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COLUMBUS APM SHELL REPAIR TEST RESULTS

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1. ABSTRACT

The issue of damage from micrometeoroids and, to a stronger extent, space debris is becoming a growing concern for satellites and manned space activities, especially for long term manned missions in Space.

This paper presents the results of a first series of tests which were carried out at the end of 1992 at ESA/ESTEC by the Columbus crew activities office.

The objective was to analyze the possibility to use simple tools and procedures for an immediate intervention by a shirt-sleeved crewmember to patch and seal differently sized cracks or holes in a space module shell, under simulated depressurization conditions.

2. INTRODUCTION

Both the international Space Station and the future ESA/Russian station will be operated in the low Earth orbit at the beginning of the new millenium to perform manned scientific and technological experiments in microgravity.

The consequent long-term exposure to the hostile space environment around our planet implies consequent risks of fast depressurization of the space station, should debris collide against the modules or the docked orbiter shell.

The subject tests were carried out at ESA/ESTEC during Autumn '92 to get some preliminary answers on the question whether the human intervention can be conceived in situ right after the unfortunate occurrance by using simple repair methods and tools without the need to evacuate, depressurize and then seal the shell micro-aperture from outside the module, under the so-called EVA conditions.

3. TESTS OUTCOME

The tests were carried utilizing a dynamic test chamber (DTC-5) at the ESA/ESTEC testing area; such a chamber provided more than 50 cubic meters, namely a sufficiently high vacuum capacity to run the test sessions in a representative fashion.

This campaign was produced and conducted under the auspices of the ESA/SSM-MCUD "Payload operations, integration and training division" (MCUD-GO) by the "Columbus crew activities and on-board payload operations office".

The test was carried out using the facilities provided by the ESA-ESTEC testing personnel; the test subjects' team was composed of this paper's authors plus other European, American and Soviet colleagues among whom F. Culbertson (Space Shuttle commander), E. Gibson (Skylab astronaut) and O. Atkov (MIR cosmonaut).

3.1 Setup of the first test

For the first test run, a portion of the APM shell provided by Alenia Spazio (Torino, I) was used as target hardware: two small apertures (holes) had been drilled into respective panels to simulate impact holes passing through the shell protection system (MDPS) down to the shell itself or "backwall" (fig. 2).

The shell portion had the following geometrical characteristics (ref. fig. 1 and 3):

- 1.4 m x 2.4 m
- 4.4 m of curvature diameter
- 3.2 mm thick

Such holes were to be connected, one at a time depending on the test run undergoing, via a flexible hose to a port of the DTC wherein a pressure of 0.2 mbar was generated.

The connecting hose was outfitted with a bellow-sealed valve to control the airflow into the vacuum chamber and a connection to a helium leakage detector (Ultratest F/F AG, see fig. 1).

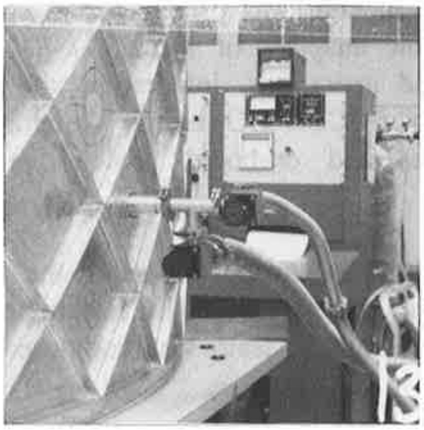

Fig. 1: test configuration

The shell material was aluminum alloy; as shown above, the shell portion had a system of webs stiffening it on the convex part, as in the flight element design.

The two passing holes had diameters of, respectively, 15 and 25 mm diameter; they had been drilled in two different shell panels to resemble in a simplified fashion the result of two different micro meteoroid damaging the shell with normal incidence.

In fact, as far as the layout and roughness to be expected for a shell hole, the highly irregular shape and borders of such an aperture (morphology which is typically caused by the spreading of energy of particles able to pass through such a two bumper shield protection system) were not reproduced when drilling the simulation holes, for simplicity reasons.

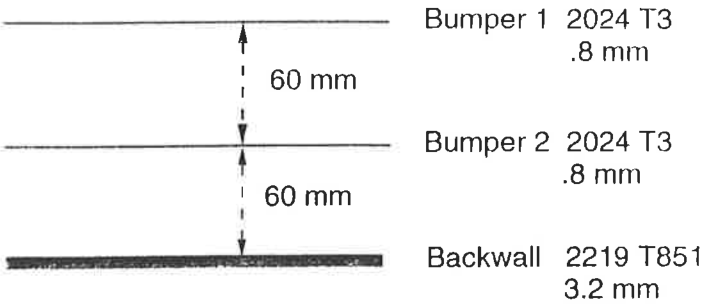

Fig. 2 The micro meteoroid and debris protection system

Only one hole at the time was to be connected to the pressure chamber, by means of the connection hose which adhered to the relevant panel via the interface device.

Repair tools

Once the pressure chamber was pumped down to the target pressure level (0.2 mbar), the valve was to be opened to simulate abrupt depressurization conditions in the ambient environment via the hole in the shell, as in the case a micrometeoroid impact had occurred in space.

Two repair methods were foreseen to be carried out for testing; namely, once the test engineer had given the go-sign to open up the valve, thereby initiating the depressurization flow through the aperture, the test subject was expected to seal the aperture by using either of the following items:

- commercial **vacuum clay** (fig. 5)
- **aluminum patching disk with adhesive sealing ring** (fig. 7)

3.2 Results of the first test

The noise produced by the sonic flow entering the chamber via either holes was in the range of 20 to 30 dB: consequently, no headset was to be required neither for the facility operator nor for the test subject during the actual test sessions.

Both repair methods (ref. above paragraph) were preliminarily exercised during a test readiness review; due to the planar surface of the aluminum plate against the curvature of the shell portion and to the relatively stiff rubber ring built on it, the "rubber-ringed plate method" resulted not effective enough to adequately seal such shell penetrations.

This disk rubber ring was tentatively changed into a layer of vacuum clay to obtain a more flexible sealing ring vis-a-vis the typical shell curvature, although proper testing of this idea was decided to be postponed to the second test session.

Two operational test runs were conducted, during which the following variables were measured by carefully monitoring temperature and pressure levels:

- **flow rate**, right after valve opening and throughout the patching exercise until the test subject considered the repair task completed
- **leakage**, right after the repair action was terminated, to check the seal quality.

By knowing pressure, volume and temperature data from the facility control panels before and after the hole was repaired, it was possible to estimate the volume of air lost during the repair activity.

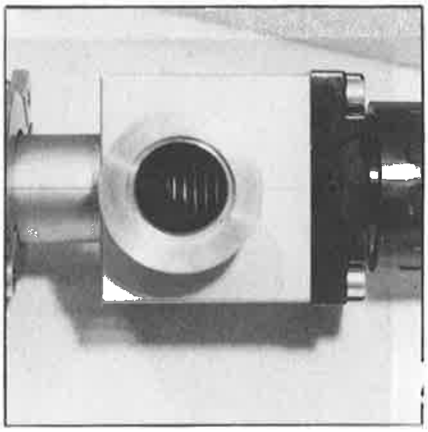

Fig. 4: clay bits, torne off by depressure, found inside the valve

o The vacuum clay ball sealing the 25 mm diameter hole was then left into place for 5 days; after this period of time another accurate leakage measurement was performed with the helium leakage detector, showing no measurable increase in leak rate.

Hole diam.	Tool	In.pr (mb)	Final press.	T (K)	Air lost(l)	Closure time (s)	Post-rep.leak (mb x l/s)
15mm	Clay	0.2	1	293	40	3	< 3x10 exp -9
25mm	Clay	0.4	2	293	80	3	< 3x10 exp-9

o The vacuum clay sealing the 25 mm hole was then analyzed after disassembling the test hardware:

- a relevant amount of material choked the hole beyond the shell backwall, by intruding into and beyond the 25 mm diameter aperture, down into the interface device for 4 cm: as a consequence, after diassembly the sample of sealing clay was found assuming a "fungus"-type shape (fig. 5)

- some tiny bits of clay were found extruded in the hoses and valves (fig. 4)

- partial cracking on the external surfaces of the mentioned intrusion appendix was identified (fig. 5)

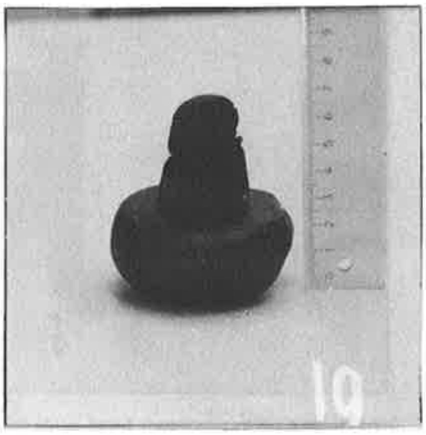

Fig. 5: sealing clay after removal

3.3 Setup of the second test

During the second test, the same facilities were used as in the first one, but with different test hardware.

The large shell portion used in the first test was replaced by a small planar shell sample which was a representative piece of Columbus APM "backwall" (see fig. 2), previously integrated with the MDPS bumper shields and subjected to hyper-velocity bombardment test.

The hole had been generated by shooting a 10 mm diameter projectile with normal incidence against the piece of MDPS at a velocity of 6.2 Km/s: such a hole was definitely bigger than the one used in the first test, namely with an approximate diameter of 35 mm, and with bigger and sharper strain ribs sticking out from the backwall panel plane.

Based on the Kessler model, the probability that such a micrometeoroid hits the Columbus APM, within the 1992 baseline scenario conditions, is roughly 6 x 10 exp(-3) in 10 years over a 160 square meter surface.

The adoption of this new target hardware, provided by ESTEC/YM, allowed to ameliorate the test in the following terms:

- increase the representativeness of the geometrical characteristics of the shell damage

- remove any obstacle downstream in the areas surrounding the damaged part, to avoid any artificial limitation to the natural strain of the clay into the hole as induced by the depressure during and after the test subject's manual intervention.

As a matter of fact, a modus operandi where a crewmember safely seals such shell holes in a few seconds (to then take care of repairing the MDPS panels from outside the module in EVA suit, without any prior depressurization of the APM), would be preferred to the baseline assumption requiring the crew to merely evacuate the module under emergency and let it depressurize, without performing any immediate intervention in situ.

The shell sample plate was mounted on a flange of a cross interface piece, provided with four nozzles (fig. 6) where two nozzles were closed by transparent panels to allow for two videocameras to film the sealing phenomena from two different viewpoints, both downstream with respect to the area from where the test subject would perform the repair test.

Fig. 6: W. Ockels testing repair methods with the cross-flanged test setup

Repair tools

Based on the experience gained in the first test, two types of repair tools were used two carry out the various test runs; namely, these tools were:

- commercial **vacuum clay**

- **aluminum disk with a vacuum clay sealing ring** (fig. 7)

The test runs were conducted by alternating the usage of the clay with the usage of the aluminum disk; at the last run, this patching disk was left on to seal the backwall hole for 64 hours to check out its long term sealing capabilities.

3.4 Results of the second test

As in the first test, **flow rate** and **leakage** were measured; two runs (here not reported) were performed with insufficiently large bits of clay, which, due to the clay inherent mildness and the limited mass used, did not withstand the depressure and collapsed, inhibiting an effective sealing and causing to abort such test runs.

After the first test run, an analysis of the clay ring sealing the aluminum plate against the backwall showed that the high pressure force, exercised via the sharp edge of the plate border at the coupling between the plate and the shell, almost fractured the clay layer forming the sealing ring (fig. 7).

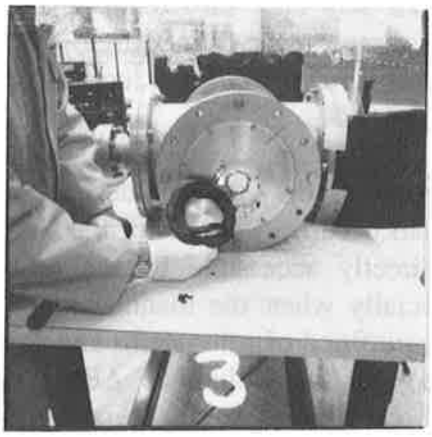

Fig. 7: the clay ring cracking at the plate-shell coupling

Hole diam.	Tool	In.pr. (mb)	Final press.	T (K)	Air lost (l)	Closure time (s)	Post-repair leak (mb x l/s)
35mm	Patch	0.2	8	293	400	8	< 3x10 exp -9
"	Clay	3	4	293	20	6	negligible
"	Patch	4	20	293	740	64hrs	< 3.5x10exp-5

3.5 Results summary

The two test sessions above reported allowed to achieve the following set of preliminary results:

3.5.1: micrometeoroid-caused holes in the shell in the order of 10 square centimeters can be temporarily sealed (up to hours) by a shirt-sleeved crewmember using commercial vacuum clay;

3.5.2: the simple repair technique based on using such a chop of clay is generally more effective than the technique based on the aluminum patching disk with sealing ring;

3.5.3: the vacuum clay used tends to fracture itself over time: means to stiffen the clay against shear forces need be looked at and tested out;

3.5.4: in most of the cases of debris impact, damage shall occur in portions of the shell not fast nor directly accessible by the on-board crew, especially when the manned module is completely outfitted of subsystems and payload utilities (e.g. in the Columbus APM "stand-off's"): a real-time impact location system, currently being defined, could definitely help cut crew intervention times down (subject for further testing);

3.5.5: since the sonic conditions at the hole interface were guaranteed only at the very beginning of the test sessions (due to the back pressure build-up and to fluid-dynamic losses in the hoses and valves), the loss of air to be expected in the real case would likely be higher (subject for further testing).

4. CONCLUSIONS

The test outcome demonstrated the effectiveness of using **commercial vacuum clay** as repair tool for immediate intervention on small cracks or penetrations (in the order of square centimeters) occurring in the shell of a manned space vehicle as result of micrometeoroid or debris impact.

Such a clay needs to be stiffened by some additional compound or by fabric: this is the subject for further tests, with the aim of bettering the clay resistance to those bending and shear forces resulting from the strong pressure differential the clay 'patch' is subjected to.

The preliminary results hereby achieved let us conclude that **conceiveing the possibility of a shirt-sleeved manned intervention on a debris damage occurred in a manned space station shell is definitely a realistic assumption to be further analyzed, insofar as the crewmember can take action in a range of seconds, thus limiting the cabin air loss down to a range of hundreds to thousands of litres only**.

This appears to be the case for hole sizes up to a few square centimeters, **5 to 10 square centimeters** in this series of tests, which is already a very rare occurrance, statistically, within the currently foreseen boundary conditions.

As far as the Columbus Programme is concerned, it stems from the above the importance of the requirement, as identified during the ESA Columbus underwater simulation campaigns (ref. doc. 4 and 5), for the capability to easily tilt down Space Station racks within 30 seconds, to ease fast shell access.

The proven feasibility of such an approach allows to conceive further tests based on larger intervention times on shell penetrations, by on board shirt-sleeved crewmembers.

The approach of recreating the same boundary conditions and operational situations expected in space by setting up and performing adequate "hands-on" tests has once more proved to be a very successful methodology: it certainly remains the preferred strategy to eventually build and operate safe and user-friendly space manned laboratories and modules for the future international space stations.

5. REFERENCES

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