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An Inspection of Spacelab Hardware

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European Space Agency
Agence spatiale européenne

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A report on
visual inspection of Spacelab hardware
at NASA's Kennedy Space Center

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Summary

Spacelab has been one of the European Space Agency's most important long-term projects and is a major contribution to the US Space Shuttle programme. All of its storage, launch and mission activities are controlled by NASA. The hardware was manufactured in Europe and qualified by ESA more than 15 years ago. Two ESA staff members who had participated in the Spacelab development activities during the 1970's and 80's have now re-inspected much of the hardware (stored at NASA-KSC) and formally discussed materials and processes problems with long-term NASA and MDAC personnel. This report summarises their finding and contains a pictorial record of inspected items which should be of interest to forthcoming projects such as the International Space Station.

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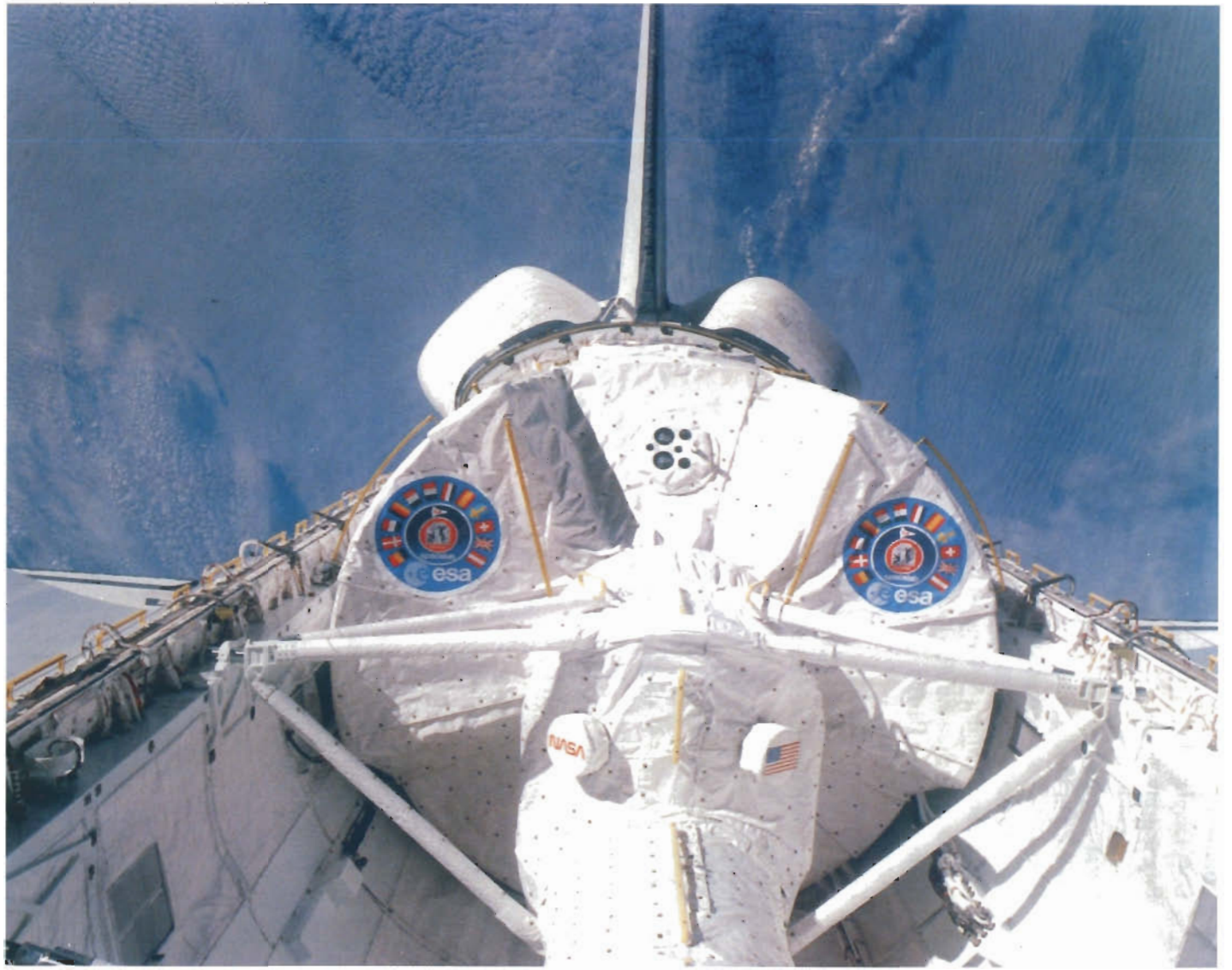
Abbreviations

AA	Aluminium alloy
C/D	Development and production phases of a project
CHX	Condensate Heat Exchanger
COF	Columbus Orbital Facility
DDU	Data Display Unit
EM	Engineering Model
EPDB	Electrical Power Distribution Box
EVA	Extra Vehicular Activity
FOP	Follow On Production
HDRR	High Data Rate Recorder
IML	International Microgravity Laboratory
IPS	Instrument Pointing System
ISPR	International Standard Payload rack
KSC	Kennedy Space Center
LEO	Low Earth Orbit
LRU	Line Replacement Unit
LMS	Life and Microgravity Sciences
MDAC	McDonnell Douglas Astronautics Company (until December 1988)
MGSE	Mechanical Ground Support Equipment
MLI	Multi-layer Insulation
MMU	Mass Memory Unit
MPRV	Module Pressure Relief Valve
MSFC	Marshall Space Flight Center
MSL	Materials Science Laboratory
O&C	Operations and Checkout
OFT	Orbital Flight Test
PCB	Power Control Box
PTFE	Polytetrafluoroethylene
RTV	Room Temperature Vulcanising
SCC	Stress Corrosion Crack (testing)
SLS	Spacelab Life Sciences
SPDB	System Power Distribution Box
STS	Space Transportation System
TIG	Tungsten Inert Gas



Spacelab 1 in the hold of the Space Shuttle

1. Introduction

Spacelab hardware was manufactured in the late 1970's and early 1980's, with design requirements of a lifetime of at least 10 years and 50 missions of approximately 7 days duration. It is now more than 15 years since the first hardware was delivered to the NASA-Kennedy Space Center (KSC) for the Orbital Flight Test (OFT) missions which utilised the Engineering Model (EM) Pallets EM 02 and EM 03. The first flight version of Spacelab was delivered on 5th February 1982, its maiden flight being in November 1983. Later deliveries of the IPS (Instrument Pointing System), the Igloo, Spacelab 2 Phase C/D and Follow on Production (FOP) systems and spares completed the inventory of the ESA-supplied hardware by 1985.

The present condition of the Spacelab hardware is a significant source of information for checking the adequacy of the qualification procedures and processes that were used to achieve the 10 year life requirement. The recent visit to inspect the various Spacelab hardware items visually and to discuss possible materials and process problems, with long-term NASA personnel who had been associated with the day-to-day use and operation of the hardware, proved to be extremely useful. It also helped to justify the choice of the same materials and processes for the construction of the Columbus Orbital Facility (COF) as well as for other future ESA projects. NASA-KSC engineers welcomed the proposal that ESA representatives should visit their facilities and made the Spacelab hardware, located in the Operations and Checkout (O&C) Building, available for viewing and inspection.

2. Objective

In addition to confirming the efficacy of the qualification, the objective of the inspection was to identify problems which had been experienced and which can be fed back into future ESA tasks, to improve performance. The hardware characteristics which were considered significant were: corrosion resistance, thermal protection, physical degradation, ageing and contamination.

Annex 1 lists the characteristics and topics discussed during the visit to KSC. The ESA participants, a project Quality Engineer and a Metallurgist, are familiar with the early Spacelab developments in Europe.

3. Method

NASA, with the support of its Spacelab processing contractor McDonnell Douglas Astronautics Company (MDAC), provided a forum of engineers and technicians (see Annex 2) with experience covering the lifetime of the Spacelab utilisation. Each item in Annex 1 was discussed in detail and comments, observations and where warranted constructive criticism, were made in very open and productive meetings. An overview of the various Spacelab hardware assignments and the STS-Orbiter assignments is given in Annexes 3 and 4.

The common sentiment of the NASA and MDAC personnel was that the Spacelab hardware had proved to be of high quality and reliability and that very few significant problems had been experienced since the anomalies on the Spacelab 1 and Spacelab 2 missions and the subsequent NASA replacement of the ESA-supplied computers and Data Display Units (DDU's) with more modern equipment. Such information was very encouraging and welcome, but as the main objective was to identify lessons that may be learned from the 17 years of Spacelab processing, emphasis was placed on negative aspects of performance.

The discussions were followed by extensive viewing of the hardware and by inspection and photography of items considered to be of interest.

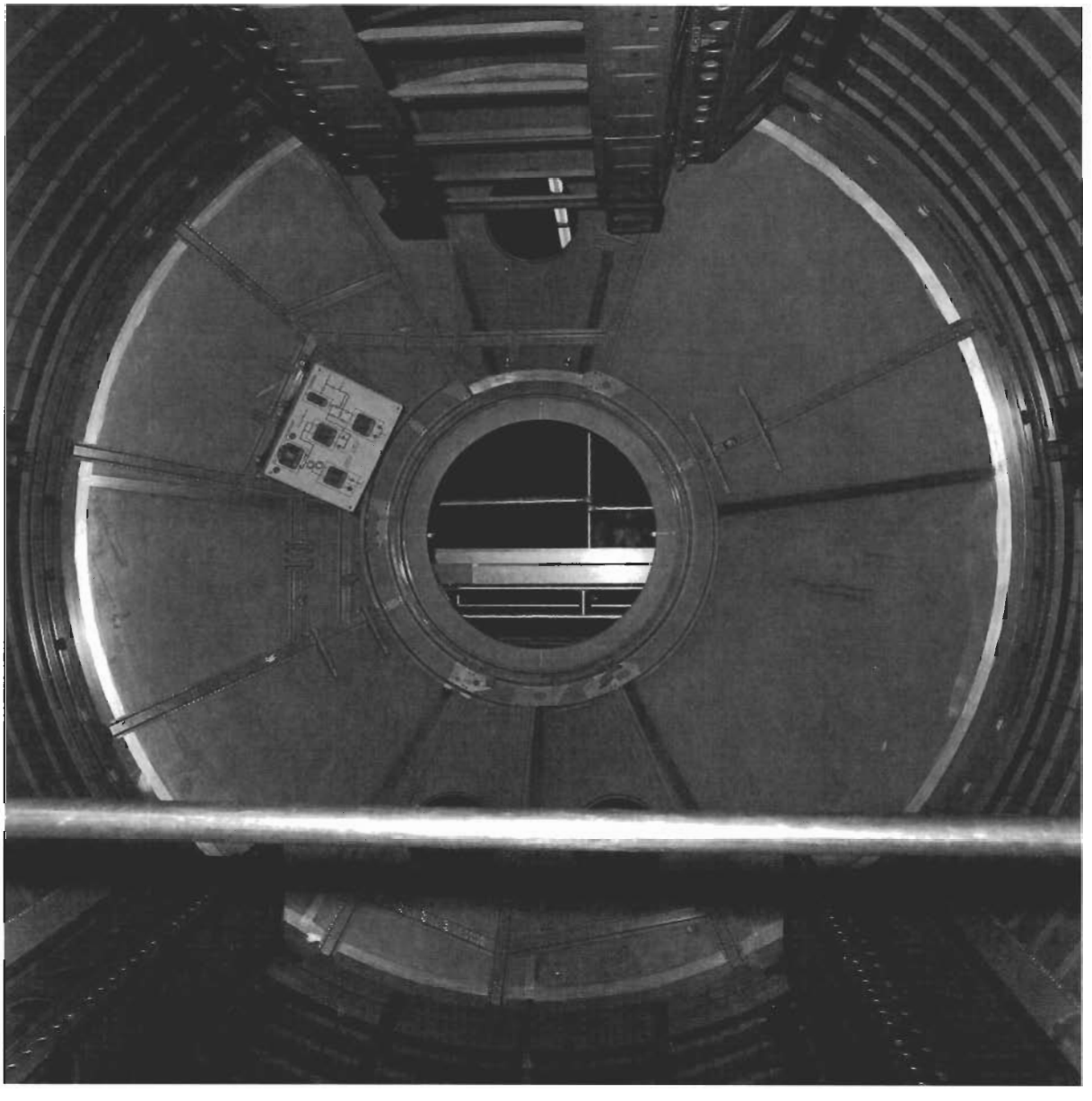


Fig. 1: Partial construction of a Spacelab module in Europe during 1979.
TIG Welding processes were used to weld panels and rings.
Base material is AA 2219-T851 (plates and forged rings).
Filler metal is AA 2319.

4. Findings

4.1. Surface Protection Treatments for AA 2219

4.1.1. Brief History

The selection of a main structural alloy for the European Space Agency (ESA) Spacelab project was made in the mid-1970's. The choice of aluminium alloy 2219 was based on the need for a material having an optimum combination of mechanical strength, fracture toughness and resistance to general corrosion and stress-corrosion cracking. An extensive programme for the qualification of the Spacelab surface protection treatments was undertaken on sheet, plate and forged rings that had been both chemically milled and TIG welded. The qualification test samples were made with the processes, heat-treatments and finishes that would be later used to fabricate the first Spacelab module (see Figures 1 to 3).

The waffle structures and general flat surfaces were chromic acid anodised. The TIG welds were ground, polished and brush Alodined. Large numbers of anodised waffle structures and welded plates finished with Alodine 1200 were subjected to salt spray testing for up to 4 weeks (672 hours). It had been proposed that a two-week (336 hours) exposure would represent the required 10 year Spacelab life. Whereas the anodised samples exhibited a good resistance to corrosion during the four-week exposure to salt spray, the Alodined surfaces showed general surface and crevice corrosion, in the weld heat affected zones, after an exposure of only 7 days. Further salt spray tests demonstrated that the Alodine finish could be "restored" periodically, but that if it was painted with Cuvertin 001 (clear varnish), corrosion could be prevented. Extensive stress corrosion crack (SCC) testing was also performed to standard procedures that had been agreed with NASA/MSFC. Plates, weldments and sections cut from four-metre-diameter ring forgings, were SCC tested and found to have a high resistance to SCC (even when tested in the short transverse direction, at a constant load of 75% of the alloy's yield strength for a period of 30 days). Accounts of these test programmes are given in [1].

4.1.2. Corrosion of Anodised and Alodined Processed Surfaces

Inspection of the Spacelab module in February 1997, under good lighting conditions and using an eyeglass with a times-7 magnification, confirmed that the surface treatments have been extremely effective as no evidence of corrosion was detected on the structural parts. The brush Alodined surfaces of the module welds showed no deterioration (see Figures 4 and 5). Similarly, none of the anodised surfaces showed any degradation or corrosion.

The only identified corrosion occurred on the flight-spare condensate heat exchanger. No problem report was available but photographs were provided (see Figures 6 and 7) and indicated that the corrosion was initiated by residual salt flux from the dip brazing fabrication process. These fluxes are composed of mixed salts (e.g. sodium chloride 23.0%, potassium chloride 47.5%, lithium chloride 24.7% and remainder sodium fluoride). The brazing operation is performed at 600°C when the salt is molten. On cooling to room temperature, all residual flux must be removed. The cleaning operation can be monitored by a silver nitrate test to ensure contamination-free flight equipment [2].

4.2. Water Condensation

Concern had been raised that the condensation of water vapour on to cold surfaces during flight operation might have introduced corrosion. Extensive inspections were made of racks, the module walls and beneath the module floor (e.g. Figure 8). No evidence of corrosion or staining was observed.

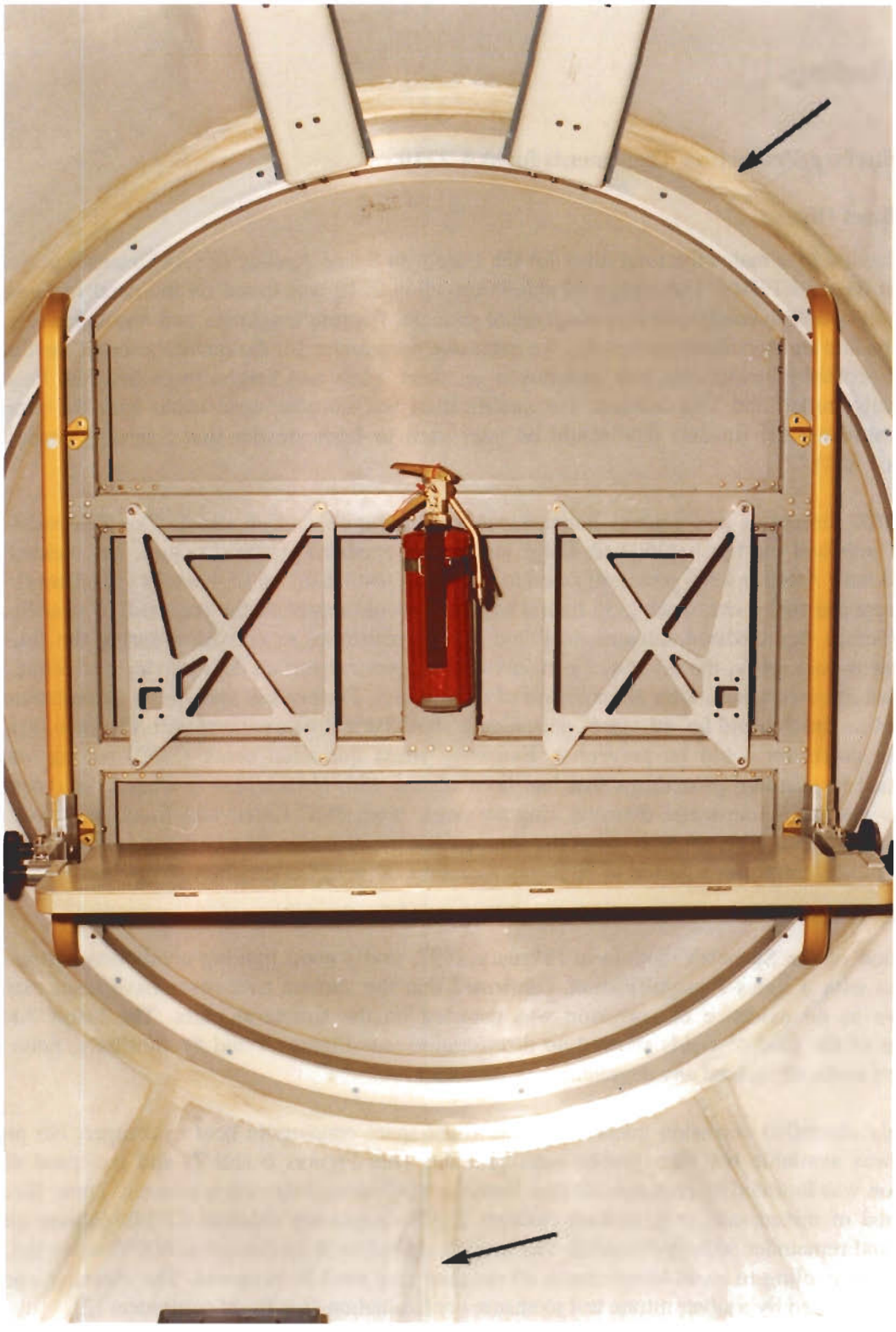


Fig. 2: Aft end cone, showing the fire extinguisher, hand rails and foot support.

All panels are chromic acid anodised.

All welds are ground, polished and brush alodined, as indicated by the arrows.

(1979 photograph)

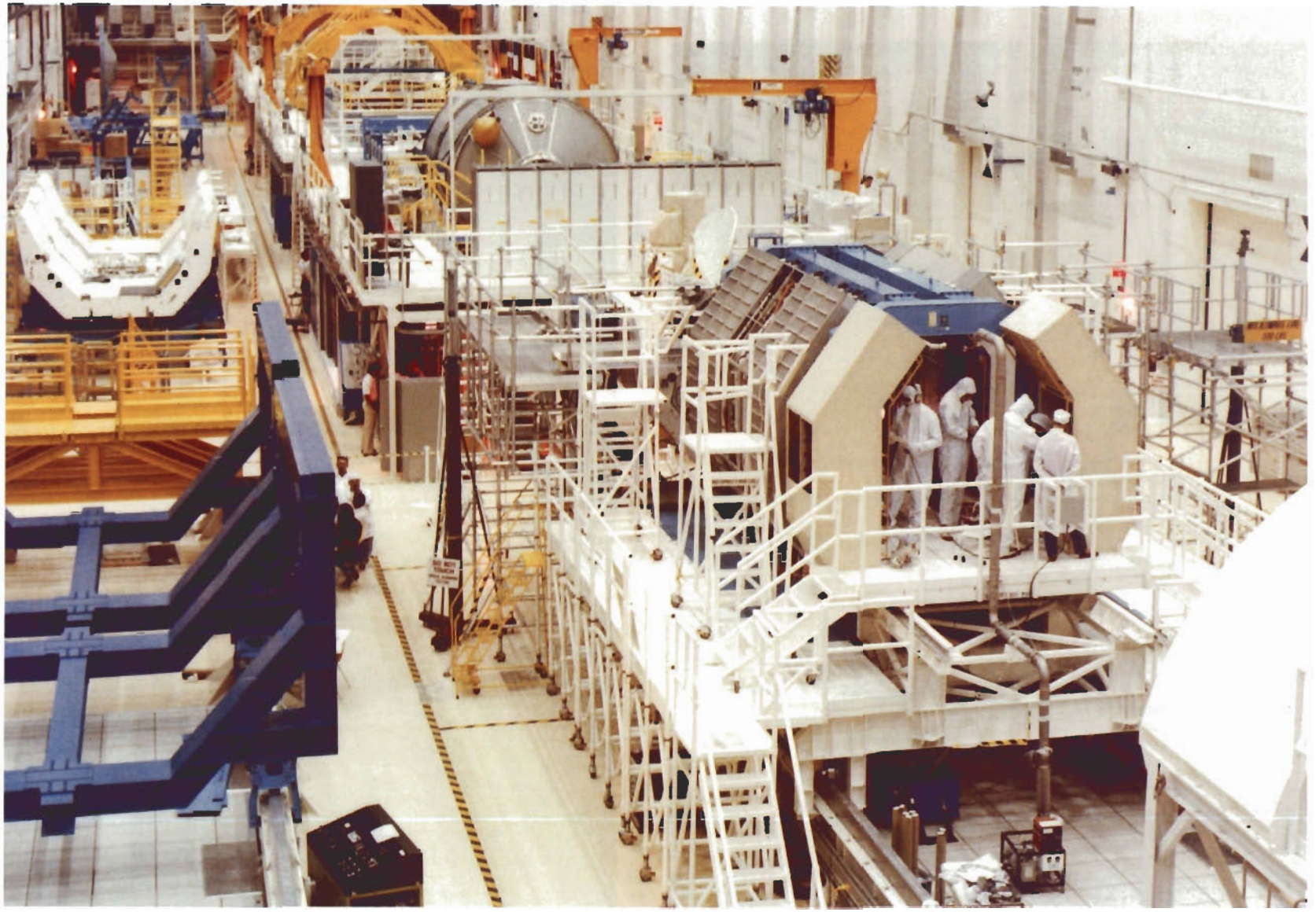


Fig. 3: General view of the Spacelab processing area in the O and C building at KSC during 1982

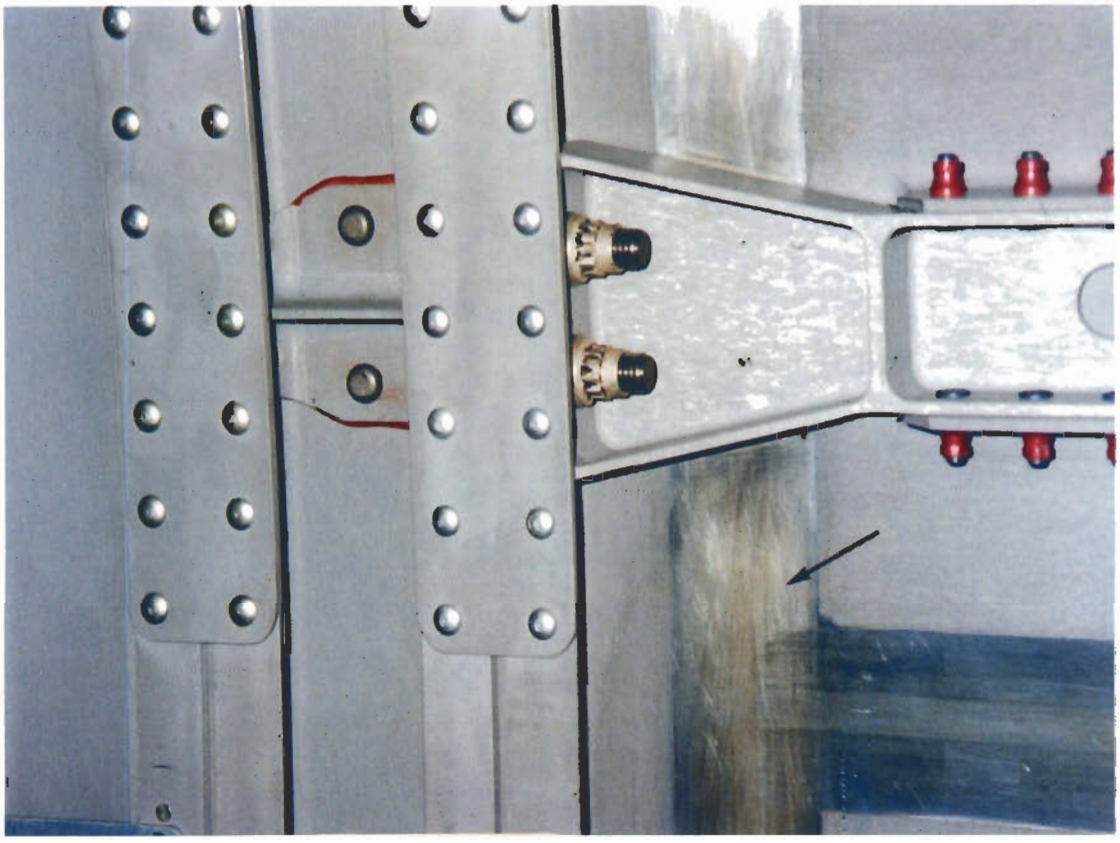


Fig. 4: Brush alodined weldment (arrowed) in 1997, showing no evidence of corrosion.

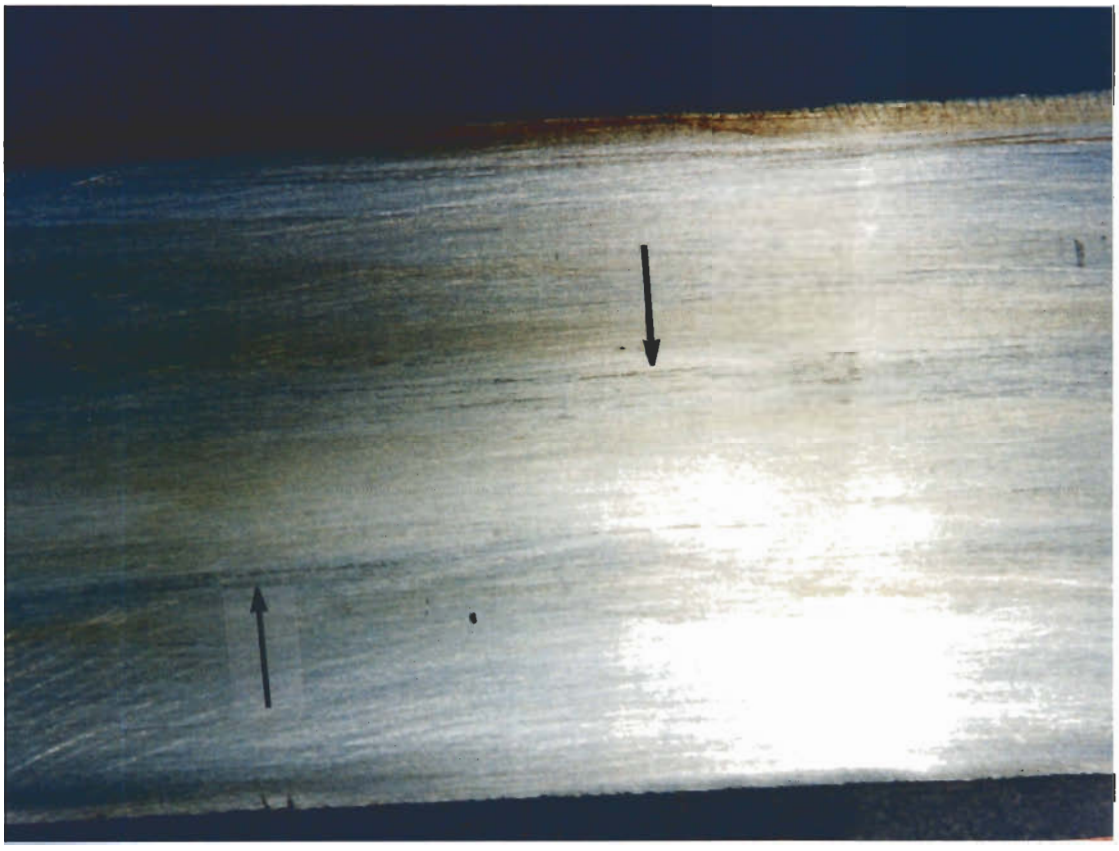


Fig. 5: Macro-photograph of 20 mm wide "weld zone" between anodised panels.

After extensive inspection of many metres of weld length,
only this small region was found to suffer from lines of tarnish (arrowed).
They were not associated with any corrosion products and appear to have no depth.

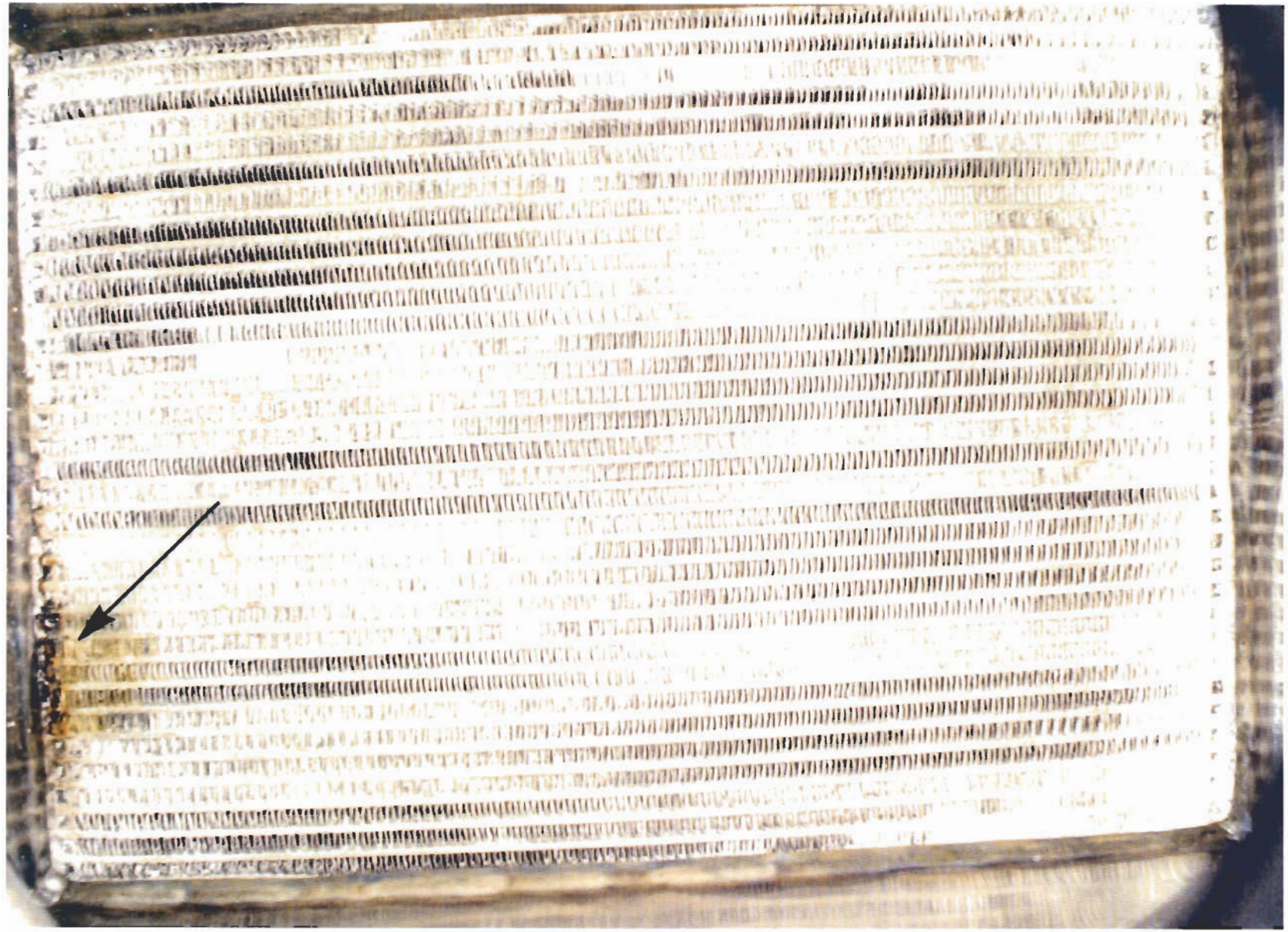


Fig. 6: General view of heat exchanger and the left-hand region of corrosion.

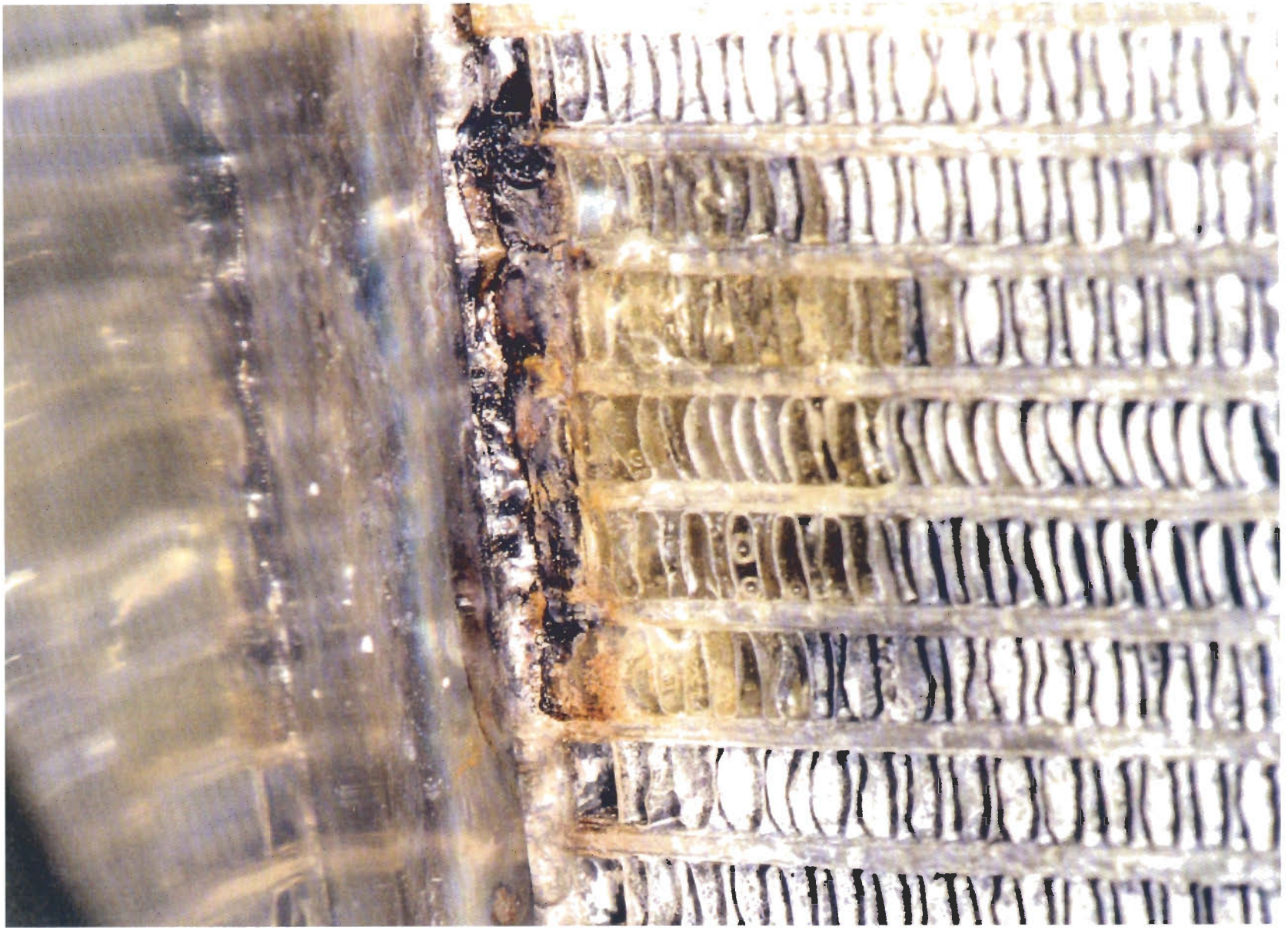
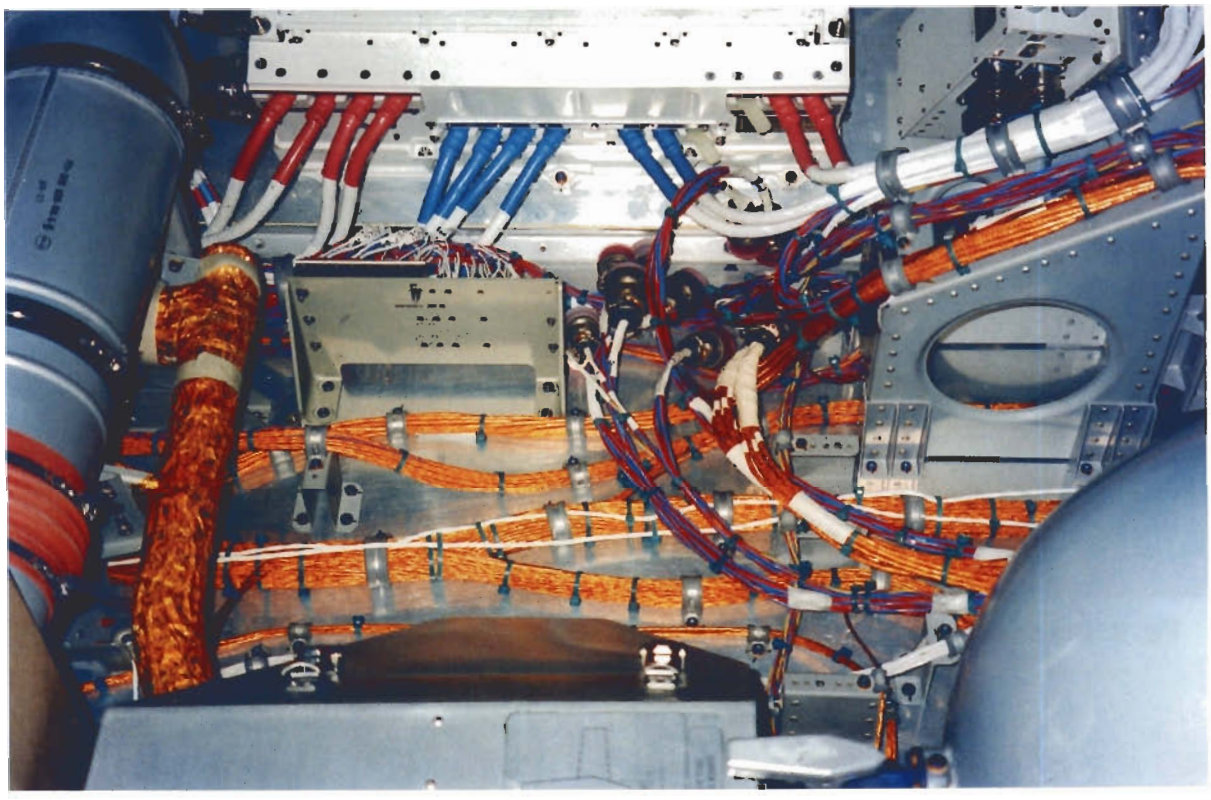


Fig. 7:The corroded aluminium and brown corrosion product appear to result from flux residues.



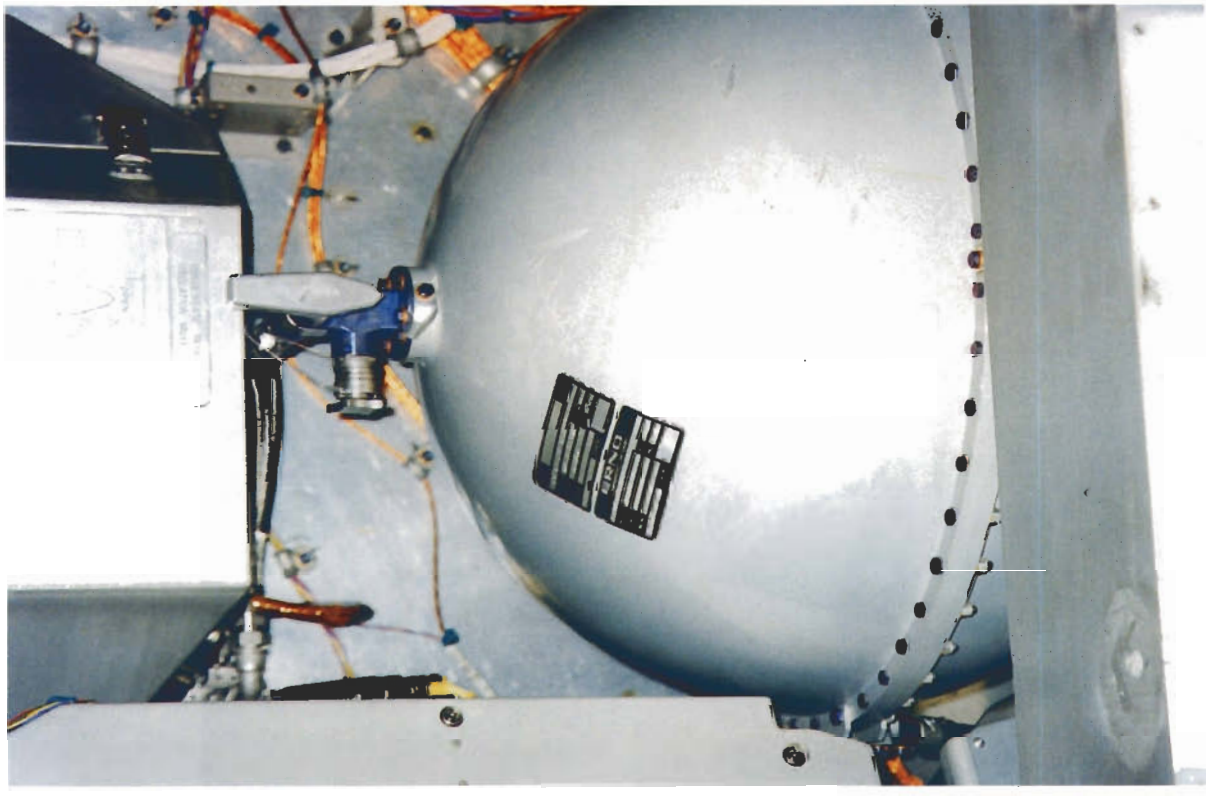


Fig. 8: Units and cable bundles situated beneath the module floor in the vicinity of the condensate tank.

All surfaces were noted to be clean and bright, with no evidence of staining.

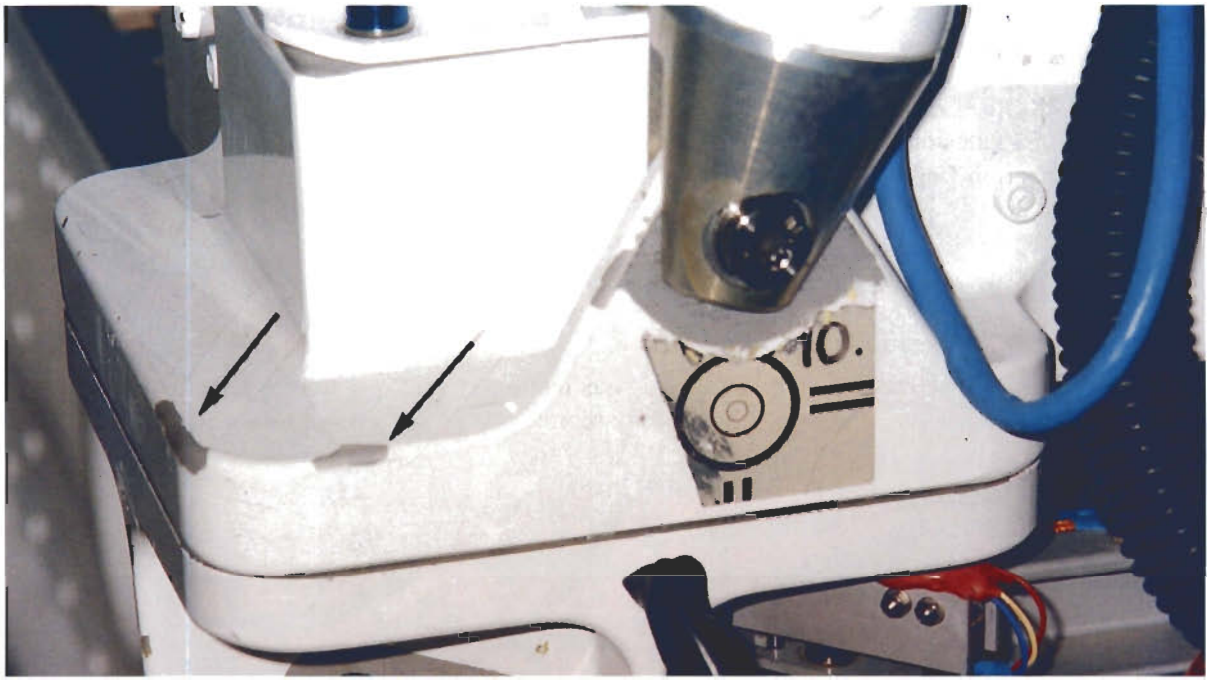


Fig. 9: Detail, showing some small areas of paint that were removed from rounded corners during ground handling operations

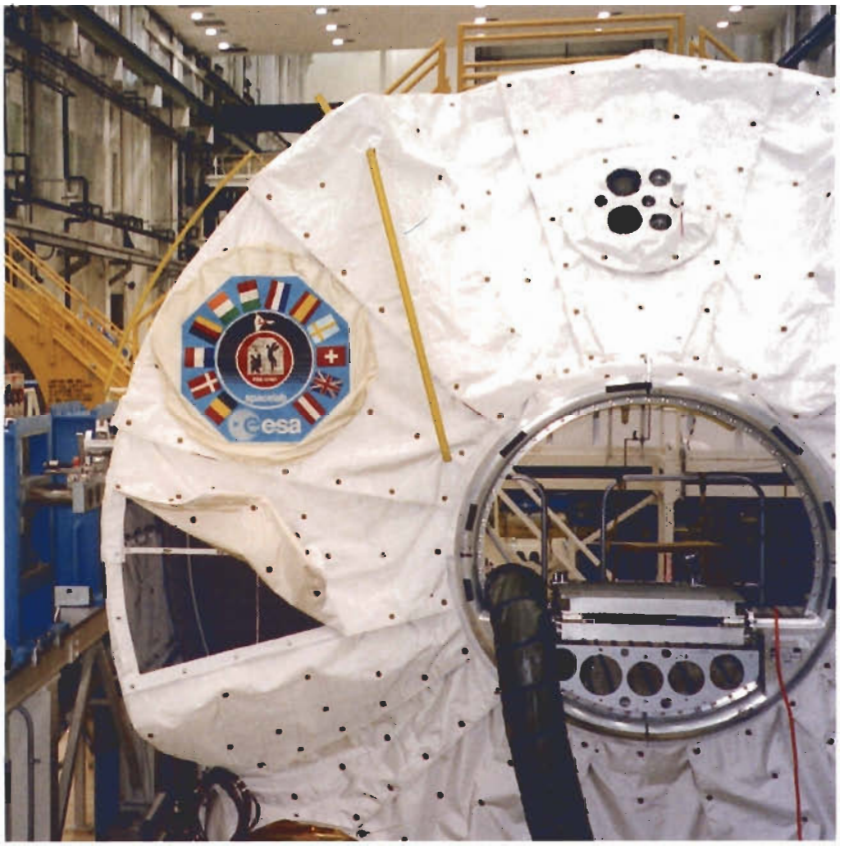


Fig. 10: Solar blankets appear undamaged.

There is only a slight darkening of the cloth surrounding the ESA emblem. None of the colours has degraded (cf. new cloth during flight -page 8).

4.3. Painted Surfaces and Optical Properties

Paint peeling, flaking or degradation of optical properties had not been experienced on flight standard hardware (although some rework painting of the EM OFT Pallets was necessary prior to flight). The Chemglaze paint adhesion was generally excellent and only one region of paint detachment was seen during the inspection (see Figure 9). This occurred at the corner of a pallet part and was attributed to handling activities. However it was mentioned that when an element returned from orbit there was a barely discernible bluish hue on the thermal blankets, but after a few days the blankets returned to their normal appearance.

Measurements of the optical properties of the blankets (Figure 10) always gave values within the acceptable range. Chemglaze paint on the pallets was reported to show a similar phenomenon. Some investigators consider that these visual effects are related to very minute amounts of silicone contamination which became modified by exposure to ultra violet radiation and atomic oxygen in orbit [3].

4.4. Mechanical Damage to Thermal Protection Systems

4.4.1. Thermal Blankets

Thermal blanket degradation, caused by wear and handling problems had occurred. It was concluded that handling damage was much more significant than degradation caused by exposure of these blankets to the orbit environment. The inner layer of all thermal blankets had been replaced by Nomex because of splitting and tearing of the original material (see Figures 11 and 12). Blankets with small bend radii were most susceptible to damage.

NASA logos are now painted directly on to Nomex cloth because less colour degradation is experienced.

Recent NASA servicing of the Hubble Space Telescope found increased thermal blanket degradation that is considered to be caused by long exposure to radiation.

4.4.2. Handling Problems

The blanket attachment devices caused problems that were relatively easy to resolve on ground but much more difficult to correct in orbit during the crew's extra vehicular activity (EVA). The blankets are held in place by plastic spigots with ball ends (poppets) which pass through eyelets in the blankets. The poppets snap into split stainless steel tubular retainers which are bonded to the exterior surface of the structure (see Figure 13). On mounting the blankets, difficulties may be experienced inserting the poppets into the retainers, resulting in a sector of the retainer bending over, thereby preventing proper insertion before a repair is performed. On occasions the friction in the retainer has caused the spigot to break, leaving the poppet lodged in the retainer. Once again, a repair in orbit may prove very difficult (see Figure 14).

4.5. Interface Problems

4.5.1. Wear and Friction on Trunnions and Mounting Points

There has been no identified degradation of the bearing surfaces of the ESA-supplied trunnions. A recent investigation of a surface defect on the Main Module Trunnion, Serial No. 001, found that the suspected damage was a deposit of aluminium alloy with trace amounts of hydrocarbon [4]. The source of the deposit was deemed to be the aluminium-rich coating used in the 'J' hooks in the Vertical Processing Facility. Sustained loads on the coating can cause pick-up on the other side of that interface (see Figure 15). Cold-welding and the transfer of aluminium can occur on to the hard chromium-plated trunnion and this metallic contact combination is not desirable (see also [2]). It is

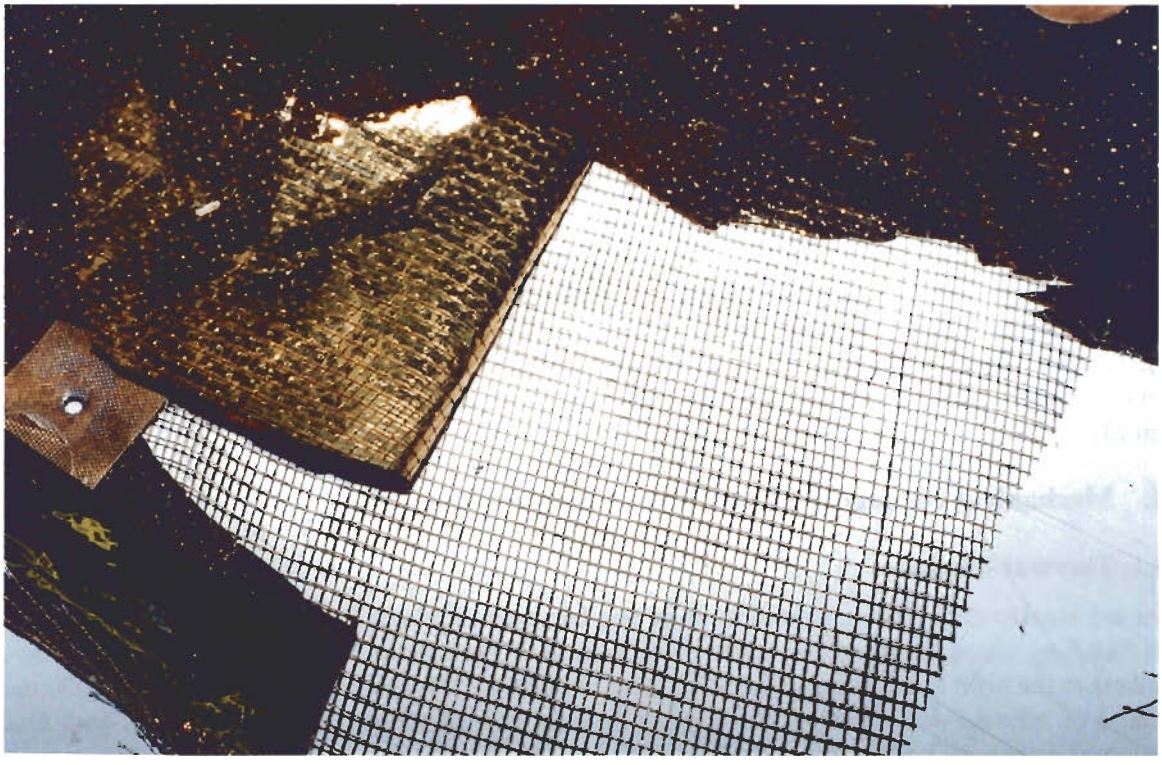


Fig. 11: De-lamination of goldised-Kapton thermal blanket, caused by repeated handling.

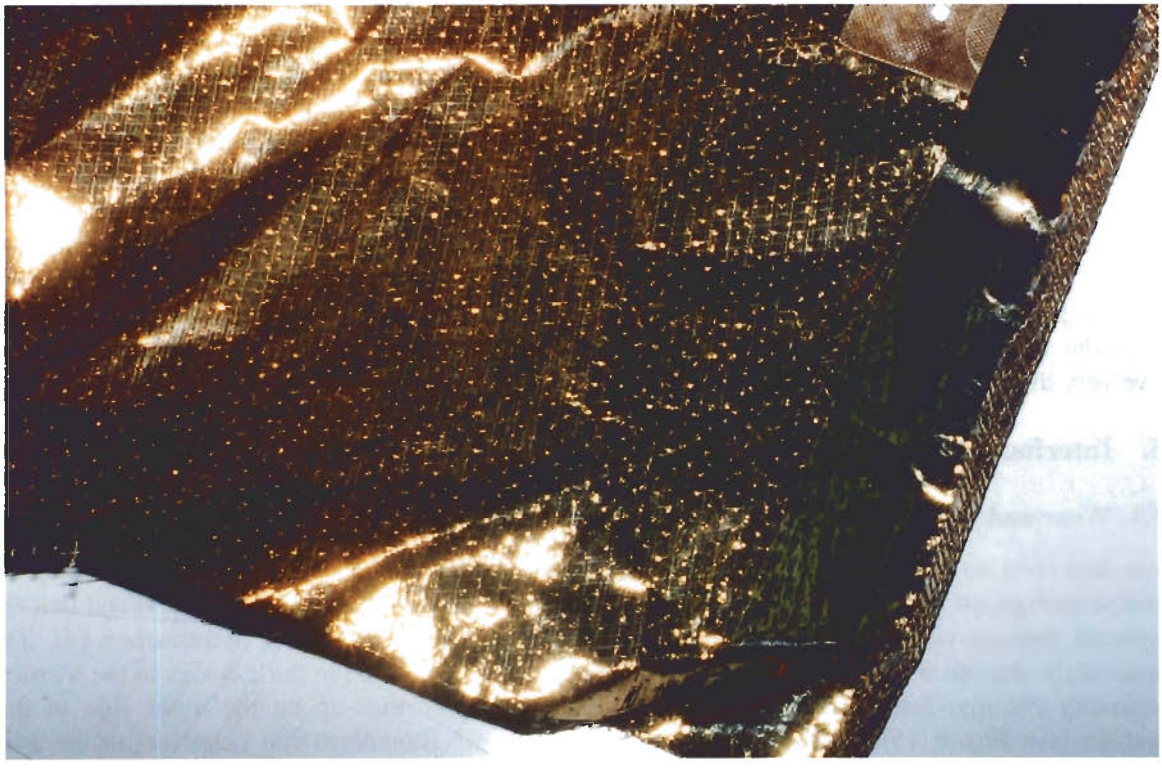


Fig. 12: Although it is hardly noticeable on this photograph, dark "staining" of this area of the goldised film has occurred during operational life.

Fig. 13: Plastic attachment devices for holding blankets.

These are easily de-assembled and the plastic ring shown here can uncontrollably spring away from the retaining groove of the tubular post during flight.

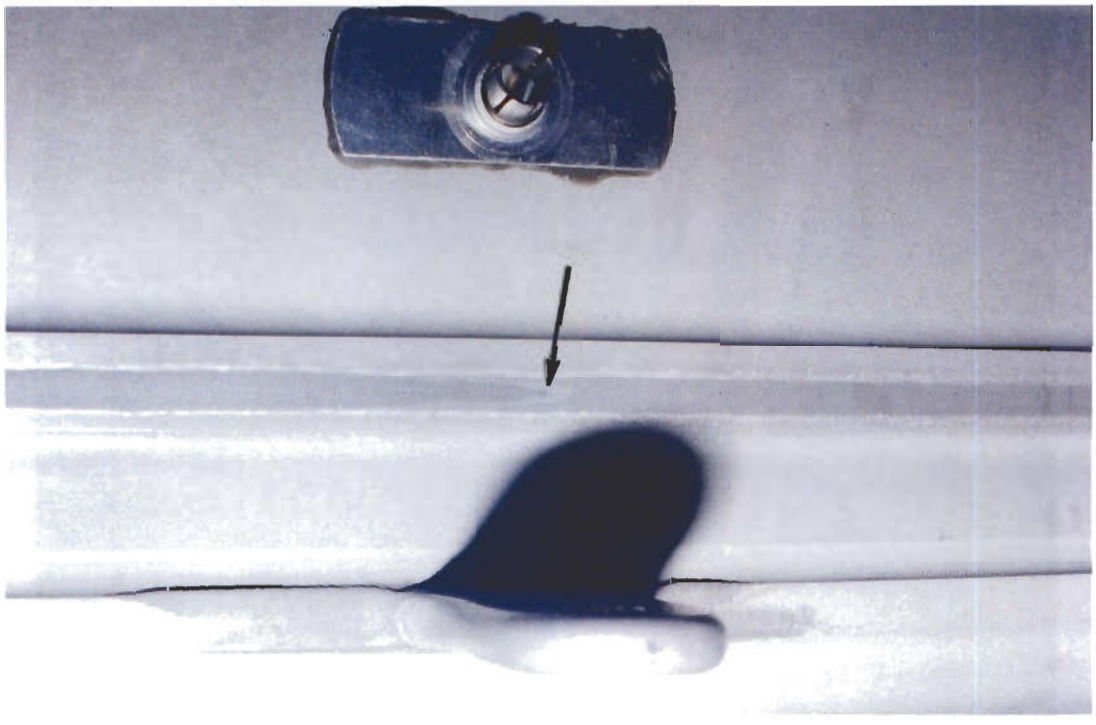


Fig. 14: Stainless steel retainers for thermal blanket attachment.

These parts are seen here adhesively bonded to an Igloo side wall. The spring-like spigots can bend, or break leaving the blanket poppets in the retainer. The arrow indicates the location of an electron beam weld run-out. The entire aluminium alloy surface has been anodised.

Fig. 15: Chromium-plated trunnion (approximate diameter 80 mm)

An extensive band of aluminium has been picked up from contact with the aluminium-rich internal surface of a handling device.

probable that the transferred aluminium could be removed by swabbing the affected surface with a weak solution of sodium hydroxide.

4.5.2. Rack Cooling Air Ducts

The ducting/bellows interface at the base of the racks created problems because the bellows material is very rigid. A more flexible material would make the connection and clamp securing operations less difficult and reduce the amount of damage to and splitting of the bellows (see Figure 16). Such an interface would be extremely difficult to make in orbit.

4.5.3. Keel Fitting - Spacelab Transfer Tunnel

The passive location of the Keel Fitting made the mating of the Spacelab Transfer Tunnel to the Orbiter a more difficult task than it would be with an active device as used on the Spacelab Module to Orbiter Keel Fitting.

4.5.4. Line Replacement Unit (LRU) Interfaces

Exchanging LRUs was complicated by the large number of fasteners and washers required for mounting, plus the difficulty of making and securing the wide range of electrical connectors employed. A less complicated solution is recommended for COF in-orbit activities.

4.5.5. Fasteners

The use of the ultrasonic extensiometer for the setting of bolt pre-loads was a very complex task and replacement of the transducers was frequently required. It is appreciated that their use was driven by a design modification introduced late in the programme. This difficult method of checking the actual stresses within bolt materials would establish that no fasteners were loaded beyond their recommended maximum stress level.

Aluminium-rich coating on the Pallet Keel and Hard Point attachments bolts had a tendency to adhere to the nuts after long periods (approximately 1 year) of sustained loads. After de-mating the coating had to be removed before re-mating was possible.

NASA does not use aluminium-rich coating for this application.

4.5.6. Captive Nuts

The rounding-off of captive-nut corners, mainly in Racks and the subsequent spinning of the nut when applying torque was probably the most frequent problem experienced. One solution was to replace the captive nut with a loose nut. This is probably not an acceptable in-orbit solution.

4.5.7. Wear of Electrical Connectors

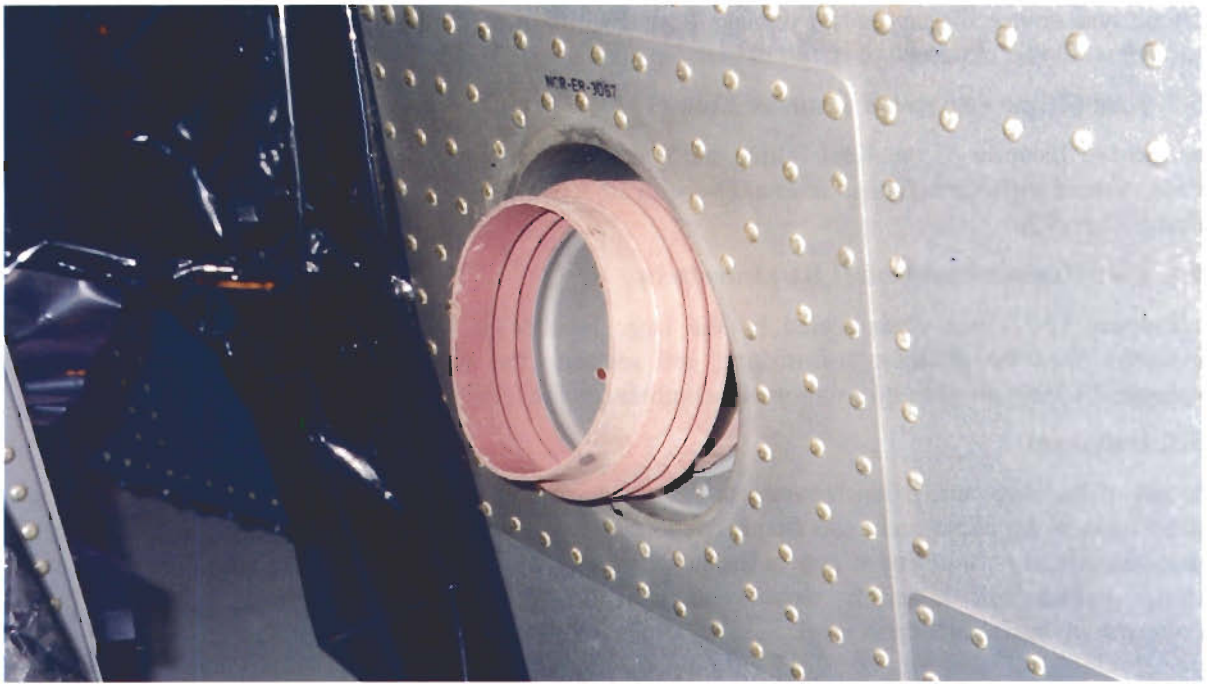
Wear was not a significant problem but the wide range of securing screws and their accessibility created difficulties. The Pyro Control Box suffered a short-circuit at the connector feed when the protective cap touched a live pin, an indication of inadequate clearance and a live male pin interface.

4.5.8 Thermal Interface Filler

The thermal interface filler, Chotherm Sheet, proved to be suitable for single use only, due to its fragility. If it were to be used in the COF, it might present difficulties in replacement in-orbit. It was recommended that standard thermal interfaces be designed, e.g. an adapter plate for the MMU.

4.5.9. Fluid Disconnect Problems

The only problem experienced was during Spacelab 2 processing in 1985 when the Freon 21 Quick Disconnect coupling failed due to over-travel. The failure mode was that the split ring retainer was forced out of its location groove by holding down the position locator button and rotating the actuating sleeve beyond the fully closed position. This allowed the support to separate from the body.



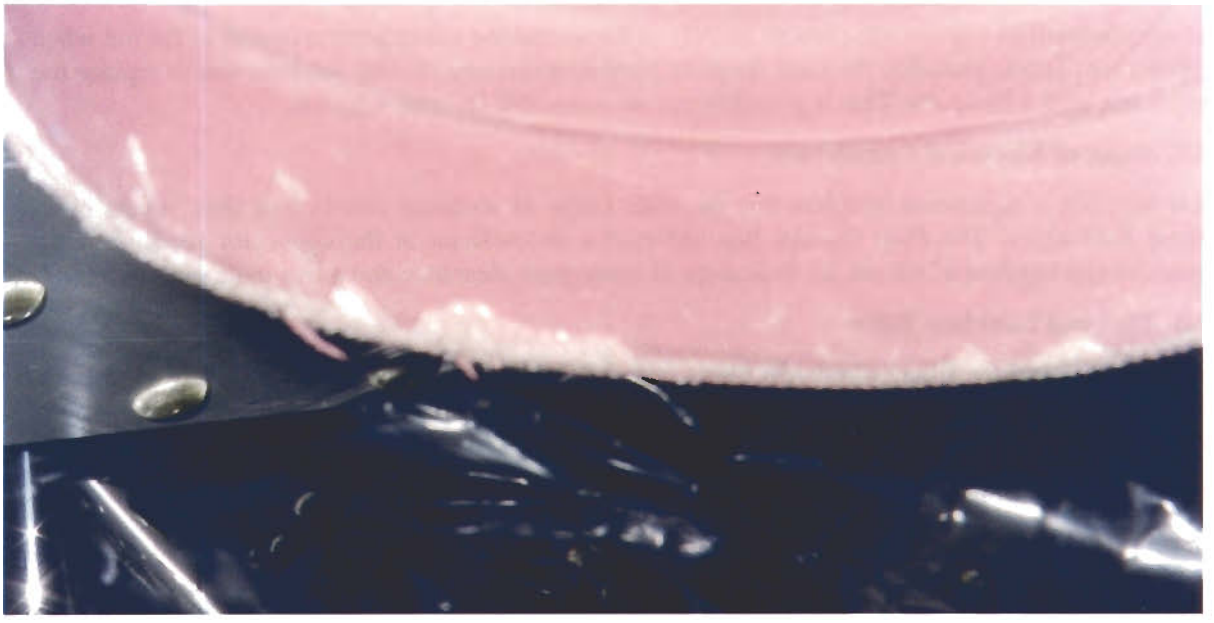


Fig. 16: Appearance of air ducts feeding into racks.
The bellows material is quite rigid and being short, causes interconnection problems. Scuffing and wear have degraded the internal surface (lower photograph).

The recommended preventative action was to increase operator training and certification [5] and there were no subsequent failures. If the same design is still to be employed on the COF hardware it will be essential to perform similar training for all operators. These fluid disconnect procedures must be well understood during both ground and flight operations.

4.5.10. Threaded Connections

Captive systems were sometimes difficult to locate and operate.

4.5.11. Accidental Damage

Damage occurred to the Module Floor during Rack handling operations (see Figure 17). Improved floor protection covers were manufactured and were used as required in Modules, Pallets etc.

4.6 Limited Life Items and Physical Degradation

4.6.1 Seals and Associated LeakRates

No seal failures were experienced during processing at KSC, thus verifying the corrective measures taken following the leak in the Water Separator in Europe in 1980 and the Igloo "Gask-O-Seal" problem that occurred during the Spacelab 2 acceptance-level tests performed during 1982.

4.6.2 Relief Valves, Positive and Negative Pressure

The relief valves were cycled prior to each mission and the only anomaly noted was when the Module Pressure Relief Valve (MPRV) (Negative) Popper was not rotated to the neutral position. This was not considered to be a problem. When cycled, all valves operated within their specified tolerances.

4.6.3 Brush Motors, Start-up After Long Periods of Non-Activation

The single occurrence of this type of problem was the failure of the oxygen latching valve in the O2N2 Control Panel [6]. The cause of the non-operation of the valve was determined to be off-gassing products from the silicone compound in the brush motor assembly, contaminating the brushes and commutator. Corrective action was limited to annual measurements of the resistance values and the operation of the valves. Design or Material changes were apparently left as a customer option while no firm recommendation was made concerning the implementation of a post-curing heat-treatment to reduce or eliminate off-gassing of this silicone material.

If the same design is still valid for the COF, it is recommended that the crew be required to activate these valves and to measure resistance values at more frequent intervals in orbit.

4.6.4 Harness Attachment Points and Insulation Damage

The harness wire and cables suffered damage which was determined have been introduced by both operator handling and the natural ageing of the wires' insulation jacket. Kapton outer insulation was the most susceptible to handling damage, which resulted in splits and tears of the Kapton wrap and exposure of the shielding braid (see Figures 18 and 19). MDAC submitted samples of damaged wires to the NASA KSC Materials Laboratory for failure analysis in January 1991. The findings of the analysis resulted in the issue of a standard repair procedure for Spacelab wire and harness insulation damage. Kapton and PTFE insulation are addressed, as may be seen in the Failure Analysis and recommended repair procedure [7].

It is of interest to note that the International Space Station baseline is to use Teflon-coated Kapton insulation, which will be less susceptible to handling damage than unprotected Kapton. However the flaking of the colour code PTFE (Kapton) layer on the ESA-supplied wire may still present a contamination source due to ageing and handling degradation over the 15-year life of the COF. It should also be considered that, based on Spacelab experience, damage may also occur to the Teflon coated Kapton wire if in-orbit maintenance is performed. Except for the incident shown in Figure 18, the harness attachment points did not present problems.

Fig. 17: General view of the Module Floor, as removed from the spacecraft.
Damage and staining are visible in the lower photograph.
The floor finish is anodised aluminium, which should perhaps be better sealed,
to reduce absorption of liquids and to improve cleanability.

Fig. 18: Photograph taken by NASA in 1995 to illustrate damaged Kapton insulation around a cable attachment point.
The bend radius of the braided cable appears to be too small.

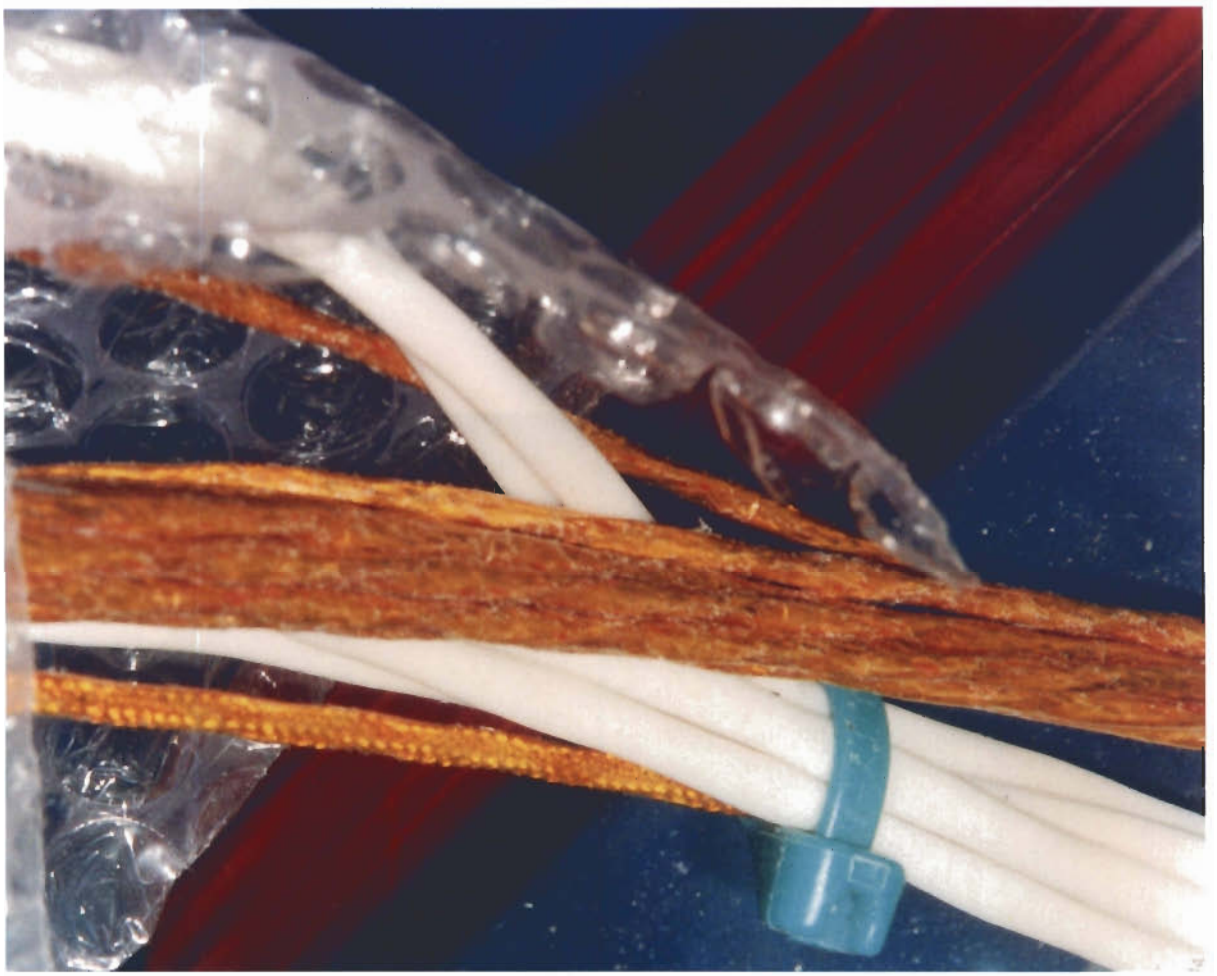


Fig. 19: Detailed view of aged Spacelab wire bundle.
It is probably 18 years since this was manufactured by Rheinshagen. The outer layer of the wrapped Kapton has crazed and embrittled, with some very small flakes being shed. (Wires, held in storage by Estec QMM and made by the same manufacturer at about the same time and to the same specification, show no visible degradation).

4.6.5 Spliced Joints in Harnesses

The ESA method of splicing wires as a joining process was questioned by NASA during the integration process of Spacelab 2. The evaluation of the process included discussions at ESTEC with NASA and a presentation of ESA's rationale for accepting splicing as a qualified process. The final disposition by NASA was to rework the IPS harness and eliminate all spliced joints. The Follow on Production (FOP) IPS harness was not reworked but has not been flown on a mission. Splicing is still an ESA-approved wire joining process.

4.6.6 Red-Plague

The existence of red-plague in wire harnesses used in Space Station hardware has recently been reported by MDAC and confirmed by MSFC metallurgical analysis [8]. This wire was not ESA-procured and was purchased in the US to a Mil. Spec. Micro-section analysis showed it to support a very thin, porous layer of silver plating. The ESA requirement for all wire strands is for a minimum of 2·0 microns of silver-plate in any one location around each copper strand. Additionally, red-plague screening tests are required [9 - 11] for all wires utilised on ESA space projects. This serves to remind users to maintain their vigilance in process control, screening and quality tasks, to eliminate the occurrence of red-plague from their hardware.

4.6.7 Condensate Heat Exchanger (CHX)

The hydrophilic coating of the CHX is common to Spacelab and the COF. Because the COF coating will be European sourced, the performance of the Spacelab hardware is therefore pertinent. There were no problems on Spacelab although there was an observable difference in the behaviour of the coatings on the Spacelab 1 and FOP items, i.e. the liquid on the surface of the Spacelab 1 coating dispersed readily to produce an overall wetting while liquid on the FOP surface formed into isolated globules. This phenomenon did not result in any water flow problems.

4.6.8 Tin Whiskers

Long filaments of tin, known as tin whiskers, can grow on tin-plated items. These whiskers have a diameter of between 0·1 and 0·5 microns, and can grow to a length exceeding 2 mm. As they are electrically conductive (32 mA can be carried by an average sized whisker), it is common to forbid the use of tin-plating on spacecraft hardware [2]. Tin whisker growths were reported, during the forum, to have caused the failure of a relay in the System Power Distribution Box (SPDB) – they had created electrical short-circuits.

4.6.9 Fuse Holder Failures

The failure investigation of a blown fuse from the Igloo SPDB, during processing of the Astro 1 mission in 1985, concluded that the probable cause of the failure was over-stressing due to mishandling. Further fuse failures, at currents lower than their rated values, led to more investigation in 1990, which identified a design problem in the fuse holders. A swaged joint, at the wire termination to the spring loaded contact to the fuse, created a hot spot during current flow, thereby causing local thermal over-stress. The selection of COF fuse holder design should avoid the use of swaged terminations, to prevent similar failures [12].

Spacelab fuse holders with crimped terminations did not suffer failures and crimped joints became the baseline.

4.6.10 Degradation of Foam

The most obvious form of degradation observed was that of Pyrel foam which was utilised for sound insulation and packaging in toolboxes, work boxes and drawers. The foam began to decompose and break up into pieces ranging from particles to clumps with a soft sticky consistency (see Figures 20 and 21). Replacement became necessary after approximately 6 years and the substitute selected was Solamide 301 coated with RTV 142 or Kapton tape. The Solamide was also found to shed particles and needs to be suitably covered in order to contain these small-sized particulate contaminants. Foamed aluminium with a density of 0.48 g/cm^3 has excellent sound absorption properties and is available in Europe under the trade name of Alulight [2].

Fig. 20: New on-board tool holder made from Solamide 301 foam.
(Compare with Fig. 21)

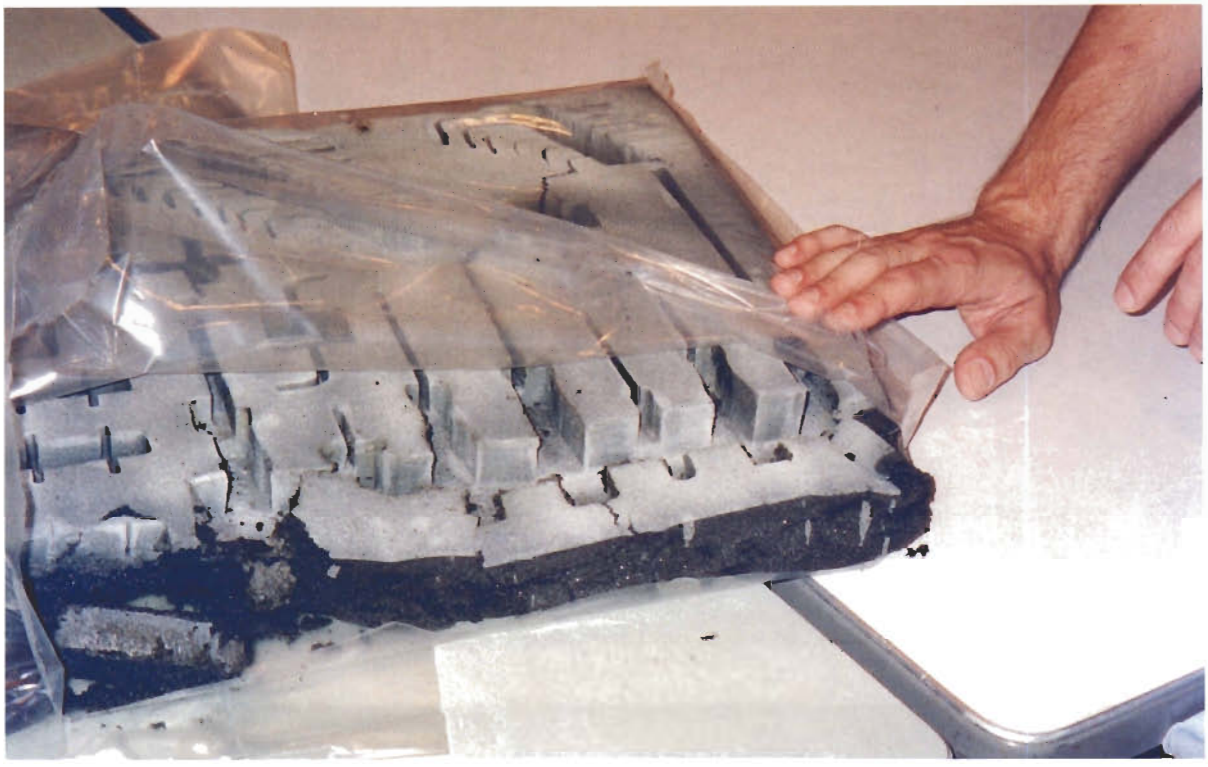
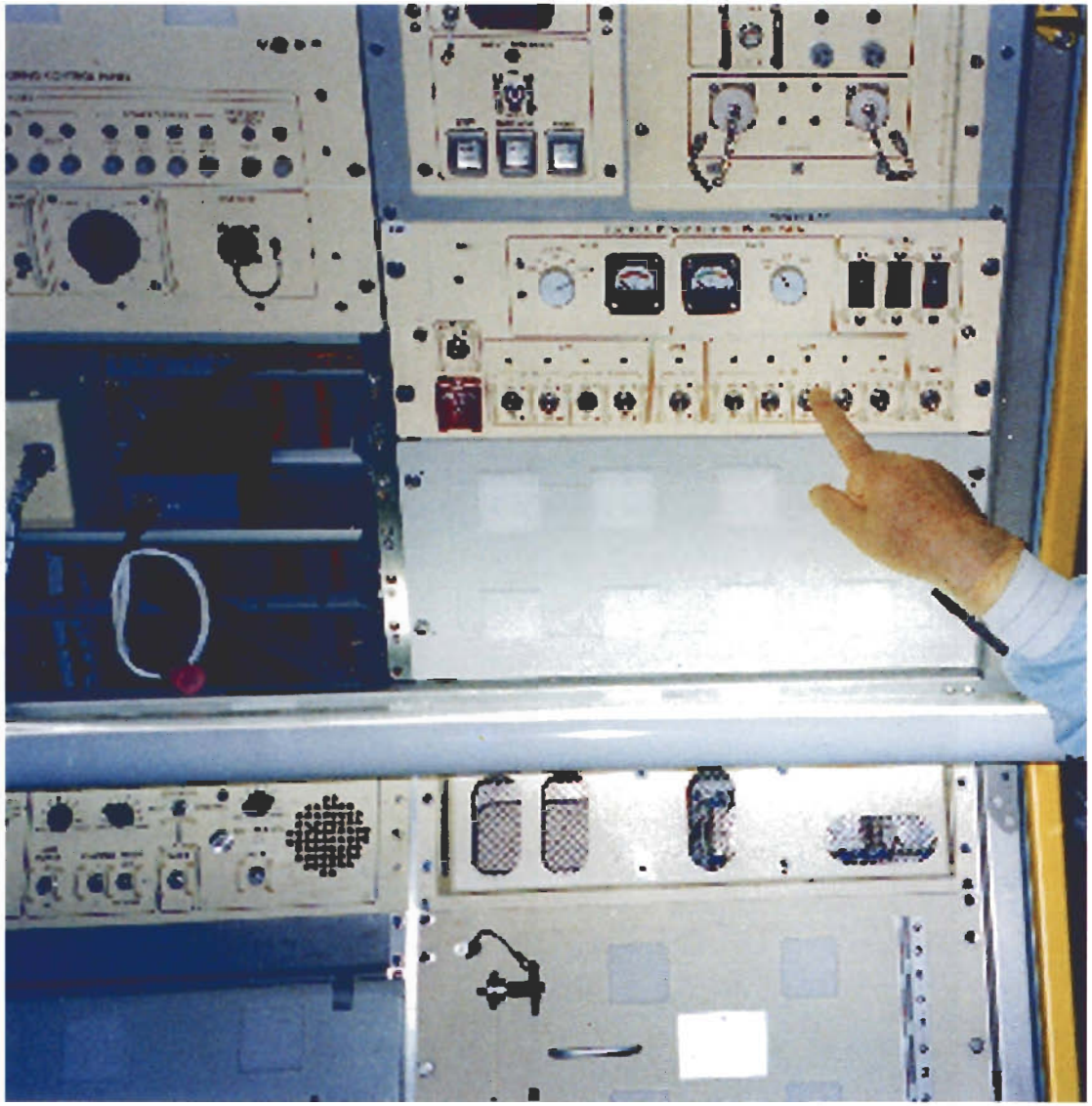


Fig. 21: Pyrel foam after 6 years of use.

The tool holder (upper photograph) has completely degraded.
When compressed by slight handling, it pulverises to the powder seen in the lower photograph.



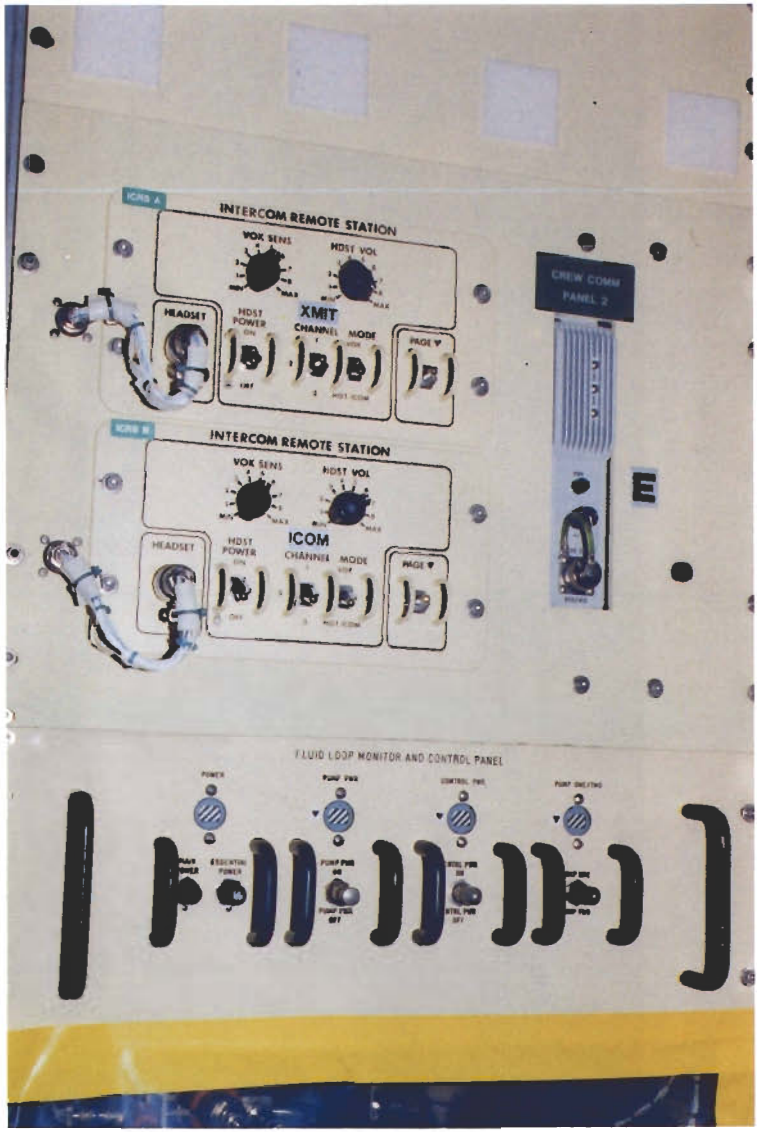


Fig. 22: The switches in the left photograph are inadequately protected against accidental contact. Covers are required. In other rack locations (right photograph), protection is provided by bars that protrude above the switches themselves.

This could be considered, subject to satisfactory qualification, as an alternative to the organic foam materials.

4.6.11 Microbial Contamination

No evidence of microbial contamination or dust accumulation was observed during pre- or post-flight processing, although microbial contamination checks were performed periodically by NASA. After the IML mission the Cabin and Avionics loop air filters were investigated and of the 40 samples taken 29 "responses" were recorded. Approximately 17 bacterial species were identified, together with one variety of fungus. Detailed results were compared with the findings of the (STS 40) microbial investigation and are presented in [13].

4.6.12 High Data Rate Recorder (HDRR)

As known, corrective maintenance was performed on the HDRR by the crew during the Spacelab 1 mission. The HDRR was replaced several times throughout the Spacelab history.

4.6.13 Crew Interface Aspects

Switch guards have been supplemented with plastic covers which clip over the original guards. This was necessary because accidental switching was possible by the astronauts' toes during zero-gravity activities (see Figure 22).

The cover plates/lids of some equipment, e.g. the power control box (PCB) and electrical power distribution box (EPDB), are considered too flexible, because under crew-induced loads they deform sufficiently to create potential hazards.

4.6.14 Equipment Obsolescence and Spares

In the early years of Spacelab, delays were experienced in processing tasks because of the non-availability of spare parts. This was later improved by better identification of so-called "long lead-time items" and early procurement of spares for these. MGSE spares for slings and hoisting equipment were a particular problem because some German DIN specifications used were obsolete at the time of delivery of the equipment to KSC.

4.6.15 Detachment of Tape

Instances of slight Velcro tape lifting were noted on a few of the Spacelab racks. This had occurred mainly at rack corners and in places where the tape was positioned over raised rivet-heads. Figures 23 and 24 show the adhesive beneath the tape to be patchy and a continuous film might be preferable.

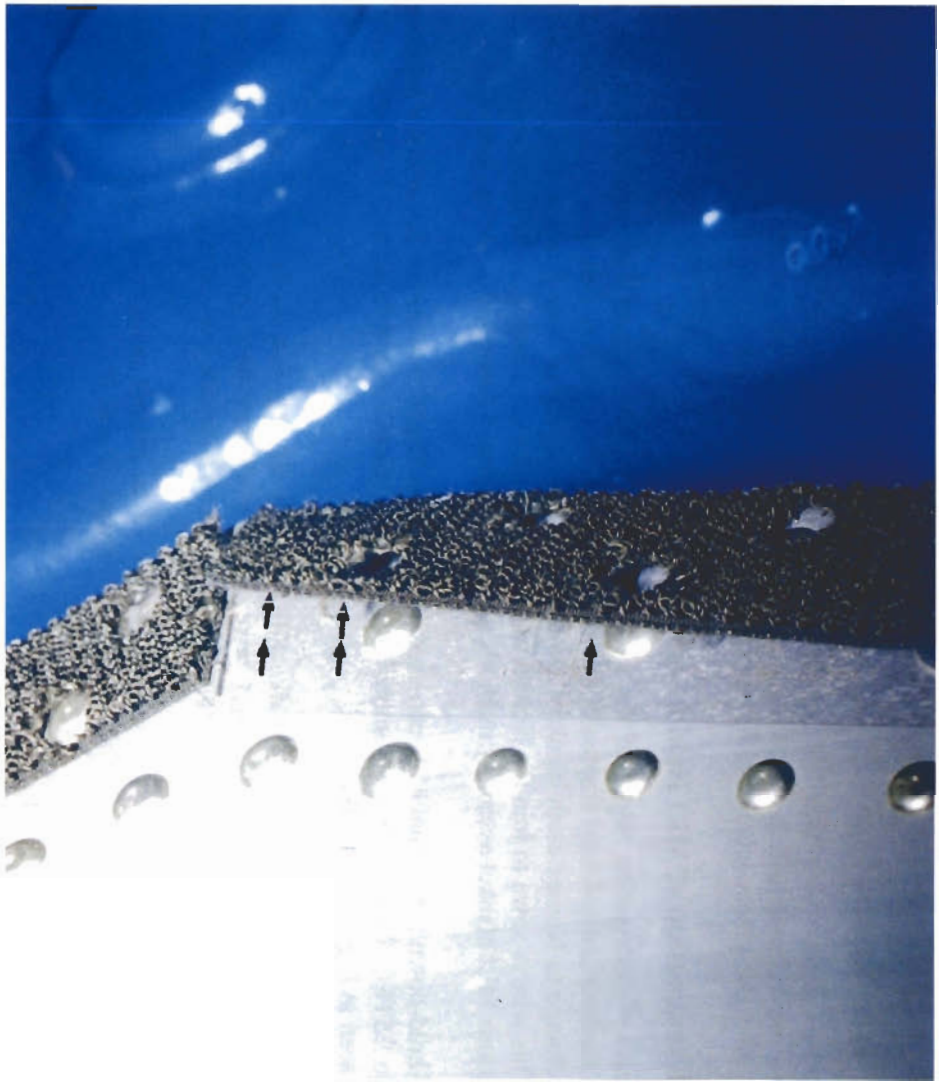
4.7. Examination of MLI Hold-down Button

A particularly interesting aspect of the visit was the inspection of post-flight multi-layer insulation (MLI) blankets and goldized Kapton blankets in the KSC Sewing Room (see also Figures 11-13). The recent change to Nomex cloth blankets also incorporates the use of very fine stranded stainless steel wire. This wire is sown to join the Nomex cloths and enables the blankets to be electrically grounded. The various MLI blanket assembly methods were demonstrated during this sewing-room visit.

A MLI hold-down button that had been used on a previous flight (duration and details not known) was given to ESTEC. This has been examined in the ESTEC metallurgical laboratory [14] and the results can be seen in Figures 25 to 29.

The button surface has become visually dull following its exposure to the LEO environment. The surface immediately beneath the lacing tape remained bright and shiny (green-brown colour) however. The figures show that lacing tape had protected the button's surface from attack by atomic oxygen.

A further remarkable observation, is the presence of an impact point (only about 120 microns in diameter) on the button surface. This is shown in Figures 30 and 31.



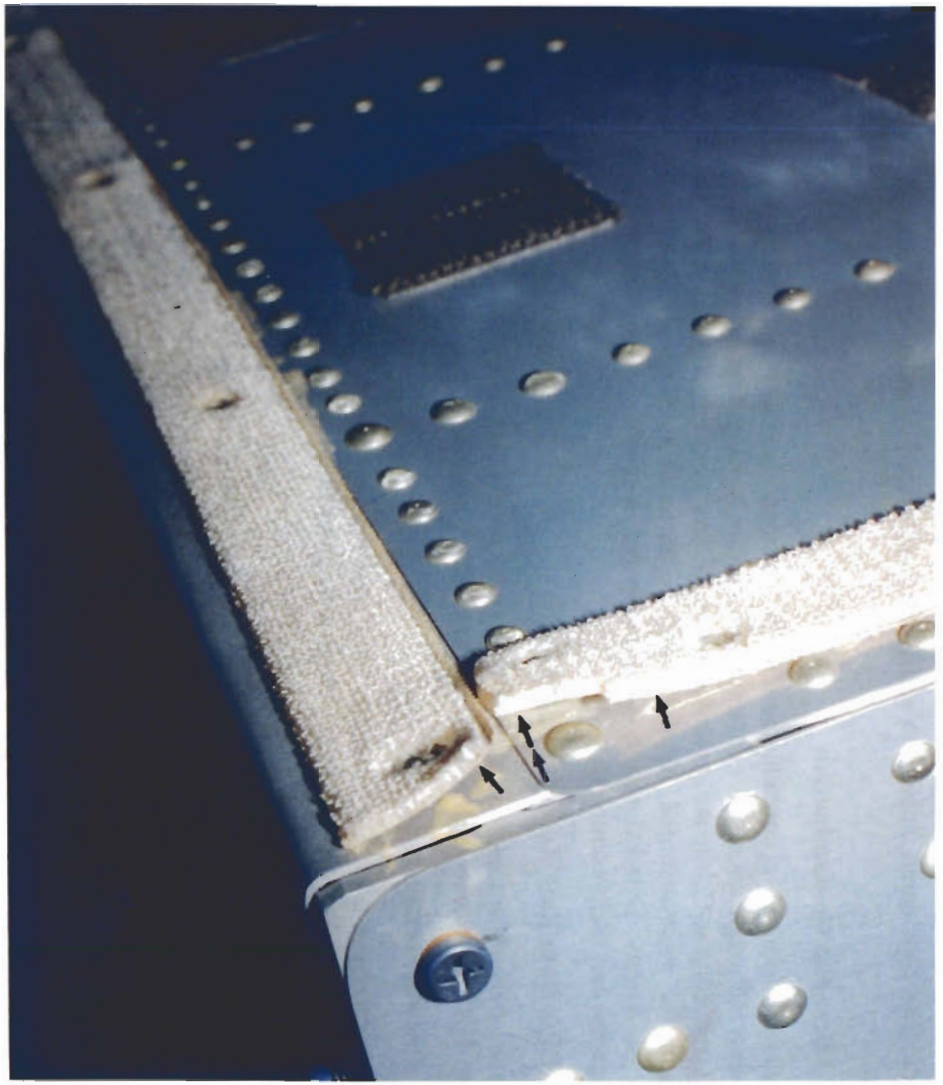


Fig. 23: General view of de-bonded Velcro tape.

Black (left photograph) and white (right photograph) varieties are shown.

(See also Fig. 24).

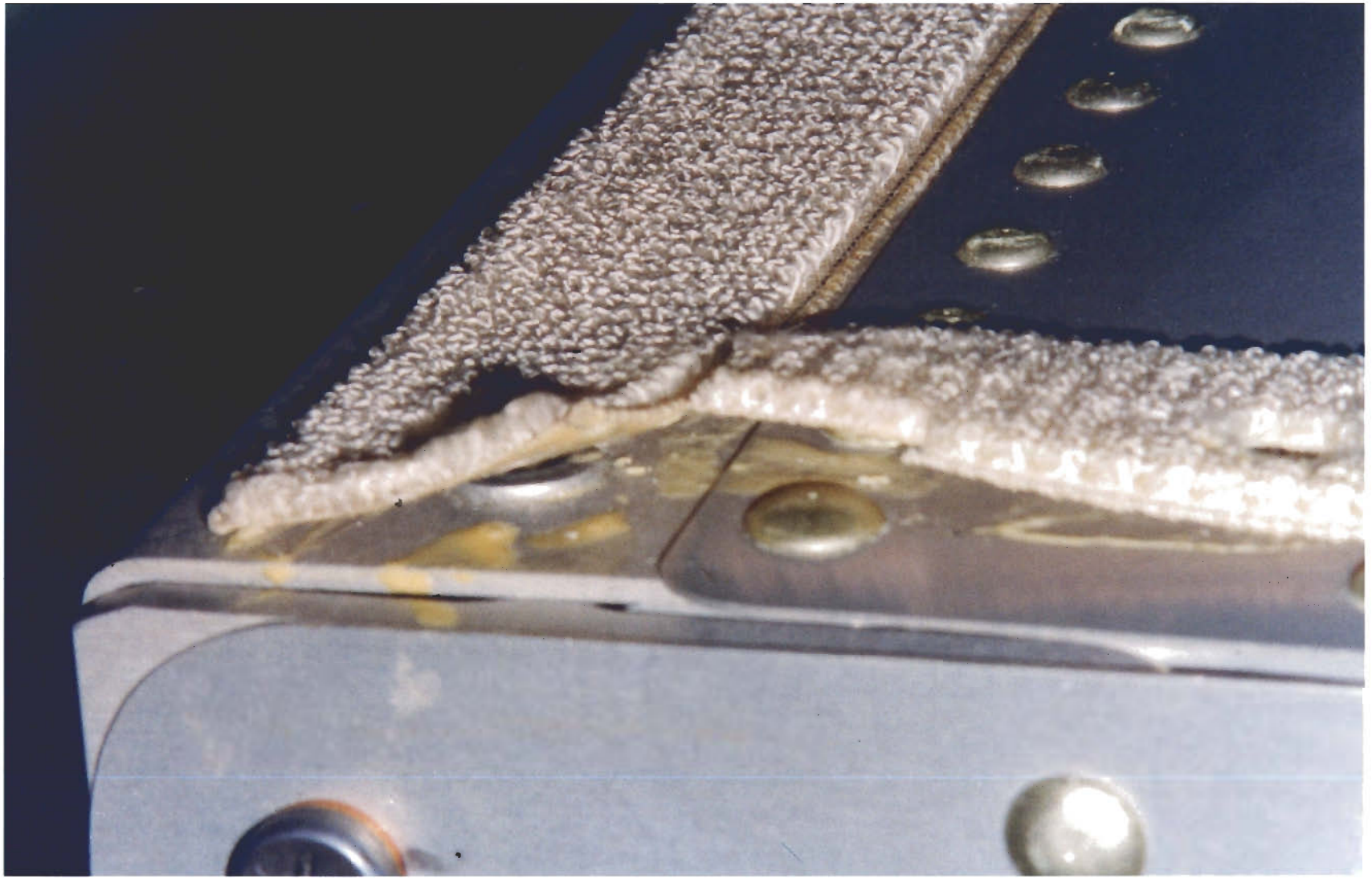


Fig. 24: Detail of lifted Velcro tape, showing non-planar aluminium rack surface and inadequate amount of adhesive.

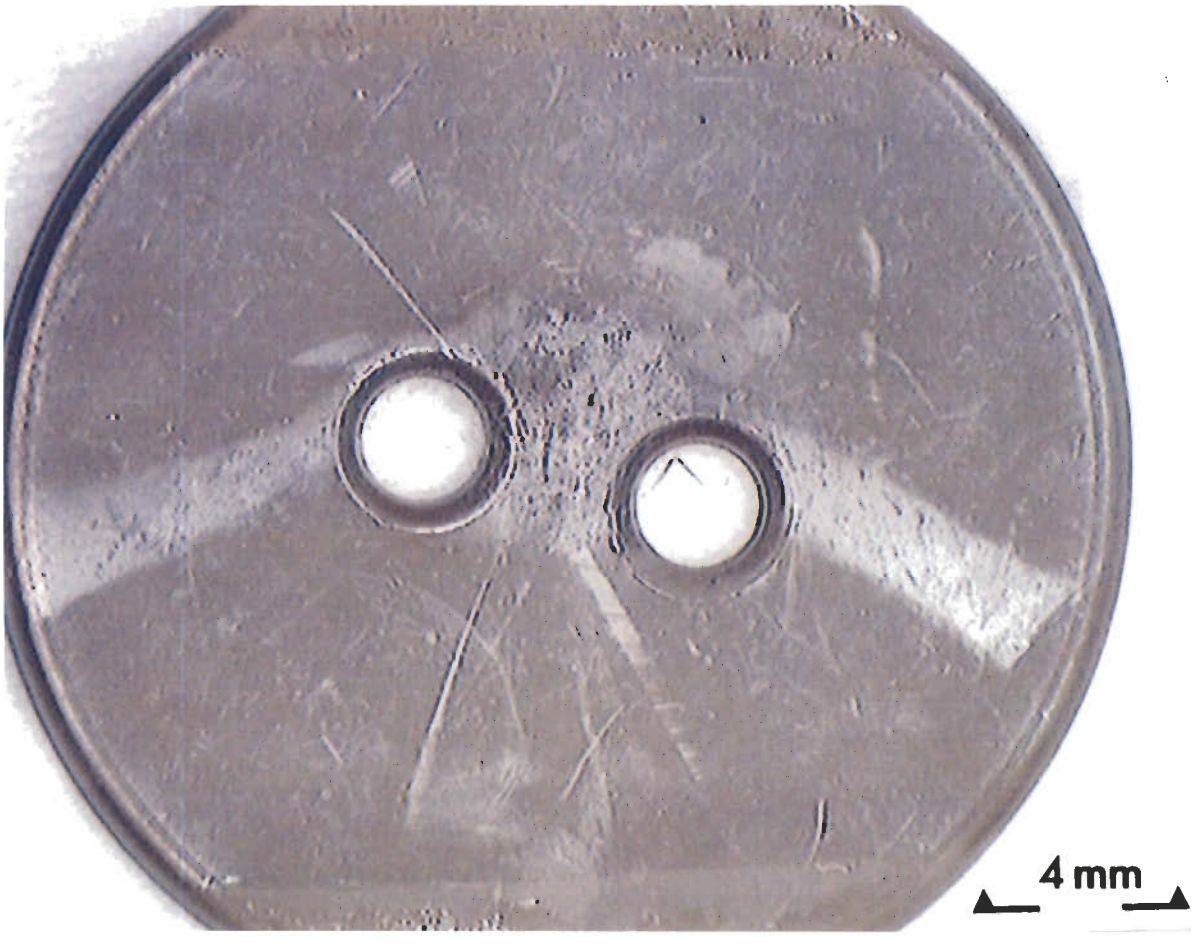


Fig. 25: Post-flight MLI hold-down button, as seen by optical microscopy.
Note the protective shadow (light band) produced by lacing tape.

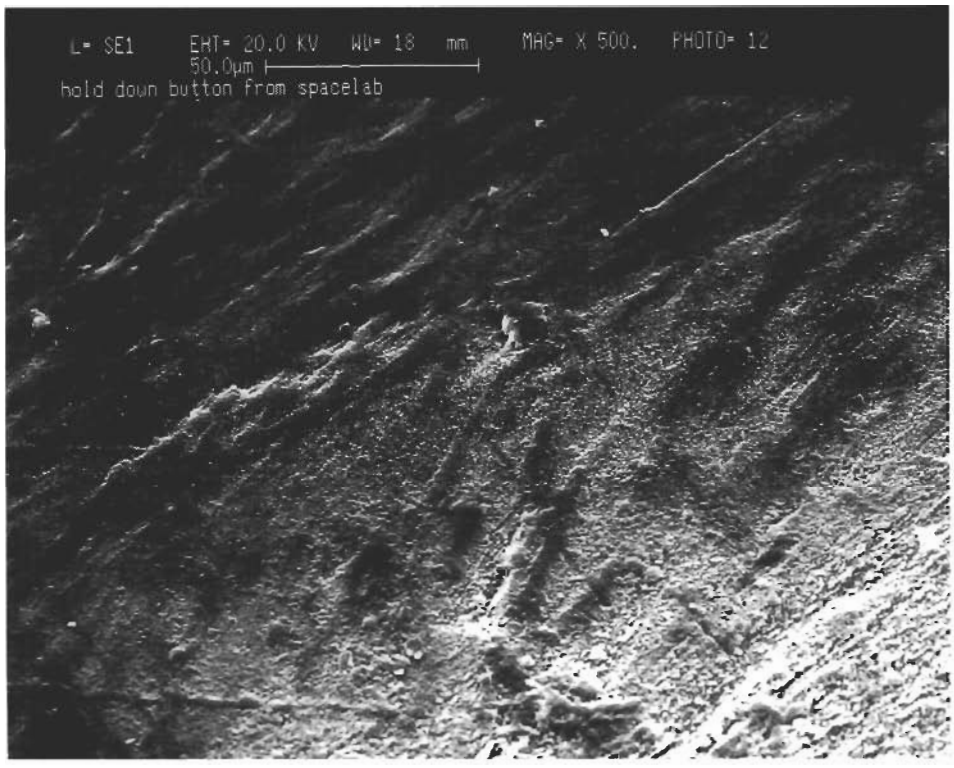


Fig. 26: SEM photograph of the non-attacked centre area of the button, showing a typical polymer surface (Magnification ×7500).

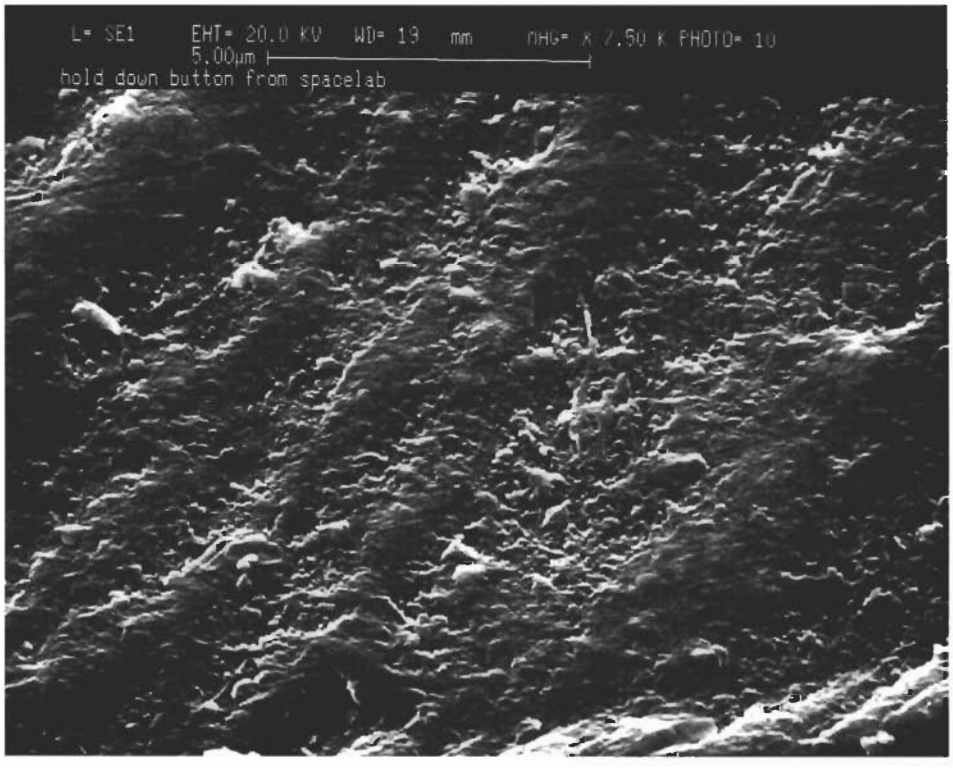


Fig. 27: SEM photograph of the border between the atox-attacked and the non-attacked area.
This border is quite sharp (100µm) (Magnification ×500).

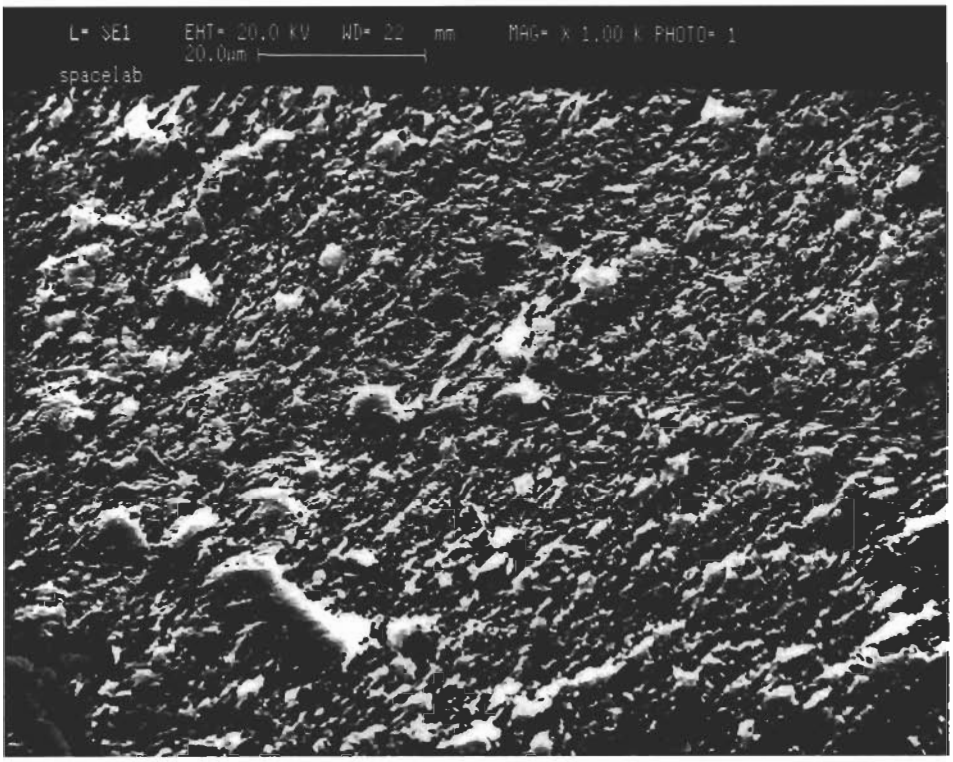


Fig. 28: SEM photograph of the atox-attacked area.
This shows the typical cone-shaped features of an attacked polymer (Magnification ×1000).

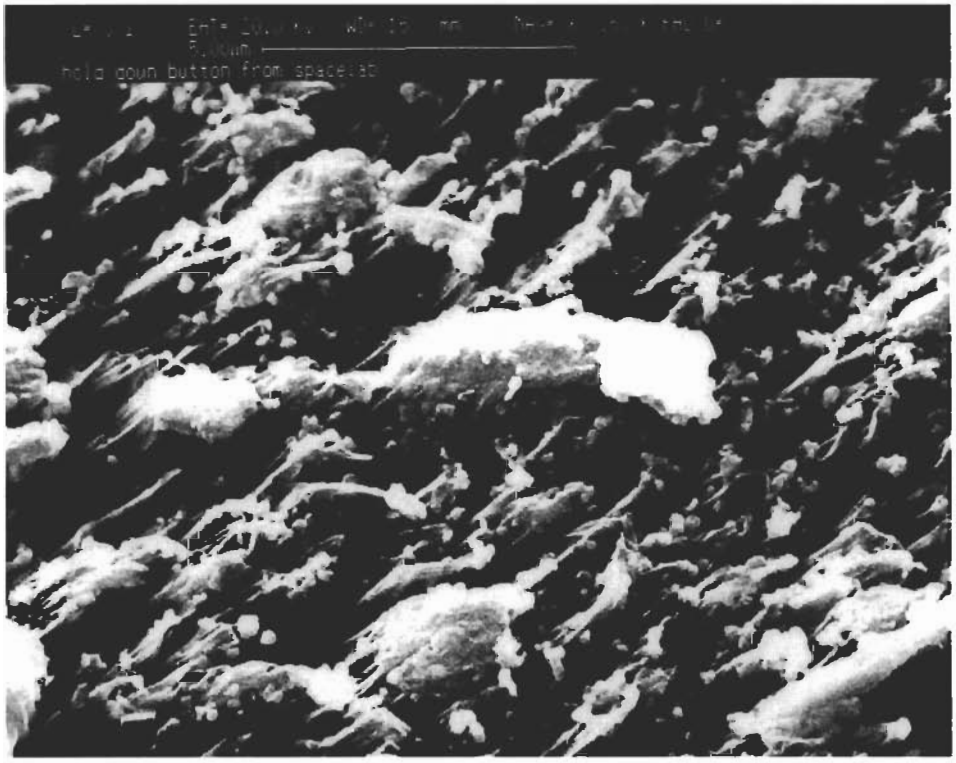


Fig. 29: Same as Fig. 28, but higher magnification (×7500).
This clearly shows the cone type structures from the atomic oxygen attack (cf. Fig. 26).

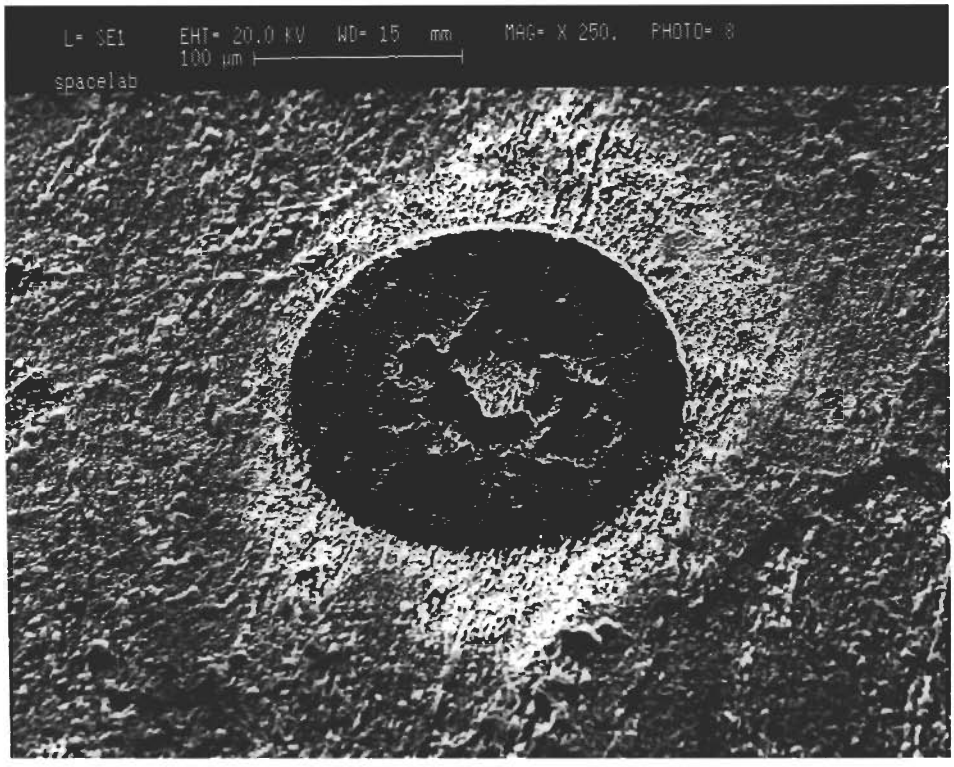


Fig. 30: A molten circle in the atox-attacked area.

This feature is probably due to micrometeoroid/debris impact during the life of the button on Spacelab. Note the irregular shaped halo around the impact. This consists of atox-attacked polymer, but with a much finer structure than the surrounding surface. (Magnification ×250).

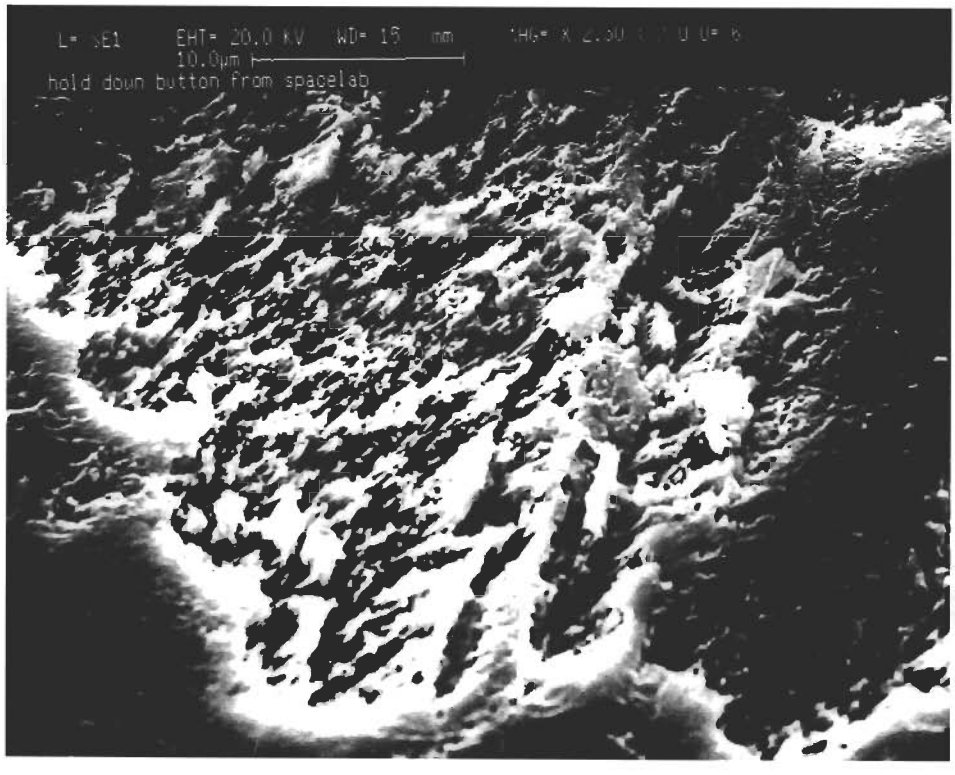


Fig. 31: Same as Fig. 30, but showing the centre area of the impact.

(Magnification ×2500).

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4.8. Space Station International Standard Payload Racks (ISPR)

The MSL payload recently integrated at KSC included an ISPR which necessitated modification of the Spacelab Rack Support Structure to simulate the Space Station-to-ISPR interface. Considerable difficulties were experienced inserting the rear retaining pins at the base of the ISPR, even with the relatively good access and the use of fibre optics viewing equipment. In the opinion of the technicians who performed the integration there will be serious problems inserting the rear retaining pins in orbit. The experience of the MSL ISPR integration should be evaluated by the responsible ISPR design authorities and improvements made if necessary.

5. Acknowledgements

The cooperation and kindness of the NASA and MDAC personnel in providing access to the Spacelab hardware and supplying the records requested is greatly appreciated. Particularly thanks are expressed to Joe Lacovitch, John Link and Melodie Porta (NASA) and to Keith Manning (MDAC).

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[12] " Failure Analysis", Spacelab Anomaly Notice, SAN-FLT-H W - 069, MDAC/KSC, 7th Feb. 1990.

[13] "IML-1 Filter Debris Characterization and Weights", MSFC-IML,. NASA/MSFC, 1st Aug. 1992.

[14] Rooij, A. de, "Examination of MLI Hold-down Button", ESTEC Metallurgy Report No. 2351, 1997.

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Annex 1 Discussion Topics

Agenda

Problem Areas for Possible Inspection and/or Discussion.

Corrosion

Alodined weld and heat affected zones.
Anodised surface degradation.
Condensation and cold areas.

Painted Surfaces

Peeling, flaking.
Degradation of optical properties.
Atomic oxygen effects.

Thermal Protection

Thermal blanket degradation.
Wear, tarnishing etc.
Handling problems.

Interface Problems

Wear, friction on trunnions and mounting points.
Wear characteristics of fasteners.
Wear of electrical connectors.
Fluid disconnect problems.
Threaded connections.
Accidental damage (dings etc.) indication need of added protection.

Limited Life Items / Physical Degradation

Seals and associated leak rates.
Relief valves (positive and negative pressure) re-calibration of crack and reset pressures.
Brush motors start-up after long periods of non-activation, possible "sticktion" problems.
Harnesses attachment points and insulation damage, particularly at flexure regions.
Condensate heat exchanger, information on hydrophilic coating status and possible degradation due to contamination and microbial effects.
Zones which accumulate dust, potential areas of stagnant air.
Evidence of microbial contamination.

Annex 2 List of Attendees at Discussion on Spacelab Processing

(O & C Building KSC - 25th February 1997)

Name	Organisation	Tel. No.
John Link	NASA - Mechanical Engineering	867-4789
Melodie Porta	NASA - BE-C1	7-4789
Kevin Takada	NASA - S/L Avionics	7-3747
John Smith	MDAC - Fluids / ECS	7-5257
Bob Becker	MDAC - S/L Mech. (LRUs)	7-3337
Greg Dawes	MDAC - S/L Mech.	7-3337
Keith Garfield	DAC - S/L Design	7-7249
Norm Jatz	MDAC - S/L Handling	7-3596
Eric Hanson	MDAC - S/L Electrical / Avionics	7-4246
Philip Lintereur	MDAC - S/L Avionics	7-4246
Dick Banta	MDAC - M & P Eng.	7-4287
Michael Pavick	MDAC - S/L Thermal Protection	7-3813
Brent Wenkstern	MDAC - M & P Eng.	7-4287
Barrie Dunn	ESA-ESTEC - Materials and Processes Division	3900
Roy Stanyon	ESA-ESTEC - Manned Spaceflight Department	3375

Annex 3 Spacelab Hardware Assignments

MODULE ASSIGNMENTS

C/D (MD001)	FOP (MD002)
SL-1	SL-D1
SL-3	IML-1
EOM1/2 (CORE)	SL-J
SLS-1	SLS-2
USML-1	SL-M
SL-D2	LMS
IML-2	NEUROLAB
USML-2	
MSL-1	

FLOOR ASSIGNMENTS

C/D (MD001)	FOP (MD002)	FOP II (MD003)	E M (EM-MD001)
SL-1	SL-D1	USML-1	EOM-1/2 (CORE)
SL-3	SLS-1	USML-2	SL-D2
IML-1	SL-J	MSL-1	
SLS-2	IML-2		
SL-M	LMS		
NEUROLAB			

DOUBLE RACK ASSIGNMENTS

DR-C003 -	SL-1 (4) - SYSTEM, LIFE SCIENCE - CAMERA
(MD002)	SL-D1 (4) - SYSTEM. BOTEX/STATEX
	USML-1 (4) - SYSTEM (4 VCR)
	MSL-1 (4) - SYSTEM (4 VCR)
DR-C005 -	SL-3 (10) - FES
(MD006)	IML-1 (10) - FES
DR-C006 -	SL-1 (7) - VITR
(MD004)	SL-3 (3) - VIDEO
	EOM-1/2 (3)
	USML-1 (8) - DPM
	USML-2 (8) - DPM
	DR-C007 - SL-1 (10) - CENTRIFUGE
(MD005)	SLS-1 (8) - LIFE SCIENCE
	SLS-2 (8) - LIFE SCIENCE
	MSL-1 (8) - CM-1
	DR-C008 - SL-1 (9) - VWF - CAMERA
(MD001)	SL-D1 (7) - RSC
	IML-1 (8) - STOWAGE
	SLS-2 (9) - REFRIGERATOR - FREEZER
	SL-M (9) - REFRIGERATOR - FREEZER
	NEUROLAB (9) - REFRIGERATOR - FREEZER

SINGLE RACK ASSIGNMENTS

SR-C001 -	SL-1 (5) - STOWAGE
(MD003)	SLS-1 (12) - CENTRIFUGE
	SLS-2 (12) - CENTRIFUGE
	LMS (12) - CENTRIFUGE
SR-C002 -	SL-1 (6) - LIFE SCIENCE
(MD004)	SLS-1 (6) - LIFE SCIENCE - ECHO
	SLS-2 (6) - LIFE SCIENCE - ECHO
	NEUROLAB (6) - BAG-IN-BOX
SR-C003 -	SL-1 (11) - MATERIAL SCIENCE
(MD001)	SLS-1 (11)-LIFESCIENCE
	SLS-2 (11) - STOWAGE - ACTIVE
	SL-M (11) - BAROREFLEX
SR-C004 -	SL-1 (12) - STOWAGE
(MD002)	SL-D1 (12) - STOWAGE
	USML-1 (6) - DPM
	USML-2 (6) - DPM
SR-D009 -	USML-1 (12) - GBX
(MD011)	USML-2 (12) - GBX
SR-D010	IML-1 (5) - BIORACK
	IML-2 (5) - BIORACK (NOT A SPACELAB-OWNED RACK)
SR-F005 -	SL-3 (12) - VCGS
(MD005)	IML-1 (12) - VCGS
SR-F006 -	SL-3 (6) - STOWAGE
(MD006)	EOM-1/2 (6) -
	SL-D2 (12) - BAROREFLEX
SR-F007 -	SL-3(11)-GFFC-MICG
(MD007)	IML-1 (11) - IMAX - MICG
	SLS-2 (5) - RAHF
	SL-M (12) - STOWAGE
	NEUROLAB (12) - STOWAGE
SR-F008 -	SL-3 (5) - PRIMATE - RAHF
(MD008)	SLS-1 (5) - SMIDEX
	SL-J (6) - STOWAGE
	MSL-1 (6) - CM-1
SR-F012 -	EOM-1/2 (5)
(MD009)	SL-J (11) - REFRIGERATOR - FREEZER
	IML-2 (6) - RAMSES
	MSL-1 (12) - MGBX
SR-F013 -	SL-J (5)-FEE
(MD010)	USML-2 (5) - GFFC
	NEUROLAB (5) - LSLE
SR-EM1 -	IML-1 (6) - STOWAGE
(MD002)	IML-2 (12) - STOWAGE
	LMS (6) - STOWAGE
SR-EM2 -	SL-J (12) - STOWAGE
(MD003)	IML-2 (11) - STOWAGE
	LMS (11) - STOWAGE
	NEUROLAB (11) - STOWAGE
SR-EM3 -	USML-1 (11) - STOWAGE
(MD001)	USML-2 (11) - STOWAGE
	MSL-1 (5) - STOWAGE
SR-EM4 -	USML-1 (5) - STOWAGE
(MD004)	LMS (5) - STOWAGE
	MSL-1 (11) - STOWAGE

PALLET ASSIGNMENTS

F001 (MD001) - SL-1, EOM-1/2, Space Station
F002 (MD009) - ASTRO-1 (AFT)
ASTRO-2 (AFT)

F003 (MD004) - SL-2 (3), TSS-1, TSS-1R
F004 (MD002) - SL-2 (1), ATLAS-1 (FWD).
Space Station
F005 (MD003) - SL-2 (2), ATLAS-1 (AFT)
Space Station
F006 (MD005) - OSTA-3, SRL-1, SRL-2, SRTM
F007 (MD006) - SRM (WESTAR). LITE-1
F008 (MD007) - SRM (PALAPA), ANT, ATLAS-2,
ATLAS-3, Space Station
F009 (MD010) - HST SM
F010 (MD008) - ASTRO-1 (FWD), ASTRO-2 (FWD)
E001 (E00I) -
E002 (EM-MD001) - OSTA-1
E003 (E003) - 0SS-1
E004 (E004) -
E005 (E005) - TSS-1 (MOCKUP)

MPESS ASSIGNMENTS

F001 - OSTA-2
F002 - LFC/ORS, USMP-1(AFT)
USMP-2 (AFT), USMP-3 (AFT),
USMP-4 (AFT)
F003 - SL-3, EOM-1/2, EOIM-III, SRL-1,
SRL-2

F004 - OAST-1, EASE/ACCESS
TSS-1, TSS-1 R, MFD

F006 - MSL-2, USMP-1 (FWD)
USMP-2 (FWD), USMP-3 (FWD)
USMP-4 (FWD)

TUNNEL ASSIGNMENTS

MD001 - SL-1, SL-3, SL-D1, SLS-1, IML-1, USML-1, SL-D2,.SLS-2, IML-2, USML-2, LMS-1, MSL-1, NEUROLAB
MD002 - SL-J, SL-M, S/MM-03, S/MM-04, S/MM-05, S/MM-06, S/MM-07, S/MM-08, S/MM-09

PALLET CONFIGURATIONS

EMP	MDM	IGLOO
TSS-1 (HDRS)	OSS-1	SL-2
TSS-1 R (HDRS)	OSTA-1	ASTRO-1
LITE-1	OSTA-3	ATLAS- 1
	SRL-1	ATLAS-2
	SRL-2	ATLAS-3
		ASTRO-2

Annex 4 STS - Orbiter - Payload Assignments

STS #	ORBITER	PAYLOAD	LAUNCH	LANDING	LOCATION
2	OV102	OSTA-1	11/12/81	11/14/81	DFRF
3	OV102	0SS-1	03/22/82	03/30/82	DFRF
7	OV099	OSTA-2	06/18/83	06/24/83	DFRF
9	OV102	SPACELAB - 1	11/28/83	12/08/83	DFRF
41D	OV103	OAST-1	08/30/84	09/05/84	DFRF
41G	OV099	OSTA-3	10/05/84	10/13/84	KSC
51A	OV103	SRM	11/08/84	11/16/84	KSC
51B	OV099	SPACELAB-3	04/29/85	05/06/85	DFRF
51F	OV099	SPACELAB-2	07/29/85	08/06/85	DFRF
61A	OV099	SPACELAB-D1	10/30/85	11/06/85	DFRF
61B	OV104	EASE/ACCESS	11/26/85	12/03/85	DFRF
61C	OV102	MSL-2	01/12/86	01/18/86	DFRF
35	OV102	ASTRO-1	12/02/90	12/10/90	DFRF
40	OV102	SLS-1	06/05/91	06/14/91	DFRF
42	OV103	IML-1	01/22/92	01/30/92	DFRF
45	OV104	ATLAS-1	03/24/92	04/02/92	KSC
50	OV102	USML-1	06/25/92	07/09/92	KSC
46	OV104	TSS-1	07/31/92	08/08/92	KSC
47	OV105	SPACELAB-J	09/12/92	09/20/92.	KSC
52	OV102	USMP-1	10/22/92	11/01/92	KSC
56	OV103	ATLAS-2	04/08/93	04/17/93	KSC
55	OV102	SPACELAB-D2	04/26/93	05/06/93	DFRF
58	OV102	SLS-2	10/18/93	11/01/93	DFRF
62	OV102	USMP-2	03/04/94	03/18/94	KSC
59	OV105	SRL-1	04/09/94	04/20/94	DFRF
65	OV102	IML-2	07/08/94	07/23/94	KSC
64	OV103	LITE-1	09/09/94	09/20/94	DFRF
68	OV105	SRL-2	09/30/94	10/11/94	DFRF
66	OV104	ATLAS-3	11/03/94	11/14/94	DFRF
67	OV105	ASTRO- 2	03/02/95	03/18/95	DFRF
71	OV104	SL-M	06/27/95	07/07/95	KSC
73	OV102	USML-2	10/20/95	11/4/95	KSC
75	OV102	TSS-1R/USMP-3	02/22/96	03/09/96	KSC
78	OV102	LMS	06/20/96	07/07/96	KSC
83	OV102	MSL-1			

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