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A COMMERCIAL APPROACH TO SPACE

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SPACEHAB
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1. SPACEHAB CONCEPT

The SPACEHAB pressurized mid-deck augmentation modules are commercial modules being developed by SPACEHAB Inc., a private American company, for use in conjunction with the Space Shuttle.

The Spacehab concept is elegantly simple: to provide an economical, easy-to-use augmentation to the Space Shuttle that will provide an expanded capability to investigators requiring man-tended access to space for research and development.

The Spacehab module doubles the Orbiter's inhabitable volume, quadruples the volume reserved for experiments and still leaves 75% of the cargo bay available to house other experiments and payloads. Access from the module in the cargo bay to the crew compartment is through the standard Orbiter airlock. Astronauts can move freely between the Orbiter middeck and the Spacehab module where they can work in a shirtsleeve atmosphere to carry out a wide variety of experiments and projects.

Spacehab is designed for easy integration of experiments, and for easy integration of the module into the Orbiter. In addition, Spacehab provides a full range of services to its users, all of which include the required interfaces with NASA.

Spacehab is available to experimenters from all over the world, and will provide easier, more frequent opportunities for space researchers and their sponsoring organizations at costs that are very economical compared to other alternatives.

What Spacehab does offer is locker accommodations like those that have come to be in such great demand by experimenters on the middeck. Spacehab also can support rack mounted experiments, providing in the near term a close simulation of the Space Station lab accommodations and support for facilities like the Mid-deck Accommodations Rack (MAR).

One Spacehab flight provides the equivalent mid-deck experiment opportunities of seven current Space Shuttle flights. Spacehab will provide a bridge to the Space Station era, both for hardware providers like Alenia Spazio and McDonnell Douglas, and for a community of users for whom Spacehab will provide ample opportunity to develop and verify Space Station era experiment hardware and processes.

Spacehab has been designed to minimize the development, production and transportation costs while at the same time providing for a reduced time interval from identification of payload complement to flight.

Spacehab Inc. is building two Spacehab modules for use by NASA, commercial users, foreign governments and the Department of Defense.

The first Spacehab module flight is planned in January 1993 with half of its capacity leased to NASA in the frame of the CMAM contract and the remaining volume leased to commercial users.

The Spacehab industrial team is led by Prime Contractor McDonnell Douglas Astronautics Company (Huntsville, Alabama), responsible for the design, development, manufacture and operation of the Spacehab system, and for users services including payload integration and de-integration and mission support. Alenia Spazio is a European Aerospace company and is the principal subcontractor responsible for the Spacehab primary structure and passive thermal control.

The Spacehab industrial team has in-depth experience and a proven record with past manned systems (Spacelab and Space Shuttles), as well as, key roles in the systems design and development of Space Station Freedom and its European contribution, Columbus. Alenia Spazio was responsible for the primary structure and thermal control of Spacelab and is Element Prime Contractor for the Columbus Pressurized Modules.

(*) ALENIA is the new Company resulting from the merger of Aeritalia and Selenia, taking over full responsibility for their functions, responsibilities and activities.
2. OVERALL DESCRIPTION

The Spacehab module is designed to be carried in the Orbiter cargo bay together with any other commercial or scientific payload without interfering with the normal operation of the Shuttle.

Spacehab Inc. is creating low cost hardware for space research using a Shuttle-based pressurized module whose technology is being derived from a proven Spacelab experience and qualification. However, there are substantial improvements dictated by the unusual shape of the module.

The modules measure three meters in length (10 ft) by four meters in diameter (13.5 ft) with an internal pressurized living and working volume of 28 c.u.m. (1000 cubic feet); the flat front and back end panels are designed to minimize the bay occupation while the cylindrical shell is truncated to permit visual line of sight to the remaining payload bay from the aft flight deck windows. The truncation also permits a suited astronaut to cross the top of the module with the payload bay doors closed should an emergency arise with the payload bay door latches.

Furthermore, experiments that need direct exposure to space can be mounted on the flat top panel. They are connected by feed-throughs to utilities and controls inside the module. The module is also equipped with two viewports for Earth and Deep Space observation.

The Flat End Caps offer an interior volume similar in size to the Spacelab Short Module but requiring only one quarter of the payload bay. The Flat End Closures provide a cost benefit by permitting cost effective utilization of the four interior walls instead of only two walls in other modules. In the microgravity environment of orbit, it is wall square footage that is valuable and not just floor space as on Earth. The underside of the truncated top is also a valuable flat surface location for experiments. Figure 1 depicts the basic Mid-deck Augmentation Module installed in the Shuttle Cargo Bay with typical interior locker arrangement with the module.

The external surface of the module has aids (handrails, tether points, etc...) to allow Extra Vehicular Activities. The total mass of Spacehab module is 4173 kg (9200 lbs).

The Spacehab modules will provide space laboratory environments for a wide variety of research and development experiments. Since the modules could fly up to four flights per year, experimenters have the opportunity of conducting the repeat trials needed for breakthrough research.

In the area of life sciences, Spacehab modules can provide larger pressurized volumes than are currently available in the Orbiter Mid-deck for research, especially in such areas as biotechnology and human space medicine.

Research and Technology activities can also be conducted for applications in the areas of gravitational research, fluid physics and chemistry, and space processing for new and improved metals, alloys, pharmaceuticals, biological products and crystals.

The development of telerobotic systems and advanced remote sensing systems, as well as the in-orbit maintenance and servicing activities in a pressurized environment, are the other areas that could benefit from using Spacehab modules as a testbed for initial studies.

The module can be used for advanced Shuttle systems and procedures development; Space Station simulation and experiment testbeds (thanks to standard Space Station racks and interfaces).

In addition, Spacehab could also serve as additional storage and habitation space for the crew during extended Shuttle missions, for food, spare parts, clothing, etc.
3. PAYLOAD DESCRIPTION

Spacehab module interior configuration is highly flexible and easily modified due to the modularity of the design. It provides up to 64 additional mid-deck lockers for man-tended experiments.

The payload that will be installed in the Spacehab module can be divided in three categories:

- Locker/tray payloads
- Rack payloads
- Top panel externally mounted payloads

The total payload mass capability is 1134 kg (2500 lbs).

The first type of payload is installed in modular containers attached to the front and rear bulkheads inside the module. Each locker can carry a payload of 27 kg (60 lbs) with a total mass of 36 kg (80 lbs) including the structure; the available volume is 57 dm³ (2 ft³).

The rack can carry a payload of 544 kg (1200 lbs) with a total rack mass (including the structure) of 635 kg (1400 lbs); available volume is approximately 1270 dm³ (45 ft³).

Mixed configuration of payloads are possible (lockers and racks) within the total mass and C.G. limits.

The top panel externally mounted payloads are planned to be attached to the external surface using a standard interface pattern. Feed Through is provided to accommodate cables and pipes which will allow the control of the external experiments. In addition, the top panel also accommodates two openings for installation of view ports or other external experiments operated from inside.

4. PRIMARY STRUCTURE DESIGN AND QUALIFICATION PHILOSOPHY

The design and qualification of the Spacehab Primary Structure subsystem is based on an approach oriented to reducing the schedule and overall cost to a minimum.

The structural design approach involves a combination of testing and analytical techniques using finite element models (FEMs) and detailed analysis.

The qualification will be based on similarity with Spacehab analysis and testing.

4.1 Design Cases

The Primary Structure has been designed to withstand the following conditions:

- Internal pressure (1100 mbar) during orbit
- Internal pressure combined with inertial loads during ascent and descent flight phases
- Inertial loads during lift-off and landing
- Deflection imposed loads due to assembly of the Spacehab module in the Orbiter
- Local loads due to equipment/payload fixation
- Thermal induced loads
- Test loads (proof test, etc).

The above-mentioned loads have been applied considering proper safety factors related to the structure type and to the selected verification method.

4.2. Primary Structure Description

The Primary Structure design relies on the experience accumulated by Alenia Spazio in the Spacelab Program. An overall view of the structure is shown in Figure 2 (page 4). The main structural elements are:

- Cylinder shell
- Forward bulkhead
- Aft bulkhead
- Fittings
- Rack support
- The Rods
- Payload and equipment fixation hardware.

All panels of the shell and the bulkheads are derived from plates by NC machining; the internal integral stiffeners have a square arrangement with pitch ranging from 120 to 185 mm (waffle panels). The total thickness of the panels spans from 25 mm in the cylinder lower panels to 50 mm in the cylinder top and the bulkheads; the skin thickness is kept near to the technological limits ranging from 1.6 to 2 mm depending on the panel size.
The Spacehab module is supported in the cargo bay by the standard 5-point Orbiter interface attachment, utilizing the proven Spacehab designed trunnion fittings. This standard interface will minimize the complexity of Spacehab physical integration into the Orbiter.

The position of the Spacehab module in the cargo bay is the most forward position available for a four longeron trunnion configuration. The aft longeron trunnions and the keel trunnion are located on the same y-z plane, 94.4 inches aft of the forward longeron trunnions. This spacing provides for possible relocation of Spacehab.

Each bulkhead has vertical and horizontal stiffening T-beams that provide mounting provisions for locker equivalent hardware and subsystem components. The forward bulkhead accommodates three subsystem feedthrough plates and the tunnel access opening of 32 inches in diameter gives free clearance.

Externally, the aft bulkhead provides for the CCTV cameras and the forward bulkhead supports an experiment water pump/heat exchanger and the fluid line/cable trays.

The flat top panel is stiffened by longitudinal and lateral T-beams that provide mounting for the lights, fire extinguisher and emergency breathing devices. The flat top and bulkheads are restrained with a set of six tie rods which control the pressure-induced strains of the flat structures. Externally, inserts are provided for experiment mounting.

The cylinder section is reinforced circumferentially with a series of stiffening ribs.

Racks are supported on the lower end with port and starboard Spacelab-derived rack support structures.

The rack support structures also support a Spacelab standard subfloor and a Spacehab-designed work station. The Spacehab flight floor, mounted to the rack support structure has hinged panels for access to the subfloor.

The truncated cylinder/flat bulkhead Spacehab module is such a unique design solution for the multi-parameter requirements of overhead clearance, bay volume minimization, efficient experiment accommodation and overall mission safety, that the U.S. Government issued a patent for its manufacture to Spacehab, Inc. in 1987.

4.3 Analytical Activity

The analysis activity that has been, and will be, performed to develop and qualify the Spacehab module can be divided into the following main branches:

- Preliminary static analysis for initial structural trade-offs and configuration selection
- Detailed static analysis on the selected configuration to size the main structural elements on the basis of the pressure and global inertial loads
- Detailed static analysis of the areas subjected to local inertial loads due to payload and equipment interfaces
• Fracture mechanics/fatigue analysis to verify the life duration requirements (50 missions with a life factor = 4)
• Dynamic analysis to verify the stiffness requirements
• Dynamic analysis to provide theoretical predictions for the modal survey test performance
• Correlation of the test results with the analytical predictions to obtain a qualified mathematical model to be used for the coupled analyses
• Static analysis to predict the behavior of the structure during the pressure static test.

The above-mentioned activities are all based on the results obtained from mathematical models of the examined structure.

The following approach will be used to size and to verify the module structure: the structural model will be loaded with the payload and equipment, attached through a statically determined suspension scheme, and the overall structure will be subject to unit load cases (linear accelerations in three directions, unit pressure and out-of-plane imposed deflection on the fittings).

The combination of these runs will be used to size the structure taking into account the global effects and to obtain the deflections without influence of the stiffness coming from payloads (especially lockers) and equipment.

The above-mentioned deflections in the interface points will be applied as boundary conditions for the detailed mathematical models of the other subsystems to derive the interaction forces that have to be used for final sizing of the local attachment areas.

Additional local analysis will be performed on particular zones, like the bolted junction between shell and bulkheads, to derive detailed stress fields.

4.4 Mathematical Models

The main mathematical models used to verify the Spacehab structure are MSC/NASTRAN finite elements models.

4.4.1 Quarter Model

The first activities were performed using a model representing one quarter of the Spacehab module loaded with pressure at limit value (0.11 N/mm²). This model has the following main features:

• N. of nodes 2870
• N. of elements 3275
• N. of D.o.F. 16348

This schematization is manageable enough to allow the performance of a trade-off study of possible structural configurations. Several models were prepared to develop a suitable design concept.

4.4.2 Full Size Model

The detailed stress analysis of the structure under inertial and/or pressure loads was planned considering the use of a larger model simulating half the Spacehab module.

The decision to use such a model was based on the fact that the structure is symmetrical with respect to the xz plane and the payload/equipment distribution was also symmetrical.

The addition of a floor and non-symmetric payload disposition required a change in the modelling philosophy with the development of a full size model.

The full size Math Model adapted for the complete Analysis campaign is based on a very detailed schematization of any items of the structure (primary shell and internal structure). The fine modelization is leading to very precise results that are directly utilized as inputs to the subsequent hand-analysis for the structure design.

The Spacehab structural Math Model uses a NASTRAN program MCNEAL-SCHWENDLER version 67 and has the following main feature:

• Math Model for Analysis and Design Campaign
  • Elements 12200
  • Grids 7950
  • D.o.F. 42000
  • Load Case 5 Unit Cases

• Math Model for Dynamic Analysis
  • Elements 1500
  • Grids 2000

• Dynamic Analysis
  • Natural Frequency
  • Eigenvectors
  • Mode Shapes
4.5 Testing

Tests anticipated to support the development of the Spacehab module structure are grouped in the following main categories:

- Qualification tests of the welding process
- Acceptance tests of all manufactured units
- Qualification tests of the STA.

4.5.1 Qualification Tests on Welding Process

The data obtained from the development tests dedicated to the welding process definition are used to start a set of tests to derive the mechanical properties of the welded junction. The properties to be derived are:

- Yield and ultimate strength without welding defects
- Fracture mechanics data
- Yield and ultimate strength with welding defects (mismatch, tenting)
- Yield and ultimate strength after weld repair (manual, automatic, repeated).

The qualification phase will cover all the welding configurations present in the Spacehab manufacturing process (longitudinal, circumferential and manual).

In addition to the above tests, performed on coupons assembled on the laboratory equipment, there will be further tests to check the influence of the actual production tool (shown in Figure 3) on the welding parameters.

4.5.2 Acceptance Tests on Manufactured Units

These tests are performed to guarantee that the manufacturing process and assembly has been correctly performed and that the structure is able to meet the specified environmental and operational requirements. Acceptance tests are:

- Proof pressure test performed applying an internal pressure equal to 1.5 times the design pressure
- Pressure decay test to measure the air leak through the seals (leak rate has to be below 0.3 Kg/day)
- Weight measurement
- Center of gravity measurement
- Electrical bonding test.

During the pressure acceptance test, the modules will be supported at the Orbiter interfaces and the installed instrumentation will provide a preliminary indication of the load paths and the structural behaviour.

4.5.3 Qualification Tests on the STA

The sequence of tests, performed after the acceptance, foreseen to certify that the module structure design is in compliance with the requirements is as follows:

- Modal survey test on the module including primary structure and dummy equipment and payload. The test will be performed in a free-free suspension mode. The results will be used to qualify the mathematical model.
Acoustic noise test simulating the environment present inside the Cargo Bay during lift-off and ascent phases. Testing will take place in the IABG test plant in West Germany. The test configuration is the same as in the modal survey.

- Static test on the main fitting.
- Fatigue test applying 50 x 4 pressure cycles to the module structure.
- Pressure decay test to verify the integrity of the seals after the simulation of the 50 missions (fatigue test).
- Ultimate pressure test at a pressure level twice the design pressure. The test set-up will support the test article on the fittings and will have a flex adaptor installed to simulate the connection with the Orbiter.

The tests prediction and correlation will be based on the specific Mathematical Models (FEM) that are also the theoretical tool for the instrumentation location definition.

The static FEMs of the pressure shell, including the transition section will be verified using data gathered during the proof, fatigue, and ultimate pressure tests. The static FEMs of the trunnions will be verified with data from the ultimate load test. The life verification is based on fracture control concepts.

For Fracture critical items, the fracture control is performed using linear elastic fracture mechanics analysis starting from initial damages whose dimensions are defined in NASA Specification (NASA - STD - 1249).

NASERO code is adapted for the analysis using a load cycle spectra inclusive of transportation handling and flight loads. These analyses will be supplemented by fatigue test of the module test article pressure boundary.

5. MANUFACTURING PROCESSES

Alenia Spazio production capability includes all of the technologies necessary for the development of flight and space systems. Construction of large components employing light alloys, special steels, and titanium alloys and using automatic bonding and welding techniques is a particular strength of Alenia Spazio.

Alenia is manufacturing the Spacehab module cylinder assembly using CNC machining centers, robotic welding equipment, and CAD/CAM technologies.

Similarities between Spacehab and Spacelab eliminate the need for original research for most production processes. Existing machining and plating processes developed during Spacelab production are being utilized.

The primary structure manufacturing has been initiated by machining various sizes of 2219-T851 aluminium alloy plates utilizing 3 and 4 axis CNC milling machines. Material has been machined leaving a waffle pattern to maintain strength without unnecessary weight.

The cylinder panels have been cold-formed to provide the outer contour of the cylinder. The cylinder panels will be joined by longitudinal welding, followed by welding of the mating flange rings using circumferential welding procedures. Due to the truncated shape of the pressure shell, particular attention is given to the parts' manufacturing tolerances and welding sequence to obtain a precise coupling of the interface between the cylinder panels and end rings (see Fig. 4). After quality inspection and cleaning, the weld zones will be treated by chemical conversion coating.
The specifically qualified welding technique utilized for the Spacehab structure is the Tungsten Inert Gas (TIG) process. The completed weld will be placed on end for final machining and truing of the bulkhead mating flanges. Internal rack support structures (similar to Spacelab) the subfloor, and additional interfaces will be installed subsequently. Then, the completed forward and aft bulkheads will be mated with the cylinder assembly utilizing a Gask-O-Seal.

Acceptance test of Flight Unit 1, Structural Test Article (STA), and Flight Unit 2 will be performed with pressure and leakage tests. The two flight units will then be cleaned and packed for shipment to the SPPF. The STA will be shipped to IABG for qualification test.

Upon completion of all qualification tests, the STA will be shipped to the SPPF to become the high fidelity mock-up.

6. PASSIVE THERMAL CONTROL

6.1 Requirements

The primary requirement of the module insulation design is to provide a "thermal bottle" effect which minimizes the changes of the module internal environment due to external environment variations. Thus, when the vehicle is exposed to the maximum amount of sunlight or to deep space, the heat transferred into or out of the module through the insulation is kept very low, compatible with the environmental control system. The Spacehab passive thermal control system will be able to maintain adequate performance over a long time period and is designed to be replaced easily or repaired at reasonable time intervals.

6.2 Design Concept

The above-mentioned requirements are very similar to those of several programs already performed by Alenia in the past. Therefore, the proposed concept consisting of MLI (Multi Layer Insulation) blankets will be very similar to several other designs already developed in the past.

Spacehab will take into account improvements due to the availability of new materials and due to the development of new internal procedures for manufacturing.

The MLI is the most weight-efficient form of insulation for space applications. It comprises several closely spaced layers of thermal radiation reflecting shields which are placed perpendicularly to the heat flow.

In order to prevent interlayer contact, which could be detrimental to the insulation properties, the layers are separated by low conductivity spacers.

The thermal control layers for Spacehab are as follows:

- One external layer of Teflon-coated glass fiber cloth (currently named Beta-cloth) This provides thermo-optical properties for the external surface [low solar absorbency and high infrared emittance]
- One layer of single aluminized Kapton 3.0 mils thick inserted behind the beta-cloth to eliminate its partial transparency
- Nineteen reflector layers of double aluminized Kapton 0.3 mils thick interposed with twenty layers of Dacron net to minimize conduction
- One layer of Nomex fabric with carbon fiber grid.

The aluminized Kapton is protected against corrosion phenomena by means of an organic coating which has recently been developed and fully employed in many programs instead of the expensive goldized Kapton previously used for Spacelab. This type of product guarantees good thermal performance without appreciable thermo-optical properties modification.

The above-described multilayer is assembled in different dimensions and shapes tailored to fit the parts to be insulated.

6.3 Design and Development

Alenia Spazio is responsible for the definition, manufacturing and delivery of the complete sets of MLI blankets for the Spacehab units.

The first step in the design and development of the blankets is the freezing of all mechanical interfaces between the MLI and Spacehab bulkheads, feed throughs, cable trays, handrails, flex section, etc.

Then, a dedicated venting analysis is performed considering the maximum and minimum Orbiter cargo bay internal pressure during ascent in order to define the venting system necessary to maintain the differential pressure between MLI and structure within the safety limits of the blanket fasteners.

The layout of each FU blanket on a master template is performed using the installation drawings and an internal standard procedure for development and manufacturing of the blankets.
During the design of the blankets, the following features must be defined:

- Electrical grounding
- Venting boxes
- Attachment fasteners position
- Reinforcements and overlapping.

After manufacturing each MLI blanket is subjected to several measurements are and in particular:

- Thermo-optical properties of external and internal layers
- Electrical resistance between grounding straps and internal layer
- Mechanical interface with supporting structure via fit-check of the first set of MLI blankets.

An acoustic noise test performed at IABG (Germany) will verify the integrity of the connection fasteners between the blankets and the structure.

7. SPACEHAB MODULE TECHNOLOGICAL ENHANCEMENT

The Spacehab module’s D-shape shell with Flat End Caps requires a significant technological advancement with respect to prior experience in the design and manufacturing of cylindrical welded modules or launcher elements. Major areas of technical improvements are as follows:

- Sophisticated design of the unusual pressurized shell that requires 6 internal tie-rods to minimize the flat items deflection.
- Overall mass limitation which forced the optimization of the structural design of all components. This design optimization was achieved by extensive use of hand local analysis based on the math model results for each structure area.
- New size of sealing elements that have to guarantee a very tight interface with D-shaped flanges.
- Production of D-shaped end rings with extremely tight tolerance able to interface in a predetermined and unique position with the welded shell. During the production of preforged discs of 2219 Aluminium alloy (3200 kg each), the technological limits of the most experienced suppliers have been reached (ALCOA USA).
  The forging, D-shaping forming and stretching to the final T851 Aluminium Temper, in accordance with the very severe requirements, has been revealed as one of the most difficult tasks ever experienced. Aachen University’s theoretical support, and the wide experience in this field of our German supplier VSG HATTINGEN, led to a very positive result in terms of metallurgical characteristics and mechanical properties which resulted also in extremely good and appreciated stability during the final machining. The milling of the ring with very close tolerances represents a difficult and risky operation which has been performed with large sophisticated machinery continuously operating in a controlled environment.
- The forward and aft end bulkheads represent an example of how very severe requirements can be successfully applied to extremely large items (4 meters diameter). Starting from the material procurement up to the final machining and assembly operation, these non-standard elements require enormous skill to certify the production tool equipment and manufacturing techniques able to meet the very close tolerances.
- Cold-forming of large and very stiff panels represents a technological problem on which Alenia focused considerable attention and effort for many months which resulted in an efficient and repetitive break-forming process supported by special and sophisticated tooling.
- The longitudinal welding of the shell panels and the circumferential welding of the D-shaped rings require massive and extremely precise tooling and welding equipment which must guarantee both correct component interfaces and uniform application of the qualified welding process.
  The D-shaped size of the module requires the application of three different welding techniques for each circumferential welding (longitudinal, circumferential and manual processes).

8. SCHEDULE CONSTRAINTS FOR A SUCCESS ORIENTED PROGRAMME

The Spacehab program, being a privately financed program, suffered extremely from the limited funding availability and fluctuation. However, the unlimited willingness of the two major participating companies (MDSSC and Alenia) led to acceptance of increased financial risks and therefore support for the key activities was never denied. As a result, the Spacehab programme is being accomplished with very tight schedule requirements and unique design and manufacturing problems. These conditions have required the development of an exceptional industrial team, in order to satisfy the needs of a success-oriented schedule plan.

The schedule approach adopted for the Spacehab program was heavily based on the proven Alenia experience in this type of space product, on the full knowledge of the potential problems and the establishment of specific methods for problem solving.
The schedule and cost constraints have caused the development of a plan based on the Flight Unit manufacturing and integration while the Qualification Unit (STA module) is undergoing the various qualification tests. However, parallel tests on development samples for each of the critical items have been carried out to establish process and design feasibility verification.

This solution provides reliable information at reasonable cost levels and within the program schedule constraints.

In this way, the traditional technological unit has been "spread" across many test items for the most critical elements and processes. This, linked with the required engineering assessments of the individual test results, has influenced the overall system development.

The parallel activities of design, tool production and parts manufacturing are another element of the short schedule that requires very tight management control in order to minimize the risks of future modification.

High program priority within the company and very close cooperation of the dedicated management, engineering, product assurance and manufacturing team, along with problem solving on a day-to-day basis, make it feasible to satisfy the unusually tight schedule.

The present program schedule is based on the first Flight Unit - FU1 - delivery from Alenia by the end of September 1991, and the qualification campaign completion (STA module) by August 1992, with Flight Module FU2 delivery from Alenia planned for February 1992.

9. HIGH TECHNOLOGY AT LOW COST - KEY ELEMENTS

The Spacehab program is the major program within the general Alenia strategy for a family of space products based on the experience developed during the Spacelab program. Alenia is also producing approximately 200 welded Ariane boosters and is involved in the study phases of the Columbus module, Hermes Pressurized Cabin and Logistic Space Station Module.

Therefore, Spacehab represents the right program, at the right time, for the technological continuity required for future programs and is a unique opportunity to demonstrate Alenia's competitiveness in this field. The great advantage to the Spacehab program is the proven experience for these types of products in all areas of the project. This guarantees validated design approaches and procedures, as well as the presence of key people previously involved on Spacelab program.

The technological improvements and the vast investments necessary to support the program have been committed taking into consideration possible future applications and therefore are not attributed to the Spacehab program only. Consequently, the company is willing to invest today in Spacehab in order to benefit on a long-term basis.

The tight schedule is creating a very challenging situation that needs great attention but, on the other hand, is demanding an increased efficiency which leads to costs reduction.

The privately financed Spacehab program is considered the new frontier for space commercial activities and therefore Alenia has accepted the challenge to participate in a very positive manner. Consequently, the effort to reduce the cost of the product and maintain the schedule is an extremely high priority which permits Spacehab Inc. and the Scientific Community to benefit from a high technological product at reasonably low cost.