Int. J. Engng Ed. Vol. 13, No. 5, p. 380–387, 1997
Printed in Great Britain.

0949-149X/91 $3.00+0.00

The MASR Project: A Three-Dimensional View of a Cooperative Industry/University Space System Design Experience*

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This paper discusses a unique cooperative space systems design project from three perspectives: industry (the 'buyer'); university (the 'provider'); students (the 'labor'). The needs of each group were successfully brought together in the Manned Assembly, Service and Repair (MASR) Project, providing valuable products, experiences, and knowledge for all participants.

THE STUDENTS' efforts and benefits were many. This project provided insights into the 'real' world of industry, taking the next logical step after traditional textbook engineering education and introducing concepts beyond the obvious engineering design challenges. Various disciplines and individuals came together, enabling students to experience the advantages, challenges, and rewards of teamwork, applying their knowledge to a specific task in an environment very much like that of the aerospace industry. This project joined the separate courses that each student had taken and introduced other concepts to bring a systems design product to fruition. It was an enjoyable and worth-while effort from the students' perspective.

INTRODUCTION

In 1988 McDonnell Douglas Space Systems Company and Utah State University joined a unique design relationship which combined McDonnell Douglas professional engineers with students and faculty from Utah State in the design of large, orbiting service and repair spacecraft. This paper describes this unique cooperative space systems design project from three perspectives: industry (the 'buyer'); university (the 'provider'); students (the 'labor'). Since the study, R. J. Levesque, the student, has become a part of industry at McDonnell Douglas.

This effort built on prior studies with a specific goal of extending findings and concepts. A system engineering process extended requirements, ensuring that new or unique design solutions demonstrated traceability to needs of each mission. This effort was subject to critical reviews by senior program managers. Many new concepts were surfaced and explored during this project. A scale model of a piloted Space Servicing Station was also created.

One of the greatest challenges facing engineering educators is the formulation and integration of meaningful engineering design experiences into the educational process. McDonnell Douglas supported the project by providing funds, experienced counsel, technical information, and formal project reviews. The final review was conducted at the contractor's facilities, affording the students an opportunity to see a real industrial plant in operation. This joint design effort was truly the 'best of all worlds' from the university perspective. Engineering educational objectives were met by providing a real design experience on an actual project in cooperation with a real engineering industrial firm.

HISTORY

While participating in an Air Force sponsored Military Space Systems Technology Panel, Dr. Frank Redd of Utah State University (USU) and Bob Dellacamera of McDonnell Douglas discussed the merits of joining industrial firms with student teams for the design of real space systems. Such arrangements should enable students to participate in authentic design experiences under the guidance of professional engineers. The products would include the design itself plus the training of the students during transition from the educational institution to the workplace. Funding from the industrial firm would support student assistantships, faculty released time, and travel to the industrial work site. Although immediate benefits to the industrial firm were not apparent, continued

* Accepted 5 May 1997.

discussion of possible joint venture arrangements began to reveal potential values. In exchange for funding the project, the industrial firm could profit from the low-cost labor and creativity of a well-chosen student team while training potential new employees. If the project was well guided by the professionals, the resulting design could support the company's technical goals.

Utah State University Space Development Lab Evolution.

At the time of the above discussions, Frank Redd was expanding Utah State's astronautical engineering curriculum. This expansion focused on increasing the courses and on broadening the courses themselves. Former Air Force systems development experience caused him to seek ways to introduce more realistic system design experiences into the educational experience. In 1986 NASA funded a student-led space systems design project under the NASA-Universities Space Research Association (USRA) Advanced Design Program. The output of the first year's project was impressive, and it was desirable to expand this experience. Industry was a source of expert guidance and funding and the future employer of the students. Joint-venture, system design projects with industry would provide invaluable opportunities for student participation in authentic design experiences while providing valuable design products to supporting industrial firms. The discussion of this concept by Bob Dellacamera and Frank Redd eventually led to the Manned Assembly, Service and Repair (MASR) project (Fig. 1).

McDonnell Douglas Business Situation.

From 1985 to 1988 the Advanced Logistics Group, business activities were expanding, with multiple contractual efforts and a growing IR&D project. Business had been acquired in neutral buoyancy testing activities for the USAF; support was required for Space Station Phase B, Advanced Development, and Phase C/D activities; we had teamed with TRW and Grumman on the SAMS for the USAF; there was participation in the Advanced EVAS Study with Houston colleagues for JSC; a Space Maintenance Study for MSFC as well as a vigorous six-task IR&D project.

With all these diverse activities, it was difficult to commit personnel resources to looking for subsequent business opportunities. Previous efforts had been successful because planning had been done based on good analysis, the judgment of experts in space operations that we had in-house, our peers in industry, and our current and potential customers.

Many people were postulating what would happen after the space station was deployed, and the operational requirements needed expansion to present a clear picture of the magnitude and direction that the US space program might take in the future.

Over the years there have been many studies on

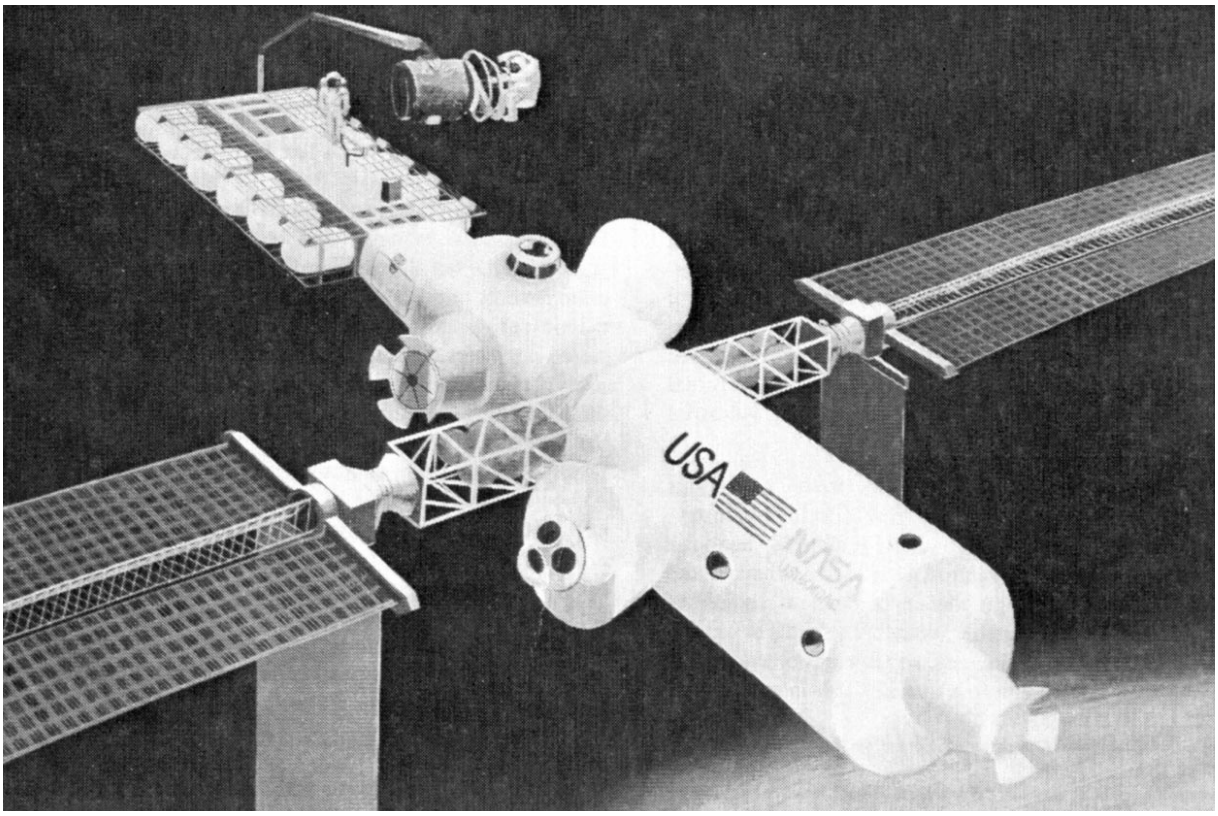

Fig. 1. Artist's manned concept of assembly, service, and repair project.

the nature of future interplanetary programs. The significant difference at this time was a real program in existence, Space Station Freedom, that was going to develop real hardware building blocks that could serve as a foundation for these programs.

Student Needs.

It is common in the university environment that students attain a high level of knowledge in their area of study through reading and lectures, and exercises and problems based on these two approaches. This very effective method of learning can be greatly augmented by an integrated learning experience that simulates the working environment of industry. Such a project allows the student to apply knowledge gathered in many or all of their diverse classes to a new and real engineering challenge. The MASR Project provided just such an challenge.

This project presented several graduate students with an exciting opportunity by providing them with a taste of the industry environment that they would soon graduate into while also meeting many other needs. A major component of the engineering graduate program at Utah State University is the master's thesis, which was recently modified in scope to include design-oriented projects. The MASR project was broad enough in scope that several areas in need of research, development, and design could be defined within the overall needs of the project. Consequently, a number of challenging topics suitable for master's theses were identified.

The areas which were studied in master's projects received intense attention and improved the overall results of the project. The diversity of the MASR project was attractive to students because it pulled together several different aspects of study that had previously been dealt with separately in traditional classroom study.

APPROACH

Utah State University.

USU's interest was to provide as realistic a learning environment as possible. This meant receiving a bona fide request for proposal (RFP) from the contractor with a realistic work statement. The system-level requirements were drafted from the work statement and negotiated with McDonnell Douglas. Bob Dellacamera traveled to USU for face-to-face discussion with Frank Redd and the students to decide the final work statement and freeze the system requirements. Bob stressed the fact that USU was to be responsible for the accomplishment of task in an IR&D project. The student team was selected and leadership was chosen from students who had completed the NASA/USRA-sponsored Space System Design course. The team was assigned the responsibility for constructing a schedule and deriving a work breakdown structure.

It was important that timely communications with industry engineers be maintained to ensure satisfactory progress, to check technical accuracy, and to provide needed technical information to the student team. McDonnell Douglas Aerospace (MDA) and USU conducted a weekly telephone conference to meet these needs. Design data were faxed to each location before each teleconference to be used during the weekly review. The USU portion of the review was conducted by the student team leader.

Formal reviews were inserted into the project to ensure design integrity and to provide realism to the project. During each phase of the project a formal mid-project review was conducted at USU. At the end of each phase the final review was conducted at MDA. The value of these reviews to the students and to the quality of the project results cannot be overestimated. It was also important to ensure that this project fit within the university educational structure. One way to accomplish this was to identify portions of the project that were suitable for master's degree theses. Largely as a result of this project, the department thesis guidelines were expanded to include design projects. With this sanction a total of four mechanical engineering thesis topics were identified.

McDonnell Douglas.

An IR&D additional task examined advanced manned missions that had been postulated before with the specific purpose to apply present and/or space station technology or developments. The objectives were limited, and new discoveries were not desired. Using USU for this task seemed to be a way to get the job done.

In conversations with Dr. Redd his enthusiasm for the project became infectious. He saw more in this relationship than was imagined. He remained focused on producing a product, the study report, on time for the promise of tangible results. He also saw benefits of having a real problem for students to use for their masters' theses. This would provide a good motivation for the students to complete the study. McDonnell Douglas subsequently drafted a work statement for USU to do a paper study.

The contractual relationship was accomplished by the Procurement Group. Because there was an initial concern that the students would go off on tangents that were not productive, a method to run this study was set up to guide, monitor, and schedule results with much interaction. It was decided that Bob Dellacamera would go to USU, sit down with the students and professors, to lay out the project, face to face.

Students.

Guidance was provided to the students by the university professor Dr. Frank Redd, and the industry customer, Bob Dellacamera, but the majority of the scheduling and work responsibilities was given to the students. An important first step was to establish a working schedule for coordination among team members. This was a new experience, stepping outside of the familiar classroom framework and moving toward an organization more like that in industry. The work to be accomplished was clarified and split off into tasks with associated schedules tying into related tasks by need dates and deadlines. This allowed identification of a suitable work breakdown, as well as areas for master's thesis research for selected projects from this work.

A major portion of the initial approach involved researching and collecting background information sufficient to establish a suitable familiarity with the design environment for the MASR platform. The time required to accomplish this task was initially underestimated by the students. Guidance and support from industry customer and professor helped to determine a functional scope of study for the project. Nevertheless, becoming familiar with the unique design environment of low Earth orbit, such as the effects of microgravity and the complexities of inhabited spacecraft, was a major undertaking. This made the need for good planning even more obvious as the schedules were identified for management and customer reviews and product deliveries.

The outputs of this system design project consisted of periodic reports, system-level drawings, reviews with university management's, and formal reviews with our industry customer, including visits to MDA's plant. Additionally, providing the completed master's thesis to our industry customer as a supplemental analysis of subject areas made the effort more than an academic exercise. The master's theses included radiation shielding for the inhabited portions of the vehicle and guidance, navigation, and control of the entire spacecraft.

EXPECTATIONS

Utah State University.

The primary objectives of this project were threefold:

1. provide a realistic engineering design experience which would prepare the students for successful employment in the space industry;
2. provide a quality product that met the requirements and satisfied the customer needs;
3. fit the whole effort into the university educational system.

Individually, each of these objectives was quite formidable; collectively, they presented a challenging alteration to the standard university educational process. Bob Dellacamera's incredible enthusiasm for the educational potential of the project and his faith in the students' ability to accomplish its technical and programmatic objectives provided great encouragement.

McDonnell Douglas.

A credible product from this effort was needed to maintain IR&D quality. For this planning to be of value, a thorough systems engineering study was needed. By rigorous approach to analyses, exploration of new ideas, and no hesitation to stretch the edges of the technology envelopes, good scores were achieved with the IR&D project.

To demonstrate to government evaluators that this was not simply an academic exercise, in the project description it specified that this effort would be managed as an adjunct to MDA. Bob Dellacamera was the major focal point and selected individuals within his department had specific interface responsibilities to help this effort. Systems engineers, designers, cost analysts, and a professional training specialist participated during various stages of the study to help the students on an as-needed basis.

Student.

As a student on this project, Ray LeVesque was excited by its uniqueness and challenge; it was a 'real' project instead of a contrived textbook problem with an answer in the back pages, and the project was representative of industry. Further, this project enabled satisfaction of some important educational needs: master's thesis research and or design, and providing financial assistance. This work would enable learning the practices typical of the aerospace industry, promote familiarity with NASA and other relevant government documents and resources, and possibly (hopefully!) visit and tour the MDA facilities. In any event, he was confident that an experience of this type would be very desirable on his resumé.

WHAT REALLY HAPPENED

Utah State University.

Student experience and confidence gained in the previously completed NASA/USRA Advanced Design Course proved invaluable in getting the project moving. The student leader quickly organized the tasks and the students began to work. Although the scope of the effort proved to be much broader than they originally had anticipated, the students never lost their enthusiasm.

The weekly teleconferences with MDA were tremendously successful. The advent of the fax machine greatly enhanced the process because charts and diagrams were essential to the communication. Bob Dellacamera and his staff provided timely, relevant technical support and, at key times, invaluable engineering judgment. As time went on, the MDA engineers and the USA students became a unified engineering team working together on a challenging space craft design.

One previously undescribed benefit was the necessity for the students to learn accepted documentation procedures. Although it was tedious at times, they learned that such procedures are essential to ensure design integrity.

The formal review process proved to be extremely beneficial. The knowledge that their work would be thoroughly examined by professionals during a formal design review was extremely motivating (and frightening) to the students. Preparation for these reviews was intense as the students worked to ensure that nothing had been neglected and that all their design decisions could be well supported. This was a much different preparation process than that associated with in-class examinations. The success of these reviews was extremely rewarding, especially those conducted at McDonnell Douglas.

As the project continued, it became necessary to develop accurate cost models. The lack of cost modeling skills among the engineering students led to the selection of an MBA student who, with support from Business School faculty and MDA cost analysts, developed a systems cost model. In its final phase, the project was extended into the Psychology Department for support in assessing pyschosocial requirements for a human crew in long-term space flight.

Overall, the MASR project became totally integrated into the lives of all the students who worked on it. Not only was it part of their education, it became part of them. All the essential parts of the program worked very well. In that sense, expectations were more than realized. The unanticipated characteristic was this integration of the project into the lives of the students. They transitioned from working on the project for a grade, or a thesis, into a feeling of responsibility for the success of an enterprise that transcended the educational goals. This transition was wonderful to behold.

McDonnell Douglas.

The group of students appeared to attack the tasks. They divided up the effort and assigned leaders for each of the subtasks, and McDonnell Douglas initiated weekly meetings. The organizational structure came from both the group and the faculty and the job seemed to be progressing and they took direction without a problem.

The breadth and depth of work were beyond expectations, their literature search was good and they started to categorize things and identify possibilities and issues that needed to be traded off and analyzed. To keep the effort manageable a select series of scenarios was developed and worked. This kept free-wheeling and tangents to a minimum.

Analyses accomplished and concepts developed were fairly thorough and realistic. McDonnell Douglas provided some analysis suggestions, but basically let the students have their lead. Initially, Bob felt that the students did not really believe that their opinions and work were credible. This seems to be common among newly hatched engineers and stems from the differences between the academic environment and industry. In academia, individual achievement is thoroughly checked by professors whereas in industry, team efforts by peers focused on specific goals with unknown answers are the norm.

Management turned out to be easy. Datafaxes were exchanged prior to the meeting, and the telecons went this way: The USU team gave a report on what progress was made each week, identifying problems, questions, etc., Bob Dellacamera gave his opinion of the work presented, all parties agreed on any refinement in the tasks, checked to see that the schedule was being met and then assigned any action items.

At the end of the second phase, the USU team came to MDA in Huntington Beach and gave a review. This review was done in typical view-graph presentation format, and the team handled a few probing technical questions very professionally and backed their answers with vigorous, analytically derived data.

Subsequently, the effort was expanded to do economic analyses using students form the USU Business School guided by personnel from our economics analysis group at MDA. Then the final expansion was to explore the human factor of operating in remote outpost operations with the School of Psychology. The $2\frac{1}{2}$ years of then current analyses of operational requirements and the possible application of space station developments were applicable to the Space Exploration Initiative. This work was subsequently used as a starting point for several in-house efforts to look at transitioning specific SSF developments to SEI.

Students.

As mentioned previously, the time invested in researching and developing appropriate background for this project consumed a large amount of the students' time. The mountains of resources that were available were amazing and constituted significant learning aside from the information they provided. The time committed to the MASR Project definitely exceeded the typical class project.

The value of teamwork became increasingly evident as the project proceeded and various tasks were taken on by individuals who probed them in depth, while keeping others apprised of the potential impacts on other aspects of the design. Team meetings were a necessary and frequent part of the process. The team which evolved among the students, as well as the overall team of students, the university and the customer, worked well in this situation. A free flow of information took place, significant and steady progress was made, and perhaps most important of all, the process was enjoyable.

While a few aspects of the process were about as much fun as a final exam (preliminary design reviews are nerve-wracking!), the entire process was very rewarding and educational in a fashion which cannot be duplicated in a traditional classroom environment. In addition to creating computer-aided drawings of the MASR Platform, scale models of the spacecraft were built. The model building process was quite enjoyable, causing re-examination of design decisions after seeing their results in three-dimensional form.

BENEFITS

Utah State University.

The most thrilling aspect of this project was to see the actual realization of the idea that an industrial firm and an educational institution could join together to create a realistic engineering design project that was of substantial value to each organization. It was necessary to break down some perceived cultural barriers on both sides of the partnership, but these barriers proved to be less formidable than was first expected.

The benefits to the university exceeded our expectations. The partnership with McDonnell Douglas injected all the realism of an actual design project because it was an actual design project. MDA's move to identify the MASR design as a line item in an actual IR&D project made it real. The students had to meet actual schedules with documentation that met industry standards. Their design was reviewed in accordance with industry practices. In the end, it provided the basis for an actual McDonnell Douglas proposal.

The completed product proved valuable to McDonnell Douglas. The real-time interaction and team spirit of the industry/student team helped to provide that value. The review process ensured that the final design met the customer requirements. Again, the knowledge that they were responsible for meeting the requirements of an actual IR&D line motivated the students to provide a quality product to meet the customer needs.

Although it took some work and a little salesmanship, the entire project was fitted into the educational system. The identification of selected areas of the design for these topics was the key to the integration into the graduate program. It is worthwhile to point out to those that question the 'scholarly' nature of the design process that the creativity involved in synthesizing a new design from fundamental engineering building blocks meets the highest standards of creative activity. The thesis activity on this project exceeded the standards normally associated with a master's degree.

Probably the greatest benefits were to the students. Although these are best assessed by the students themselves, as Ray LeVesque so nicely does below, the faculty could also see the value of the overall experience in the growing maturity of the students as they applied a wide array of engineering skills to the solution of a real design challenge. Many of these skills were learned in the classroom, but many new ones could only be obtained by expanded study into formerly unknown areas. It was wonderful to see the students become professionals as they realized that they possessed the intellectual tools to explore beyond the boundaries of their documented course work. Their competence grew with their confidence as they began to converse on nearly equal terms with their industry colleagues.

McDonnell Douglas.

McDonnell Douglas really got a good look at the possibilities for the future of the space program, from the eyes of a third party that did not have corporate biases. This exercise expanded our strategic thinking by allowing USU some freedom in their effort. Much work was accomplished economically. The activity was managed within the existing management structure with little additional time. A good IR&D score was achieved on this project, in fact the relationship was looked on favorably by most government evaluators. And finally McDonnell Douglas hired a valued new employee with the great confidence of having worked with him for many months.

Students.

The benefits realized by the students in this endeavor were substantial and varied. To some, it was the highlight of their graduate school experience. To all, it demonstrated the integrated nature of complex engineering efforts. As expected, the knowledge accrued from many diverse courses, as well as much time spent in research, came together in a team effort which presented a taste of what students could expect in the aerospace industry. It was exciting to deliver product to our customers which met their needs, and in some areas exceeded their expectations. Several students went on to find employment within the aerospace industry. Ray LeVesque came to MDA and was able to apply much of the knowledge gained in the MASR Project directly to work as a new aerospace engineer on the Space Station Freedom program. In all aspects, this project was an excellent experience for the students. It was a meaningful, challenging, and interesting project.

CONCLUSION

Utah State University.

The key to the success of this project was the realism introduced by the relationship with McDonnell Douglas. The requirement to respond to a real RFP with a realistic work statement supported by a realistic schedule began the process. The necessity for writing, negotiating, then freezing system level requirements carried the project into an authentic design phase. The weekly interaction with McDonnell Douglas engineers resulted in team building that greatly enhanced the final product. The understanding that the students were responsible and accountable for a product that contributed to the overall success of a real McDonnell Douglas IR&D project was a great motivator. Finally, the requirement to meet formal industry project-review standards made it genuinely real.

At a time when industry and higher education are wrestling with how to inject authentic engineering design into the education of an engineer, this project stands out as an outstanding example of how that can be done. There is no educational experience that can match doing the real thing. This project provided that opportunity for such an experience to an enthusiastic group of graduate students at Utah State University.

McDonnell Douglas.

Bob Dellacamera would not hesitate to enter a relationship like this again if a job like this was needed in the future. If you are contemplating a relationship with a university, first look for good chemistry between the professor-in-charge and yourself. Then make sure that there are compatible interests in your respective institutions. Run the project like your business, because it is. Contractual relationships are mandatory to make sure that achievable project result. The 'realness' of this project was evident to all involved. The students knew that McDonnell Douglas needed this effort done as a part of our business, and that we were depending on them to do a good job. When deadlines were set, there was no doubt that they were real and important to them and their 'customer'.

Students.

Do this at your university! Provide as many opportunities for students to do this as possible. This is encouraged for several reasons. This approach:

- enables students to gain an understanding of what lies ahead in their careers;
- provides industry with relatively low-cost, good-quality research and design products;
- prepares students for working in industry by teaching them valuable experience-based skills, such as scheduling and teamwork;
- integrates and reinforces previous engineering course work by applying the breadth of students' skills to a project, rather than constraining the scope, as is often necessary in the classroom;
- perhaps most importantly, this approach enables challenging engineering projects to be fun.

Make this type of project the norm in engineering education, instead of the exception.

Frank J. Redd was appointed Executive Vice President of Utah State University's Space Dynamics Laboratory in April 1996. Dr. Redd has more than 25 years experience in all phases of research, development, and management of high technology programs in space and ballistic systems. In addition, he has over 16 years university teaching experience in Mechanical and Astronautical Engineering. At Utah State University (USU) he organized and was appointed Director of a State of Utah sponsored Center of Excellence in Space Engineering. In 1991 that Center was recognized by the State of Utah as a Distinguished Center of Excellence. He has also been appointed Director of the Rocky Mountain NASA Space Grant Consortium, a consortium funded under the National Space Grant College Program whose members include Utah State University, the University of Utah, the University of Denver, Brigham Young University, Weber State University, Southern Utah University, the Thiokol Corporation, and the Idaho National Engineering Laboratory (DOE). Dr. Redd served as the Vice Commander of the Air Force Space Technology Center (AFSTC) providing oversight of programs in excess of $400 million. He also served as the System Program Director for the Air Force's Inertial Upper Stage program, where he managed the design, development, test, production, and initial flight of this $700 million advanced space program. He later served as the Deputy to the Air Force's Space Shuttle Program Director.

Raymond J. LeVesque, II earned his BS in Aerospace Engineering in 1986 at the University of Southern California, and his Master in Mechanical Engineering in 1989 at Utah State University. Since 1988, he has worked on the International Space Station project at McDonnell Douglas Aerospace in Huntington Beach, California. He currently specializes in the development, specification and production support of passive thermal control coatings for spacecraft. His work experience also includes spacecraft systems design and integration, and spacecraft interior architecture research and development.

Robert J. Dellacamera has earned degrees in Mathematics and Business from Adelphi University in Garden City, NY and Saddleback College in Mission Viejo, CA respectively. He has worked in the Aerospace Industry for 38 years and is currently assigned to International Program Development at McDonnell Douglas Space & Defense Systems in Huntington Beach, CA. He has worked in electronics design/development, instrumentation, logistics, manufacturing, field operations, business development, and program management

for a variety of space launch vehicles and unmanned and manned space systems. He has served as the civilian contributor to the development of DOD Directive 4100.35, 'Development of Integrated Logistics Support for Systems and Equipment' and as a member of the organizing committee and charter member of the Society of Logistics Engineers (SOLE).