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COLUMBUS PRESSURIZED MODULE VERIFICATION

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ABSTRACT

The baseline verification approach of the COLUMBUS Pressurized Module has been defined during A and B1 project phases. Peculiarities of the verification programme are the testing requirements derived from the permanent manned presence in space. The model philosophy and the test programme have been developed in line with the overall verification concept. Critical areas as meteoroid protections, heat pipe radiators and module seals are investigated and tested. Verification problem areas are identified and recommendations for the next development are proposed.

INTRODUCTION

The european space station programme COLUMBUS is now starting the B2 design and development phase. It foresees several elements (Pressurized Module, Platform, Service Vehicle, Resource Module) which will be time phased to form different on-orbit configurations with indefinite life/operation. AERITALIA has system responsibility for the Pressurized Module element which is designed to be part of COLUMBUS scenario together with the other elements, the US Space Station, the Space Transportation System and associated TDRSS, the launchers, etc. ...

The COLUMBUS Pressurized Module is a manned laboratory derived from Spacelab with the capability of being a free flyer, to have periodical upgrading of its features, to receive different payloads (life science/material science) and to be capable of joining the space station. The life requirements of the Space Station dictate that all the components with limited life are considered interchangeable units and will be replaced on orbit as required, the structure and the service parts are considered not changeable.

Redundancy criteria are strongly affected not only by reliability but also by above requirements. The baseline verification approach for the Pressurized Module has been established on the basis of previous consideration and taking into account the testing requirements imposed by the permanent presence in space. The proposed philosophy foresees development/qualification models at unit/subsystem level and two complete models (Engineering and Flight) at element level. The overall system qualification campaign is carried out on the

Engineering Model, which will be maintained for ground simulation after launch, while the flight model undergoes acceptance tests only.

Environmental qualification is performed at subsystem/unit level because of the dimensional constraints of Pressurized Module. Dedicated pre-development technological programmes investigate and test the critical areas of meteoroid protections, heat pipe radiators, and module seals. The paper presents the status of above Pressurized Module verification activities including problem areas and recommendations.

COLUMBUS PRESSURIZED MODULE (PM)

CONFIGURATION

When the invitation came from the USA government to participate in the Space Station, it seemed likely that, with some modifications, the Spacelab module could be used as the primary building block for the COLUMBUS PM. Being modular in concept, not only to accommodate various combinations of experiments, but also to give flexibility for later growth, studies had been carried out to find ways of extending the time Spacelab could stay in orbit, increasing its power and cooling capabilities, and increasing the volume (in terms of length) of the module.

Starting from the Spacelab experience, ESA, together with AERITALIA as its COLUMBUS PM Phase B1 contractor, began to consider the utilization and operational scenarios which would lead to a set of preliminary requirements from which design concepts could be developed. At the time of writing the Phase B2 proposal has been presented (see ref. 1) and it is based on a programme which foresees:

- a four (Spacelab) Segment Laboratory Module attached to the US Space Station, which should be ready for the first operational use of the Space Station (described by the acronym IOC - Initial Operational Capability), planned by NASA for January 1994.

- Two segment PM, together with a Resource Module (RM), in a combination called the Man-Tended Free Flyer (MTFF) that can be updated, reloaded, serviced etc., at the US Space Station but can then be detached and operated in an unmanned mode for extended periods while formation-flying (co-orbiting) with the Station. Its major characteristic is its very low gravity environment, currently anticipated to be one order of magnitude lower than that of the core station (in parallel, other, unpressurized elements such as a polar, and a co-orbiting platform, a service vehicle and a man-tended servicing unit are under study). The PM within its COLUMBUS scenario is shown on figure 1.

- The layout and facilities offered in the PM should provide a number of user friendly features:
  - Earth-like working conditions i.e. one-g layout (floor and ceiling),
  - standard rack spaces for payloads,
  - racks which can be configured as experiment carriers, work benches, or storage areas,
  - power, cooling and data interfaces allowing maximum flexibility for users,
  - racks themselves and payload inserts to be replaceable (Orbital Replaceable Units - ORU's),
  - module and hatches allowing passage of crew and ORU's,
  - modern ergonomic features.

To comply with above requirements the PM consists of the following subsystems: Primary and Secondary Structures, Thermal Control, Environmental Control and Life Support, Data Management, Electrical Power Distribution, Communications, Docking/Berthing Mechanisms and appendices like Scientific Airlock/Window and Viewports.

REQUIREMENTS

In terms of requirements, the ground rule of the Space Station applies: design for indefinite life by means of on-orbit maintenance, re-configuration and growth. As part of the maintenance concept, a problem has arisen in allowing for interior and exterior access to the module shell for inspection/repair. The aim is to use European subsystem equipment and infrastructures to the maximum extent feasible. This also includes achieving compatibility with Ariane 5, Hermes and the European Data Relay Satellite. The induced microgravity environment gets particular attention from the designers, as experiments requiring such conditions could be a major part of the payloads.

It is mainly for this reason that the MTFF would be detachable from the Station since the crew movements, various docking/undocking manoeuvres, service activities etc. will cause considerable disturbance to the microgravity environment. Therefore, for critical experiments/production processes a free-flyer with a minimum of mechanical movements on board is preferable. Detailed COLUMBUS requirements are listed on ref. 2 and PM specific requirements on ref. 3. Many technical trade-offs have been performed during the phase B1 in order to optimize the design is light of the above requirements. All subsystems in the various COLUMBUS elements are being scrutinised and where possible cost saving common items and systems are being incorporated. Major trade-results were:

Basic PM physical skeleton

Spacelab isostatic scheme and trunnions, four 2.7 m Spacelab segments, US Space Station common separate interconnect elements.

Operations and verification

Empty launch, transportation of integrated PM, Engineering Model philosophy, segmented integration approach, internal pressure.

Payload and crew size

Mixed laboratory payloads (material + life), 8.5 crew for PM experiment conduction.

Avionic and software architecture

Data exchange via system local Network, standard acquisition unit to interface with the network, software architecture and requirements.

Detail configuration

Meteoroid and debris protection, radiation analysis, Spacelab location for Window/Viewport, Airlock and Grapple Fixture.

VERIFICATION APPROACH

OVERALL CONCEPT

The COLUMBUS PM verification approach has been established through the following steps:

- investigation of the mission to define the sequence of events, the environments present or induced during occurrence of these events and the related element/subsystem functions;
- definition of the project requirements to be verified and their subdivision in categories (interfaces, performance, design, etc.);
- identification of the qualification status of the subsystem candidates (considering the existing Spacelab and EURECA hardware to the maximum extent) with respect to the COLUMBUS requirements and applicable environments;
- preparation of a verification matrix showing the method (test / analysis / similarity / inspection / demonstration / review of design) and the level of verification (Unit/Subsystem /Element) for each identified requirement.

The verification philosophy will be implemented in the following programme phases using the standard verification logic based on the Verification Control Document (VCD) as shown on figure 2. In agreement with the above overall concept, the PM model philosophy and test programme have been established in light of the following guidelines:

- minimum model philosophy taking into account spacelab experience.
- No environmental tests at element level (except EMC), only at equipment & subsystem level.
- All flight equipment & spares to be subjected only to acceptance tests.
- Qualification testing to be performed at the lowest practical hardware level, at the earliest opportunity in the verification programme.
- Optimization of the number of tests, simulators and support equipment and their utilization.
- Element level tests verify and demonstrate element functional performance, prove compatibility of the subsystems and verify the functional and dimensional interfaces to standard payloads and external elements.
- The verification programme must, in principle, demonstrate compliance with all requirements, and should therefore not rely on "on-orbit" verification.
- Verification of all element external interfaces should be included in the element verification programme.
- Validation of operational software as well.

MODEL PHILOSOPHY

For the model philosophy a prototype approach has been selected which foresees two system models: Engineering Model (EM) and Flight Model (FM). The EM will be used for the functional performance qualification of the PM element and will have the following characteristics: full flight design, no redundancy, whenever possible (cost saving), limited flight standard hardware (no hi-rel parts). The FM will be accepted for the flight and will present full flight design and full flight standard hardware (hi-rel parts included). A development fixture (DM) is foreseen at element level, with the major objectives of interface assessment, operation/maintenance preliminary verification, training of integration team and procedures. The EM will be maintained after launch for ground simulation activities.

At subsystem/unit level development hardware (breadboard, test bad, etc.) is foreseen only for items of new design. A Qualification Model (flight standard) will be used for the qualification test campaign of the hardware not qualified or requiring a delta qualification. These qualification units, after partial refurbishment will become integration spares for the element activities. EM and FM units/subsystems will then be accepted and delivered for the element Integration and test campaign. Spare model (SP) is also foreseen as required by on-orbit maintenance and operations. Figure 3 summarizes the proposed model philosophy.

TEST PROGRAMME

The verification of PM requirements by testing is performed, on the basis of the defined model philosophy, through the following test programme:

Development Model

Development activity on development fixture (a three segment demonstration mock-up has been already manufactured and utilized in phase B1 - see fig. 4).

Engineering Model

Element functional qualification: subsystem functional performance, Integrated System Test (IST), interface test (Payloads, STS, US Space Station, PM), support equipment demonstration, interchangeability (ORU's etc.), ground operation demonstration, audible noise, offgassing, crew habitability demonstration, maintainability demonstration, mission simulation, physical properties, electromagnetic compatibility (EMC), pressure decay, ground simulation of flight operation.

Flight Model

Element flight acceptance: subsystem functional performance, IST, interface tests, support equipment demonstration, interchangeability, crew habitability demonstration, physical properties, system leak, EMC.

COLUMBUS programme characteristics and PM configuration impose some constraints on the test programme and on its feasibility. For example the PM dimensions necessitated performing thermal testing at subsystem level, and spacelab main structure reuse to avoid dedicated acoustic testing on the overall PM. However erious difficulties will remain in performing the EMC test (many COLUMBUS parts will meet for the first time in orbit), interface verifications (the several elements must be properly simulated together with the other external interfaces), maintainability demonstration (man interfaces, airborne support equipment and check-out procedures must be suitably addressed), software validation (complete and represen- tative validation facility will be necessary to offer the opportunity to intervene on the software in real time).

The environmental qualification test campaign will be performed mainly at subsystem/unit level within dedicated subsystem programmes. Significative activities will be:

- Radiator system functional qualification in vacuum with a parametric verification of radiator performance within the LSS ESTEC chamber.
- Active thermal control loop breadboard test in line with similar Spacelab activity performed in AERITALIA (see ref. 4).
- Cabin/Avionic loop functional performance at power using a suitable test bed.

- Latching performance verification of docking/berthing mechanism with SENER provided interface rig including a three dimensions simulation table.

Concerning the PM payloads, they will be installed inside the racks in order to satisfy the PM modularity and on-orbit exchangeability requirements. The PM interface to payload will be verified by means of standard payload simulators, while the payload verification programme will see environmental qualification at equipment and payload level. The various payloads will be installed inside the standard PM racks and then subjected to functional verification, interface test with PM, IST and mission sequence test. A two model philosophy is foreseen for qualification and acceptance activities.

TECHNOLOGICAL DEVELOPMENT

As complement to the main programme activities and to support the new technologies necessary to comply with COLUMBUS requirement, dedicated Preparatory Programmes have already been commissioned by ESA to the european industries and are now in progress. The areas involved are: Thermal Control components and software tools, Power Generation components and EMC mathematical model, Energy Storage batteries and rotors, Attitude and Orbit Control design, Communication High data rate terminal, Structure meteoroid protections and seals/welding, Environment & Life Support components, Power Management Switches, Data Management optical fibre devices, Rendez-vous and Docking operation test bed, In-orbit Propulsion engine and plume dynamic interactions, Robotics, Telemanipulation test bed and servicing interfaces. Within the PM oriented technological development AERITALIA is involved as described herein.

METEOROID/DEBRIS PROTECTION

The reason for the technology improvement is that the impact of meteoroids and space debris on primary structure could produce puncture and consequent depressurization. The environment specification (see ref.'s 5 and 6) and the COLUMBUS requirements (see ref. 2 and 3), with the help of previous studies and applications on the subject (see ref. 7 and 8) are pushing towards a solution of dual shield concept especially to cover the range of velocity around 10 km/sec.

The meteoroid is allowed to perforate the first alluminum shield, there it usually evaporizes, the debris cloud expands and it is stopped by the second shield kevlar-form sandwich plate. The phenomenum has been computer simulated (see ref. 9) and confirmed by a series of test that AERITALIA is performing at the Ernst-Mach Institut of Freiburg investigation different parametric condition of meteoroid diameter, impact speed and protection configuration. Figure 5 shows the computer simulation and the hypervelocity impact facility used.

MODULE SEALING AND WELDING

The reason for the technology support programme for seals and welding are respectively: to minimize maintenance and improve Spacelab joint reliability in relation to the uncertainty about sealing material behaviour in space environment for indefinite life, to improve welding quality and minimize joint distortion and residual stress in the whole assembly. Trade-offs have been performed between several solutions to improve Spacelab joints and the result suggested a minimization of the number of joints (welding almost all 4 m diameter joints) and, for the remainder using a back-up seal to be inserted in orbit. A specific leakage test will be carried out on a 4 m diameter seal to demonstrate that the concept is working and that the amount of leakage during the seal substitution (1 m^3 of module air) will be an acceptable leak.

The welding process will be improved from the Spacelab TIG method to the Variable Polarity Plasma are one. The variable polarity approach will have the advantage of cleaning the welding, resulting in a well balanced coupling. The process is now under investigation (cooling system, support hardware, etc.) and will be completed by performing static and fracture mechanics tests on samples. Figure 6 shows the proposed welding set-up.

HYBRID RADIATOR

The standard fluid radiator (i.e. TDM/EURECA concept, see ref. 10) would imply high maintenance activity with increased risk of contamination in case of perforation due to high freon leakage. The standard heat pipe radiator (i.e. OLYMPUS concept, see ref. 11 are not adequate in terms of heat rejection capability). For this reason a hybrid radiator concept is required allowing autonomous heat dissipation (essential in MTFF mode) with high life and minimum maintenance.

The hybrid radiator proposed design consists of heat pipe assemblies coupled to a liquid, or two phase loop heat exchanger which interfaces with a central heat transportation system. Micrometeoroid protection is also included (see figure 7). Qualification testing in the Aerospatiale thermal vacuum chamber is planned, with performance verification during hot, cold, steady state, and transient conditions, at different flow rates and inlet temperatures, including the demonstration of the capability to recover from heat pipe freezing.

CONCLUSIONS AND RECOMMENDATIONS

The PM verification approach has been defined on the basIs of COLUMBUS programme requirements for a manned space station permanently present in space. Starting from the Spacelab qualification status a two system models philosophy has been established with functional qualification on EM and flight acceptance on FM. Subsystem/Unit development and qualification test campaigns will be performed on dedicated hardware including major environmental tests. Pre-development support programmes in the new technology areas offer the availability of early results.

The B2 phase activities which are starting now will refine the technical content of the design together with the operations and verification philosophies in view of the starting of C/D phase presently planned for January 1988. The major areas to be furtherly investigated are the development and qualification activities at subsystem/unit level on which the impact of new technologies and risk assessment is direct. Particular care will be devoted to investigate the following:

- telescopic flexible fluid lines for Docking mechanisms
- leak detection and isolation within the active loop
- cabin pressure regulator, CO_2 storage, hand wash and microbial control equipment of Environmental subsystem
- ORU connectors and high power gauges crimp joints
- computer chips, magnetic and optical disks, space qualified comale, within the Data Management hardware
- communication interface requirements.

In summary, the COLUMBUS PM is being engineered to make best use of Spacelab hardware/experience, allowing experimenters to reuse their Spacelab equipment with minimum changes. On the other hand, total system requirements dictated by the U.S. Space Station and the long term European scenarios is being incorporated. Both aspects will be achieved within a tight development budget, with the aim being to minimize operational and verification costs.

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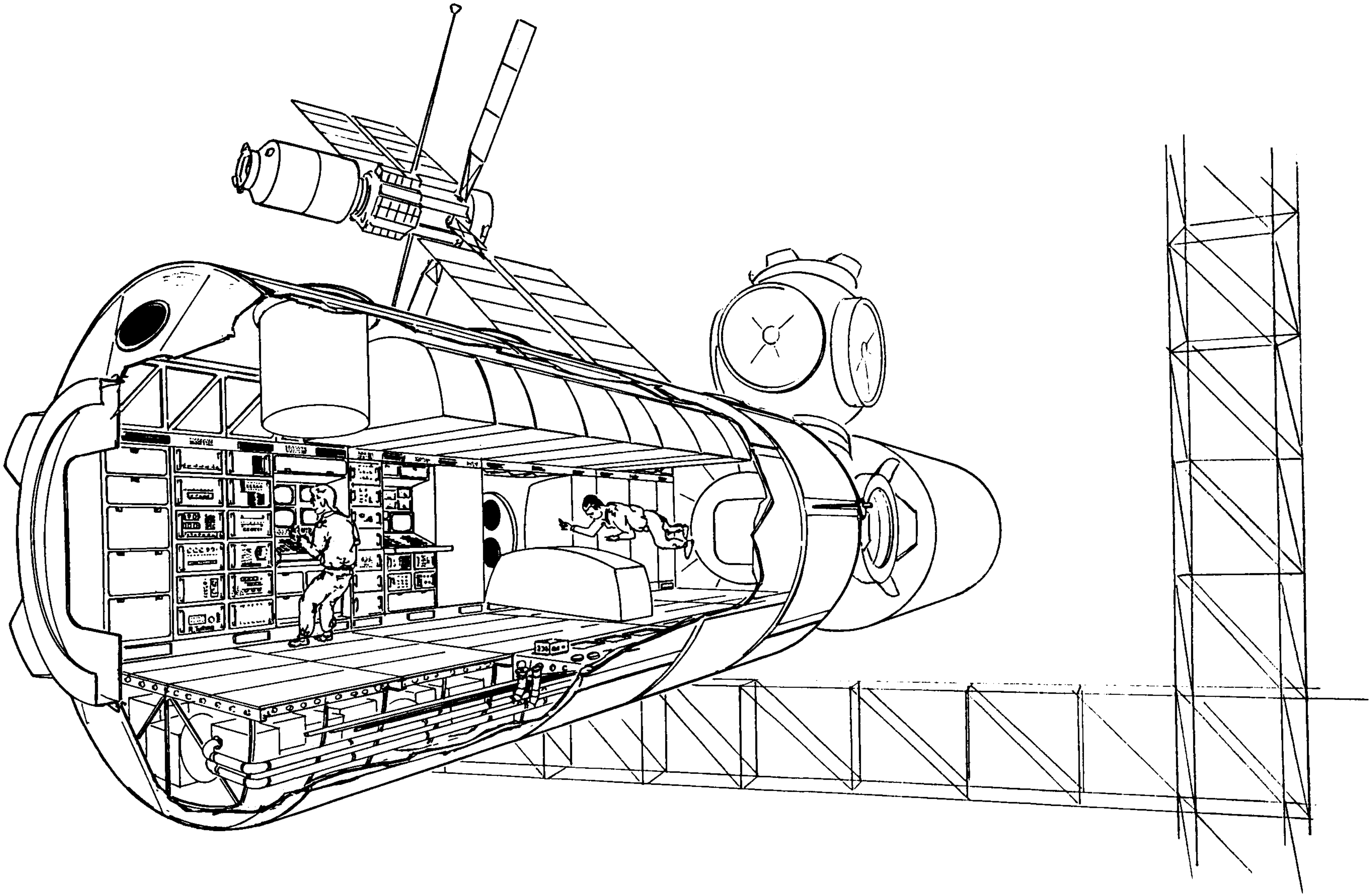

Figure 1. Pressurized module and columbus scenario

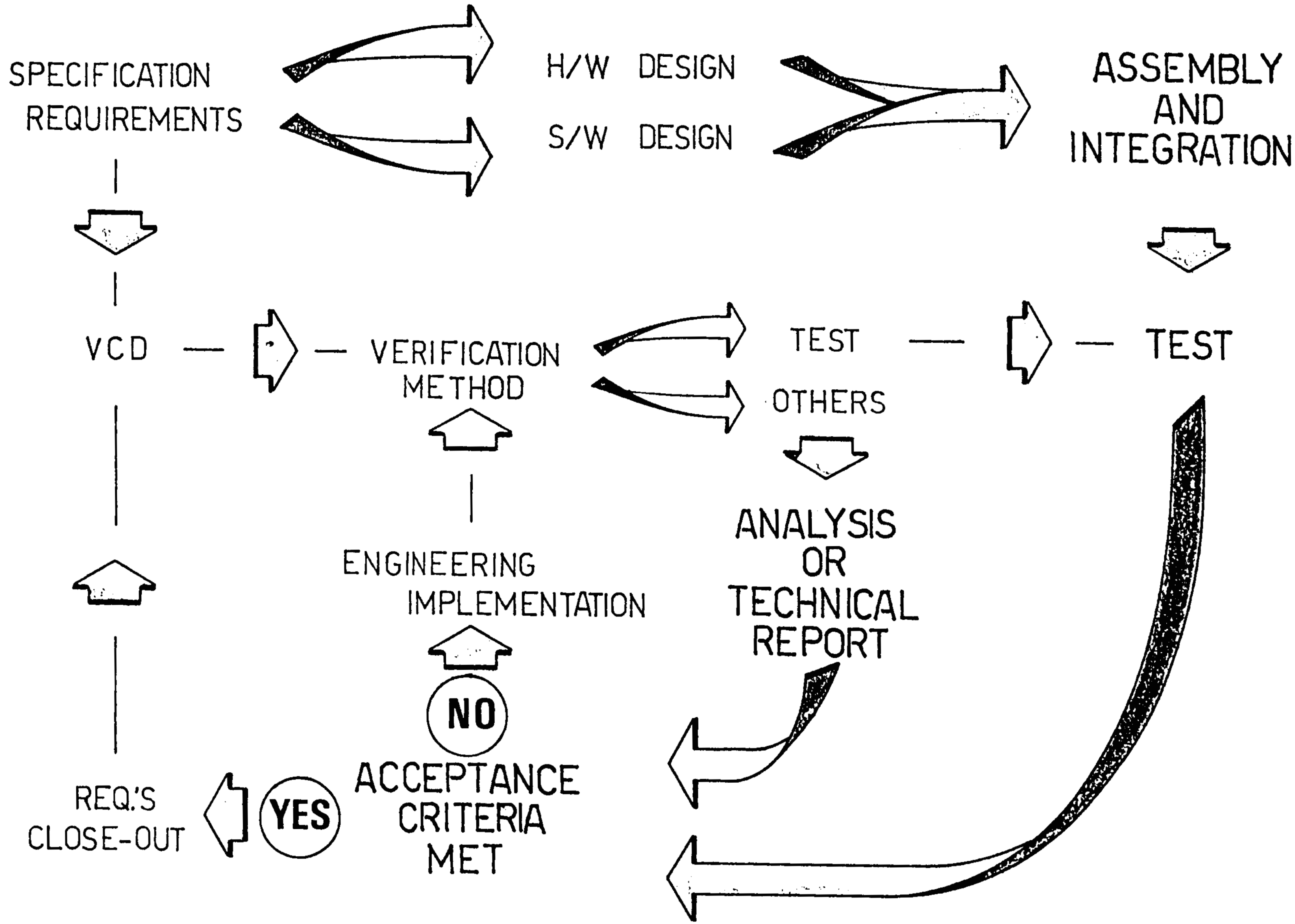

Figure 2. Verification logic

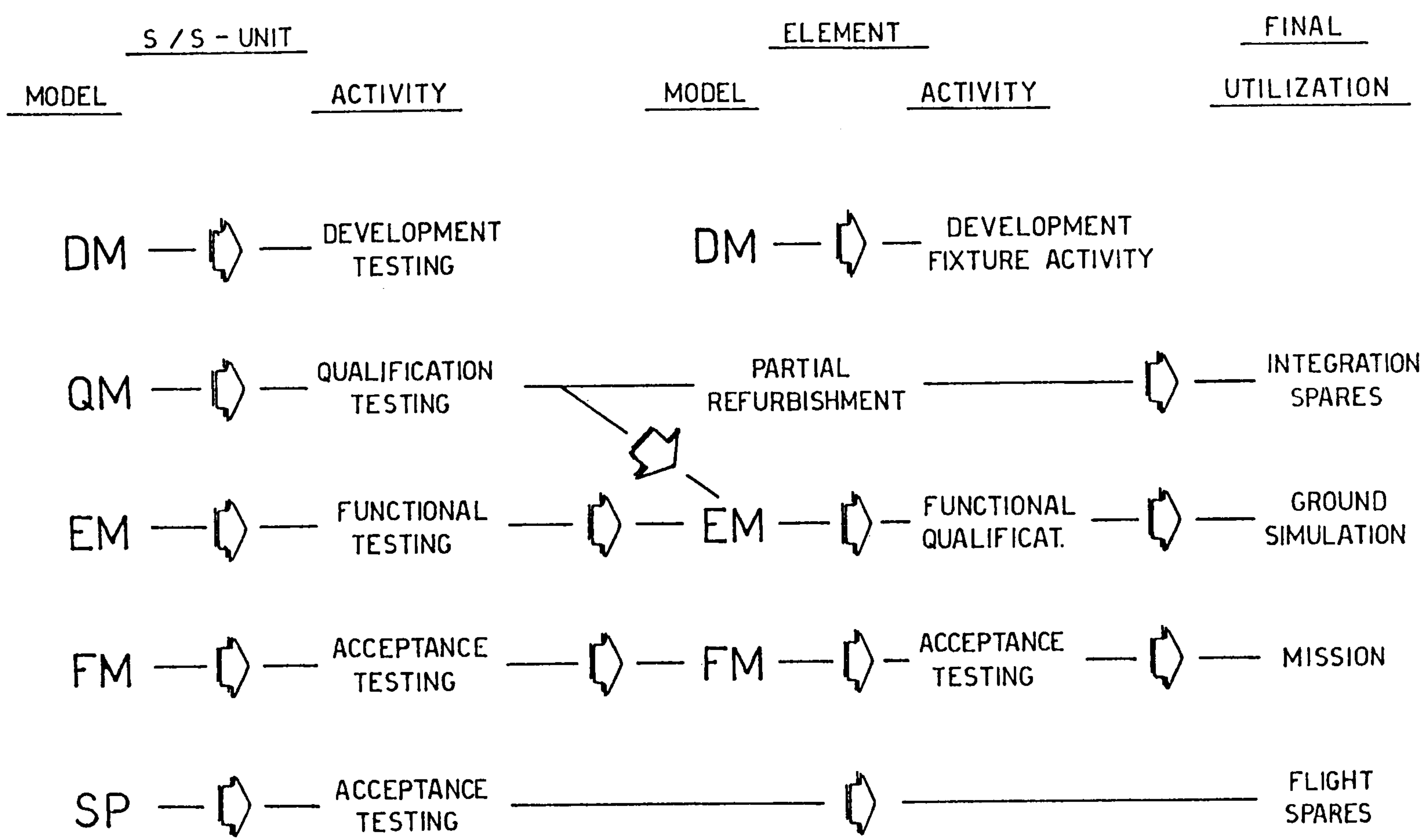

Figure 3. Proposed model philosophy

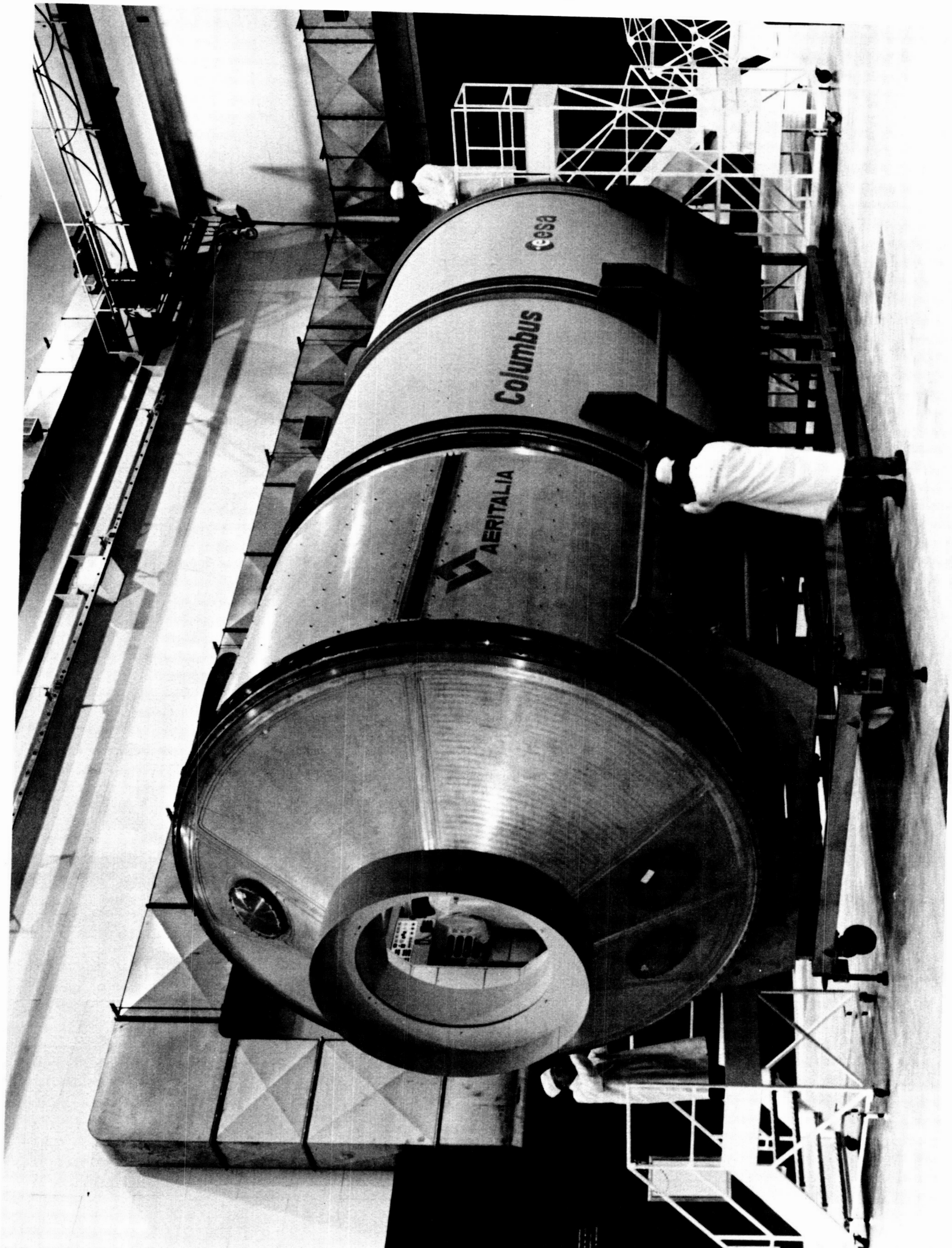

Figure 4. PM phase B1 mock up

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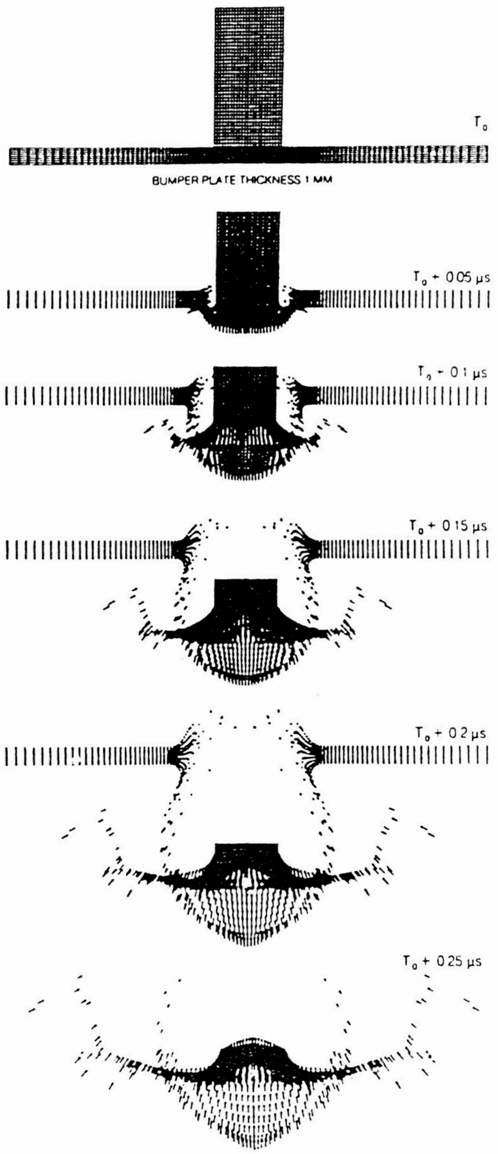

Perforation sequence (velocity vectors) predicted by the Lagrangian code (HEMP/ /ESI) for a foamed silica meteoroid (4 mm in diameter, 100 mg in weight) impacting on an aluminum alloy bumper shield at 68 km/sec

Impact vacum facility, having gun gas hydrogen, (for projectiles caliber 4.5 mm, 100 mg in weight, velocity up 10 km/sec) equipped with two shadow graph stations at X-Ray and optical laser system for velocity measurement. Impact tank reaches a vacum 10^{-7} torr

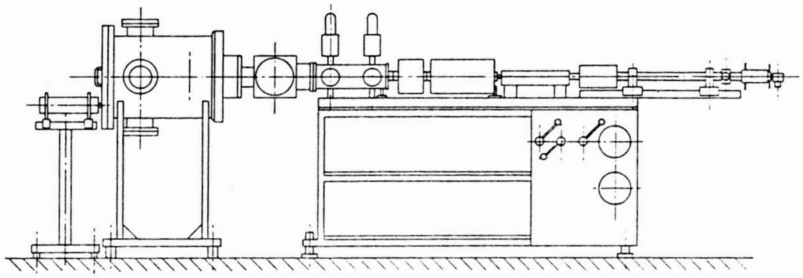

Figure 5. Meteoroid impact computer simulation and test facility

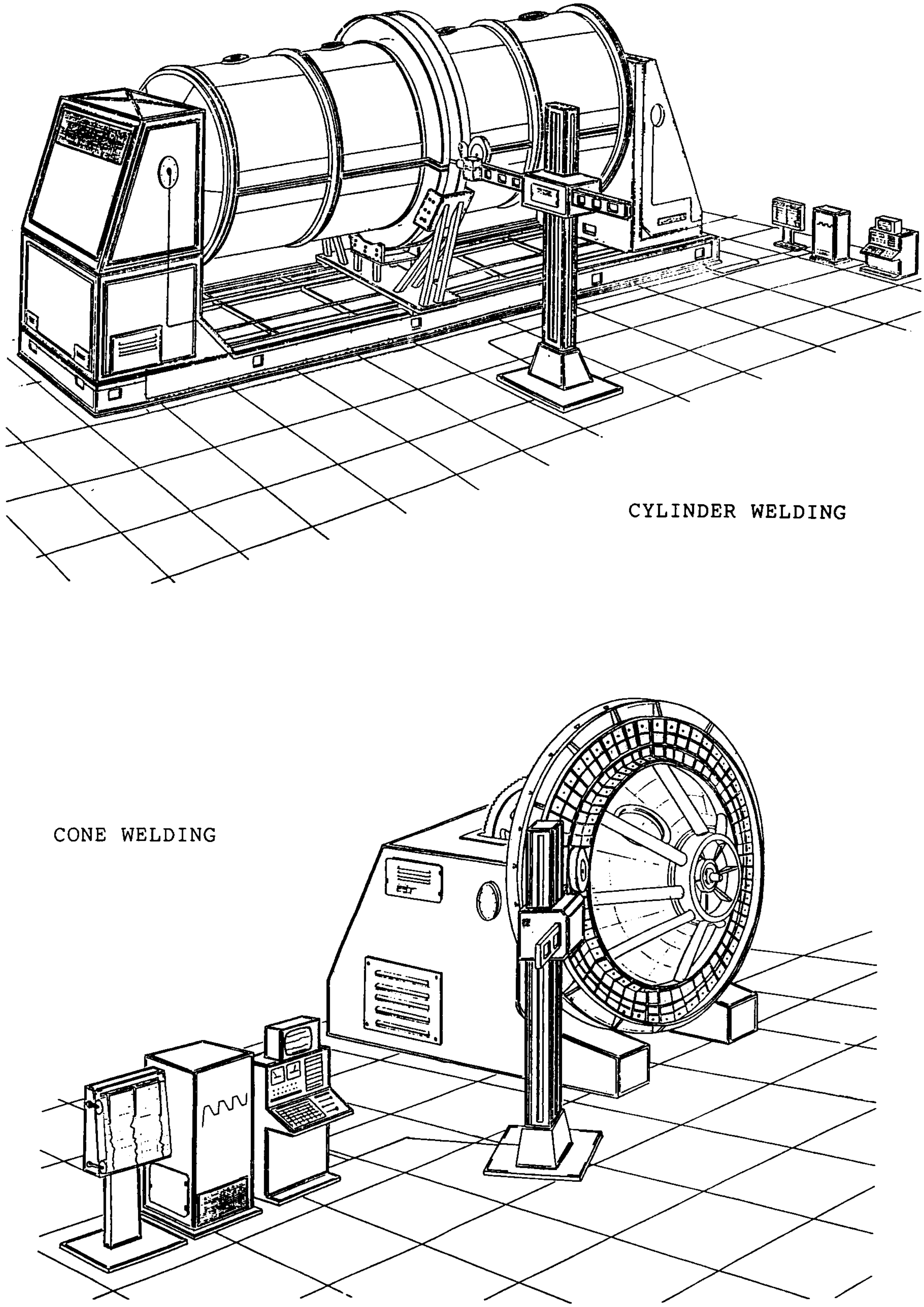

Figure 6. Module welding set-up

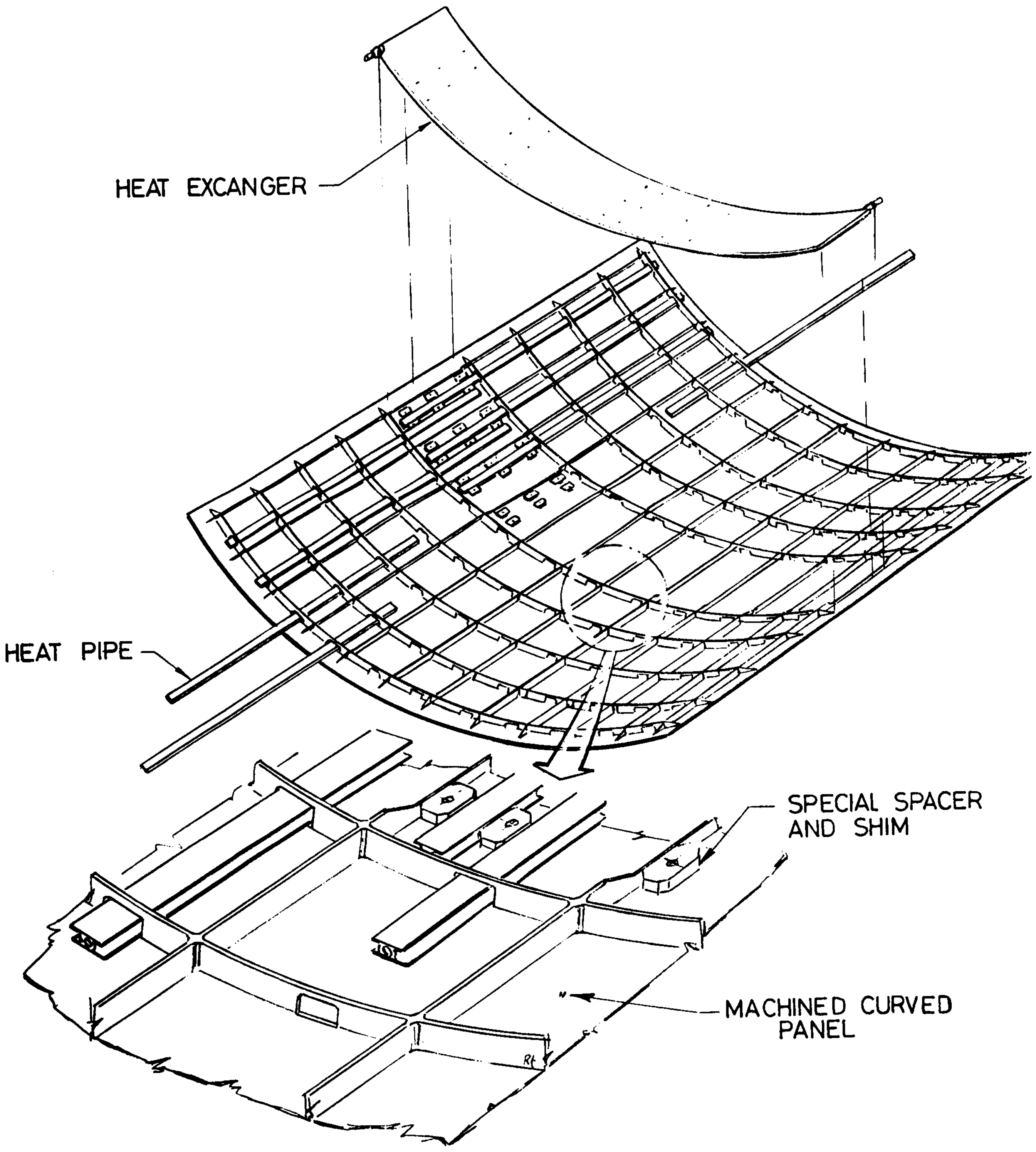

Figure 7. Hybrid radiator concept