TECHNIQUES FOR SUCCESSFUL UTILIZATION OF EXTRAVEHICULAR ACTIVITY IN PAYLOAD OPERATIONS

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The Space Transportation System (STS) offers a number of advantages over the use of expendable launch vehicles in payload operations. Paramount among these is the presence of a flight crew and the ability of the payload manager to use that crew. A prime example is the conduct of Extravehicular Activity (EVA) in support of payload operations (Figure 1). This is a very effective method of accomplishing tasks which heretofore required the use of complex automated mechanisms. The spectacular successes of the Apollo and Skylab programs clearly illustrate how man's capabilities as observer, mechanic, builder, and scientist can be utilized when extended beyond the confines of his space vehicle. The applications of EVA techniques are not limited to planned mission objectives, but include a capability to conduct unanticipated maintenance and repair operations as well. As demonstrated by the saving of Skylab, EVA can make significant contributions to a program.

The Shuttle Orbiter has EVA provisions which are baselined on all missions. These include two Extravehicular Mobility Units (EMUs), an airlock, translation and restraint aids, general purpose hand tools, and equipment stowage containers (Figure 2). Through proper planning and program development, the payload manager is able to take advantage of this existing STS service and increase reliability while at the same time reducing costs. The difficulty is in determining when and how to utilize EVA in payload operations. This issue can be divided into two areas:

- Cost effectiveness of accomplishing a task with EVA, and
- Proper development of EVA hardware and procedures.

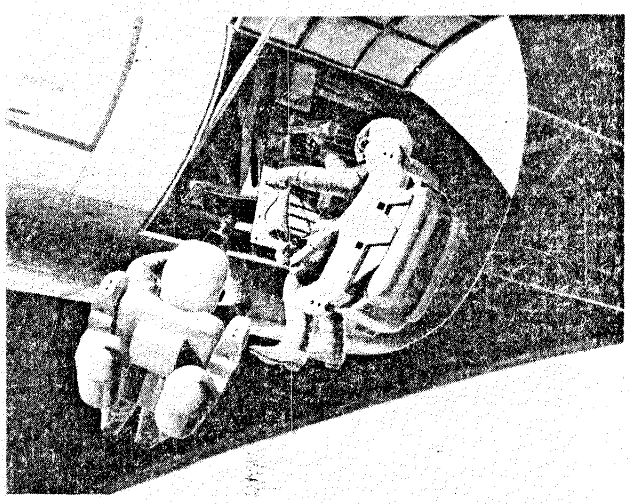
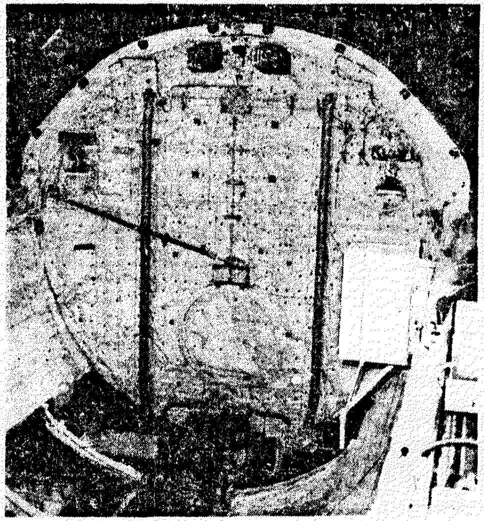


Fig. 1 - EVAs conducted for on-orbit maintenance of payloads

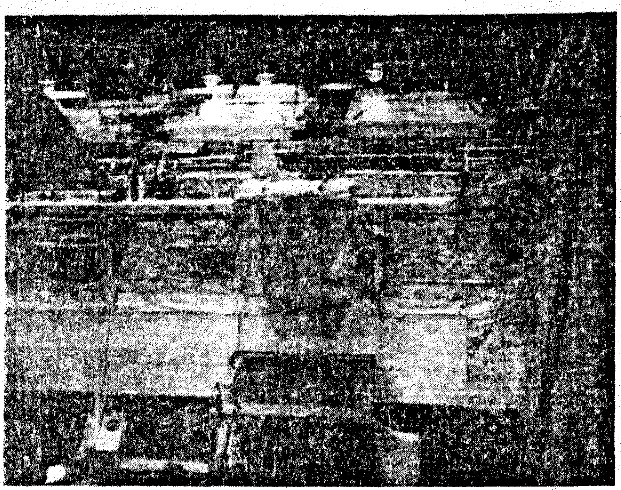
Determining whether or not an EVA is the most effective method of accomplishing a task requires an understanding of the relative merits of using manned systems versus automated systems. Usually, this is a question of having an EVA crewmember operate a mechanism rather than designing a remotely operated device. In order to make a rational decision, the payload manager must conduct trade studies to weigh these alternatives. In basic concept, these trades are similar to those conducted to select other systems in the payload.

The most important point is that these trades be performed at the same time the other studies are being conducted. That is, during Phase A of the design and development process (Figure 3). The payload manager is then able to establish EVA design requirements early in the program and costly modifications or "add-ons" will be avoided later. Also, design funds are not expended on the normally more expensive automated devices. A Manned Activity Manager should be appointed early in Phase A with the

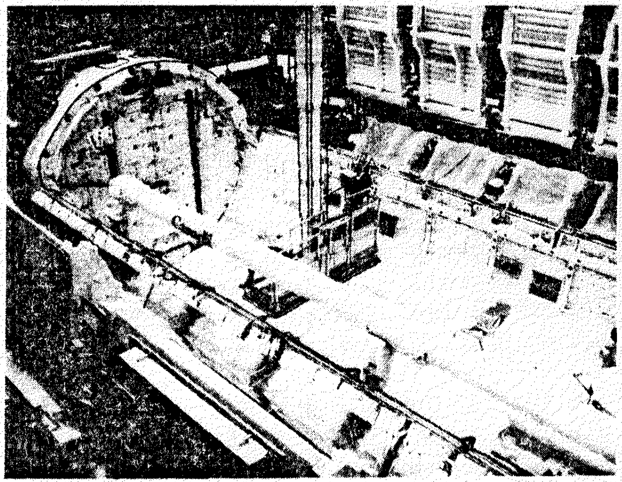
Extravehicular Mobility Unit (EMU) Two are flown on each mission



Forward bulkhead showing handrails, airlock, CCTVs, and the Tool Box. The Portable Foot Restraint platform is mounted below the Tool Box



Tool Box mounted on sill longeron of payload bay. Slidewire standoff is visible above box



Overview of payload bay with RMS, hingeline handrails, RMS, and slidewires in place

Fig. 2 - Orbiter EVA Provisions

responsibility of insuring continued compliance with EVA design criteria through all phases of the program.

One example of a payload being developed for EVA maintainability is the Space Platform being proposed by the McDonnell Douglas Astronautics Company (MDAC). In defining this system, MDAC conducted numerous trade studies to arrive at the most effective maintenance approach for this low earth orbit satellite. Trade studies considered the following:

- Costs of orbital maintenance
- Complementary ground logistics system requirements
- Ground-to-orbit transportation requirements
- Shuttle Orbiter revisit opportunities and cost-sharing possibilities with other payloads

PHASE 0	PHASE A	PHASE B	PHASE C	PHASE D
RESEARCH	CONCEPT STUDIES	CONCEPT SELECTION	DESIGN ▲ PDR ▲ CDR	PRODUCTION

Fig. 3 - Payload Design and Development Process

The common selection criteria used in each of these trade studies was the life-cycle cost of the alternatives. The approach selected is to design the Space Platform with sufficient reliability (through redundancy and and failure tolerance) that an autonomous back-up capability will maintain system operation until on-orbit maintenance can be performed (Figure 4). Although maintenance is accomplished during premium (EVA) mission time, analyses show the costs associated with conducting EVAs is minor compared to the alternative concepts of either extensive redundancy in all automated systems or ground servicing. Providing on-orbit servicing will extend the life of the Space Platform and substantially reduce total costs.

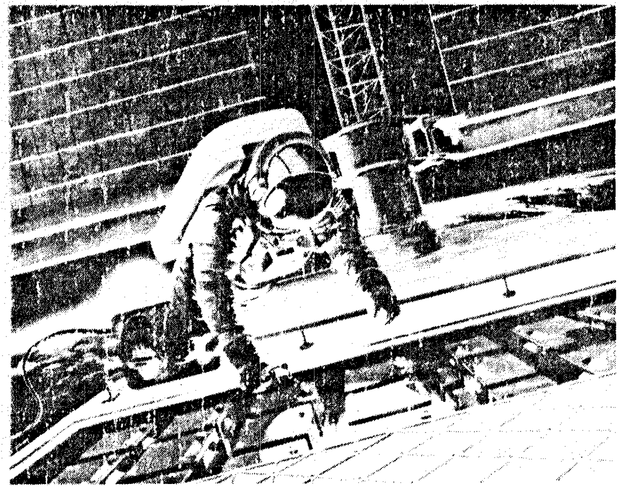


Fig. 4 - Space Platform EVA maintenance

In conducting the trade studies, the payload manager must keep two considerations in mind: (1) if a manually operated device is not the best primary system, it may still be the most effective back-up method, and (2) even though no specific EVA tasks are identified in the trade studies, the payload should still remain EVA compatible. In this case, compatibility would include: positioning mechanisms for accessibility by a suited crewmember, insuring all hazards (sharp edges, stored energy) are avoided or can be safed, and sizing fasteners, disconnects, fittings, and other hardware to be compatible with the EVA tools flown on the Orbiter and the force application capabilities of an EVA crewmember.

EVA compatibility in a non-EVA payload is a particularly sticky issue. However, a review of both past and present space programs will quickly underscore the wisdom of providing this compatibility. The exterior of the Skylab for example, was designed to MSFC STD 512, MAN/SYSTEM DESIGN REQUIREMENTS FOR WEIGHTLESS ENVIRONMENTS. Although no EVAs were planned in the vicinity of the Orbital Work Shop (OWS), the following are typical of the modifications MDAC made to insure EVAs were not precluded in that area.

- Round-off all corners
- Install caps on the end of all hat sections
- Remove sharp edges and corners on radiator panels

These modifications were responsible in part for allowing the conduct of ten EVAs during four Skylab missions which accomplished 15 repair objectives, 23 investigative activities, and enhanced 16 experiments (Figure 5). None of these EVAs were planned prior to the launch of Skylab, however they were the means by which the mission was saved.

More recently, a number of EVA tasks have been developed for the Shuttle Orbiter. These tasks are primarily designed to return the Orbiter to a safe configuration for entry and include: (1) closing the deployable radiators and payload bay doors, (2) latching the payload bay doors, and (3) restowing and securing the Remote Manipulator System. In

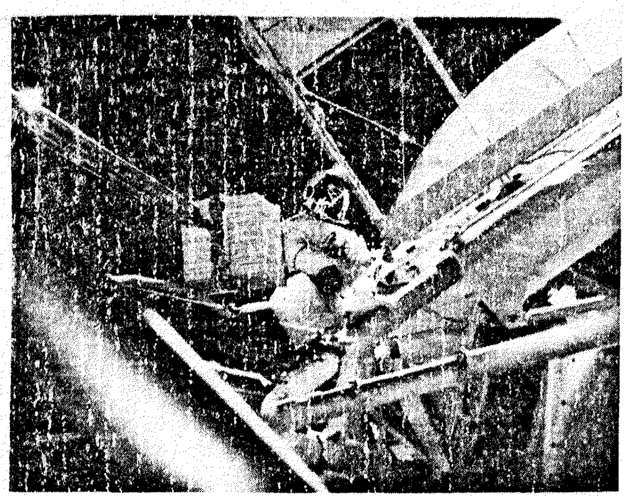


Fig. 5 - Skylab EVA

each of these cases, the EVA was an "add-on" capability which involved significant costs not only in hardware development but also in training the crew for tasks which were not optimized for EVA (Figure 6). The importance of developing this EVA capability, however, was demonstrated on STS-3 when the port aft bulkhead latch gang failed. Fortunately, thermal conditioning allowed the latch gang to close, however, post-flight inspection revealed severe structural damage to the power drive unit mounting lugs (Figure 7). Had this system failed completely while on-orbit, the only way to bypass the failure would have been to conduct an EVA to install the tool shown in Figure 6. Although these systems were originally considered adequate without manual back-up, an EVA capability developed late in the program was very nearly required to bypass an actual flight failure. The really unfortunate aspect is that a back-up EVA capability could have been designed into the systems originally at no additional cost. This failure to remember lessons learned in previous programs has already proved to be very costly in developing "work-arounds" and bandaids.

If the trade studies show EVA to be the most effective approach to a task, then EVA compatibility must be considered a programmatic requirement with EVA design criteria set at the beginning of Phase B (Figure 3). Initially, design criteria will be general in nature and are intended to insure the various elements of the program do not establish system designs which will preclude the EVA. These criteria are contained in JSC 10615, EVA DESCRIPTION AND DESIGN CRITERIA DOCUMENT, and may be grouped into the following three areas:

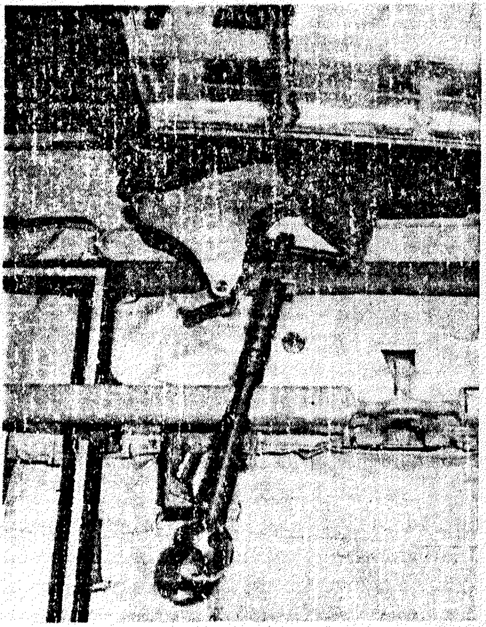


Fig. 6 - 3-Point Latch Tool installed on aft bulkhead of Orbiter

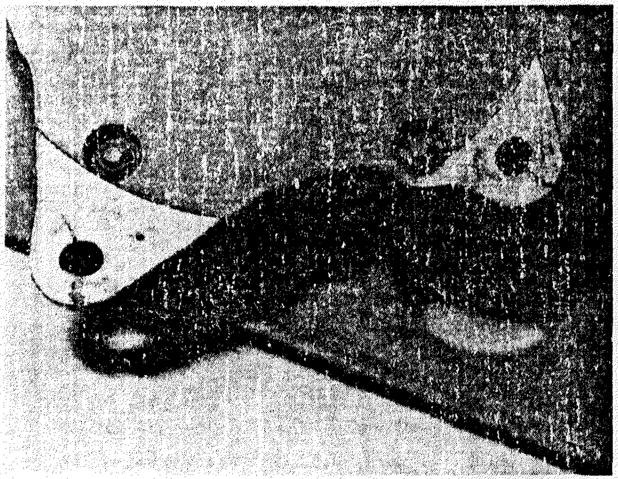


Fig. 7 - Port aft bulkhead latch gang power drive unit (STS-3)

- Access to the worksite - provisions must be made to get the EVA crew and any required equipment or tools safely to the worksite

- Worksite environment - the worksite must be safe and provide adequate volume, lighting, communications, and restraint for both the crew and and any necessary equipment

- EVA mechanism design - the crewmember interfaces and manually operated mechanisms must be designed and positioned so as to minimize the affects of zero-G and the pressure suit

These three groups also represent a decreasing order of impact to the overall payload program. Safe access to the worksite will probably affect most payload elements, while the actual environment at the worksite may only impact those systems in the immediate vicinity. The area of tool and mechanism is the most critical item in terms of EVA success but probably affects the fewest payload systems. This flow is in concert with most program design and development processes in that, as systems mature, design specifications become more firm. When the design is to provide an EVA back-up to an automated mechanism however, the manual capability must be developed from initial concept selection in Phase A in parallel with the remotely operated portion of the system.

Often, the automated section is designed without due consideration for the crewmember operated section. The EVA mechanism is added at a later date (usually one week prior to the PDR), and turns out to be a device which bypasses few if any of the creditable failures, requires excessive force to operate, and is virtually inaccessible. These problems can be avoided by developing both the automated and manual systems to compliment each other.

> For example, a power drive unit uses two redundant motors to drive a gear box via a differential. The gear box operates a push/pull rod. If analyses show the best EVA approach to be bypassing failures in the power drive unit, the wrong technique would be to simply provide a tool to manually operate the gear box. This device would only bypass electrical failures. A better technique would be to provide an independent means of turning the rotary actuator after disengaging the gear box. This system would then bypass both electrical and mechnical failures.

The important point is that this system cannot be designed piecemeal. The manual drive capability must be integrated into the system from the beginning. Other advantages of totally integrating the two systems include:

- Keeping force levels and throw distances low
- Utilizing optimum crewmember dynamics
- Incorporating the "tool" into the basic mechanism, or at worst being able to use an existing Shuttle EVA tool
- Minimizing "overhead time" (tool/equipment transfer, restraint set-up, repositioning)
- Causing the least impact to the baseline EVA crew training

At this point, it is apparent that manned activities are essentially no different from other elements in a payload program. The trade studies conducted to analyze the potential benefits of EVA operations are analogous to those conducted to select other payload systems. EVA compatibility is a programmatic requirement in EVA payloads, design criteria must be set early, and manually operated devices must be included in all system development phases. By doing so, the payload manager is able to consider more options in selecting systems, save money and weight while increasing reliability, and enjoy a high level of confidence in those payload activities which are being supported by Extra Vehicular Activity.