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Mir Environmental Effects Payload Handrail Clamp/Pointing Device

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Abstract

The Mir Environmental Effects Payload (MEEP) consists of four International Space Station Alpha (ISSA) Risk mitigation experiments to be transported and deployed in a common carrier. This carrier is to be transported to the Mir Space Station aboard the Space Shuttle and deployed during a US Extravehicular Activity (EVA) on the handrails of the Mir Docking Module (DM). This paper describes the design of the handrail clamp/ pointing device used by the astronauts to attach the carrier to the station.

Introduction

In an effort to increase the probability of success and the overall safety of ISSA, the National Aeronautics and Space Administration (NASA) ISSA office requested proposals for a series of risk mitigation experiments. NASA Langley Research Center (LaRC) proposed a universal carrier to be deployed on the Mir Space Station as an exposure facility. Four different researchers expressed an interest in having experiments deployed in the carrier. Two were micrometeoroid and debris experiments: Orbital Debris Collector, an experiment that uses a material called aerogel to capture the hyper velocity particles; and Polished Plate Micrometeoroid and Debris, an experiment in which the impact craters in witness plates are analyzed to validate statistical models of debris at station altitudes. The remaining two experiments are materials exposure and contamination experiments: Passive Optical Sample Array (POSA), an experiment to study the effects of the contaminants that surround a working space station on optical coatings and various other “space-rated” materials; and POSA II, a similar experiment to POSA, with different material samples and an additional requirement to experience atomic oxygen effects as well. After negotiations with the Russian Space Agency (RSC), an agreement was reached — the experiments could be deployed on the DM that was being delivered by the Space Shuttle (STS) to Mir, and the units could be deployed with a US EVA. To preclude modification to the Russian-manufactured DM, the decision was reached to mount the experiments to handrails on the DM with an EVA-deployable clamping mechanism. Each of the four experiments had different viewing requirements. Two of the experiments required ram/wake viewing, which required Mir flight orientation data. This data was difficult to ascertain, and with the compressed schedule, time was not available to wait for resolution of the flight orientation. Consequently, it was necessary to develop a pointing device with a great deal of flexibility.

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The Handrail Clamp/Pointer

One generic device was developed to mount each of the four payloads. Each device had two mechanisms: one to clamp on the handrail, and one to point the payload. A simple over-center mechanism was chosen for the handrail clamp, and an adjustable preload ball and socket was chosen for the pointer. Since the items were being designed for space flight, materials were selected that would not outgas. The POSA experiment set even more stringent guidelines for outgassing than normal STS guidelines and, as a result, did not allow the mechanisms to be lubricated. Also, dissimilar materials were chosen to prevent "cold welding".

The Handrail Clamp

On the DM, several straight sections of handrail were available for clamping. Initially, RSC agreed to provide several 1000-N clamps, shown in documents from joint Johnson Spaceflight Center (JSC)/RSC EVA requirements working groups. After several unsuccessful attempts to acquire these clamps, the decision was made to develop the clamps in-house. The 1000-N clamping force was chosen as a design point. Only rough external dimensions were available on the RSC clamps, so it was not possible to simply manufacture a duplicate. An entirely new clamp had to be designed (Figure 1). Experience has shown that "simple works best" when designing tools for use during EVA, so an over-center mechanism was chosen to provide the clamping action. The cross-section of the handrail was given as 25 mm square with a tolerance of ±1 mm. The wall thickness was shown to be 2 mm, with no tolerance given. An analysis was performed to verify that this clamping force would not damage the handrail. A problem arose in providing a consistent clamping force with the 2-mm variation in handrail external dimensions. The variation of the handrail dimension would probably be less than the given tolerance over the width of the clamp, but the clamp had to allow for the tolerances shown on the drawings since the actual handrail was not available for measurements at the time of the design. Using a stack of disk springs, a spring-loaded button was developed to provide a consistent load for any handrail with external dimensions within the tolerance range. To make the clamp more stable and decrease the concentrated load on the handrail, the clamp incorporated three load points. A simple four-bar linkage was used to provide three uniform over-center motions with one actuation lever. Roller bearings were used at the over-center contact points to provide a lower, more consistent actuation force and to prevent unnecessary damage to the handrail. A spring-loaded lock (lever lock) was provided for the clamp lever to prevent the lever from being inadvertently knocked back over-center. For additional safety, a capture plate with a simple push lock (capture plate lock) was provided to keep the payload attached to the handrail in the event the clamp became unlocked while on orbit. Since the clamp was being designed for free-floating EVA, the mechanism had to be designed for one-handed operation. There were also several general design requirements for EVA tool design: big actuating levers to facilitate EVA-gloved operation, sharp corner/edge guidelines, and a maximum 120-N actuation pulse [1].

The Pointer

The pointer employs a ball in a spring-loaded socket and relies on friction to provide the locking torque (Figure 2). To prevent accidental overloading of the handrail, the pointer had to provide a torque-limiting feature, which allowed the payload to slip in the socket in the event of an inadvertent kick load (550 N, 125 lb). Locking torque of the ball and socket was driven by two items: ball diameter, which determines the moment arm at which the friction force acts; and spring force, which determines the magnitude of the friction force. Because the pointer device mounted atop the clamp body, the external dimensions of the clamp body limited the maximum ball diameter. Disk springs stacks were again used to provide the spring force on the socket. A lead screw controlled the spring stack compression, thus providing an adjustable spring load. A locking knob (similar in operation to a knob in the EVA tools catalogue [2]) was provided to control the position of the lead screw. The lock was needed to prevent the lead screw from backing out once the preload position was achieved. The spring rate and screw pitch were sized per the following requirements: maximum hand-applied torque, 4.5 N-m; maximum on-orbit acceleration (station reboost or shuttle docking), 0.06 g. This acceleration value was found in a presentation that was the best source of information available at the time of design development. Later, after the pointer design was in fabrication, another document [3] became available that showed a 0.5 g requirement for Mir payloads, with a first mode below 20 Hz. This new requirement caused an order of magnitude increase in the spring force. The higher spring rate was achieved by rearranging the disk spring stacking sequence. The increased locking torque required to maintain pointing at 0.5 g acceleration did not exceed the break-away torque value that satisfied the kick load constraint. The increased spring rate did, however, drive the knob actuation torque well beyond an acceptable range. As a result, a 7/16-inch hexagonal protrusion was added to the knob, thus allowing the use of an EVA contingency tool to tighten the knob.

Testing and Development

By late December, 1994, it was apparent that the Russian handrail clamps would not be available for MEEP. Therefore, design and manufacturing of in-house hardware began in earnest. By April 17, 1995, one high fidelity proto-flight unit of all the MEEP hardware (experiment container, handrail clamp, and an STS payload bay sidewall carrier) was delivered to the JSC Weightless Environment Training Facility (WETF) for crew evaluation. In general, the eight astronauts who trained with the hardware were satisfied with the overall performance of the hardware. Three requests for changes that affected the handrail clamp/pointer device were made: to shorten the handrail clamp lever; to modify the method of attachment of the experiment container to the pointer; and to modify the bayonet fitting that interfaced with the astronaut mini-workstation, thereby facilitating simultaneous transport of the two devices. These requests were incorporated into a new proto-flight unit that was delivered to JSC for a manned thermal vacuum test on June 29, 1995. The test was conducted at -80°C and 10^{-3} Pa. The handrail clamp performed flawlessly, but the pointer developed an interference that prevented the ball from moving freely. The unit was returned to LaRC for disassembly and inspection. The designed clearance that provided for thermal growth mismatch was substantially reduced by manufacturing inaccuracies. As a result, the body of the pointer had pinched the ball at the cold test temperatures. In order to meet the delivery schedule to JSC, dimensional verification was not performed, and, as a consequence, the inaccuracy was not discovered. The problem was corrected with the use of shims. By August 1, 1995, all four flight units were delivered to Kennedy Space Center for a fit check with the Russian DM and the application of final flight markings. The devices were once again returned to LaRC to have those flight markings engraved and painted with a special ultra-low outgassing black ceramic paint (RM 550 IB). A second WETF unit was manufactured along with the flight units. Both WETF units were delivered to JSC to assist with mission timeline testing and continued crew training. The flight units were delivered to SpaceHab December 15, 1995, to be packed in soft stowage in the SpaceHab Module.

References

1. Extra Vehicular Activity (EVA) Hardware Generic Design Requirements Document, JSC-26626
2. EVA Tools and Equipment Reference Book, JSC-20466 Rev B
3. Hardware General Design Standards and Test Requirements, US/R-002, Dec. 1994

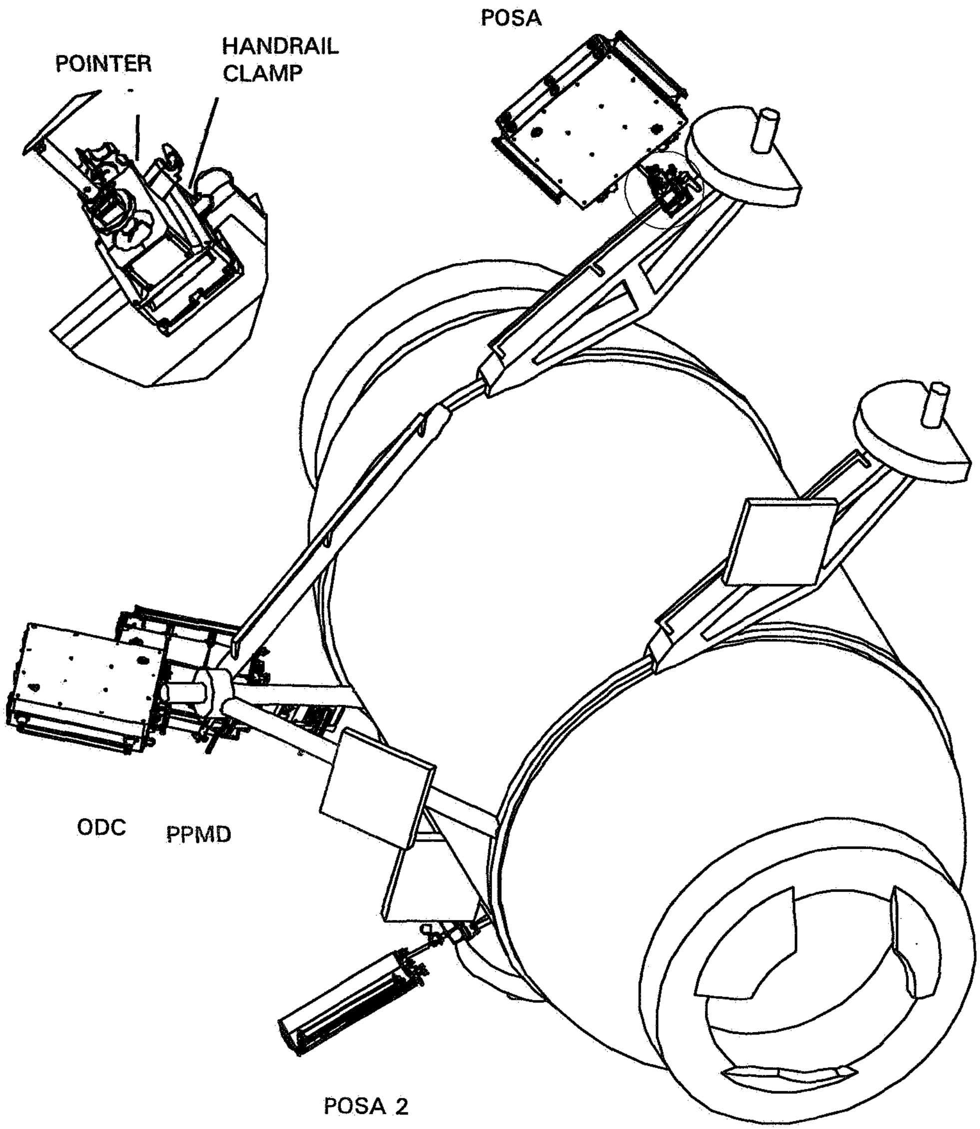

FIGURE 1. MEEP DEPLOYED ON DOCKING MODULE

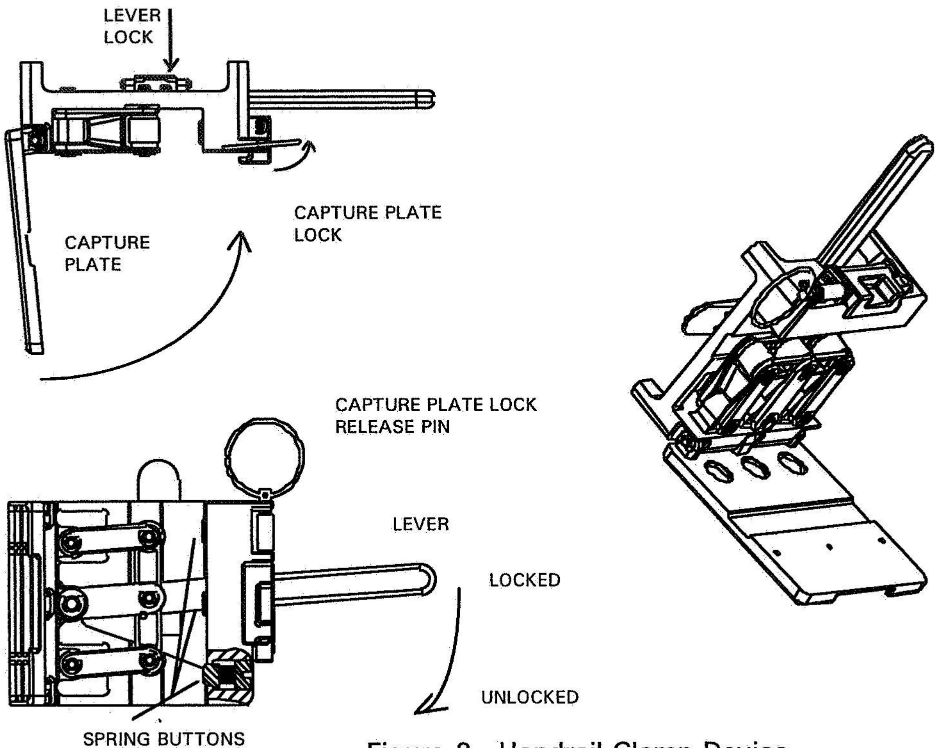

Figure 2. Handrail Clamp Device

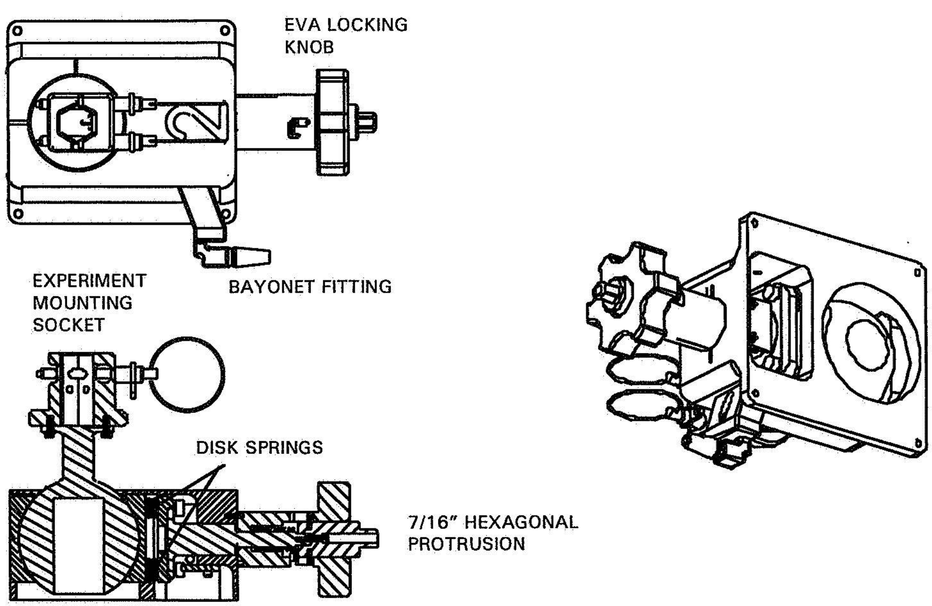

Figure 3. Pointer Device