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EVA Access Facility: A Comparative Analysis of Four Concepts for On-Orbit Space Suit Servicing

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EVA ACCESS FACILITY: A COMPARATIVE ANALYSIS OF FOUR CONCEPTS FOR ON-ORBIT SPACE SUIT SERVICING

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This study presents four concepts for on-orbit space suit donning, doffing, servicing, check-out, egress and ingress. The four concepts are: the Space Transportation System (STS) Type (shuttle system enlarged), the Transit Airlock (Shuttle Airlock with suit servicing removed from the pump-down chamber, the Suitport (a rear-entry suit mates to a port in the airlock wall), and the Crewlock (a small, individual, conformal airlock proposed by William Haynes). Each of these four concepts is compared through a series of seven steps that represent a typical Extra Vehicular Activity (EVA) mission: (1) Predonning suit preparation; (2) Portable Life Support System (PLSS) preparation; (3) Suit Donning and Final Check; (4) Egress/Ingress; (5) Mid-EVA rest period; (6) Post-EVA Securing; and (7) Non-Routine Maintenance. The different characteristics of each concept are articulated through this step-by-step approach. Recommendations concerning an approach for further evaluations of airlock geometry, anthropometrics, ergonomics, and functional efficiency are made. The key recommendation is that before any particular airlock can be designed, the full range of space-suit servicing functions must be considered, including timelines that are most supportive of EVA human productivity.

The capability for extra-vehicular activity (EVA) contributes significantly to the overall productivity of humans in space. A dramatic increase in the number and complexity of tasks assigned to the pressure-suited astronaut characterizes the historical evolution of EVA from Gemini through Apollo. The Skylab EVAs demonstrated that the fundamental creativity and flexibility of humans in the space environment could compensate for mechanical and structural failure. During the development of the Skylab EVA system, crewmember assist mechanisms and EVA scenarios were made significantly less complex as mission planners realized the capability of the EVA astronaut (ref. 1). The EVAs performed during Skylab 2 were relatively simple in terms of support equipment, yet they were crucial to the success of the mission. The Skylab Airlock Module played a critical role in these EVAs and provided the first precedent for a space station EVA airlock. The first data on airlock sizing equipment stowage and free volume was obtained during the Skylab mission (ref. 2).

Since 1982, the Space Transportation System (STS) places increasing emphasis upon the regular use of EVA for in-flight development, recovery, and repair of space systems. This trend is expected to continue on the Space Station. The dexterity of the human operator in EVA is transmitted through the human/machine interface imposed by the protective envelope of the suit; hence, significant advances in EVA capability are due primarily to improvements in the design of the space suit. The primary goal of space suit design is to reduce losses in human dexterity and in mobility to the extent possible within safety constraints. The shuttle Extravehicular Mobility Unit (EMU) represents a refinement in technology over the cumbersome pressure suits of the first EVAs. Despite these improvements, the use of EVAs on space stations will require a new generation of space suits with capabilities that exceed those of the current EMUs. In addition, the demands and constraints imposed by planned space station EVA operations necessitate the development of new hardware and procedures for EVA support, including servicing of the suit and its life support systems.

Beginning in the 1960s NASA Ames Research Center has conducted several studies aimed at developing the technology of EVA suits. The Ames AX series suits demonstrated the use of low-friction rotary bearings between segments to achieve exceptional mobility in a hard suit (ref. 3). The current AX-5 suit under development by Vic Vykukal at Ames Research Center incorporates state-of-the-art technology to provide excellent mobility and low leakage in a low maintenance suit with a long projected service life. This totally hard suit is durable enough to allow work in areas that may have sharp edges and pointed structures. It is equipped with replaceable sizing rings to permit major suit parts to be used by crewmembers of differing body sizes. The modular construction of the suit will enable rapid repair or service changeout of individual suit parts.

This paper describes and compares four concepts for an EVA suit servicing facility on board the space station. The functional requirements and constraints of such a facility are drawn from the projected space station EVA operations baseline (ref. 4). All four concepts assume the use of an advanced space suit, with sufficient operating pressure with respect to the space station cabin pressure to eliminate the need for EVA crew to "prebreathe." Prebreathing is a

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procedure by which the crewmember breathes pure oxygen for a number of hours prior to beginning the EVA. Prebreathing reduces the risk of decompression sickness (the "bends"): the development of nitrogen bubbles in soft tissue and body fluids that may occur if suit operating pressure is low with respect to the space station cabin pressure. When the initial cabin pressure for an STS based EVA is 14.7 psi, the prebreathing time is approximately 3 hr. In order to reduce this prebreathing time penalty, an operational protocol has been developed to gradually lower the cabin pressure to 10.2 psi prior to beginning prebreathing. The required prebreathing time under this protocol is reduced to approximately 1 hr (ref. 5).

Although this prebreathing protocol appears to be adequate for STS operations, it would not be appropriate for the Space Station. The Space Station internal environment will be much more complex than that of the Space Shuttle. With a greater emphasis on scientific and commercial users, the requirement to accommodate these payloads in an atmosphere that regularly fluctuates between 10.2 and 14.7 psi would impose a severe hardship on the users. In particular, it would become necessary to develop pressure variation testing programs on Earth for each of the scientific and commercial users. Such a requirement would not only add cost and complexity, but for life sciences experiments especially would introduce additional variables. Finally, there would be an added cost associated with testing for flammability, toxicity, and outgassing of all materials at the lower mean pressure, but with a higher partial pressure of oxygen. The arguments for a 14.7 psi space station atmosphere are persuasive.

The concepts presented here are applicable generally to any suit design meeting the above requirements. Hardware design and integration may affect the acceptability of certain configurations, but is beyond the scope of this work. This study attempts to exploit the unique properties of the AX-series of hard suits in some candidate configurations.

The principal differences between the four suit servicing concepts are the allocations of servicing functions inside the airlock and inside the space station module adjacent to the airlock. Certain assumptions have been made in this analysis concerning the volumetric properties of the EVA airlock. From a purely structural point of view, the most efficient shapes for the airlock are spherical or cylindrical. However, a second constraint on airlock shape is imposed by the geometric properties of the space station. The space station common modules are considered to be cylindrical and sized to fit in the STS orbiter payload bay. This external size constraint imposes limits on the habitable volume within each module and shifts the design driver somewhat from total mass to total size. Therefore, the shapes of the airlocks presented in this analysis are designed to make most efficient use of the space within each module at the expense of some efficiency in structural mass. Procedural schedules associated with each of the four facility configurations are illustrated in parallel for engineering and human-factors comparison. As a result of this comparison, recommendations for an optimum design configuration and identification of research issues may be formulated.

EVA OPERATIONS

After the initial operating capability in 1992, the current space station operations baseline will require an estimated 2000 to 3000 hours of EVA per year (ref. 6). Each EVA shift will last approximately 9 hours, including suit check-out, donning, doffing, and any post-EVA cleaning and servicing that is necessary. The EVA itself will last from 6 to 8 hours with the capability for a 1 to 2 hour break at the midpoint during which the crewmembers will doff the suits, rest, and eat. When the post-EVA cleaning and servicing is complete, the suits and life support equipment must be ready for a second crew shift who will repeat the 9-hour EVA cycle during the following 24-hour day. The space suit must be compatible with space station architecture in terms of maneuverability and physical size, and it must also be able to pass through the existing STS Orbiter airlock external hatch (ref. 7). The suit must have a useful lifetime of approximately 1000 operational hours without major refurbishment, and it must be 90% repairable on orbit with the majority of repairs requiring no more than 4 hours to complete (ref. 6).

Consistent with these time requirements, the suit must be donned and doffed easily with no assistance and with no need to prebreathe. Suit portable life support systems (PLSS) must support up to 8 hours of vigorous activity, including provisions for some food and drink. Because the suit will operate in proximity to structures that may have sensitive optical or chemical surfaces, the venting of water or other materials to support suit function will not be acceptable, except for emergency operation (ref. 8). Recharging and check-out of the suit and the life support system must be automated to the degree possible to minimize the crew time required for these operations.

For the puposes of this analysis, EVA procedures shall begin with the entry of the EVA crewmembers into the module containing the suit servicing facility and will end with the post-EVA stowage of suits and servicing equipment so that the facility is prepared for the next shift of EVA crew. The 24-hour cycle considered here will include two EVA shift operations of 9 to 10 hours each. Each of the two crewmembers assigned to a shift will be responsible for the operations without assistance from each other. However, even though one crewmember may perform all the operations associated with the preparation for, and the securing from, EVA, a second crewmember will be operating in parallel to ensure the safety of the operation during the EVA.

FUNCTIONAL REQUIREMENTS AND CONSTRAINTS OF FACILITY

This analysis assumes that some portion of a "common module" will be devoted to EVA operations. For all operations, the airlock is assumed to be internal or external to the common module with EVA support equipment located within the airlock or in close proximity to it. The possibilities for an external, relocatable airlock will be reviewed later for each of the servicing concepts. The portion of the space station devoted to EVA operations will be termed the EVA Access Facility and will have three major functions: Operation Support, Stowage, and Service and Repair.

Operation Support

The EVA Access facility will contain the airlock and appropriate suit donning, doffing, and check-out equipment so as to permit the crew to exit the station to perform the EVA, to reenter the station, and to secure all equipment.

Stowage

When not in use, the space suits and PLSS will be stowed in the facility as will all equipment and supplies that are necessary for service and repair of those items.

Service and Repair

Routing cleaning and servicing of the suits and PLSS must be possible in the facility as well as repair of damaged or faulty suit components.

The specific crew procedures performed within the EVA Access Facility may draw on more than one of these functional capabilities. The constraints associated with the facility are those which are applied to the station in its entirety: safety, size, mass, complexity, time, cost, and human factors.

FOUR FACILITY DESIGN CONCEPTS

In order to arive at candidate configurations for the EVA Access Facility, it is necessary to determine design drivers that are consistent with the requirements and constraints defined above. The method selected here involves the assignment of function according to the module volume that those functions occupy. A natural division of volume occurs as a result of the structural requirements of the airlock. Whereas the operations support that is associated with egress and ingress must be allocated to the interior of the airlock, there is considerable flexibility in the assignment of stowage, servicing, and repair functions. Four EVA Access Facility concepts (labeled A, B, C, and D) have been chosen to represent alternative function allocation strategies. Each of these configurations is described below.

Concept A, STS-Type Airlock

The functional allocation associated with this configuration is based on current STS orbiter EVA design criteria (ref. 8). Almost all of the operation support, stowage, and servicing/repair functions take place in the interior of the STS orbiter airlock. EVA suit storage, donning, doffing, and servicing take place entirely within the airlock. Stowage volume associated with spare suit parts and nonroutine repair equipment is located outside the airlock.

Concept B, Transit Airlock

The functional allocation associated with this configuration is based upon the STS EVA criteria except that the interior of the airlock is used only for transit (egress and ingress). EVA suit donning, doffing, service, and repair all take place exterior to the airlock, in an adjacent interior volume.

Concept C, Suitport

The functional allocation associated with this configuration is based on a model developed at NASA Ames Research Center. Operation support, stowage, and service/repair functions are distributed more or less equally between the interior of the airlock and the interior of the station adjacent to the airlock. The airlock is constructed to exploit a design feature of the hard EVA suit. In addition to the main interior airlock hatch, two smaller hatches are located on the airlock wall (fig. 1). An EVA suit may be attached to one of these hatches (suitports) in the airlock by means of a pressure seal around the PLSS interface. The PLSS may then be removed through the suitport and the crewmember may don and doff the suit while the airlock itself remains depressurized. The use of the suit as a barrier integral to the airlock wall is similar to the donning and doffing procedures used with contamination protection suits by workers in the nuclear industry.

Concept D, Crewlock

This configuration is based on the "Crewlock" prototype developed by William E. Haynes of the Aerospace Corporation (personal communication, Crewlock Description and Analysis). As in the Transit Airlock concept (concept B), only egress and ingress are allocated to the interior of the airlock. Each airlock (there are two) is cylindrical and accommodates a single-suited crewmember (fig. 2). Void fillers surrounding the crewmember may minimize the vented air volume within the airlock. The suit is donned, doffed, and serviced at a suit-servicing crew station that is located within the space station adjacent to the airlocks.

DEFINITION OF PROCEDURAL STEPS

Operations which occur in the EVA suit servicing facility break down into 6 procedural steps. Each step is listed in expected time-order of performance during a typical EVA shift. Each step is defined as a group of tasks with a common function. These steps were developed from an analysis of the current Space Shuttle EVA procedures (ref. 9), and the future requirements described previously.

CONCEPT SPECIFIC PROCEDURAL STEPS

The procedural steps described in the section entitled "Definition of Procedural Steps," are described as they would be performed in each of the EVA Access Facility configurations in the following sections. The application of the procedures to the alternative concepts is carried out in parallel by referring to each one by letter and by name. The tasks described below represent those to be performed by a shift of two EVA crewmembers in the EVA Access Facility.

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STEP 1 – PRE-DONNING SUIT PREPARATION (fig. 1)

Each crewmember will take responsibility for the preparation of his or her suit. The totally hard suit consists of major parts that are connected by replaceable sizing rings which enable the suit to be custom fitted to a particular crewmember. Therefore, the crew selects and retrieves the appropriate suit parts and assembly of the suit in preparation for donning. Specialized end effectors or tools may be added at this time. In addition, the crew performs any checks of suit systems or tools such as lighting, cameras, communications, etc.

A. STS-Type Airlock

Crewmembers assemble suits at storage fixtures/ donning jigs within the airlock and test all systems that are integral with the suit itself immediately prior to each EVA. Specifications for suit parts and inventory are displayed on a data terminal within the airlock. If necessary, the suits may be pressure-tested at the storage fixtures prior to donning.

B. Transit Airlock

Crewmembers assemble suits in the suit-servicing fixtures/ donning jigs at the suit-servicing crew station and test all systems that are integral with the suit itself. Specifications for suit parts and inventory are displayed on a data terminal at the suit-servicing crew station. If necessary, the suits may be pressure-tested at the servicing fixtures prior to donning.

C. Suitport

Crewmembers assemble suits at ports in the airlock and test all systems that are integral with the suit itself. Specifications for suit parts and inventory are displayed on a data terminal within the airlock. If necessary, the suits may be pressure-tested at the ports prior to donning. This configuration would permit suit assembly at three locations: two in the airlock and at least one servicing fixture within the servicing facility outside the airlock.

D. Crewlock

Crewmembers assemble suits in the suit-servicing fixtures/ donning jigs at the suit-servicing crew station and test all systems that are integral with the suit itself. Specifications for suit parts and inventory are displayed on a data terminal at the suit-servicing crew station. If necessary, the suits may be pressure tested at the servicing fixtures prior to donning.

EVA ACCESS FACILITY
A COMPARATIVE ANALYSIS OF FOUR CONCEPTS

PRE-DONNING SUIT PREP

SPACESUIT DONNING, SERVICING AND EVA ACCESS PROCEDURES:

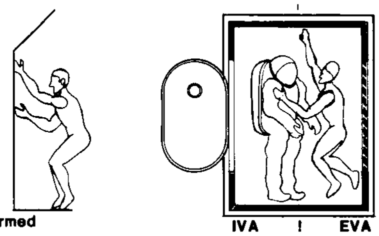
STEP 1

Crewmember assembles suit at storage/donning fixture and refers to adjacent status display for automated checkout of suit systems.

A

STS-TYPE AIRLOCK

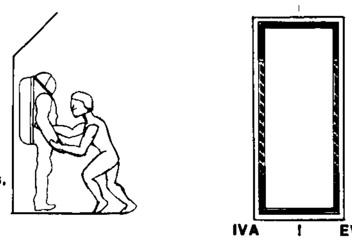
Crewmember retrieves sizing parts and spares by leaving airlock unit. Checkout equipment and status display are located inside airlock. All assembly and checkout is performed with suit and crewmember inside airlock.



B

TRANSIT AIRLOCK

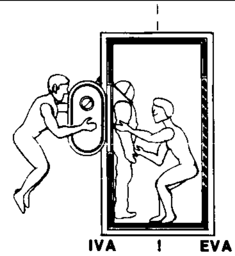
Crewmember performs suit assembly and checkout outside the airlock. Sizing parts, spares, checkout equipment, and status display are adjacent to storage/donning fixture.



C

SUITPORT

Crewmember performs suit assembly and checkout with suit attached to suitport. Sizing parts and spares are retrieved from outside the airlock. Suit status display and checkout equipment are located on wall of airlock.



D

CREWLOCK

Crewmember performs suit assembly and checkout outside airlock. Sizing parts, spares, equipment and status display are adjacent to storage/donning fixture.

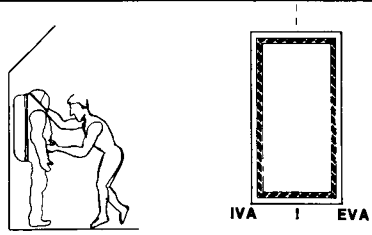


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Figure 1.– Step 1.

STEP 2 – PLSS PREPARATION (fig. 2)

The hard suit has a removable and interchangeable backpack-type PLSS that is charged prior to use. Assuming that there is an automated charging system, the PLSS gas reservoirs, heat sinks, and batteries will be ready for use at the beginning of the EVA shift. These items will likely be integral with the PLSS backpack and will require infrequent removal for service. Perishables such as ice pack heat sinks are inserted just prior to suit donning. Each crewmember performs check out of the PLSS by connecting an electrical sensing cable to and obtaining a go/no-go indication from the data display used for the predonning suit preparation. Detailed diagnostics are available if desired, for servicing or repair, but in the event that a PLSS fails the check out, another PLSS may be substituted (if additional PLSSs are stowed on board for these purposes) and the faulty unit will be tagged for service.

A. STS-Type Airlock

The PLSS is checked out within the airlock at the suit storage fixture or in the suit-servicing facility and then is transferred to the airlock interior. PLSS recharging and service will take place outside the airlock in the suit-servicing facility. Perishable items such as removable ice pack heat sinks must be carried into the airlock and then placed in the PLSS.

B. Transit Airlock

The PLSS is checked out in the suit-servicing fixtures at the suit-servicing crew station adjacent to the airlock. All servicing supplies are co-located with the PLSS fixture. After check out, PLSS is carried into the airlock and is placed in a position for suit donning.

C. Suitport

The PLSS is checked out at the suit-servicing crew station outside the airlock in a fixture designed for this purpose. The PLSS can be swung or translated from its position on the airlock wall. All servicing supplies are co-located with the PLSS fixture. The checked-out PLSS is then transferred to the suit at the airlock port where the suit has been assembled and the PLSS is attached to a hinge or articulating mechanism so that it may be swung into position during suit donning.

D. Crewlock

The PLSS is checked out in the suit-servicing fixtures at the suit-servicing crew station outside the airlock. All servicing supplies are co-located with the PLSS fixture. After check out, the PLSS is placed in a position for suit donning.

EVA ACCESS FACILITY
A COMPARATIVE ANALYSIS OF FOUR CONCEPTS

PLSS PREP

SPACESUIT DONNING, SERVICING AND EVA ACCESS PROCEDURES :

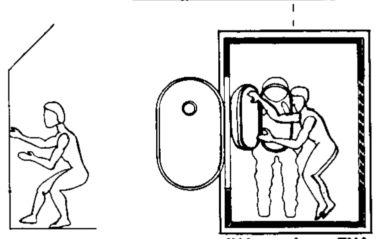
STEP 2

Crewmember performs PLSS checkout using automated test equipment and status display. Batteries, heat sink and other consumables are added as necessary.

A

STS-TYPE AIRLOCK

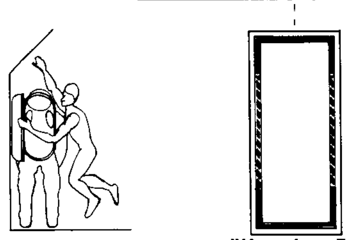
Crewmember retrieves PLSS supplies from outside the airlock, installs them in the PLSS and performs PLSS checkout.



B

TRANSIT AIRLOCK

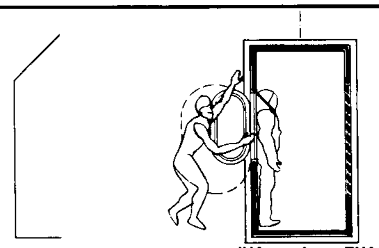
Crewmember performs PLSS installation and checkout outside airlock. All supplies and checkout equipment are adjacent to donning/storage fixture.



C

SUITPORT

Crewmember performs PLSS installation and checkout outside airlock at suitport hatchway. Supplies and equipment are located on airlock wall or in nearby storage location.



D

CREWLOCK

Crewmember performs PLSS installation and checkout at donning fixture outside airlock. All supplies and checkout equipment are located adjacent to fixture.

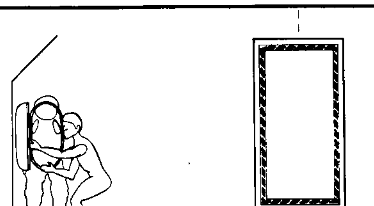


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Figure 2.– Step 2.

STEP 3 – SUIT DONNING AND FINAL CHECK (fig. 3)

Prior to entering the suit, the crewmember will don the liquid-cooled ventilation garment (LCVG). This undergarment is connected to the PLSS nd provides body temperature control during EVA. For the purposes of this analysis, it shall be assumed that advanced suits will use this method of thermal management. To don the suit, the crewmember enters the suit through the PLSS interface opening, then attaches the PLSS to the suit, sealing the assembly. The sealed suit is pressurized and a final check of suit systems is carried out. The monitoring instruments for this final check out are contained and are displayed in the suit itself.

A. STS-Type Airlock

Each crewmember dons the suit inside the airlock at the suit storage fixture and begins the final check of suit systems. At the conclusion of this check, the suited crewmember may be exposed safely to hard vacuum.

B. Transit Airlock

Each crewmember dons the suit in fixture at the suit-servicing crew station adjacent to the airlock and begins the final check of suit systems. At the conclusion of this check, the suited crewmember may be safely exposed to hard vacuum.

C. Suitport

Each crewmember enters the suit through the airlock port to which the suit is affixed. The PLSS is then mated to the suit and the hatch is closed over the assembly. It is possible that the PLSS will be nested into the PLSS port hatch so that these last two operations can take place simultaneously. The final check out of the suit then takes place. At the conclusion of this check, the suited crewmember may be safely exposed to hard vacuum.

D. Crewlock

Each crewmember dons the suit in fixture at the suit-servicing crew station adjacent to the airlock and begins the final check of suit systems. At the conclusion of this check, the suited crewmember may be safely exposed to hard vacuum.

EVA ACCESS FACILITY
A COMPARATIVE ANALYSIS OF FOUR CONCEPTS

SUIT DONNING & FINAL CHECK

SPACESUIT DONNING, SERVICING AND EVA ACCESS PROCEDURES :

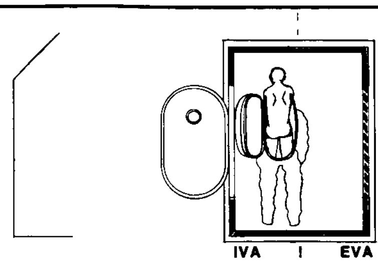
Crewmember dons suit, seals PLSS interface, and performs final operational checks.

STEP 3

A

STS-TYPE AIRLOCK

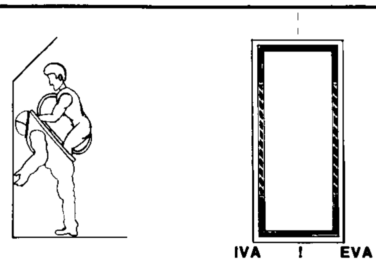
Crewmember dons suit at donning fixture inside the airlock and performs final operational checks.



B

TRANSIT AIRLOCK

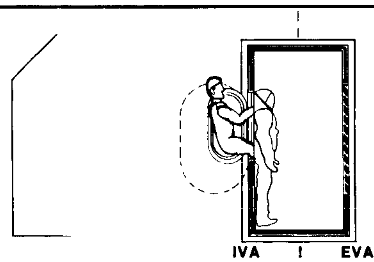
Crewmember dons suit at donning fixture outside the airlock and performs final operational checks.



C

SUITPORT

Crewmember dons suit through suitport hatch, closes and seals PLSS interface and performs operational checks.



D

CREWLOCK

Crewmember dons suit and performs final operational checks at donning fixture outside the Crewlock.

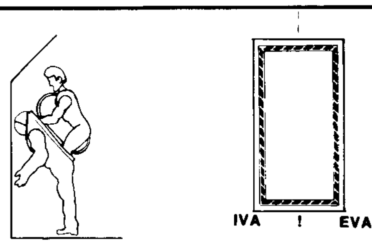


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Figure 3.– Step 3.

STEP 4 – EGRESS/INGRESS (fig. 4)

During this operation, the suited crewmembers perform the appropriate airlock pressurization and hatch procedures to exit the airlock; they perform the EVA task(s), reenter the airlock, and repressurize the airlock. Essentially, egress and ingress are reciprocal operations.

A. STS-Type Airlock

The suited crewmembers depressurize the airlock and exit to the outside of the station to perform the EVA.

B. Transit Airlock

The suited crewmembers depressurize the airlock and exit to the outside of the station to perform the EVA.

C. Suitport

With both suitport hatches secured and sealed, the crewmembers depressurize the airlock and detach the suits from their respective ports. The crewmembers will then open the outer airlock hatch and exit the airlock to perform the EVA tasks.

D. Crewlock

The suited crewmembers depressurize the airlock and exit to the outside of the station to perform the EVA.

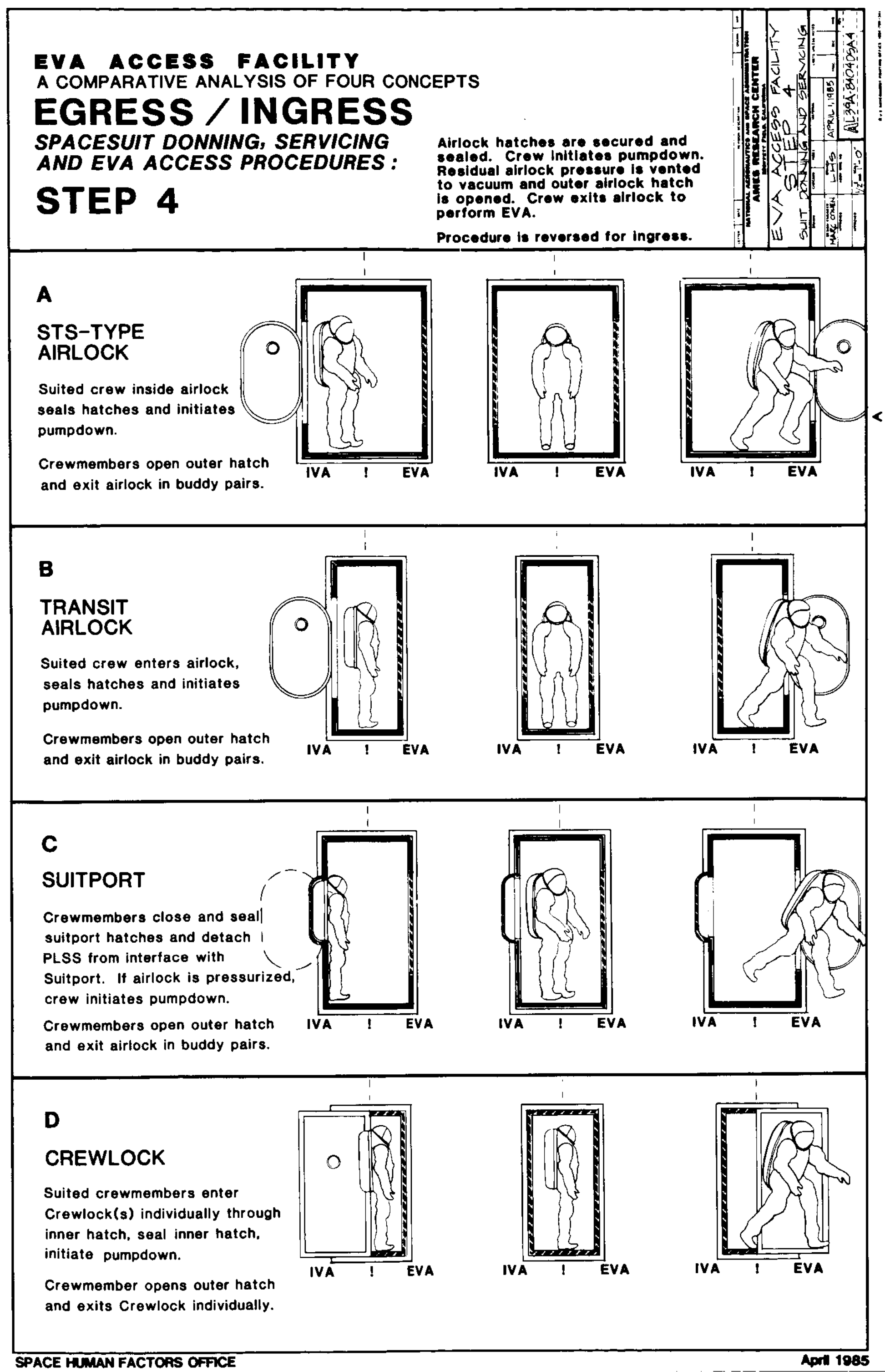

Figure 4.– Step 4.

STEP 5 – MID-EVA REST PERIOD (fig. 5)

In the event that a prolonged EVA is necessary, a mid-point rest period may be desirable. This procedural step will involve entering the airlock and doffing the suit as well as performing a donning and check out procedure prior to resuming the EVA. Suit consumables may be recharged during this period, but recharging will not be required until the next full EVA.

A. STS-Type Airlock

The crewmembers reenter and repressurize the airlock and doff the suits inside the airlock before entering the module for the rest period.

B. Transit Airlock

The crewmembers reenter and repressurize the airlock, exit the airlock into the module interior, and doff the suits at the suit-servicing crew station. Redonning and egress will proceed as above.

C. Suitport

The crewmembers reenter the airlock and attach the suits to the suitports. The suitport hatches may then be opened and the PLSS removed without repressurizing the airlock. In general, if the suits do not require servicing, the airlock may remain depressurized. The crewmembers may then exit the suit for the desired rest period. Redonning of the suit and egress will proceed as above.

D. Crewlock

The crewmembers reenter and repressurize the airlock, exit the airlock into the module interior, and doff the suits at the suit-servicing crew station. Redonning and egress will proceed as above.

EVA ACCESS FACILITY
A COMPARATIVE ANALYSIS OF FOUR CONCEPTS

MID-EVA REST PERIOD

SPACESUIT DONNING, SERVICING AND EVA ACCESS PROCEDURES :

STEP 5

EVA crewmembers re-enter station module and doff suits for mid-EVA rest period.

Tools and consumables may be exchanged.

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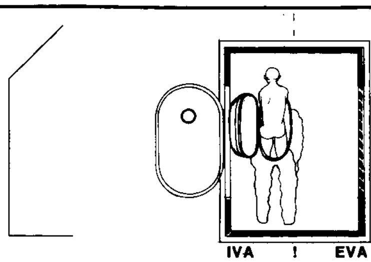
MARC COHEN
LHS
APRIL 1, 1985
1/2" = 1'-0"
AL39A-8404D5A5

A

STS-TYPE AIRLOCK

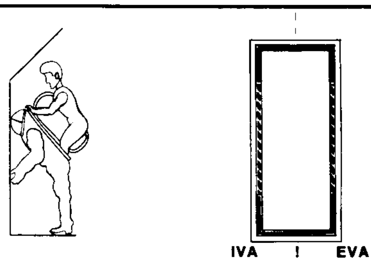
Suited crewmember repressurizes airlock, doffs suit at donning fixture inside airlock and passes through inner hatchway to interior of module.



B

TRANSIT AIRLOCK

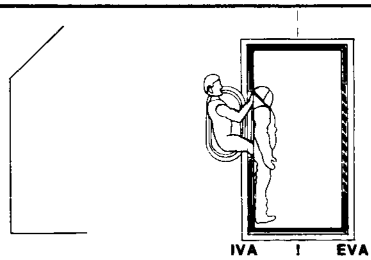
Suited crewmember pressurizes airlock, passes through inner hatchway and doffs suit at donning/storage fixture.



C

SUITPORT

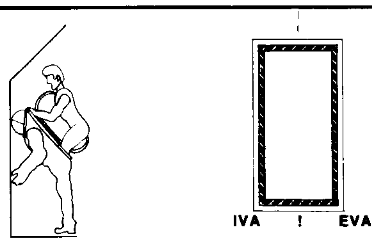
Suited crewmember attaches suit to Suitport at interior PLSS interface. The Suitport hatch may be opened and the PLSS swung open to permit doffing without repressurizing the airlock.



D

CREWLOCK

Suited crewmember repressurizes Crewlock, passes through inner hatchway and doffs suit at donning/storage fixture.



SPACE HUMAN FACTORS OFFICE — April 1985

Figure 5.– Step 5.

STEP 6 – POST-EVA SECURING (fig. 6)

After finishing the second or final portion of the EVA, the suited crewmembers reenter the airlock and repressurize it if necessary. They will then doff the suits and prepare them for cleaning if required. PLSS recharging is automated (except for manual removal of perishable materials). The division of responsibilities between crew shifts will assign all safety-related operations to the rested crew. The LCVG may be cleaned in the station laundry facility along with comfort gloves or other body covering that is worn inside the suit. Routine cleaning of the suit consists of an antibacterial wipe of internal suit surfaces with the suit disassembled and on a holding fixture. Periodically, the entire suit may be steamcleaned or gas-sterilized. The basic requirement of the post-EVA securing is to restore the suits to a condition so that they are ready for use by the next shift of EVA crew.

A. STS-Type Airlock

After the crewmembers have reentered the airlock and repressurized it, they doff the suits at the storage fixtures inside the airlock. They remove the PLSS and place it in the servicing facility for recharging or it may be recharged within the airlock itself. The next EVA crew then takes over.

B. Transit Airlock

After the crewmembers have reentered the airlock and repressurized it, they enter the suit servicing facility and doff the suits at the suit-servicing fixtures. They remove the PLSS and place it in the servicing facility for recharging. The next EVA crew then takes over.

C. Suitport

After the crewmembers have reentered the airlock and secured the outer hatch, they mate the suits to the airlock ports. The airlock is then repressurized. The airlock ports may then be opened and the crew can exit the suits. The suits and PLSS may be removed, if necessary, and placed in the servicing facility racks. The next EVA crew then takes over.

D. Crewlock

After the crewmembers have reentered the airlock and have repressurized it, they enter the suit-servicing facility and doff the suits at the suit-servicing fixtures. The crewmembers remove the PLSS and place it in the servicing facility for recharging. The next EVA crew then takes over.

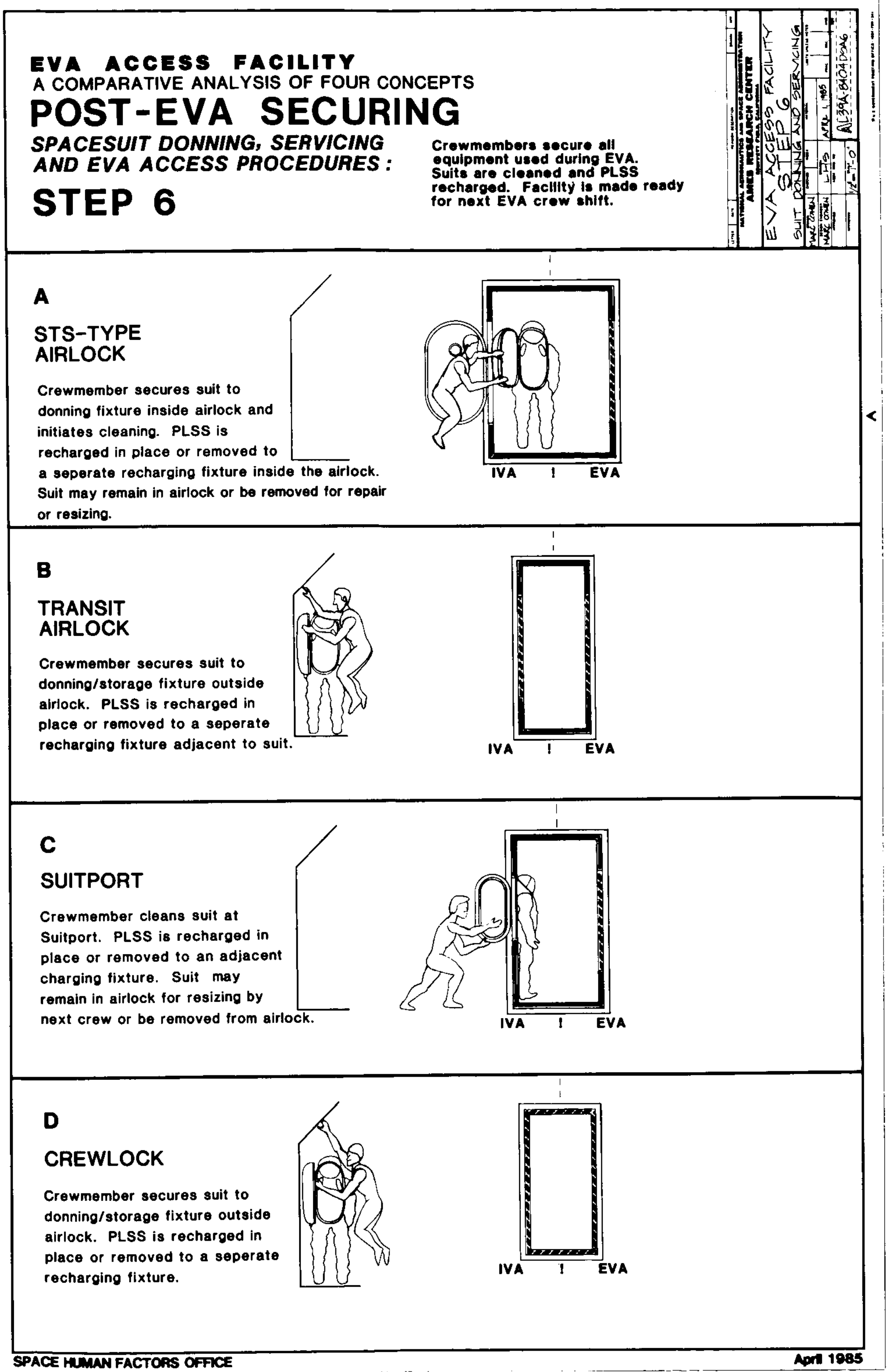


Figure 6.– Step 6.

STEP 7 – NONROUTINE MAINTENANCE (fig. 7)

Nonroutine maintenance will occur when special repairs or part replacement require more time than can be accommodated during routine suit preparation (steps 1, 2 and 3). In some cases it may be necessary to remove the assembled or disassembled suit from its servicing or donning fixture to carry out repairs. Special repairs may occur at the servicing fixture or at a general repair workstation elsewhere in the space station. In the event of the need to remove a suit from service altogether before its on-orbit service life has expired, the availability of complete on-orbit spares must be considered.

In the event that nonroutine maintenance or repair must be performed on the suit that does not involve the simple changeout of a modular suit part, the servicing will be performed at a servicing fixture within the module adjacent to the airlock. Configurations A and C require that the suit be transferred from within the airlock to this servicing fixture. This function lacks clear definition compared to the other six steps.

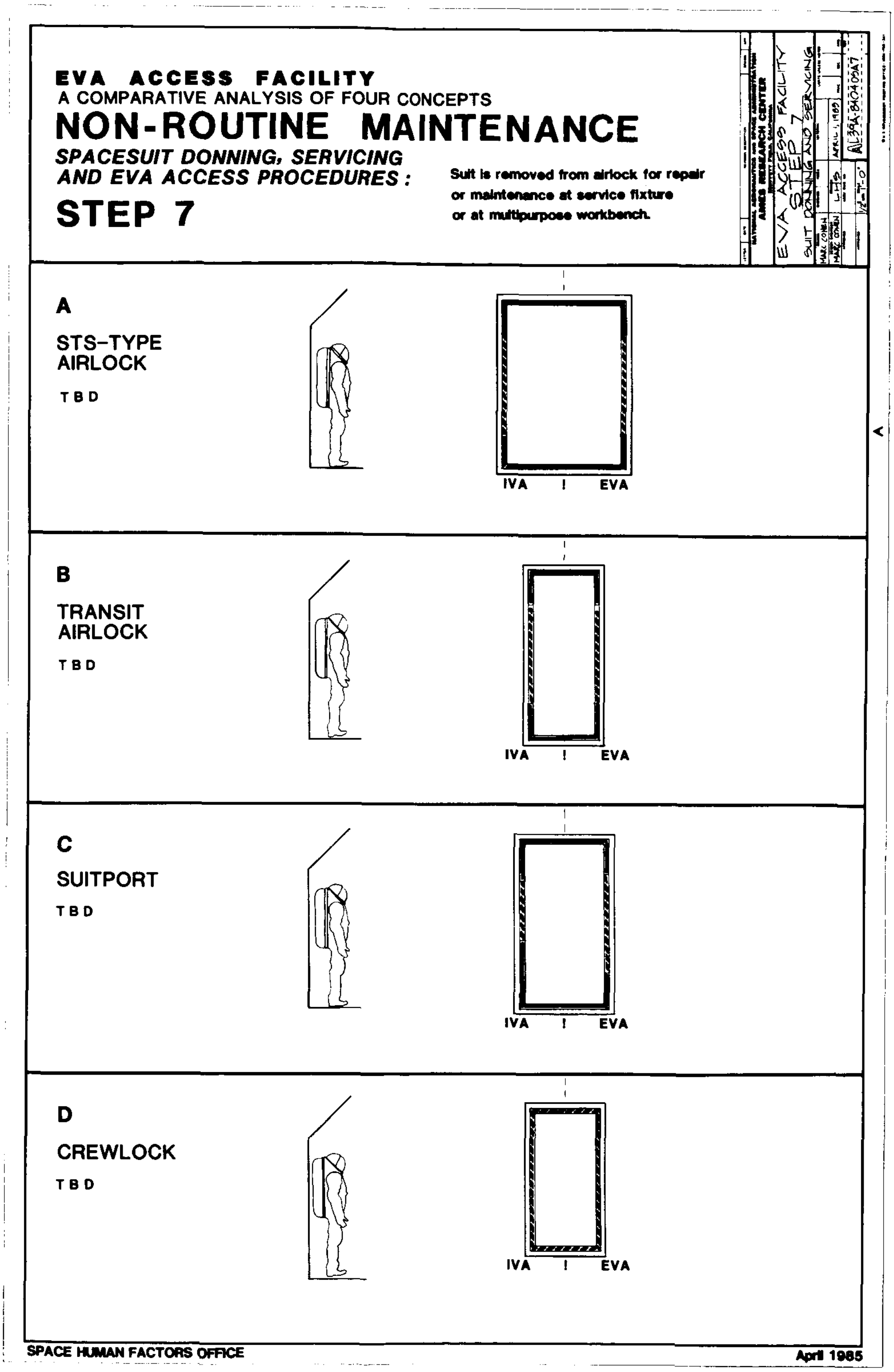


Figure 7.– Step 7.

ARCHITECTURAL AND GEOMETRIC OPTIONS

In addition to the allocation of function between airlock and the interior of the space station module, it is necessary to consider the architectural and geometric options available to the facility designer and how they will impact each of the four configuration concepts described above.

Airlock Location

Two basic airlock locations are considered here: a fixed location within the module itself, and an external, relocatable airlock module that will be berthed to one of the berthing ports on the common module. The external, relocatable airlock module is now included in the space station Reference Configuration (ref. 2). If an external airlock module is used, the stowage and servicing/repair functions may be: (1) co-located in the airlock module; (2) located within the common module adjacent to the berthing port to which the airlock module is berthed; or (3) distributed between the interior of the airlock module and the interior of the common module.

Internal Geometry of Facility Module

The interior layout of the EVA Access Facility is further influenced by the internal architecture of the common module. Given a cylindrical shape for the common modules and the airlock module, the orientation of the equipment and workstations (that is, the natural orientation of the crewmember while working at the workstation) within the modules may be either parallel or perpendicular to the long axis of the module. In the "horizontal" configuration, the workstations are oriented perpendicular to the module long axis and in the "vertical" configuration, they are oriented parallel to the module long axis (fig. 8). If the airlocks are external spherical nodes, the interior spatial orientation is equipotentially "horizontal" or "vertical."

Design Matrix

The four functional allocation concepts presented in the section entitled "Concept Specific Procedural Steps" (STS-Type Airlock, Transit Airlock, Suitport, and Crewlock) form a matrix with the geometric and architectural considerations of airlock location and orientation. The geometric and architectural options are defined as:

1. "Internal Vertical," with the facility and airlock internal to the common module in an orientation parallel to the long axis of the module.

2. "Internal Horizontal," with the facility and airlock internal to the common module and oriented perpendicular to the long axis of the module.

3. "Internal/External," an option that distributes the facility between the common module and the external airlock module.

4. "External Vertical," where the facility is located entirely within the external airlock module with the airlock and workstations parallel to the long axis of the module.

5. "External Horizontal," in which the facility is located entirely within the external airlock module and the orientation of the airlock and workstations are perpendicular to the long axis of the airlock module.

A graphical depiction of the matrix showing the airlock location and orientation for each of the 20 possible matrix elements is given in figure 8. In some cases, a geometric option is, by definition, incompatible with a particular facility concept. In these cases, the matrix element representing the intersection of the two incompatible definitions is not drawn.

ENGINEERING AND HUMAN FACTORS ISSUES

The procedures associated with each of the four EVA Access Facility concepts raise several engineering and human factors issues which include airlock size, automated check out equipment, location of Servicing functions, and external relocatable EVA Access Facility.

Airlock Size

The amount of activity and the stowage allocated to the airlock in each of the four concepts are the key considerations for airlock size. The mass and cost of the airlock and associated pump-down equipment as well as the amount of station atmosphere that is lost with each airlock cycle are all scaled with respect to the airlock size. The use of the airlock interior in the STS-type airlock (Configuration A) for suit donning requires it to be large enough to accommodate the two crewmembers and the two suits simultaneously, with enough room to maneuver during the sizing, check out, and donning procedures. This requirement results in the largest airlock size of the four configurations. Configurations B and D utilize the airlock only as a pass-through to the exterior of the station. The airlock is sized to accommodate two suited crewmembers in configuration B and one in configuration D, and are, therefore, significantly smaller in

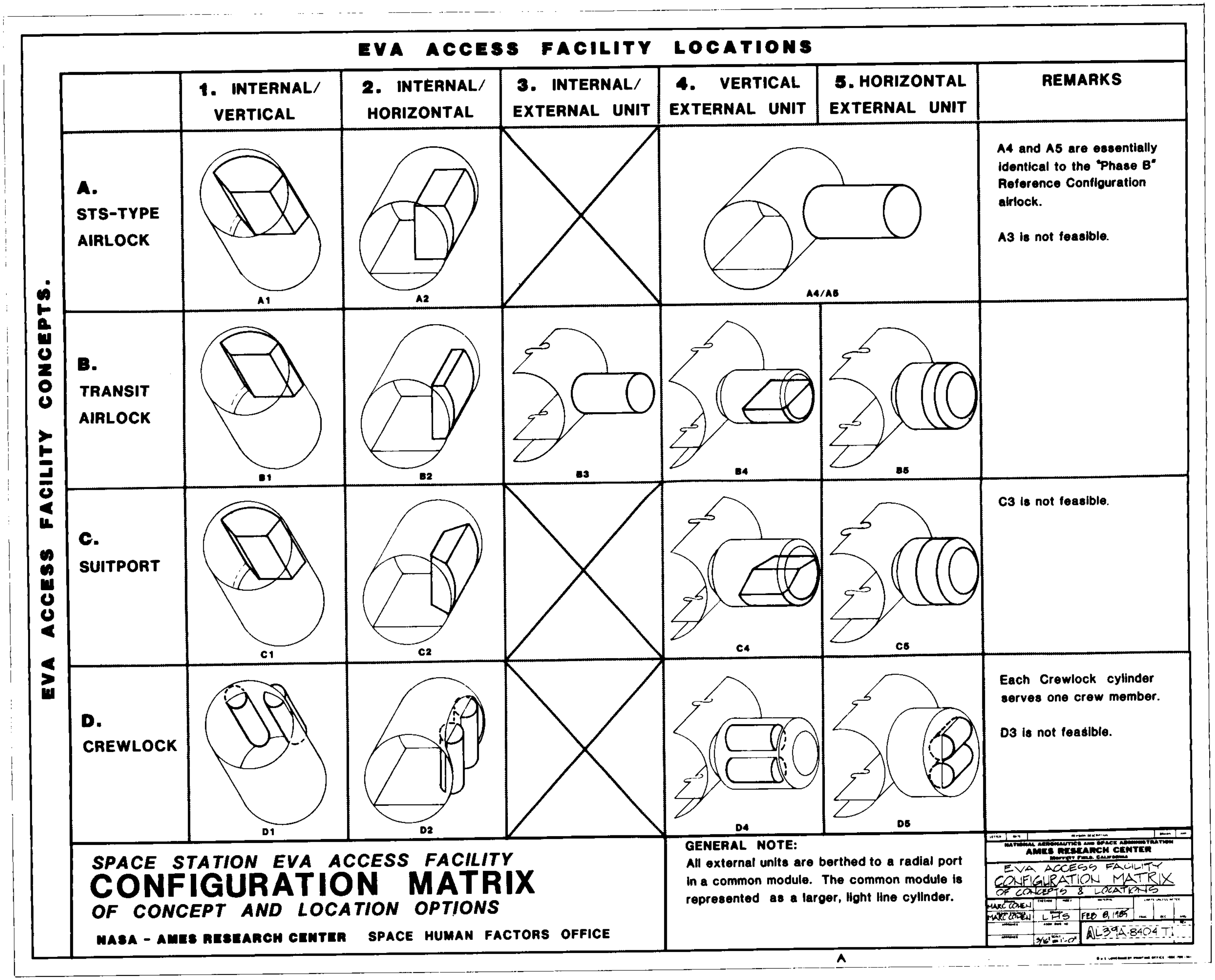


Figure 8.– Internal geometry of facility module.

size than that of configuration A. The airlock size in configuration C is similar to that of configuration A in that the crewmembers must be able to work within the airlock with the suits attached to their respective airlock ports. However, the donning operation takes place from within the space station that is adjacent to the airlock and therefore requires less space within the airlock itself. Because the crewmembers may exit the suits during a mid-EVA rest period without cycling through the airlock, some savings in station atmosphere and power are possible with concept C.

Automated Checkout Equipment

The status of the suit and PLSS systems during donning and check out will be displayed to the crewmembers. The allocation of these functions between the suit caution and warning system (CWS) and a display external to the suit determines the complexity and cost of measurement systems in the suit-servicing facility. An appropriate allocation of functions would be to use the internal suit display for system status associated with operation and reserve diagnostic displays for servicing in the suit-servicing facility. Configuration A requires that suit assembly and check out take place within the airlock itself. A distribution of check-out function may be achieved by incorporating test instrumentation into the suit itself with provisions for a connection to an external status and check-out display to supplement the suit head-up display.

Location of Servicing Functions

The existing protocols for EVA suit-servicing (STS procedures) rely on Earth-based facilities for all maintenance except for expendable recharging and some minor repair or for changeout of parts. As a result, the Space Shuttle volumetric requirements for suit-servicing operations tend to be small. The autonomy baseline for space station requires significant capability for suit repair and for refurbishment on-orbit, including the storage of replacement and sizing parts. The volume required for a servicing facility of this capability will almost certainly require that it be located outside the pumpdown portion of the airlock and within the common module. In this case, there is a choice as to the allocation of space for the servicing itself, that is, whether or not the suit is brought from its storage location to the facility so that it can be serviced, or whether or not the kits and parts are brought to the suits at their storage fixtures. Configuration A allows for servicing within the airlock itself at the expense of increased airlock volume and reduced locational convenience of materials and supplies. The constrained airlock size in configurations B and D requires the suits to be moved to the suit-servicing facility outside the airlock for any significant maintenance. The allocation of the function of configuration C allows servicing to be performed inside or outside the airlock, depending upon the complexity of the tasks to be performed.

External Relocatable EVA Access Facility

Consideration is being given to the design of a small, relocatable module that may be berthed at any one of a number of berthing ports on the exterior of each common module (ref. 4). These external airlocks may be cylindrical or spherical, and may be based on the spherical "interconnect nodes" that connect the space station modules (ref. 10). This module would contain the airlock, suits, and any support equipment necessary to perform EVA. It is possible that all suit servicing, including repair and resizing, will take place in the external EVA module. The allocation of functions within the external module will strongly affect the size and mass of such a relocatable EVA facility. Concept A, with its integration of servicing functions inside the airlock is compatible with the use of an external airlock. In fact, the airlock size of concept A is such that it may be preferable to externalize that structure. Concepts B and D require considerable support equipment to be located adjacent to the airlock itself. This may be accomplished by dividing the relocatable module into two compartments, one of which serves as the airlock. A similar division of the relocatable module is applicable to concept C, including the storage of the suits inside the airlock portion of the relocatable module.

CONCLUSIONS AND RECOMMENDATIONS

This paper is the first of a series that investigates advanced EVA Access Facility concepts, critical requirements, and performance. This first paper is a conceptual introduction to the scope of the problem to which more specific recommendations will be presented in the following papers.

This comparative analysis shows that a wide range of potential solutions can be found for space-suit servicing, donning, and ingress/egress on board the space station. The key observation is that any airlock and support facility design must consider this complex of functions. It is neither sufficient nor appropriate to limit EVA Access Facility considerations to variations on the current STS airlock system because the space station EVA Access Facility is fundamentally different from the STS airlock that supports two EMUs for approximately 22 hours each of maximum cumulative EVA time. The space station airlock is instead a replacement for the ground-based facility at Johnson Space Center that currently employs a substantial number of technicians to service those two EMUs for 6 weeks in several thousand square feet between Shuttle flights. On the space station it will not be possible to accommodate the personnel, the floor area, or the time required by the current EMU system. It is necessary to consider some entirely new possibilities.

Given the analysis in this paper, it becomes clear that several steps for evaluation and exploration must be taken. Each of the 16 possible spatial envelopes described in the configuration matrix needs to be explored from the anthropometric and ergonomic perspectives. The volumetric, structural, and other performance aspects of these concepts must be evaluated on a systematic and objective basis of comparison. Finally, the functional factors of time, volume, power consumption, reliability, and resistance to human error must be interpreted for their design implications.

The EVA airlock for space station must be more than just an enlargement of the space shuttle airlock. It must be a complete EVA Access Facility that supports sustained EVA productivity and maintenance on orbit. The suitport and crewlock concepts in particular merit further study.

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October 22, 1985

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15. Supplementary Notes

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16. Abstract

This study presents four concepts for on-orbit space suit donning, doffing, servicing, check-out, egress and ingress. The four concepts are: the Space Transportation System (STS) Type (shuttle system enlarged), the Transit Airlock (Shuttle Airlock with suit servicing removed from the pump-down chamber, the Suitport (a rear-entry suit mates to a port in the airlock wall), and the Crewlock (a small, individual, conformal airlock proposed by William Haynes). Each of these four concepts is compared through a series of seven steps that represent a typical Extra Vehicular Activity (EVA) mission: (1) Predonning suit preparation; (2) Portable Life Support System (PLSS) preparation; (3) Suit Donning and Final Check; (4) Egress/Ingress; (5) Mid-EVA rest period; (6) Post-EVA Securing; and (7) Non-Routine Maintenance. The different characteristics of each concept are articulated through this step-by-step approach. Recommendations concerning an approach for further evaluations of airlock geometry, anthropometrics, ergonomics, and functional efficiency are made. The key recommendation is that before any particular airlock can be designed, the full range of space-suit servicing functions must be considered, including timelines that are most supportive of EVA human productivity.

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