded acceptable criteria as a result of orbiter-supplied equipment. ESA was near its weight limits, and could not be expected to make adjustments, so NASA's Spacelab Program Office suggested that upgrading landing capability was the most acceptable solution, and that reduction in payload weight should be considered only as a last resort. The issue demonstrated the importance of coordination between the Spacelab and Shuttle programs, and also the fact that resolution of problems required the cooperation of both Marshall's Spacelab and Payload Offices, as well as representatives of Headquarters and the JSC Shuttle Office. Headquarters believed that manipulating landing capability would set a bad precedent, and NASA found ways to absorb the difference for each mission without modifying the Spacelab module or significantly impacting payloads.[115]

Recession and Realignment

Costs, schedule, and technical challenges continued to be the three problems that defined Spacelab, but by the late 1970s the issue of money dominated. Simply put, the European dilemma was that costs rose inexorably while expected benefits dropped. Besieged by the oil crisis, the economies of the United States and Western Europe declined during the late 1970s, and the space programs of both were not immune to economic contraction.

ESA worried that design changes, additions to the program, development difficulties, and schedule slippage had increased "cost-to-completion" estimates to the point that member states began to question whether the commitment to Spacelab had been worthwhile. "Our biggest problem is cost," reported a senior ESA official.[116]

Not only were Spacelab costs rising, but returns in terms of technology for manned spaceflight, cooperative flights, and opportunities to support Spacelab integration seemed to be crashing. Even worse for ESA, the operating cost per mission—estimated at $60 million in 1979—meant that the returns from Spacelab operations would likely be less than originally expected. ESA had entered the program expecting that Spacelab would be less expensive to experimenters, but by 1979 the estimated cost per mission had tripled. Meanwhile, the Europeans had been counting on "follow-on procurement"—the sale of additional Spacelabs and support equipment to NASA after the completion of the initial program—as a means of recouping part of their investment. Now the Americans seemed unlikely to buy more than required under the narrow terms of the Memorandum of Understanding.[117] Complicating the reduced likelihood of follow-on procurement was an ESA concern that NASA and American contractors were violating the Memorandum of Understanding by duplicating Spacelab equipment, producing their own versions of the instrument pointing system and pallets.[118]

NASA tried to accommodate ESA's concerns, but only to a point. The Agency suggested that if ESA was not getting what it expected out of Spacelab, it might be their own fault; officials expressed "amazement" that ESA was not "utilizing Spacelab commensurate with their development investment."[119] NASA agreed to "descoping," cutting back some of the originally agreed upon ancillary equipment. On matters unrelated to cost, NASA tried to meet the Europeans more than halfway, conceding to most ESA technology requests, encouraging cooperative flight proposals, giving ESA the same data rights as U.S. Government civil agencies, and forming a joint Duplication Avoidance Working Group. When money was at stake—and it was the root of most of ESA's problems—NASA was less forthcoming. The Carter years were lean for NASA, and the Agency could ill afford to loosen its purse strings. Marshall even sought legal opinion to ensure that NASA would not be compelled to purchase follow-on equipment the Agency no longer desired.[120]

Before NASA and ESA could resolve their differences, the European member states had to decide how much money they were willing to commit to Spacelab. Participating members already had pledged up to 120 percent of their original commitment, and that money would last only until September 1979. After long deliberations, only Italy refused to increase its contribution beyond the 120-percent level, and ESA agreed to present a proposal of 140 percent to the Spacelab Program Board.

By the end of the 1970s, with the first Spacelab flight still years in the future, both Europeans and Americans had reason for disappointment with the partnership. The new ESA funding arrangement left both parties dissatisfied. ESA nations resented that they were going to have to pay far more than they expected; NASA resented that ESA was unwilling to take risks normal to the space business by honoring their commitment to bear responsibility for Spacelab design through the first two flights. "The concern here is ESA's inability to anticipate operational changes and fund for them," Lee told Lucas. "NASA has essentially the same problem in planning for unforeseen changes."[121] Furthermore, the initial agreement between the Europeans and NASA had no cost ceiling.[122] Evaluating their Spacelab experience shortly after working out the new funding relationship, ESA's Spacelab Programme Board concluded that "At the present time, Spacelab is the only possible base from which Europe could make significant progress and thus be able to play a role towards the end of the 1980s."[123] Lucas admitted that this was "shaky" support. "The only thing to drive the Board in the direction of support will be that there is no other choice," he wrote.[124] Ultimately, ESA delivered two pressurized module assemblies to NASA, the first under the original Memorandum of Understanding, and the second as part of follow-on procurement.

For Marshall, there was another reason for disappointment. One of the attractive aspects of Spacelab was the opportunity to further diversify. But while Marshall's Spacelab work gives indication of the success of the Center's diversification, NASA had no intention of making Marshall the Agency's sole payload integration Center. The Center remained in a precarious position, and Center administrators and the Huntsville community watched NASA decisions for indications of Marshall's fate. Thus it was not surprising that when NASA transferred some of Marshall's projects including important Spacelab work (sending Spacelab sustaining engineering to KSC) and gave managerial authority over six Spacelab missions to Goddard, alarms went off in Huntsville. Congressman Ronnie Flippo, who represented the Alabama Fifth District (including Huntsville), alleged a trend of moving projects out of Marshall, and asked NASA administrators if they had plans to backfill the losses. He questioned the wisdom of moving Spacelab activities out of Huntsville since Marshall had developed both the expertise and the facilities to manage the program.[125]

NASA's response was barely reassuring. Headquarters told Flippo that there was no conscious effort to erode Marshall on a project-by-project basis.[126] John Naugle insisted that it was reasonable to have JSC and Goddard involved in

Spacelab mission management. "It is essential that there be Centers other than MSFC involved," he insisted. "A monopoly by MSFC would seriously inhibit the kind of innovation and competition that is required to develop Spacelab into a cheap, effective research laboratory in space."[127]

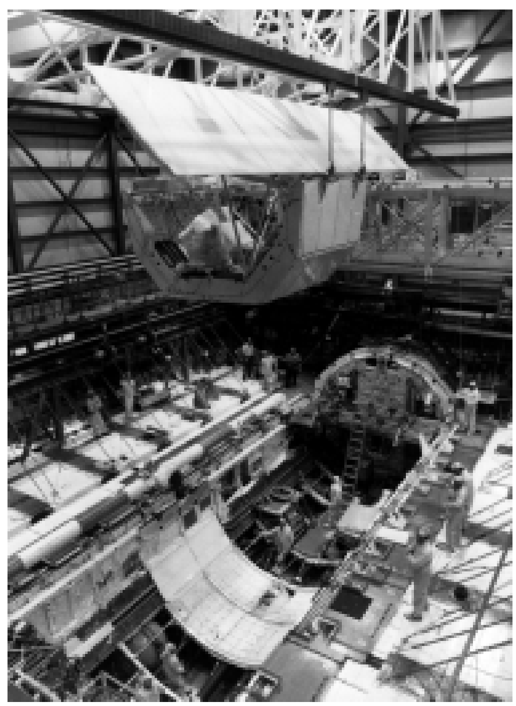
Budget problems continued to plague NASA in the early 1980s as the Agency had to absorb reductions similar to those experienced by other federal organizations. Cuts in NASA's Space Science budget for Fiscal Year 1981 forced one-year schedule slips for Spacelabs 4, 5, and 6.[128] James C. Harrington, who had succeeded Lord as the director of the Spacelab Program at Headquarters, lamented the impact of these reductions: "Over the past four years the planned SL-1 launch date has slipped three years. Worse yet, over the past 13 months we have slipped this milestone 17 months. Additionally, the manifest of SL flights has been reduced from 4–5 flights per year to the current 2 flights per year through 1986."[129]

Harrington presented an insightful analysis of the impact of budget reductions on Spacelab that by extension demonstrated the plight of all NASA programs in hard times. Preparing the budget for Fiscal Year 1982, Headquarters first slashed field Center Spacelab budget requests by 20 percent, then subtracted another 8.5 percent before submitting the NASA budget request to the Office of Management and Budget. Then the Reagan Administration amended its budget, reducing NASA's line by another $30 million. Harrington argued that NASA had no alternative but to slip the schedule for early Spacelab missions, which was costly in terms of user interest and support, ESA confidence, and overall program costs. Delay never saved money; runout would add costs to maintain program readiness, increase expenses for users or force them to abandon experiments, and "will not aid in relieving our budget difficulties, but only compound them." Although few in NASA would have disputed Harrington's persuasive argument, the Agency had little choice but to implement cutbacks. Harrington proved prescient.

The Early Missions

While Marshall's administrators worried about budgets and transferred projects, technicians continued their preparations for the first three Spacelab missions. In addition to checking out Spacelab systems, Marshall wanted to incorporate a wide variety of experiments into the first two missions in order to demonstrate what the new spacecraft could do. The payload plan for the first mission was to use experiments to demonstrate the capability to investigate a wide variety of phenomena in a microgravity environment. Marshall's Harry Craft explained that "the emphasis was on microgravity, life sciences, materials processing, although we flew an array of experiments in just about every discipline." Included were research on Earth's atmosphere, crystal growth, cloud microphysics, observations to monitor Earth's surface for environmental quality and for the development of remote sensing methods, investigations of ultraviolet and infrared radiation, and life science experiments involving humans, animals, plants, cells and tissues. The second mission also intended to be multidisciplinary, emphasizing "astronomy, solar physics, and high energy astrophysics," according to Craft. Spacelab 3 would be the first mission dedicated entirely to applications and science, and would emphasize processing in space.[130]

The mission plan was indeed ambitious, and Houston's Kraft believed the schedule for Spacelab 1 was overly so. In Kraft's view, Marshall was "structuring the 7-day first flight of Spacelab to be as complex and ambitious as *Skylab*."[131] Lucas insisted that the wide variety of experiments was important to maintain the interest of potential users, and that less than half of the experiments selected would place moderate to heavy demands on the crew. Most experiments required no crew activity, or merely the flipping of a switch.[132] Reviews conducted at Marshall and in Europe in the fall of 1979, however, confirmed Kraft's worries, and NASA simplified the first mission.[133] Budget problems also forced reevaluation of the schedule for early missions, and compelled NASA to delay experiments.[134]



Installation of OSTA–1 in the orbiter Columbia *before the second Shuttle mission in November 1981.*

While administrators debated the budget, payload, and schedule, preparations continued for the first mission. Two early Shuttle flights prior to the first Spacelab mission served to validate Spacelab hardware. The OSTA–1 (for the Office of Space and Terrestrial Applications) mission in November 1981 used an engineering model of the Spacelab pallet. The following March the OSS–1 (for the Office of Space Science) used an engineering model of the pallet to mount eight of its nine experiments.[135]

Spacelab offered an opportunity to merge NASA's two primary activities, space science and manned space flight. As one of the Agency's manned space flight Centers, Marshall was under the umbrella of the Office of Manned Space Flight. But post-Apollo diversification had established expertise in science at the Center that prepared it to lead a merging of the two ventures, and Marshall would work closely with the Office of Space Science. "Manned spaceflight and science came together really for the first time in *Skylab*," explained Rick Chappell, mission scientist for Spacelab 1 and later Marshall's director of science. "But that was a one shot deal. It was with the Shuttle [that] we're going to take these two major pieces of what NASA did, science and manned spaceflight, and merge them."[136]

Marshall conducted training in a Spacelab mission simulator at the Center. "We have a full scale Spacelab pressurized module and pallets as a part of our training capability," explained Ralph Hoodless, a manager for the development of Spacelab. "We configured that for Spacelab I and II and actually used that to train hands-on."[137]

Payload specialists for Spacelab 1 train in mock-up at Marshall in June 1981.

Marshall began assembling the hardware for Spacelab 1 at Kennedy Space Center late in 1981. Equipment for experiments began arriving in October, and the Spacelab module and pallet followed in December. In February 1982 Vice President George Bush attended the unveiling of Spacelab, and NASA formally accepted flight hardware for Spacelab 1 (SL–1).

Over the next several months, engineers tested components and began integrating experiments. Marshall technicians installed the life sciences mini-lab and its flight rack in the module in February, and in May began placing equipment on the pallet. Integration of major assemblies, including a platform of 12 European experiments, continued through the summer. In December the team moved the pallet into position behind the module, and completed integration by installing experiment racks in the module. Mission sequence tests during the early months of 1983 culminated in July with remote operation of experiments from the POCC in Houston. The orbiter *Columbia* arrived at Kennedy in November 1982, and the integration team began modifications necessary to place Spacelab in its cargo bay.

“The experiments were brought in by their various scientific teams,” recalled Mission Manager Craft. “We would let them check the experiment out initially in an off-line capability and then we’d bring them into a room and just make sure the instrument had met the transportation environment and still worked. They would do some checkout and they’d turn it over to us.” Then the Marshall-Kennedy team integrated the experiments “into a Spacelab rack if it was inside the module or integrated onto a pallet if it was outside.”[138]

While preparations proceeded in Florida, all Spacelab systems and Shuttle interfaces underwent reviews. The design certification review in January 1983 followed months of preparation during which Marshall and MDTSC reviewed performance and design requirements and examined all Spacelab subsystems in collaboration with representatives of ESA and ERNO; Headquarters lauded the team’s careful preparation and considered the session “exemplary.” Other reviews examined flight operations and all aspects of integration.[139]

On 15 August 1983, technicians moved Spacelab to KSC’s Orbiter Processing Facility, and the next day placed the module and pallet in *Columbia’s* cargo bay. On 23 September *Columbia* moved to KSC’s mammoth Vertical Assembly Building, and five days later to the pad in preparation for a scheduled launch on

30 September. Unfortunately a problem with the solid rocket booster nozzle delayed the mission, soon rescheduled for 28 November.

The 28 November launch date of Spacelab 1 culminated years of preparation. With Spacelab nestled in the cargo bay of the orbiter *Columbia*, Marshall representatives in Huntsville, Houston, and at the Cape took their stations to support the mission. Experimenters huddled with the Marshall team in JSC's POCC, where a large Marshall Center banner hung on the wall, signifying a Marshall beachhead in what former Program Manager Douglas Lord called "intercenter warfare."[140] The Huntsville Operations Support Center (HOSC) operated much as it had during the *Skylab* mission, supplying technical advice. The composition of the six-man crew—a commander, pilot, two mission specialists, and two payload specialists—signaled the beginning of a new era in space science.[141] As the crew settled into its routine for the 10-day mission, Marshall's central role soon became apparent to those monitoring the flight. The communications call, "Marshall operations, this is Spacelab 1," registered more often than calls to JSC's mission control. The crew divided into two teams for 12-hour work rotations, and by the end of the first day they had already initiated 25 experiments. Instrumentation problems slowed progress as the mission went on, but NASA believed that the success of the crew in repairing balky equipment demonstrated the value of humans to space science.[142]

The mission experiments required 40 instruments, 18 on the pallet, 19 in the module, and 3 with components in both locations. In order to demonstrate Spacelab's capabilities, the crew conducted 72 experiments ranging across five disciplines: atmospheric physics and Earth observations, space plasma physics, material sciences and technology, astronomy and solar physics, and life sciences.[143]

Mission Payload Operations.

The variety of experiments aboard Spacelab 1 makes that mission a useful measure of the range of activity that attracted Marshall scientists and mission managers. Spacelab provided an exciting environment from which to study the chemical composition of the atmosphere and the effect of Earth-based human activity on the upper atmosphere. The Imaging Spectrometric Observatory (ISO) could measure multiple constituents in a slice of Earth's atmosphere, and proved its value by providing for the "first comprehensive spectral atlas of the upper atmosphere." The Grille Spectrometer aboard Spacelab 1, designed to measure constituents in the atmosphere between altitudes from 10 to 95 miles, found methane (produced by biological decay and the burning of fossil fuels) at the surprisingly high altitude of 30 miles above the surface of Earth. Two cameras aboard Spacelab 1 recorded aerial photographs of Earth's surface in three days that would have taken 10 years to accumulate using conventional methods, providing data for agriculture, archaeology, and cartography.[144]

Space plasma physics experiments studied the ionosphere, Earth's uppermost atmospheric envelope which extends from 40 to 60 miles above Earth's surface. Using both passive and active instruments, Spacelab scientists examined the behavior of the ionosphere's electrically charged gasses, or plasmas. Among experiments employing active instruments, the Space Experiments with Particle Accelerators (SEPAC) and the Phenomena Induced by Charged Particle Beams (PICPAB) were ambitious attempts to inject particle beams into the ionosphere to examine changes in electric and magnetic fields. In both cases, passive instruments measured the effect of particle injection on theories of particle acceleration. Among the surprising results of these experiments was the discovery that neutral gas injections could quickly neutralize induced charges on the spacecraft.[145]

Because NASA hoped that the private sector might demonstrate interest in manufacturing in space, experiments in materials processing aboard Spacelab 1 were particularly important. Crystal growth experiments have been among the most successful on several Spacelab flights, and Spacelab 1 set the tone. The mission demonstrated the practicality of reducing defects by growing crystals in microgravity. Crystal experiments in the Mirror Heating Facility demonstrated that certain defects in silicon crystals grown on Earth were not gravity-induced, but rather were caused by surface tension. Other materials processing experiments proved that microgravity was an ideal environment for determining the diffusion coefficient of liquid metals—a measure of how metals diffuse through each other.[146]

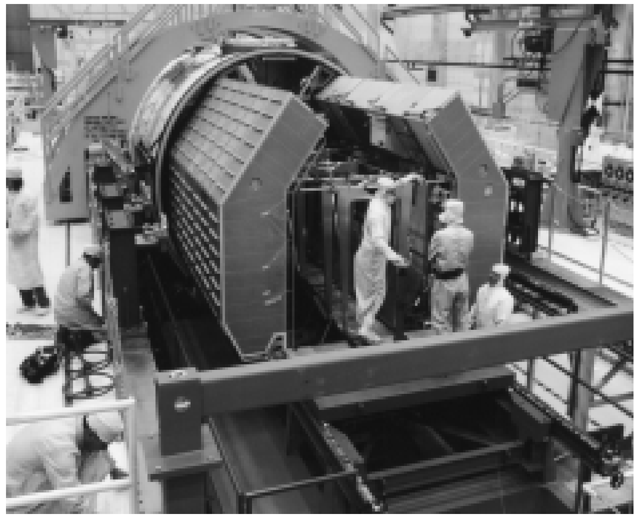
Spacelab 1 carried instruments to make observations in the ultraviolet and X-radiation portions of the electromagnetic spectrum and contributed to knowledge of astronomy and solar physics. The Very Wide Field camera, which could survey a 60-degree field of view, made 48 photographic images of 10 astronomical objects, and returned excellent images of stellar clouds in the ultraviolet range. The Far Ultraviolet Space Telescope (FAUST) experienced problems with fogged film and overexposure, but scientists expected that equipment modifications would yield promising results on future flights. Because the background level of cosmic ray activity in space was lower than anticipated, X-radiation data collection surpassed expectations; the astrophysics experiments aboard Spacelab 1 included 200 hours of accumulated X-ray data. NASA and ESA instruments designed to measure energy output of the Sun also yielded promising results.[147]

The scientist-astronauts aboard Spacelab 1 served as subjects for life science experiments, several of which sought to evaluate the response of the human vestibular system, vision, and reflexes to microgravity. The vestibular system, which is located in the inner ear, controls balance and orientation. Experiments found a relationship between balance and eye movements, and provided data on the effect of head movements on motion sickness. These and other experiments helped evaluate the adjustment of the sensory motor system to microgravity, the ability of people to estimate mass in space, and the effect of microgravity on muscle mass and blood.[148]

The flow of data from Spacelab generated excitement on the ground even before the Shuttle returned to Earth. By the time the mission ended when the Shuttle landed at Edwards Air Force Base in California, Mission Manager Craft could report that the mission had accumulated 20 million pictures and 2 trillion bits of data.[149]

The mission achieved most of its goals, and Samuel Keller, deputy associate administrator for Space Science and Applications, deemed Spacelab "an unqualified success." Chappell considered the flight a "very successful merger of manned space flight and space science." The crew accomplished all systems verification objectives, with only minor anomalies. Several months later, Chappell and his ESA counterpart Karl Knott reported that the mission had achieved 80 percent or more of its objectives in all but atmospheric physics and Earth observations (which achieved 65 percent). Spacelab proved its viability for research in all five disciplines investigated.[150]

In the months following the first Spacelab mission, NASA realigned the Shuttle payload schedule. Because of changes in Defense Department Shuttle requirements, redesign of the instrument pointing system required for Spacelab 2, problems related to the satellite tracking system, and Shuttle-related delays, Headquarters moved the Spacelab 3 mission ahead of Spacelab 2.



Spacelab 3 rack/floor installation at KSC in May 1984.

Spacelab 3, NASA's first dedicated mission, concentrated on the acquisition of scientific data with a focus on microgravity rather than a wide range of disciplines. Again, Marshall provided management of mission development and operation; J. W. Cremin served as mission manager, George H. Fichtl as mission scientist. The mission, which flew in the orbiter *Challenger* from 29 April to 6 May 1985, included experiments in materials science, life sciences, and fluid mechanics, and carried out atmospheric and astronomical observations. A Marshall ground control team managed the mission from JSC's POCC, and scientists stationed in rooms adjacent to the POCC had opportunities to confer directly with mission and payload specialists aboard Spacelab.

By maintaining a stable attitude for the six-day experimentation period, the crew established an ideal setting for microgravity research and developed methods "to provide the best low-gravity environment achievable from this system." Materials science experiments focused on crystal growth, testing ways to grow more homogeneous crystals by reducing the effect of gravity as a means to produce crystals that might be used for applications such as Earth resources surveys, medical diagnostics, and infrared astronomy. The fluid dynamics experiments were the first controlled experiments on free-floating drops, thus providing an opportunity to test theoretical predictions without the acoustic forces that impact such experiments on Earth. Two monkeys and 24 rats accompanied the crew into space to assist in life science experiments, and on return to Earth the rats demonstrated loss of muscle, bone loss mass, and other data that researchers said "may well be the most significant contribution on biological systems in space ever gained from a single mission."

The mission's atmospheric observations gathered more data on trace elements in the upper atmosphere. Spacelab 3 recorded the first observations of the Southern Hemisphere aurora from a lateral perspective; previous observations had been only from Earth or from satellites in a higher orbit. The mission's most successful astrophysical experiments focused on low-energy cosmic-ray observations.[151]

After repair of a problem with the Shuttle main engine, Spacelab 2 launched on 29 July, three months after Spacelab 3. The delay in launch provided opportunity for one of the experimenters to rework hardware, and showed the range of Marshall mission support. The Jet Propulsion Laboratory planned an experiment to test the behavior in space of superfluid helium, which they hoped could be used as a coolant for infrared telescopes. Mission Manager Roy Lester and other Marshall resident personnel at the Cape facilitated repairs that enabled the experiment to fly successfully. They helped rebuild and test an essential vacuum pump and coordinated trouble-shooting between the Marshall Center and KSC. Personnel responsible for the Infrared Telescope took time from servicing their own equipment to assist JPL's experimenters.[152]

Shutdown of a main engine late in ascent forced the Shuttle to orbit lower than planned, but did not interrupt the experiment schedule. The troubled instrument pointing system performed erratically, working best when relying on one of the independent telescopes for alignment rather than its own optical sensor package. Astronauts, directed by experts from Marshall's Huntsville Operations Support Center, attempted to make repairs. At times the IPS worked perfectly, demonstrating the capability of the system once repairs could be made, and the mission succeeded in gathering invaluable data about the Sun.[153]

Marshall's work on Spacelab 2 won praise from one of its experimenters, who suggested that the records set by the mission "will stand until the era of the Space Station because no payload now under consideration matches the complexity of SL–2, which tested the limits—of hardware, software, and people—

everywhere in the system. The success we experimenters are now enjoying was made possible because all of the people at MSFC associated with SL–2 did their utmost to make it so."[154] The eight-day mission officially marked the completion of the Spacelab development program. A German mission, Spacelab D–1, flew in October; it was the last Spacelab mission before the *Challenger* accident.

The hiatus on Shuttle flights following the *Challenger* accident interrupted Spacelab as it did all NASA's manned space flight programs. The Marshall-managed Astro–1 mission in December 1990 was the first Spacelab mission to fly after the return to flight. The Astro–1 payload featured four telescopes—three Marshall ultraviolet instruments and Goddard's Broad Band X-Ray Telescope. Spacelab's pallet-borne instrument pointing system aligned the telescopes for observations of distant galaxy clusters, white dwarfs, binary stars, and active galactic nuclei.

Marshall Spacelab Mission Operations Control facility during Astro–1 mission in December 1990.

For Huntsville, the Astro–1 mission marked another milestone, the first use of the new Spacelab Mission Operations Control facility. No longer did the Marshall team have to travel to Houston's POCC to direct payload operations. In the early morning hours shortly after launch on December 2, Mission Specialist Robert Parker opened his communication lines saying, "Huntsville, this is Astro," marking the first time that there had been direct communications between Huntsville and astronauts in space.[155]

Like most of NASA's post-Apollo Programs, Spacelab was plagued by budget problems from its inception, and forced the Agency and its European partner to confront the question of whether space development programs can be designed to cost. Inevitably tight money led to delays, but concurrent delays in the Shuttle program lessened their impact. The problems that plagued Spacelab development traced back to tight budgets, and successful completion of the system testified to Marshall's accomplishment under trying circumstances. Program Manager Lord praised Marshall as "an effective and responsible Lead Center."[156] Ultimately Spacelab proved to be one of NASA's workhorses, and Lee's successful management of the program at Marshall paved the way for his selection as Center Director after J.R. Thompson.

Spacelab anticipated Space Station. Delays in Space Station development made Spacelab all the more valuable as a platform for space science research into the 1990s. Like Spacelab, station would be undertaken as an international partnership, and both ESA and NASA entered the latter program having learned their own lessons from Spacelab, determined not to repeat the same mistakes.[157]

If Spacelab benefited from Marshall's contributions as Lead Center, the Center also gained from its management of the project. The Marshall Center emerged from Spacelab development more diversified in terms of technical capabilities, and with experience in science operations, international relations, systems integration, systems management, payload integration, and space science. By the mid 1980s, Spacelab helped expand the Center's expertise to the point that no other NASA field Center could match the range of Marshall's experience.

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143 Chappell and Knott, p. 164.

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145 NASA MSFC, *Science in Orbit: The Shuttle & Spacelab Experience, 1981–1986* (Washington: U.S. Government Printing Office, 1988), pp. 71–77, 84–89; David Shapland and Michael Rycroft, *Spacelab: Research in Earth Orbit* (Cambridge: Cambridge University Press, 1984), p. 139.

146 *Science in Orbit: The Shuttle & Spacelab Experience, 1981–1986*, pp. 55–59; Shapland and Rycroft, pp. 137–139.

147 *Science in Orbit: The Shuttle & Spacelab Experience, 1981–1986*, pp. 27–33; Shapland and Rycroft, pp. 143–147.

148 *Science in Orbit: The Shuttle & Spacelab Experience, 1981–1986*, pp. 97–107; Shapland and Rycroft, p. 136.

149 *Science in Orbit: The Shuttle & Spacelab Experience, 1981–1986*, pp. 6–15; Shapland and Rycroft, pp. 148–152.

150 Lord, pp. 352–60; Craig Covault, “Spacelab Returns Broad Scientific Data,” *Aviation Week & Space Technology* (5 December 1983), 18–20.

151 Lord, pp. 363–64; *Marshall Star*, 14 December 1983; Chappell and Knott, pp. 163–65.

152 George H. Fichtl, John S. Theon, Charles K. Hill and Otha H. Vaughan, editors, *Spacelab 3 Mission Science Review*, NASA Conference Publication 2429 (Washington: NASA Scientific and Technical Information Branch, 1987), 1–10.

153 Lew Allen to W.R. Lucas, 8 August 1985, Spacelab Payloads 1985 folder, MSFC History Archive.

154 Lord, pp. 374–88.

155 Dianne K. Prinz to William R. Lucas, 25 September 1985, Spacelab Payloads 1985 folder, MSFC History Archive.

156 *Marshall Star*, 29 August 1990, 25 November 1990, 5 December 1990.

157 Lord, p. 401.