AMSAT-NA Phase IV Project
Lessons in Distributed Engineering

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The academic year 1988-89 has provided AMSAT with some really new experiences in engineering and fabricating a moderately large "small satellite". While most of the AMSAT engineering forces were engaged in a truly small "small satellite" - the Microsat Project - a few of us have been engaged in the Phase IV project in conjunction with Weber State College, a new working environment for AMSAT.

This experience has provided us with insights on what kinds of tasks that we can expect to assign and be completed. We know that the basic planning, task descriptions, people interfaces and organizational interfaces are different from our prior experience with an all-volunteer operation. Through a recounting of these experiences, it is hoped that insights in working in this atmosphere will be passed on to those who need to conduct future satellite projects in the academic arena.

INTRODUCTION

The effective conduct of a satellite design and construction project involves many non-engineering aspects. Such programs in a commercial or governmental environment are conducted under a set of organizational work rules that follow well established patterns. AMSAT has built and orbited small satellites for a number of years and we have done so under considerably different work rules that those typically seen in commercial establishments.

An even different satellite construction environment has been experienced in our teaming with Weber State College for the fabrication of the AMSAT-NA Phase IV spacecraft model. A study of the implications of this people-to-people interaction is useful so that we can capitalize on the positive aspects of this relationship. Concurrently, we need to avoid those traps which would otherwise cause the project to have a less than desired output.

CONVENTIONAL PROCESSES

Performing engineering tasks, such as the design and fabrication of small satellites, in commercial or governmental work-places, is done under organizational patterns that promote appropriate divisions of authority and responsibility, Figure 1, left side. Worker control, communications and motivational rewards are well established and generally provide smooth operating results. Leaders, such as Program Managers (PM) and Project Engineers (PE) are able to achieve program objectives by motivating workers through conventional means of job satisfaction and wage rewards.

Very often an organization needs the services of other entities to achieve the program objectives. The contracting organization then becomes the "Customer" and obtains the needed services of the "Vendor" through a process using one or another form of a contract, the tie that binds. In these relationships, inter-organizational communications *must* be conducted through the contractual "pipeline", so that those employees responsible for the contract can maintain a reasonable control of that contract and its costs. There is, generally, an inhibition about communications and other inter-organizational activities that are not done through those responsible for the contract. This process is only one of good business sense and is often referred to as a single-point-of-contact, within each organization.

AMSAT PROJECTS

For a couple of decades AMSAT has spearheaded the design, construction, and operation of small satellites for Amateur Radio communications purposes. This has been done even though there was a total lack of interest in the aerospace industry in truly "small satellites". Academically, that lack of interest vanished when the US Government became interested in the value of small satellites, and now it seems that everyone is interested in small satellites.

The Radio Amateur Satellite Corporation, also known as AMSAT, is incorporated as a 501(c)(3) nonprofit, scientific and educational organization for the purposes of constructing and operating Amateur Radio satellites. This is a lean operation with only a single employee (an Office Manager) and depends upon the efforts of volunteers for its outputs. Gone are the common work-place motivational rewards of wages, gone is the conventional job-control hierarchical structure, and also gone are the close-in face-to-face communications of an organization located in a single facility. Still remaining in this AMSAT operation, though, are the rewards of "job satisfaction", as that reward is *the* principle motivator for a volunteer worker.

Figure 2 illustrates this AMSAT Project way of life, substituting dashed lines, for the communications and controls applied to volunteer motivation, in place of the solid lines of direct employee control, previously shown in Figure 1. This AMSAT process also shows several other significant elements, discussed forthwith.

As we are employing the services of volunteers from across the North American continent, and even from abroad, we need ready, efficient and cost effective communications. These communications have been found to be best served through the facilities of a commercial "Electronic Mail" bulletin board system (BBS). While electronic mail serves the function well and with expediency, it is, again, no better than how effectively the volunteer makes use of the facility. If a volunteer does not frequently check his mail, the communications system fails and the leaders must resort to more costly telephone services to achieve the needed communications.

Volunteer efforts are most often focused and led by a single operating entity, or individual, the combined Program Manager and Project Engineer (PM/PE). Though this type of combination is not foreign to commercial organizations, it is not commonly practiced on modest to large projects. AMSAT does not have a surplus of qualified and motivated personnel to be able to afford separate PMs and PEs on its projects.

Another different aspect of an AMSAT project is that we do not have a single manufacturing facility. The individual designer must resort to the fabrication of the outputs of his creation in his own locale, be it his home of that of a nearby supporter. In the previous millennia the AMSAT assembly process would have been called a "Cottage Industry". As an example, whole electronic assemblies are made in the Washington, DC area, computers in Arizona and California, power supplies in Connecticut, specialized molded components in Florida, battery selections in Ottawa, Canada, and insulation blankets in Florida or Colorado. With this spatial diversity for designing and fabricating spacecraft assemblies, it is amazing to many that anything actually gets built, much less into orbit.

On the face of it, the AMSAT process may seem totally unwieldy and without reasonable controls. The key elements to the success of these projects depends upon the skilled dedication of a few leaders who will fearlessly motivate the volunteer corps to actions that are in step with the program needs. On the downside of this process is that the personal price paid by these same few leaders can be unacceptable and unbearable to many.

THE WEBER STATE COLLEGE PROCESS

Weber State College, in Ogden, UT, (WSC) is a four-year technology college offering degrees in various engineering "technologies" as opposed to engineering "degrees", for whatever that distinction means. Each senior student in the School of Technology is required to apply himself/herself to a "Senior Project" of 300 hours of effort. The senior project process, thereby, provides a labor base for projects of common interest to the school and students. Senior projects are monitored and controlled through the typical Instructor/Student relationship, the solid connecting lines on the right of Figure 3.

The objective of the senior engineering technology program is to round out the student's education with a project that will let the student apply all of the academically acquired knowledge into a team effort simulating an industry environment. The project must be well chosen such that the students can be assured a reasonable chance of success and yet extend and challenge the student's capabilities.

A senior project has an organizational structure similar to those found in commercial work-places, with a "Student Leader" for the project, and with the help of a number of "Group Leaders" as befits the magnitude of the project. Each Group will undertake only a portion of a project so that the whole project work load is (more or less) uniformly divided among the entire group of students assigned to the project.

A technology "Center of Excellence" facility is also located at WSC in the form of the Center for AeroSpace Technology, CAST. CAST's role in life is to assist the enhancement and expansion of aerospace technology-based business activities that have meaning to the State of Utah. One of the tools at CAST's disposal is the student Senior Project labor base. CAST also encourages the participation of technologically specialized volunteers in this student senior project process, thereby gaining the direct inputs of practicing professionals. As with other volunteer communication links shown in these illustrations, these CAST volunteer links to the students are by the dashed lines shown.

As with AMSAT projects, the organization of any one Senior Project may seem rather loose and unfocused, certainly in reference to the close project structure seen in commercial work-places. Marrying an AMSAT project with the WSC Senior Project through the CAST operation could be chaotic.

THE AMSAT Phase IV PROJECT AT WEBER STATE COLLEGE

Directing our attention to the one-year experience of the AMSAT Phase IV program at Weber State College, AMSAT-NA sought the assistance of WSC to fabricate a structural study model of the Phase IV spacecraft. This step in modeling of the spacecraft was seen necessary, as we are dealing with a spacecraft size and structural complexity that is outside our prior experience and we needed to employ materials technologies that are new to AMSAT. WSC, in turn views Phase IV as a very good student training tool for the Senior Project participants. Even the "new" relationship of dealing with an "outside" organization was viewed as a good experience for those students.

The projects chosen in the past, in engineering technology at WSC, have been totally conceived, designed and managed by student, faculty and local volunteer engineers. This process provided easy communication paths and a direct management chain to solve problems.

The opportunity to work jointly with AMSAT in satellite development programs added a new dimension of challenges for the local management team. AMSAT has worked for many years in a geographically distributed engineering mode. This joint AMSAT/WSC effort would decentralize the design and management efforts used in past WSC projects, but added great depth in engineering skills and exciting new project challenges from AMSAT. It was anticipated that the decentralized management would make the project more difficult, but the added benefit for the students would more than offset this difficulty.

The following is a summary of the findings of this one-year experience in dealing with the WSC as a "Vendor", a term that loses its applicability in this relationship. We have found that the conventional process in which "Customer" designs devices, and for them to be blindly fabricated by the "Vendor" does not work in the AMSAT/WSC effort and the terms inappropriate. A more suitable description of the ASMAT/WSC relationship is as "team members".

In the construction of a device, the basic design objectives, specified by the AMSAT drawings needs to be met, but the process of getting to that point of the fabrication is subject to the tools that are available at WSC (and they are *good*, too) and to the design-fabrication reviews by the students. Student suggestions for design modifications to ease fabrication were valuable inputs, and provided a degree of feedback to the design that is different and more free than has been experienced in industry. Student innovation was encouraged by both WSC and AMSAT, although this innovative process could not be allowed to run unchecked. These processes, Figure 4, must involve the whole range of modern communications techniques, a new element for the WSC/CAST participants.

In the AMSAT/WSC arrangement originally implemented, CAST supplied a Program Manager to guide the student efforts from the CAST view point (a function different from that of the academic instructor). This PM was intended to be the single point of contact with his AMSAT counterpart, and the information flow would then spread out to the student groups. The dedication and time requirements placed upon the PM, especially in the close interfacing with student groups, created a large burden upon this individual and the PM had difficulties functioning in accordance with the program needs.

With WSC performing work for AMSAT, strict budget allocations were required for each task undertaken. In addition to the student leaders, previously noted, one student was also selected as a purchasing director and had the responsibility to monitor all purchases for each team. To maintain further monetary control, each major purchase had to be approved by the AMSAT project director. This communications was accomplished by use of an electronic mail system for quick review and the regular mail for signed document approvals.

The students met weekly for program progress review with faculty and local engineers. Notes from this meeting were compiled and sent to the AMSAT project director for review.

In this AMSAT/WSC relationship, another heavy emphasis is placed upon the CAST volunteer specialists, as they are expected to provide technological inputs and continuity for the student groups. In a number of cases the CAST volunteers have also been incorporated into the AMSAT project structure, making the separation between the two organizations (at least from the viewpoint of the CAST volunteer) rather indistinct. This blending of the volunteer corps is viewed as good for both organizations and there have not been any negative aspects to that conjunction.

As the Phase IV model construction effort evolved at WSC, it was found that the involvement of the AMSAT PM/PE was substantially increased, more so than had been anticipated at the start of the program. Some of this additional involvement was a result of the problems in the CAST PM operations, but more of the involvement was the result of the effects on the design by the innovations of the students. This student innovation activity could not be discouraged as it resulted in substantial cost savings and the completion of some elements of the model that had not been planned to be fabricated in this phase of the effort. An example of the innovation was the Adaptor cone, which is anticipated to be of carbon fiber composite material, an undertaking not warranted at this time. Instead, the students fabricated a skin-rib Adaptor cone that filled the needs of the model quite well. Another example is the key structural spacecraft element, the Top Plate. This Top Plate had been planned to be a custom formed aluminum honeycomb sandwich. The students found that such a panel would be prohibitively expensive whereas they could purchase 4'x8' standard panels with the proper skin thickness. An abutting joining process was evolved with the students to form the single panel from two standard pieces, a process that will probably find its way into a flight design.

As a result of the interactions between the AMSAT distributed engineering efforts and the fabrication efforts in Ogden, every conceivable form of communications was employed in this past year, as indicated by the central box of Figure 4. These communications formed the central hub of a very complex network of person-to-person linkages amongst all parties, and are the key to a successful functioning of a design/construction teaming across continental distances.

PROGRAM ADVANTAGES

The new relationship with AMSAT provided a greater degree of interest for the students in working on a project to the specifications for a customer outside Weber State College. Quarterly reviews by the AMSAT project director provided valuable mass updates for the students as compared to the electronic mail and telephone conversations.

The project in building the first engineering model of the AMSAT Phase IV geostationary satellite proved to be an exciting and challenging opportunity for students. There was constant exchange of new design and fabrication ideas between the students and AMSAT.

AMSAT received its first engineering model of a cost of less than $8,000 for materials. A savings of almost $3,000 from the projected cost at the beginning of the project. The model has proved to be a good public relations asset for AMSAT and Weber State.

PROGRAM DISADVANTAGES

The difficulties encountered in this new program management approach was most difficult on the WSC faculty, senior projects program manager and the local engineers. The faculty and local engineers suffered a degree of frustration in not having complete control in the design and fabrication decisions. This lack of participation or feeling of contribution lead to the loss of some of the past local volunteer engineering talents.

The long distance communication and distributed project monetary control added additional project management work loads that past, locally originated projects did not have.

Only those tasks that were very explicitly defined at the beginning of the project were completed successfully. Some tasks were undertaken and not complete due to the lack of technical and management resources both locally and from AMSAT.

LESSONS LEARNED

The lessons learned from the joint development programs with AMSAT has shown that the benefit to the students is much greater than with locally conceived and managed projects. This greater benefit to the student requires that the program management at WSC must be better prepared before the program begins by:

> Have the tasks well defined at the program start such that major hardware accomplishments can be made by the students.
>
> Select local engineers that can gain satisfaction in participation where the design and fabrication efforts can be a joint effort of local and distant AMSAT engineers.
>
> Increase the frequency of visits by AMSAT engineering representatives, permitting concentrated problem solving sessions with the WSC students.
>
> Provide an opportunity for the AMSAT engineers to share their experience and talents in formal classes for students.
>
> Provide monetary control on more general purchases rather than detailed items.

Phase IV STRUCTURAL STUDY MODEL

A discussion of the details of the Phase IV structural study model is outside of the context of this paper. Some illustrations of the student efforts should suffice to convey that the AMSAT/WSC teamed program effort was a success. Figure 5 is a

CAD illustration of the flight configuration of the Phase IV spacecraft in orbit, and is provided as a reference for the illustrations to follow.

Numerical machine tools were extensively employed for the Phase IV fabrication, Figure 6. Figure 7 illustrates two items of student/CAST-volunteer innovation. The ring, which in a flight configuration is a 1.9m diameter single piece aluminum machining. This version was constructed by the students in twelve sections and bolted together. A second item of interest is that an assembly fixture plate was needed to locate spacecraft components for the assembly and the 8'x8' steel plate on beams satisfied that need very well. Figure 8 shows the partially completed Adaptor cone and the Top Plate being check fitted by the students. This group of students does not appear to be too unhappy in their labors. Figure 9 displays the spacecraft model without its simulated solar panels.

PHASE IV PROGRAM CONDUCT FOR ACADEMIC YEAR 1989-90

From our experience of the past year, it is clear that the personal contact with the students is exceedingly important to the conduct of the program. It is almost immaterial whether that contact originates from CAST or from AMSAT, the point being that the contacts are needed. Students need to be attracted to the program so that they will commit themselves to it for their Senior project. This effort to attract students is different that of attracting volunteers to CAST or AMSAT, whose participation in the program was a result of the individual's interest in the program in the beginning.

The students are semi-captive participants in a project, in that while they may have some choices in which project they select for their senior year, the breadth of choices are limited. We must motivate and attract students for both their learning activities and a willingness to deliver a quality output. Similarly, WSC instructors need to be attracted to participating in details of the project, another form of volunteerism, which is very important as their interest and enthusiasm for the project is felt into the student ranks.

CONCLUSIONS

The additional effort required to manage this distributed engineering program with technology students provides significant benefits to the education of the students and gives AMSAT a bargain of over 500 hours of local engineering labor, nearly 4000 hours of student labor and the use of over $500k worth of CAD/CAM equipment.

ACKNOWLEDGEMENTS

It is only fitting to give credit where it is due. Obviously this effort represents the product of many persons, but two of these are notable in this AMSAT/WSC relationship. Firstly, I want to thank Bill Clapp, of WSC, for his initiation of the AMSAT ties to Weber State College and making it happen. The biggest thanks go to Bob Twiggs for his enthusiasm and support for this project and his bullet proof hide, resistant to the barbs continually sent his way, while he keeps on smiling and supporting.

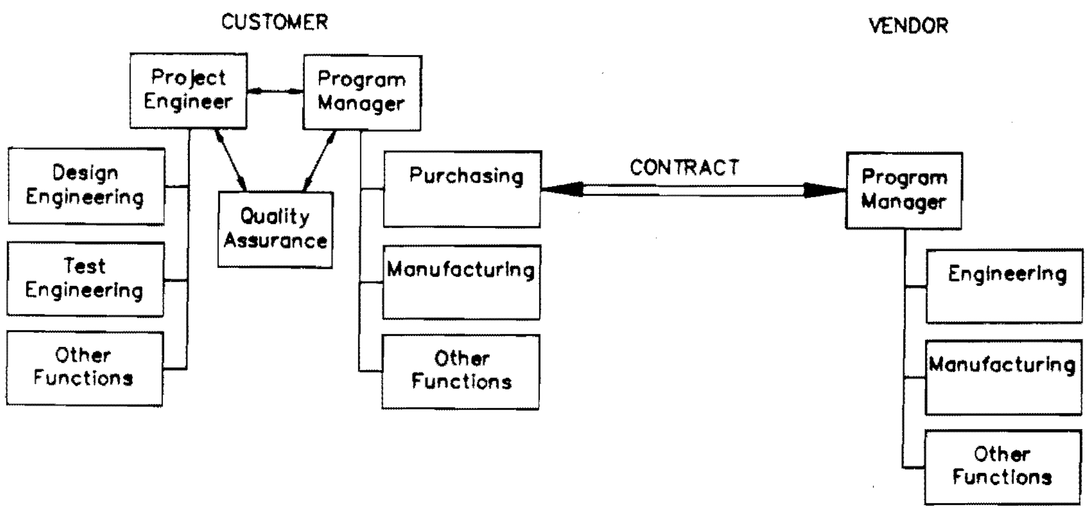

Figure 1

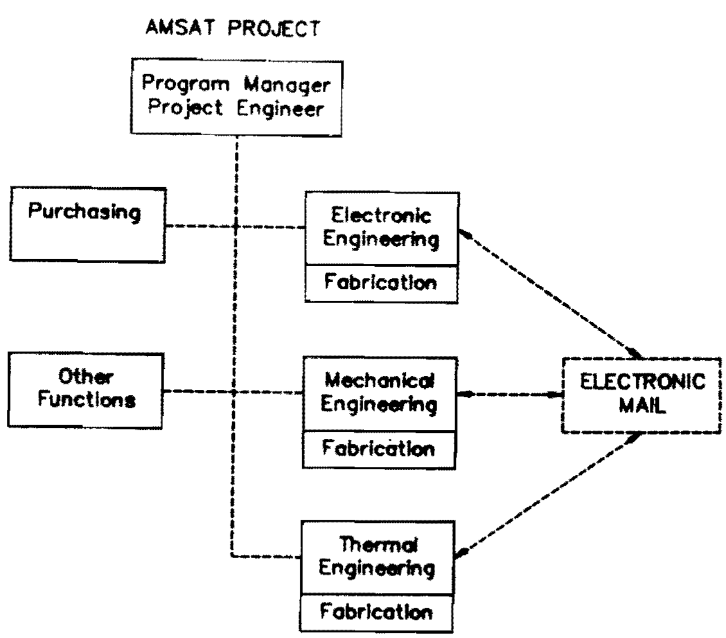

Figure 2

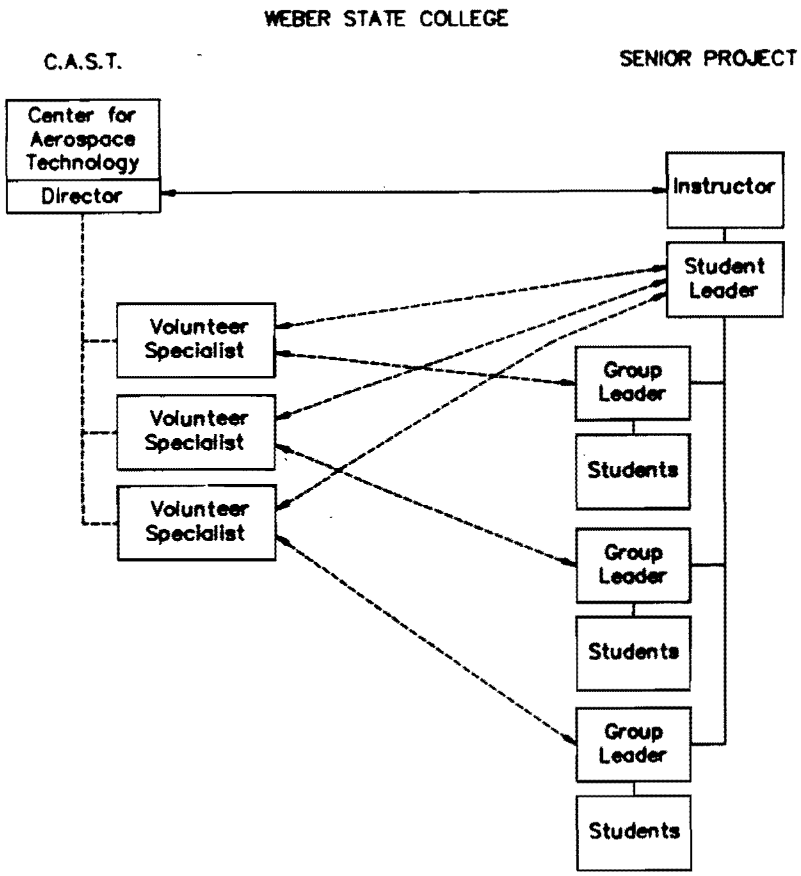

Figure 3

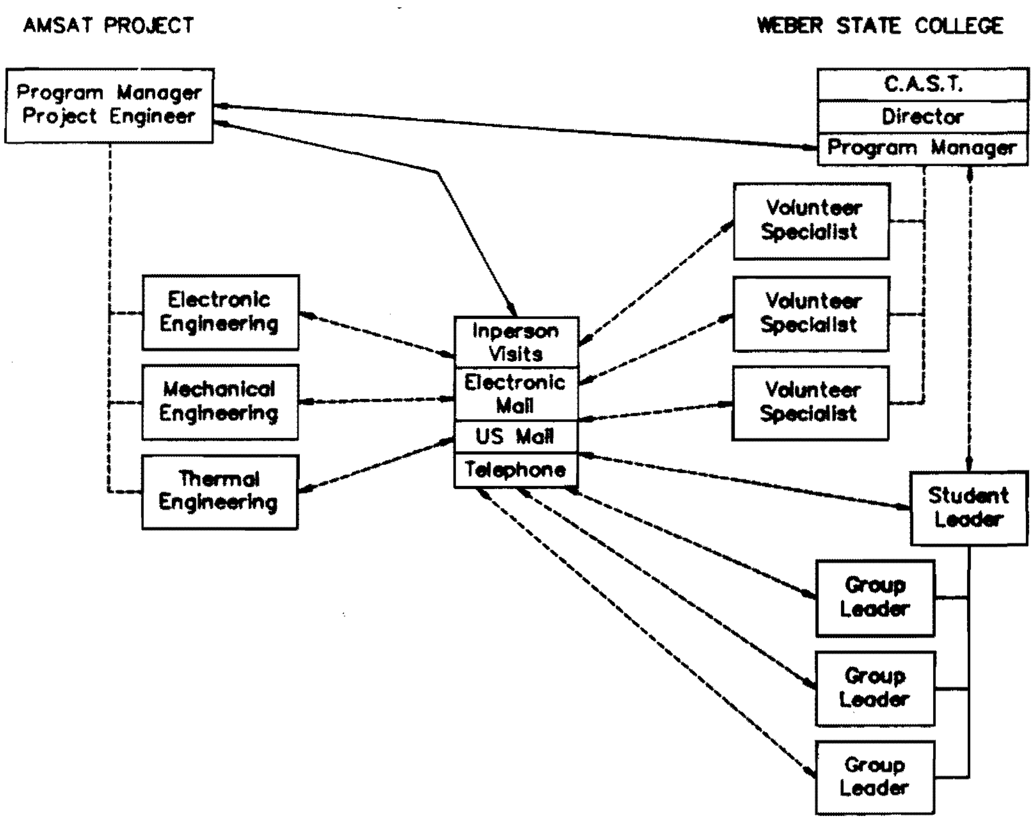

Figure 4

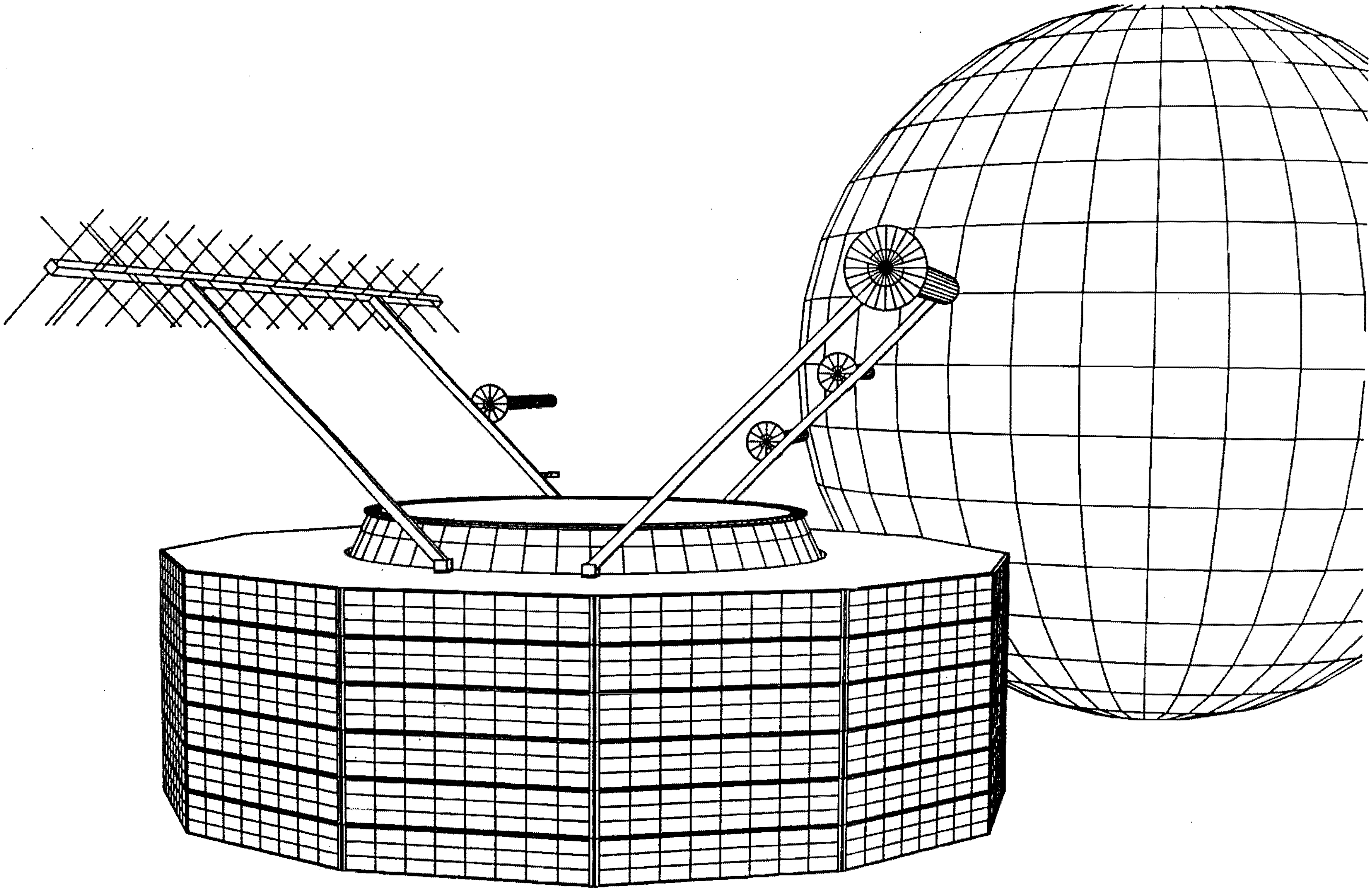

Figure 5

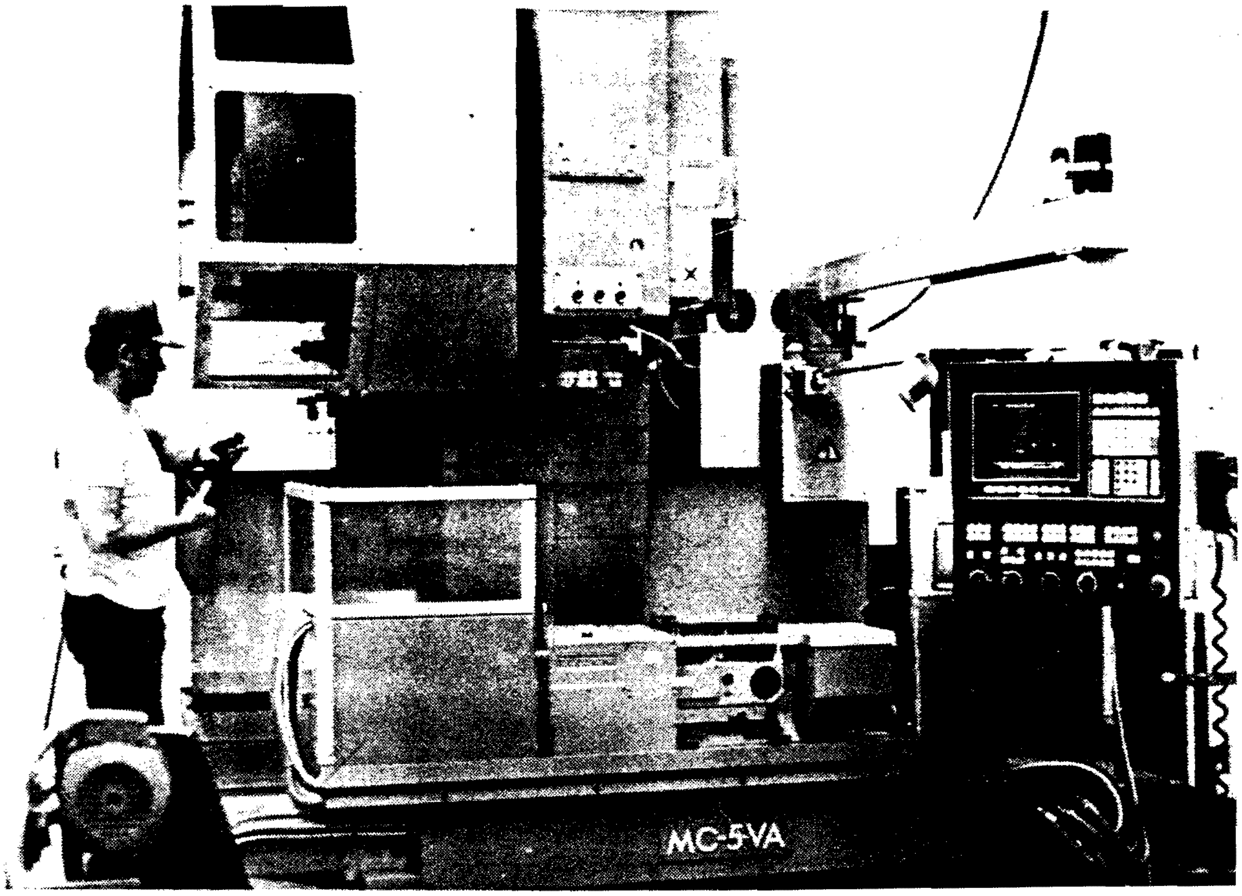

Figure 6

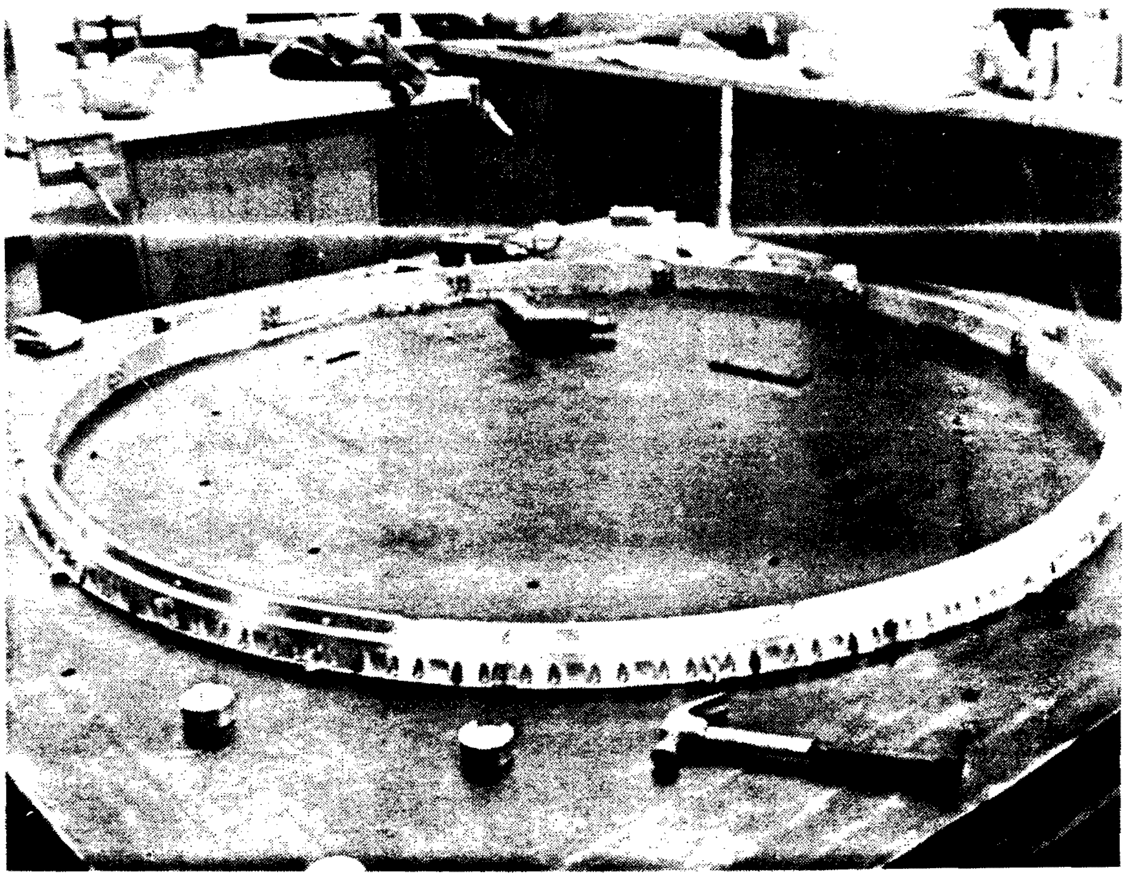

Figure 7

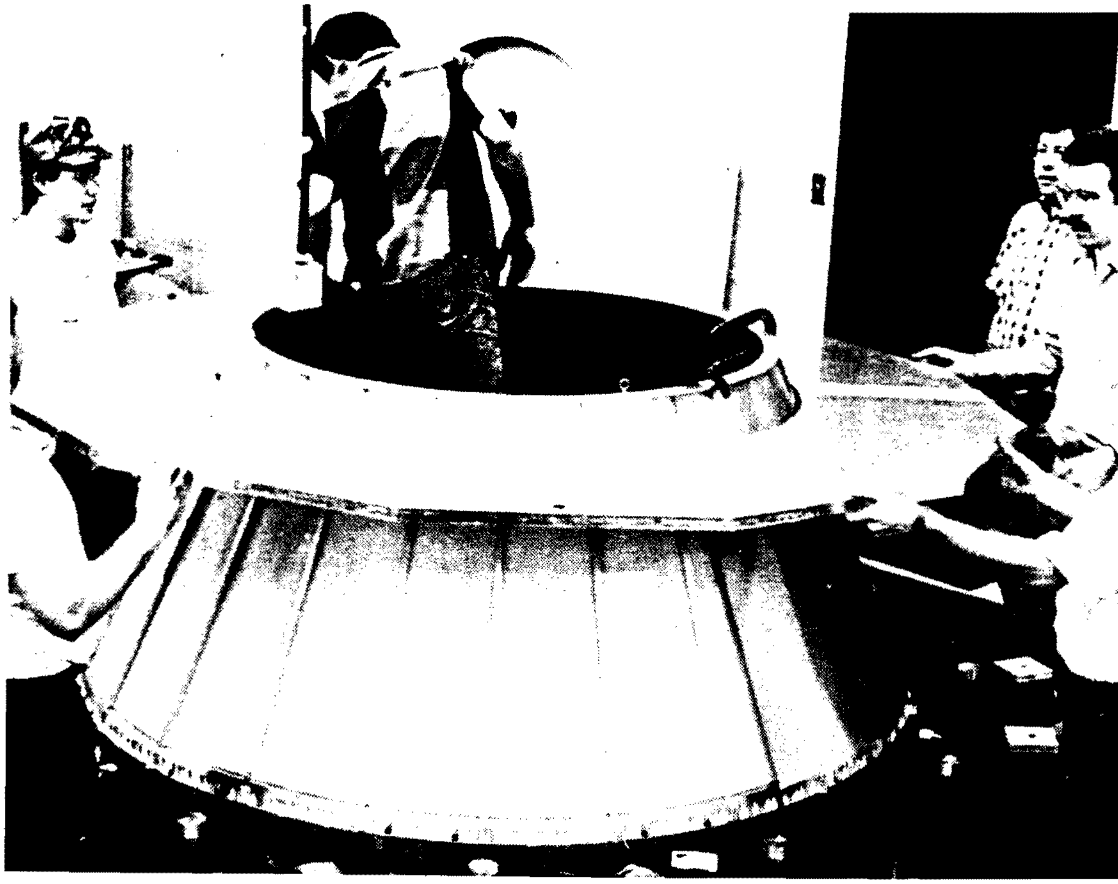

Figure 8

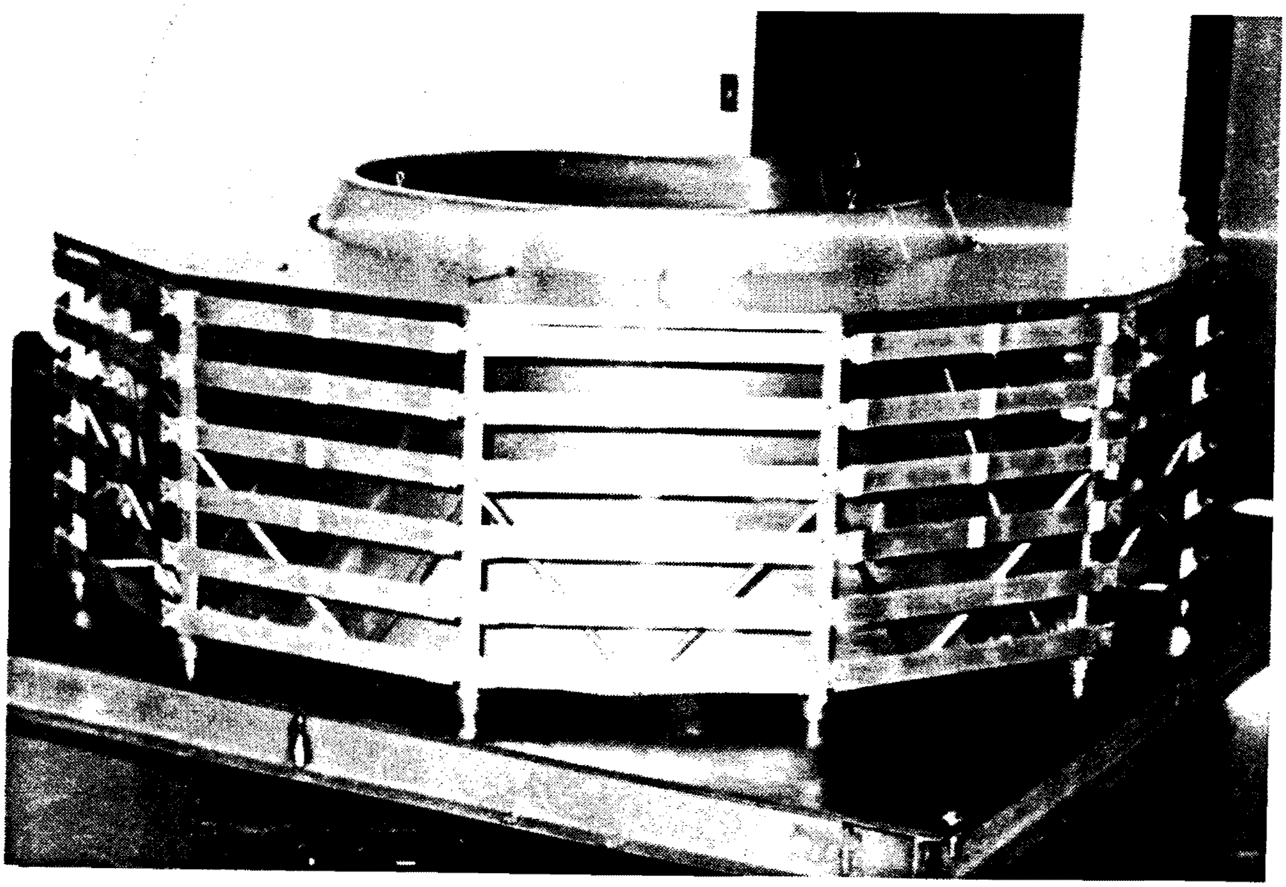

Figure 9