Design Considerations for a Free Space Transportation and Work Station Capsule

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DESIGN CONSIDERATIONS FOR A FREE SPACE TRANSPORTATION AND WORK STATION CAPSULE

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A concept for a low cost, low development risk Work Station Capsule for manned extra-vehicular operations is presented.

Requirements for such a capsule are established and a conceptual design is outlined.

The result is a low cost design providing the astronaut with improved protection and mobility and the means to make his activities more effective and safer.

Operational considerations with emphasis on handling of emergencies are discussed.

The authors conclude that such a design represents a highly desirable interim approach as a supplement to safe extra-vehicular operations.

1. INTRODUCTION

The time is fast approaching when the first astronaut will leave the vehicle in free space to perform simple experimental tasks for the first time. If these first trials are successful, more intricate tasks will follow with the ultimate aim of performing repairs, assembly, crew transfer, and inspection tasks in operational activities. Present planning provides the astronaut with a life support system, communication link, and a means of propulsion in addition to the space suit utilized to protect him from the hostile space environment.

The bulkiness of the present propulsion and life support back-pack necessitates the storage of this unit, as in the "Gemini" service module, in a remote position from the crew compartment. Thus, the astronaut must be provided with a supplemental small life support system, which is now in the form of a chest pack for the present system, in order to proceed to the back-pack location. Upon arrival he then has the task of strapping on the back-pack which now submits the astronaut to bulky packages front and rear. The astronaut is now ready for flight into space or transit between vehicles. However, to make the man more effective and perform the tasks such as repair, etc. as mentioned previously necessitates the use of tools and supplies which require transportation. To date no provisions have been made for their transportation. If these items are attached to the man in addition to what he already has, the control and propulsion will be further complicated.

Another item of concern for the astronaut in free space is the low protection that the space suit offers against micrometeoroid penetrations and resistance to possible tear or damage during any repair or assembly operations. NASA is planning to provide meteoroid protection capability in the Gemini space suit for
extra-vehicular activity. This type of protection in the form of an aluminum woven coverall will further restrict the astronaut's freedom of motion and make the performance of tasks even more difficult.

Although extra-vehicular activities will be conducted in the relative weightlessness in space, all bodies still have mass. Thus, these moving masses still present a hazard to the astronaut. In the present arrangement the astronaut is relatively unprotected against the impacts created either by his own body impacting against a stationary object or a moving object impacting against him. One example might be that of pulling two large objects together such as two containers filled with propellant for assembly purposes as contemplated in some long range plans. This could be a very hazardous operation to perform in space and could result in injury or damage to the life supporting equipment of the astronaut. Tearing of the space suit, crushing of the back-pack components, or crushing of the body parts are all possibilities of such an operation.

The disadvantages of an astronaut thus equipped in an operational activity have been recognized and design studies for shuttles, taxies, etc. have been performed. Upon analysis of the proposed designs it is obvious that the jump from the space suited astronaut with a back-pack to a space capsule with all the comfort where the astronaut is carried along as a decision making computer is rather large and costly. In some designs the vehicle resembled a full fledged spacecraft with the environmental control system, living quarters, automatic stabilization, propulsion capable to transport large masses, grappling arms for remote manipulations, stores for spare parts, waste disposal units, food storage, air locks, and other support equipment lacking only reentry capability. The weights of such vehicles range from 1000 pounds to 5000 pounds. Thus both their weight and size preclude their use in any missions presently planned and in addition seem to present a costly penalty to be paid, by today's standards, to provide such luxuries.

It is the opinion of the authors that the above exotic and heavy vehicles are not yet required since:

1. Payload capabilities up to 1970 preclude their use.
2. There is no immediate operational application at hand which requires the heavy vehicles.
3. Costs are excessive.
4. The step from a "bare" space suited astronaut to the fully automated and "comfortized" vehicle is too great compared to the pace of other development of space hardware.
5. Chances for funded programs are dubious due to the high development cost and lack of justification.

It appears that there is an interim solution which would readily fit present operational plans, present a minimum weight penalty and could be procured at relatively little added cost. The design considerations for such a solution called the "Transportation and Work Station Capsule" are the subject presented in this paper.
2. TECHNICAL APPROACH

The basic aim is to provide the astronaut with 1) added protection against the environments, and 2) support him in the performance of extra-vehicular tasks with the added stipulation that all of this should be accomplished at a minimum of new hardware, a minimum of weight and a minimum of cost without compromising the basic simplicity of the suited astronaut and back-pack approach.

In addition the approach must preclude major modifications in planning of extra-vehicular activities and must provide a logical link in future planning without imposing an undue budgetary drain which would impair the main efforts.

Among the important environmental factors deserving attention is the meteoroid. Present soft suits display a high probability of penetration even in the short periods of extra-vehicular exploits presently planned. Added protection against micro-meteoroid penetration therefore is very desirable.

The soft space suit is also vulnerable to tearing during the performance of tasks whether in the use of special tools or while maneuvering close to objects. Any improvement in this respect will also help to raise an astronaut's confidence in reducing the probability of emergencies.

Protection against crushing is also desirable and should be considered in any design approach.

The task to perform assembly or repair can be facilitated and the exposure time to space environment reduced if the astronaut freedom of motion is improved. Such would be the case if the cumbersome back-pack and supplemental life support system could be removed from the body and relocated into a capsule. Making a variety of tools available would further facilitate operations eliminating time consuming trips back to the mother-spacecraft.

Improvement in survivability in case of an emergency, as in the case of suit decompression, is also highly desirable.

From the above we can conclude that an improved system should at least contain the following features:

1. added meteoroid protection
2. protection against crushing
3. protection against tearing of the suit
4. improved survivability in case of suit decompression
5. utilization, as far as possible, of components and subsystems developed for the back-pack approach
6. increase the astronaut's freedom of motions required to perform manual tasks
7. provide a handy selection of special tools to facilitate work tasks.

In addition to the above features we should try to reap the added benefits such as added radiation protection, opportunity to provide work area lighting and attachment devices, etc., if possible.
What then should be the basic design philosophy for a device which could assure the above features?

It seems that an encapsulation approach, whereby the astronaut is enclosed by a protective structure, would satisfy the requirements. The structure of the capsule would then serve to provide meteoroid protection, improved radiation protection, protection against bumping and crushing, and would contain and support all components and, of course, a suited astronaut.

A simple structure such as a cylinder with end covers is visualized. Entry and exit will be through split, sliding doors. Since sealing of such large openings to a leakage level comparable to the suit leakage is as yet impossible - the Gemini hatch leakage amounts to 1250 cm$^3$/Min as compared to a suit leakage of 200 cm$^3$/Min - the capsule will not be pressurized. However, it is most desirable to be able to pressurize in case of an emergency. A further reason for not pressurizing the capsule lies in the fact that we want the astronaut to perform extra-vehicular tasks manually - without the use of remotely controlled grapplers or manipulators. The decision is based upon results from tests$^2$ which indicate that performance with manipulators is 3-4 times less efficient than manual performance of a man in a pressure suit. Manual operations can be accomplished by opening the doors when the work object is reached and relocating the body somewhat to extend reach.

In the performance of assembly work it will be most desirable to avoid any structural "hang-up". The outer contour of the capsule, therefore, should be smooth and void of protrusions.

Any provisions to attach the capsule to a work object, should be retracted into the capsule prior to closing the doors. Attitude control and propulsion nozzles should be so mounted that no part protrudes beyond the contour of the capsule.

In summary the design approach calls for:

1. a capsule to enclose the astronaut
2. easy ingress and egress
3. a simple capsule shape and structure
4. use of developed components
5. a provision for emergency pressurization
6. manual performance of tasks without use of grapplers
7. minimum "hang-up" hazard
8. provisions to carry tools
9. provision for work area lighting
10. provision for attachment to the work object
11. sufficient size to accommodate all components and a suited astronaut and provide the astronaut with ample freedom of motion during the performance of tasks.

3. ESTABLISHMENT OF REQUIREMENTS

The following section covers the effort to establish the basic requirements which must be considered in the design of a system satisfying the basic design approach.
Life Support

A life support system has been developed for the Air Force back-pack (SMU). This system provides a pure oxygen breathing atmosphere, the necessary pressurization of the suit, circulation of the gas and gas temperature control, CO₂ removal, solid and water removal. For the purposes of this paper the details of the system, weight and volumes as given in an Air Force study were considered. Other information indicates that these values might be conservative even for the 4-hour duration of extra-vehicular activity considered.

In any case, the life support system is capable to cope also with the leakage rate from the suit which in the case of the Gemini suit amounts to 200 cm³/Min. Therefore it seems that the same system can be used only for a pressurization task where the leakage does not exceed that of the suit. Since we are still using it only for the suit and not to pressurize the compartment, we have no problems.

In addition, a supplemental life support system is necessary so that the astronaut can proceed from the command module to the location where the capsule is stored. It will remain attached to the man while he is in the capsule. A safe and foolproof switch-over from the supplemental supply to the capsule stored life support system must be assured. Such a system is being developed for the Gemini program and is known as the Extra-vehicular Life Support System (ELSS). It is a semi-open loop system and is supplied with oxygen from the spacecraft through an umbilical and provides for heat dissipation in a water boiler and CO₂ purging by blowing part of the return flow overboard. In addition it contains a small emergency oxygen supply which in itself can assure 30 minutes of semi-open loop operation. For this application we might, however, relocate it to the back of the astronaut.

Let's assume that during the performance of extra-vehicular tasks a tear develops in the space suit. If the leakage is low, it will manifest itself in increased consumption, if it is high it will manifest itself in a serious drop in suit pressure. The latter case does constitute an emergency. Return to the mother-spacecraft might be out of the question. Sufficient oxygen supply, however, could be made available to pressurize the whole capsule if sealing is possible. Therefore some means of sealing the originally unsealed capsule should be devised for just such an emergency.

The flow rate necessary to pressurize the capsule within the maximum allowable time may not be available from the ISS, and the astronaut might still be in trouble. Such difficulty could then be met by providing an emergency pressurization system which would be capable of quickly pressurizing the compartment and maintaining its pressure for a short period of time. A cursory evaluation indicates that for short ranges (up to 1000 ft), and providing time for docking, etc., about 10 minutes of emergency operation will suffice.

Since the suited astronaut is normally contained in an unpressurized compartment, the suit heat load will not be changed from the original and the life support system will be satisfactory also from this aspect.

A 100% oxygen atmosphere is planned for both the spacecraft and the space suit. The pressure in the space suit has been set at 3.5 psi or approximately 180 mm Hg. According to literature the lower limit which would create undetectable hypoxia lies at 144 mm Hg or 2.7 pisa. The latter value therefore must be considered as the lowest to which the suit pressure should be permitted to drop temporarily in case of an emergency.
b. Meteoroid Protection

A great deal of data has been accumulated concerning the meteoroid flux in the near earth and cislunar region, however, individual interpretations still prevent establishment of a standard. Uncertainties, such as the higher flux rates, caused by periodic and sporadic streams, seasonal and diurnal flux variations, and planetary shielding further complicate the problem.

Literature 3, 4, 5, 6, 7 deals extensively with the meteoroid environment. An analysis of this data indicates that micrometeoroids (mass of less than \(10^{-7}\) grams) are predominant and should be considered in the calculations concerning protection. Above references also indicate that for orbital altitudes between 200° and 300 nautical miles a mean meteoroid flux of

\[
F_{\text{mean}} = 10^{-14} M^{-0.9} \text{ [Particles/m}^2\text{ sec]}
\]

should be assumed. This flux is based on a 1963 revision of the numerical flux expression by Whipple.

Many authors use this value in their analysis without applying corrections for deviations from the mean value. The main reasoning behind this approach lies in the fact that there is still considerable uncertainty in the description of the mean environment. Based on an analysis by S. D. Black, the correction factor for near earth, accounting for deviation due to meteoroid streams, earth shielding and seasonal variations could amount to \(1.9 \times 0.5 \times 1.8 = 1.7\). This factor seems rather insignificant compared to the possible orders of magnitude uncertainty in the basic environment and therefore will not be considered by the authors of this paper.

The subject of penetration presents similar uncertainties as the flux. The uncertainty is based on the treatment of the empirical penetration equations by individual investigators. Most of the uncertainty is found in the treatment of material factors in the equations. As more results from hypervelocity penetration tests become available, these uncertainties will be reduced.

The authors performed an evaluation of two well known penetration equations. One is the equation by Bjork\(^9\) and the other by Summers and Charters\(^10\).

Bjork's Equation:

\[
D = K(MV)^{1/3} \text{ [cm]}
\]

where \(D\) = depth of penetration in cm

\(M\) = mass of particle in grams

\(V\) = velocity of particle in km/sec

\(K\) = 1.22 for Nylon

1.09 for Aluminum

.606 for Iron
For thin single thickness targets the depth of penetration is 1.5 times larger and the equation then reads

\[ D = 1.5 \, K(MV)^{1/3} \, [\text{cm}] \]

The Summers and Charters Equation:

\[ D = \gamma \, d \left( \frac{S_p}{S^*} \right)^{1/3} \left( \frac{V}{C} \right)^{1/3} \, [\text{cm}] \]

Where

\[ \gamma = 2.5 \, \text{for aluminum} \]
\[ \gamma = 2.0 \, \text{for butyl rubber and fiberglas} \]
\[ d = \text{diameter of the particle in cm} \]
\[ S_p = \text{particle density} \, \text{g/cm}^3 \, (0.4 \, \text{recommended as average}) \]
\[ S^* = \text{target material density} \]
\[ 2.8 \, \text{g/cm}^3 \, \text{for aluminum} \]
\[ 1.88 \, \text{"} \, \text{for fiberglas} \]
\[ 0.91 \, \text{"} \, \text{for butyl rubber} \]
\[ v = \text{velocity of particle km/sec} \]
\[ c = \text{velocity of sound in target material km/sec} \]
\[ c = 0.054 \, \text{km/sec for butyl rubber} \]
\[ 0.945 \, \text{"} \, \text{for fiberglas} \]
\[ 5.104 \, \text{"} \, \text{for aluminum} \]

For thin targets

\[ D = 1.5 \, \gamma \, d \left( \frac{S_p}{S^*} \right)^{1/3} \left( \frac{V}{C} \right)^{1/3} \, [\text{cm}] \]

In calculating the particle mass \( M \) from the particle diameter \( d \) for a certain depth of penetration and substituting in the above particle flux equation, we can arrive at the penetration rate [penetrations /m²sec].

An example calculation for a depth of penetration of 0.035 cm in aluminum and a particle velocity of 40 km/sec yielded values of 0.56 penetrations/m²day using Bjork's equation and 1.06 penetrations/m²day using the Summers and Charters equation. Since the latter would result in a more conservative design the Summers and Charters equation was used by these authors.

Figure 1 presents for four different materials the plots of material thickness vs. penetrations/m²day for a single thickness (no bumper design).

As can be seen the materials used for space suits will experience from two to three orders of magnitude higher penetration rates for the same material thickness as aluminum. To provide satisfactory probability of no penetration for missions
of up to 30 days, a penetration rate of between $10^{-2}$ and $10^{-3}$ should be set.

This will place the aluminum skin of a protective enclosure at about a thickness of between 0.1 and 0.2 cm or 0.04 to 0.08 inches.

We are concerned only with the protection of the astronaut and therefore punctures of the structure which would not affect the space suit are of no consequence. Penetration rates, therefore must be computed only for the exposed area of the space suit and not the exposed area of the capsule. This is in contrast to a computation for a pressurized capsule design where its whole area is to be considered. With this arrangement the astronaut enjoys the, however meager, original protection of the space suit plus the added protection of the capsule.

Assuming a nylon soft space suit thickness of 0.07 inches, we can see from Figure 1 that its penetration rate would amount to about 0.2 penetrations/m²·day or one penetration every 5 days. Providing a 0.06 inch aluminum skin would in itself experience 0.033 penetrations/m²·day or one penetration every 300 days. The combined protection therefore will result in a penetration rate of approximately 0.001 penetrations/m²·day.

Assuming an exposed space suit area of 2.0 m², the penetration rate will be 0.002 penetrations/day or one penetration every 500 days. Of course, this figure does not reflect the added protection due to components mounted in the capsule, which is considerable.

The capsule will require a transparent portion to allow visual contact with the target during transfer operations. A material such as used for the space suit visor is recommended. The transparent panel should provide a protection comparable to that provided by the aluminum skin. Figure 2 gives an indication about "weight effectivity" of different materials with respect to penetration. As can be seen, aluminum has an edge on fiberglass and a considerable advantage over nylon and rubber.

So far bumper designs have not been considered, nor have effects of structural shape on penetration been considered.

Results from tests performed indicate that the use of spaced-sheets permits a reduction in the total material thickness required by a factor of five (5). This design approach is known as the "Whipple bumper". Another source calls out a factor of 4. Further improvements can be reached in the use of honeycomb between the bumper and hull or filling the space with energy absorbing material or both.

A discussion of the design for this application will be presented in a later section.

What is the probability of survival with the above protective values?

The probability of no penetrations occurring is

$$S = e^{-N}$$

where $N$ is number of penetrations in the selected environment, area and time.

For our case $N = 0.002$ pen/day x 30 days = 0.06 pen.

$$S = e^{-0.06} = 0.942$$
The probability to be penetrated once is

\[ P(1) = N(1-N) = 0.06(1-0.06) = 0.056 \]

Both indicate a very low probability of penetration especially when we consider that 30 days constitute a large number of extra-vehicular mission periods.

c. Radiation Protection

A satellite in an earth orbit is exposed to protons and electrons of the Van-Allen belts. The dosages received will depend on the orbital parameters such as orbital altitude and inclination. With lower orbital altitudes the dosage decreases rapidly. For example, lowering the altitude from 400 to 200 N.M. will decrease the dosage by approximately two (2) orders of magnitude.

In addition solar events will emit high energy protons. The frequency, duration, and intensity is not adequately predictable, but a few events such as the 1956 and 1959 events, are well recorded and serve as a criteria for the present.

High energy protons and alpha particles, classified as cosmic radiation, further add to the radiation environment.

An evaluation of these radiation sources for earth orbit missions indicates that only the Van-Allen radiation will be of concern in extended orbital missions and must be considered in the design of the basic orbital spacecraft.

Solar flare radiation at low earth orbits represents a low level hazard except for the very infrequent high intensity events. The earth orbit, however, presents the advantage of shadow shielding by the earth and the opportunity of mission termination. Cosmic radiation, likewise, does not require special treatment in an earth orbit since their effects greatly decrease with a decrease in orbital altitude and inclination.

The planned extra-vehicular activities at present will involve only a few hours exposure to the higher doses inside a space suit. It can, however, be visualized that the advent of space stations and assembly operations of deep space probes will require longer exposure periods in order to be economical. More effective shielding will then be necessary which cannot be provided by a soft space suit alone.

The design of the work station capsule will consider radiation protection only as an effect of secondary importance. Improvements in radiation protection will be the result of the added meteoroid protection which is treated as an effect of major importance.

d. Attitude control and translation propulsion

In view of the design approach, the presently established requirement for automatic attitude stabilization will not be disputed. The automatic attitude stabilization system does position stabilize around three axes during maneuvers. In order to provide capability to orient the body at any desired attitude, rates can be manually introduced by control stick motions. This is accomplished by the use of miniature rate gyros through electronic integrating and summing networks and reaction nozzles. A stabilization accuracy of \( \pm 10^\circ \) seems to be acceptable. A DC system is used in order to minimize system weight. The attitude control system will be active in presence of disturbing torques and in case of manually initiated attitude commands.
Disturbing torques can and will be created by translation thrust if the resultant of this thrust does not point to the center of gravity. If the center of gravity location is well known and can be maintained, a very low requirement for stabilization due to these torques will exist.

Any translation from one point to another in an orbit does actually involve an orbital transfer operation. Performance of this operation by use of only optical reference will result in a number of corrective thrust applications. The longer the transfer distance, the larger the number of corrections required and the larger the impulse requirement. In addition, manually induced rotations will be necessary to either permit scanning of the surroundings or to align the line of sight with the translation velocity vector. To initiate and stop the translation during transfer an additional amount of impulse will be necessary. After arrival at the target or work area, sufficient amounts of propellant must be available to maneuver in the local vicinity.

In summary it can be said that the total propellant requirement is affected by:

1. stabilization impulse
2. translation start-stop cycles
3. manually induced rotations
4. orbital transfer corrections
5. work area maneuvering.

A thorough analysis of the orbital transfer problem is given in the literature. Computer analysis clearly indicates that ranges to 1000 feet pose a minimum of problems since these require low impulse and are less affected by the initial orientation angle. Also indicated is the need for terminal velocities between 10 and 20 ft/sec, where the lower velocity is fixed as the limit which is necessary to avoid missing the target.

For initial orbital operations the authors of this paper therefore recommend a maximum action radius of only 1000 ft. This could be extended, if found to be desired, by increasing the propellant capacity.

A total impulse of 5000 LB-sec was considered for the initial design. The detailed discussion of how this capacity was determined will not be presented here; however, the method used was based on the method used in reference with slight deviations in basic assumptions.

Since a hydrogen peroxide system for the back-pack has been developed and since the propellant has reached a high level of reliability in present usage, it is selected for this application. With a vacuum specific impulse of 184 sec for \( \text{H}_2\text{O}_2 \), the total propellant weight will amount to 27.2 lbs. Adding 10% for ullage and unusable line capacities, the required propellant quantity will amount to a weight of 30 lbs. This weight amounts to a volume of 600 IN. but for purposes of packaging a volume of 0.5 ft\(^3\) will be used.

The analysis on a back-pack system indicates that low translation thrust levels along the roll (forward and backward) and yaw (up and down) axes can be used without any sacrifice in performance and at a beneficial savings in impulse.

A thrust level resulting in an acceleration of 1.0 (ft/sec\(^2\)), is therefore recommended.
For rotation a rate of 0.5 rad/sec seemed satisfactory. A minimum of nozzles should be required to accomplish the stabilization and translation tasks. Only an on-off thrust application will be considered and no reaction control propellant will be spent to react against the torques created by tools.

e. **Navigation aids and displays.**

Man will be faced with a navigation task in an unusual environment when he enters the period of extra-vehicular activities. He will have to perform the navigation task without the aid of intricate instrumentation. Just maneuvering in close vicinity of an object or objects probably will not pose any problems, but as soon as longer distances are involved, the problem will become more serious. Assuming a requirement for transfer of up to 1000 feet exists, the first task will be to not miss the target and secondly the relative velocity must be reduced to zero when the target is reached to avoid a collision.

Man is unfortunately able to judge distances accurately only for distances up to 50 feet and is not a very good rate-of-closure estimator. So, in extra-vehicular operations, misjudgements will result in propellant waste and could lead to injury. For example, during orbital transfer corrective up/down thrusts could add to the relative approach velocity but will not be readily evident. Application of retro thrust to stop at a target must depend on estimates of velocity and of distance.

The best approach for initial operations therefore appears to consist in limiting velocity. Only short bursts of translation thrust will be applied and the operator could be provided with a timer which would run whenever thrust is "on" thus adding the total thrust "on" time. Since an on-off system is used, this time could be calibrated in velocity. This would not be very accurate, but certainly better than just estimating.

In order that thrust is applied in the proper direction, a wide angle optical aiming device can be easily provided. Such a device has been proposed by Chrysler in connection with a strap-on propulsion unit. For more advanced missions, at extra cost, a small radar set or a laser range finder in conjunction with a closure rate calculator could be provided.

The possibility to provide the operator with information through his communication link with the mother spacecraft also deserves merit for activities where only one work capsule is utilized. Spacecraft-borne radar could be used to determine range and rate of closure, and the information could be passed on to the extra-vehicular operator.

In summary:

1. Initial operation with the back-pack will probably not use navigation aids.

2. For ranges and targets considered in extra-vehicular operations acquisition of targets should be possible by sight.

3. The capsule approach should provide for optical aiming and thrust/time integrating capability along at least two major translation axes.

4. Advanced capsule missions, especially if longer distances are involved, could use radar or laser ranging devices.
In addition to navigation aids the operator must be supplied with a limited number of system status displays and warning devices. These displays should include:

1. propellant capacity
2. propellant pressurization capacity
3. life support system capacity
4. suit pressure
5. emergency pressurization status
6. power supply status

In most cases, visual warning should be provided when minimum safe values have been reached.

f. Tools and supporting hardware.

The final purpose for placing a man outside his mother spacecraft is to have him perform certain necessary tasks. In order to perform these tasks in an efficient manner he must be provided with tools and supporting hardware. Tools, which require a minimum of reaction torque, have been or are being developed. Universal types, where one basic unit can perform different functions using a variety of attachments, have been developed and have been tried under simulated conditions or even in OG flights in aircraft. A selection of such tools, therefore, should be carried in the work station capsule.

Provisions, therefore, are necessary to place these tools in a location which is easily accessible.

Obviously, we do not want to spend stabilization or translation propellant to maintain the capsule's position with respect to the work object. Even low torques and forces, however, will cause rotation and drifting. Body motions and placing of a tool against the work object would cause relative motions. It will, therefore, be necessary to provide some sort of attachment means to prevent the above relative movements.

If work is to be performed on objects which were designed with such operations in mind, provisions will probably be made for attachment of straps or telescoping rods.

If the object is "non-cooperative" - just smooth skin - we will have to resort to an adhesive pad approach. Such pads have been proposed and tested by Lockheed, and indications are that these are feasible. The design of such pads and their supporting structure must include provisions for convenient and reliable attachment and detachment.

The end of the supports could be designed so that they can carry either an adhesive pad or a hook device to engage a counterpart provided on a target.

At times, the work location will be on the shadow side of the object. Therefore, lights must be provided which are capable to illuminate the immediate work area.

g. Communication

Voice communication will be necessary between the mother-spacecraft and the extra-vehicular operators, and also between individual extra-vehicular operators. This link will be utilized to supervise the operations from the mother-spacecraft and to give each operator a means to keep the spacecraft controller informed about his status, problems encountered, etc.
A telemetry data link probably will also be desirable in order to provide the controller on the spacecraft with an independent means to monitor the operator's physical condition and the status of some vital subsystems, such as propulsion and life support system capacities. A frequency of 250-300 Mc probably will be utilized. Due to the low losses in free space, a very low power level will be required (10 to 20 milliwatts). Quarter wave dipole antennas can be employed.

It appears that equipment to satisfy these basic requirements has been or is being developed and should be readily adaptable to this application.

h. Basic capsule sizing.

Capsule size is going to be affected mainly by the size of the operator. The shape of the capsule will be determined by the attitude which the operator will maintain. A 95 percentile man was used as the basis for sizing and for weight and balance purposes. An appropriate added amount to accommodate an inflated spacesuit and helmet must be considered. Sufficient clearance to reach various controls and tools and to perform the primary tasks must be provided.

In addition to the astronaut the capsule must contain the necessary subsystems. Weight and volumes for these subsystems were either taken from available references or estimated.

An erect attitude was selected for the operator since this attitude would, in the particular environment, cause a minimum of discomfort over extended periods, would provide maximum freedom of motion, allow easy relocation of the body with respect to the capsule to extend arms reach, and provide maximum ease of egress and ingress. This attitude also will lead to a simple structure.

Table I presents the sizes and weights of individual major items which must be packaged into the capsule.

Table I

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<th>Item</th>
<th>Weight Lbs.</th>
<th>Volume In³</th>
<th>Height In</th>
<th>Depth In</th>
<th>Breadth In</th>
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<td>1600</td>
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</table>

4. SUMMARY OF DESIGN CONSIDERATIONS

1. The capsule will be unpressurized.
2. Subsystems or parts thereof as developed for the AF back-pack should be used.
3. The supplemental life support system for Gemini known as the ELSS should be used for the transfer from the mother spacecraft to the work station capsule and return.
4. An emergency pressurization system (EPS) for the capsule in connection with a pull-up seal bag should be provided.
5. The EPS must be capable of maintaining a pressure of 3.5 PSIA in the capsule for 10 minutes.

6. A lowest temporary suit pressure in an emergency of 2.7 PSI must be assured.

7. A meteoroid penetration rate of between $10^{-2}$ and $10^{-3}$ should be observed in the design of the skin of the capsule.

8. A bumper type design should be used to reduce weight.

9. Transparent windows must be sized to provide probability of penetration comparable to that of the aluminum skin.

10. Radiation protection should be treated as an incidental benefit arising from the meteoroid protection.

11. Automatic attitude stabilization with manual command capability must be available.

12. Translation thrust along three axes must be available.

13. A stabilization accuracy of ± 10° is desired.

14. Center of gravity must be closely bracketed to preserve propellants.

15. A range of 1000 feet should be considered.

16. A total impulse of 5000 lb-sec must be provided.

17. Hydrogen peroxide should be used as the propellant.

18. Thrust levels for translation resulting in an acceleration of at least 1.0 ft/sec$^2$ should be provided.

19. Maximum rotation rate must not exceed 0.5 rad/sec.

20. Terminal transfer velocity must be such that capsule can be stopped within 50 ft.

21. An initial transfer velocity of not less than 15 ft/sec must be used.

22. Optical aiming aids should be made available.

23. Translation thrust time integrators are desirable.

24. A minimum of system status displays must be provided as called out under 3f.

25. A selection of universal tools should be available.

26. Attachment arms to maintain position and to react torques must be provided, and they must be capable of attaching to any surface.

27. Work area illumination must be provided.

28. Voice and data communication must be provided.
29. The capsule must be sized to receive a 95 percentile man in an inflated space suit and all subsystems.

30. Provisions must be made for easy ingress and egress.

31. Access must be provided for easy replenishment of system expendables, such as propellant and oxygen, and for recharge or replacement of batteries.

32. Operator must be able to increase his "reach" for maximum effectivity in the performance of tasks.

33. The structure of the capsule must be able to contain an internal pressure of 3.5 PSIA.

5. CONCEPTUAL DESIGN

The previously discussed technical approach and the established requirements provide the basis for a conceptual design of the Work Station Capsule.

An inboard profile of this design is presented in figures 3 and 4. It is envisioned as a cylinder having elliptical dome ends. The diameter is 36 inches and the total length is 97 inches. Sliding doors permit a rectangular access opening 27 x 78 inches. The astronaut occupies a space that is oval shaped having the dimensions of 21 x 27 inches and a height of 78 inches. The remaining space is utilized for storage of the ancillary equipment.

The conceptual design has been generated using today's state-of-the-art in materials and equipment. The design considerations are based on anticipated loadings resulting from the operational launch and prelaunch environments. The operational space environment concern is mainly in providing protection from damage which may result from meteoroid impact. The launch phase environment creates inertial and vibratory loads as well as thermal conditions which must be considered. The prelaunch environment includes all of those conditions which have their origin in the manufacture, logistic and earth environments. These include handling storage, moisture, corrosion, temperature, maintenance, and so on.

The following sections describe in more detail the specific considerations related to the capsule configuration, weight and balance criteria, structural design and the design of the particular subsystems which make up the ancillary equipment. Details will be covered only to the extent necessary to convey to the reader the most important design parameters and features.

Component designs which have been developed for other programs are receiving only cursory treatment.

a. Configuration

The erect attitude of the operator, as previously determined, lends itself to a cylindrical capsule shape.

Evaluation of the ingress and egress opening leads to the conclusion that a circular cross-section of the compartment would be most desirable also from the standpoint of door design. Such a configuration would lead to a door which most satisfactorily blends into the contour in both the open and closed condition. It would also result in a most efficient structural design and deflect oblique meteoroid impacts.
Both ends of the cylinder are capped by an elliptical dome shaped structure.

The base plate of the dome forms a pressure bulkhead while only a light structured skin shapes the outer contour. The compartment between the pressure bulkhead and outer skin will contain the attitude control and translation reaction nozzles and associated valves.

While the cylindrical compartment section is not sealed, the two pressure bulkheads must be leakproof. The reason for this will be evident when the emergency pressurization is discussed.

Within the compartment the operator is placed in an erect attitude and strapped to the structure by a single waist strap and foot straps. In order to have the center of gravity at the axis of the cylinder, the operator will be placed forward of the axis while most of the heavy components will be placed aft of the axis.

This arrangement is most satisfactory since the compartment forward of the man must be free of all obstructions to assure free entry and exit, and to allow free arm and body motions. Split sliding doors are proposed to complete the protective closure during transit, and to allow free access to the work area at the target.

Since the space suit and helmet are greatly restricting the field of view anyway, only the upper parts of the doors will be provided with a transparent panel. Viewing of objects outside the field and scanning of the surrounding area will be accomplished by rotating the whole capsule by means of the reaction control system.

On either side of the operator, at about hip level, tool storage will be provided.

Slightly above this location to the right of the operator, the hand controller for maneuvering will be located. A controller similar to the Gemini controller or a slightly modified SMU controller is contemplated. The controller would be mounted on a pivotable arm to allow moving it out of the way for ingress and egress and to provide the capability of using the controller with either hand.

At four points, two on each side, extendable attachment arms will be mounted to the inner structure.

In order to leave the area in front of the operator free, vital system status displays are placed forward of the operator at the edge of the upper bulkhead. In the same location pointed outward and downward, a number of lights for work area illumination will be arranged. One or two additional small high intensity lights, on extendable arms, will be mounted internally to the structure to provide illumination for compartments inside of a work object. The seal curtain concept for emergency compartment pressurization deserves some further attention.

From the standpoint of the length of the gap or gaps to be sealed, the cylindrical pull-up curtain appears best. Only sealing at the top is required.

The question then arises why not just surround the body of the operator? This will provide for a minimum volume and a minimum gap length. Even while the seal curtain is in place, the operator must be able to control the capsule. This is possible if the controls are supported either from the top or bottom bulkhead. However, providing a smooth structure for the curtain to rest against will be rather difficult in view of the various devices the operator must have access to while the curtain is down. Such provisions as tools, attachment arms, switches, etc. must all be provided with recesses and smooth closures. Pressurization would
first require that all closures be actually closed before the curtain is pulled up. Chances for seal damage in this case are increased manifoldly.

The internal surface of the outer shell and the door, therefore, seem to be the logical backup surface for the seal curtain and this approach is used in our design.

b. Weight and Balance

Previously mentioned reference data and estimates result in the weight estimate for the system presented in Table II.

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight (Lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Operator and Suit</td>
<td>230</td>
</tr>
<tr>
<td>2. Nozzle group I</td>
<td>12</td>
</tr>
<tr>
<td>3. Nozzle group II</td>
<td>8</td>
</tr>
<tr>
<td>4. Propellant Supply</td>
<td>65</td>
</tr>
<tr>
<td>5. Communication</td>
<td>8</td>
</tr>
<tr>
<td>6. Inertial Reference System</td>
<td>20</td>
</tr>
<tr>
<td>7. Life Support System</td>
<td>45</td>
</tr>
<tr>
<td>8. Supplemental Life Support System</td>
<td>20</td>
</tr>
<tr>
<td>9. Emergency Pressurization System</td>
<td>5</td>
</tr>
<tr>
<td>10. Control Components</td>
<td>5</td>
</tr>
<tr>
<td>11. Instruments, Switches</td>
<td>6</td>
</tr>
<tr>
<td>12. Lights and Instruments</td>
<td>3</td>
</tr>
<tr>
<td>13. Attachment Arms</td>
<td>5</td>
</tr>
<tr>
<td>14. Tools</td>
<td>30</td>
</tr>
<tr>
<td>15. Structure</td>
<td>88</td>
</tr>
<tr>
<td>Total Weight</td>
<td>550 Lbs.</td>
</tr>
</tbody>
</table>

Components and the operator must be so placed that the center of gravity is located on the axis of the cylindrical body and equidistant to the location of the fore-aft translation and rotation nozzles. In addition, we must place components containing consumables close to the center of gravity in order that it remains closely bracketed even while the consumables are expended.

Preliminary packaging and CG analysis indicates that both requirements can be met.

From the standpoint of propulsion the CG location in the Y direction is the most critical since this direction presents the longest moment arms. Most deviation in the CG will be contributed by the operator. According to available test data the CG of the human body can be determined with an accuracy of \( \pm 0.5\% \). Over the percentile range of operators the CG can shift approximately 1.4 inches along the Y axis. Should the necessity arise to accommodate a range of operators, we might require an adjustable platform on which the operator stands or to which his feet are strapped which can easily be accomplished.

Preliminary packaging as shown in the inboard profile (Fig. 3 and 4) resulted in a maximum X-axis CG location of 0.25 in. from the axis of the body. This will increase to 0.7 in. as the consumables are expended. Along the Y-axis comparable values amount to only 0.1 and 0.2 inches respectively. These values produce only small increases in nozzle moment unbalance and can be tolerated.
Evaluation of moments of inertia indicates that the capsule will have a

\[ I_{\text{Pitch}} = 40 \text{ slug ft}^2; \quad I_{\text{Yaw}} = 10 \text{ slug ft}^2; \quad I_{\text{Roll}} = 30 \text{ slug ft}^2 \]

c. Structural Design

The structural configuration chosen for presentation utilizes the "bumper" type of construction throughout. Bumper construction is defined as a double walled construction with a gap or an absorber material between. The outer wall acts as a bumper which fragments penetrating particles into a cloud of smaller particles which, hopefully, cannot penetrate the inner wall. This approach appears to permit the maximum amount of protection against meteoroid penetration for the least weight. Future studies will confirm or reject this postulation.

The cylindrical outer shell is visualized as being of aluminum honeycomb construction which has inherent "bumper" qualities. An inner shell is provided to which the ancillary equipment is mounted. The space between these shells, besides acting as a second bumper for meteorites which may penetrate the honeycomb shell, provides a gap for the emergency pressurization curtain. The inner shell utilizes longeron type construction from floor to ceiling. All equipment is mounted directly to the longerons, or to frames tied to the longerons. Support members in the floor and ceiling will then transmit the point loads to the skin by conventional shear panel techniques. During the launch phase the loads may be transmitted directly, via this point source, to supporting structure in the space craft. The longerons will be enclosed in a shroud to provide a smooth surface to prevent damage to the emergency pressure curtain during its activation. This longeron approach also provides sufficient load path support at the door opening to prevent deflection of the door tracks in the pressurized capsule mode. Deflection of the tracks could permit the doors to "pop" out resulting in a disaster condition.

This construction protects the astronaut for 260°. The front 100° are protected by doors of aluminum honeycomb construction. The thicknesses selected for this application may be slightly heavier to compensate for the lack of an inner shell. The upper section of the doors will be of double walled plexiglas or similar material to permit visual perception. The gap between the walls will be equal to the thickness of the honeycomb panels utilized in the lower door construction.

The door sliding mechanism will utilize a recirculating ball bearing system to insure smooth non-cocking operation. Tracks will be provided at the upper and lower interfaces for this purpose. These tracks will also provide the load path for those loads generated when the capsule is in the pressurized mode.

The floor and ceiling will be designed as sealed pressure bulkheads to resist the loads generated if and when the capsule is pressurized during emergency operation. It is anticipated that these will be flat panels, probably honeycomb backed by beam structure. The backup structure will also serve to mount the various thrust nozzles used to maneuver the capsule. A thin outer dome is provided to protect the nozzle from damage due to accidental bumping and to prevent the nozzle from hanging up on some objects.

Beneath the floor a torroidal compartment contains the folded curtain to be used as a pressure seal should the astronaut's suit develop a leak. Provisions will be made for raising this bag by manual or automatic means as future studies may indicate as best. Sealing will be accomplished at the upper interface by conventional sealing methods. A three pin lock system is foreseen as a means of holding the seal in place while internal pressure within the seal (via holes to the inner
capsule) will accomplish the actual sealing. Leak rates of the order of 1200 cu. cm/minute are anticipated at this interface.

d. Subsystem Design

Even though the basic philosophy of the design dictates the use of components and subsystems developed for the back-pack unit, some modifications will be necessary to comply with specific requirements which are connected with the specific application proposed.

In addition, the work station capsule requires some new systems which require definition. Therefore, the following section will be devoted to discuss the most important and necessary details concerning the subsystems.

The Life Support System. The only modification required of the life support system will consist of extension and re-routing of the in- and outlet ports. Since the operator must connect the capsule LSS and then disconnect the ELSS it is mandatory that the connectors of the LSS are located on either side of the operator at a convenient location. Rigid tubing will form the extension from the LSS to the new location, supplemented with a length of hose to accommodate free motion forward and aft to allow for extended reach for performance of tasks.

The supplemental life support system (ELSS), which in its original form will be carried as a chest-pack, will be re-located to the back of the operator and, therefore, require extension and re-routing of the in- and outlet ports. Special attention will be required in the area of the hookup of both systems to assure fool-proof and foul-proof removal and replacement of the umbilical.

No re-packaging of the basic system will be necessary since sufficient space can be provided in the capsule.

A new part of the overall capsule life support will be the emergency pressurization system (EPS). This system is provided to further improve the astronauts chances for survival in an emergency. The system can fulfill its assigned task only in connection with a pull-up seal curtain. This seal curtain is located in stored condition at the outer 1.0 inch of the cylinder wall at the lower bulkhead. The seal curtain is fabricated from a CTFE Fluorocarbon material. This material has very good low temperature properties, and up to thicknesses of 1/8 inch can be made optically clear, and has good out-gassing characteristics in vacuum. It is extensively utilized as a seal in high vacuum systems. The upper part of the bag is fastened to a structural ring which also carries on its upper side an inflatable seal. When an emergency arises, which requires capsule pressurizations, the seal bag is pulled up tight against a smooth face on the upper bulkhead by a cable arrangement either manually or by a drive. Subsequently, depending on the severity of space suit leakage, either the LSS will pressurize the compartment or the ELSS will be activated to fast-pressurize the compartment. The inside of the above mentioned seal is connected to the compartment, thus providing improved sealing as pressure increases. Since the bag is backed up by a smooth structural skin, it can be fairly thin (0.05 to 0.010 In.).

The EPS will consist of a small high pressure container with a capacity of approximately 0.6 lbs. of oxygen. Flow will be initiated by a squib valve and pressure controlled by a pressure regulator. In order to keep the regulator size small a high flow bypass for the initial pressurization can be easily provided.

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It seems feasible to pull up the seal curtain and pressurize the compartment within 20 seconds which would require an average flow rate of approximately 0.05 lbs/sec. A very low flow rate of between 0.001 and 0.002 lbs/sec will take care of the leakage from the compartment.

As long as there is outflow of gas from the compartment, CO₂ partial pressure will not build up to a critical value.

Propulsion System. The propulsion system, serving rotation and translation requirements, will consist of the propellant supply and two nozzle groups. While the propellant supply is located close to the CG of the capsule, the nozzle groups are placed into the upper and lower domes outside the actual compartment.

Systems such as this have been extensively treated in various literature so that a detailed discussion here is avoided. Let us only say that positive expulsion by gaseous nitrogen is provided. The system is initiated by firing of a squib valve which releases nitrogen into the propellant container. Standard H₂O₂ thrusters with solenoid valves and catalyst beds are used.

The most efficient system is one where a maximum of functions can be performed with a minimum of nozzles. The required functions are: rotation around all three axes and translation along two axes. The axes are defined and nozzle arrangement is presented in Fig. 5. As can be seen, a total of 12 nozzles is necessary to satisfy the rotation and translation requirement. Only two thrust levels of 5 and 10 lbs. are used. For translation, this results in accelerations of 1.18 ft/sec.

Using preliminary moment of inertia values and moment arms the following rotation rates for minimum command pulse bits can be established: \( \omega \) pitch = 0.7 rad/sec; \( \omega \) yaw = 0.5 rad/sec; \( \omega \) roll = 0.34 rad/sec. As can be seen, the pitch rate is high as a result of a long moment arm in conjunction with the high thrust level required for translation. The rate can, however, be reduced if automatic pulsing is utilized, thus splitting the impulse bit to a number of short pulses at an accordingly lower impulse.

Attachment Arms. A few words should be said about the design concept for the attachment arms. Based on an evaluation of the need for such devices and of their arrangement, it was concluded that either 3 or 4 such arms will be necessary to keep the capsule positioned and to react work torques. The three arm arrangement for the present was dropped since the third arm would have to be positioned at the lower bulkhead in order to be out of the way. This would preclude manual extension and retraction by simple means.

Lightweight telescoping tubes with provisions for either manual or electrical ball-screw drive are visualized. However, simpler cable and hook methods have also been considered. At the end of each arm an adhesive pad design is mounted. Each pad consists of two flexible backup plates covered with an adhesive layer. Attachment is accomplished by lightly "bumping" into the target. Detachment is accomplished by activating manually the pealing action lever arrangement. The reaction force of the pealing action is acting upon the body from which detachment is desired.

Emergency detachment, as might be necessary in case of suit decompression, can be provided by quick release pins and leaving the attachment arms on the work object.
Other subsystems proposed for use in the capsule will not be discussed here since these are fully developed items described elsewhere in the literature.

6. OPERATIONAL CONSIDERATIONS

Some thought was given by the authors of this paper to the manner of operational application of this device and possible problems associated with such missions. Some of the conclusions from a rather cursory evaluation are presented below.

a. The Capsule and the Mother-Spacecraft.

It is assumed that the Work Station Capsule initially will be launched with the mother-spacecraft. For this purpose the capsule will be stored in space provided in the service module. It will be cradled to transfer launch loads and be provided with some means to facilitate extraction from the stored location. Extraction would preferably be accomplished by some powered device. Fig. 6 shows one concept which utilizes a docking structure to hold the capsule during storage in the spacecraft, extract it from the spacecraft, serve as a loading and launch platform, and facilitate the docking procedure.

In combination with an air-lock application, such a structure could be used to retract the capsule into the lock, and one of the arresting plates could even serve as a hatch cover.

Fig. 7 shows the Work Station Capsule in transit with doors closed, and in working condition, attached to a work object.

Fig. 8 shows a possible air lock application in a space station. The advantages of the sliding door feature of the capsule are strikingly evident in this close quarter application.

b. Emergency

Of particular interest from an operational safety point of view is the capability of a system to cope with emergencies. The most serious threat in a space application is that of a sudden decompression. Also quite serious is the fire hazard in a pure oxygen pressurized compartment.

The chances of sudden decompression are greatly reduced by removing reliance on a pressurized compartment for a breathable atmosphere. In addition, the hazard of a flash fire in case of a meteoroid penetration is eliminated, and so is the chance of compartment fires. The hazard of damage to the suit or failure of the ISS, however, still remains.

Let us take a look at what takes place in the Work Station Capsule in two emergencies: 1) tear or puncture in the space suit with flow exceeding the capability of the LSS, and 2) failure of the LSS. The worst situation will be one where the capsule is attached to a work object and doors are open. A preliminary estimate places the time from detection of a pressure drop to where suit pressure is stopped at 2.7 PSI and again rising, at 30 seconds. Tears, which cause flow rates which would shorten the time to reach 2.7 PSI appreciably, could be extremely dangerous unless a fully automated sequence is provided. In any case, one must keep in mind that the size of a hole, which would bleed the suit down to that level, is very small.

Fig. 9 shows a pressure/time plot for such an occurrence. Emergency pressurization is initiated approximately 25 seconds after the tear developed and 15
seconds later the compartment pressure has reached 2.7 PSI. If the LSS is still operating, the emergency supply can then be turned off.

As long as the LSS is still operating, a closed visor operation can be maintained. However, should the LSS fail or the oxygen supply be depleted during this period, an open visor operation will be required as described below.

Should the emergency consist of an LSS failure, breathing of the supply of oxygen contained in the suit will cause oxygen depletion, while at the same time, the leakage of the suit will cause pressure depletion.

Published test results indicate that in suits of low leakage rate, such as the Gemini and Apollo suits, oxygen depletion will be the critical factor. In a particular case, with a leakage rate of 1700 cm³/min, the critical partial oxygen pressure was reached in about 210 seconds, while the critical pressure of 2.7 PSIA was reached in 320 seconds. With lower leakage rates, the partial oxygen pressure time point will only slightly be affected.

This time, however, is sufficient to pressurize the capsule compartment. As soon as the capsule is pressurized, the visor must be opened, otherwise, oxygen depletion in the closed suit will still be a problem.

7. CONCLUDING REMARKS

In conclusion to the above it can be stated that:

1. An interim low cost transportation and work station capsule is feasible, which benefits from the use of components developed for presently projected extravehicular missions.

2. The system provides maximum operator mobility since meteoroid, radiation, and thermal protection is provided by the structure of a capsule rather than the space suit, or attachments thereto.

3. Operator protection against meteoroids has been improved by two orders of magnitude as compared to presently considered space suits and meteoroid shields.

4. Operator protection against radiation has also been improved considerably.

5. The unpressurized compartment presents an improvement in safety, in that flash fire hazard in case of a micrometeoroid puncture of an oxygen pressurized compartment has been eliminated.

6. The system lends itself to a collapsible design for easier launch phase storage.

7. Fire hazard, in general, has been reduced.

8. The pull-up seal provides an added safety feature, in that it permits emergency pressurization of the compartment with doors closed in case of a bad leak in the space suit.

9. Oxygen economy is better than for a pressurized compartment with hatches.

10. Task performance effectiveness is better than with use of manipulators or the back-pack and protective suit equipped operator.
It is our contention that the Work Station Capsule, as described in this paper, constitutes a highly desirable, low development risk, and low cost interim approach as a supplement to safe extra-vehicular operations.

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Figure 1 Meteoroid Penetration Rate vs. Material Thickness for four different Materials.
PENETRATIONS/m² DAY

unit Weight vs. Material Thickness and Penetration Rate

UPPER NOZZLE GROUP
COMMUNICATION
SUPPLEMENTAL LIFE SUPPORT
PROPELLANT SUPPLY
LIFE SUPPORT SYSTEM
EMERGENCY PRESS. SYSTEM
ATTITUDE CONTROL COMPONENTS

LIGHTS INSTRUMENTS TOOL STORAGE ATTACHMENT ARMS STORED SEAL CURTAIN LOWER NOZZLE GROUP

WORK STATION CAPSULE INBOARD PROFILE - Side view
SEAL CURTAIN CHANNEL

COMPONENT COMPARTMENT

SLIDING DOORS

OUTER SHELL

INNER SHELL

LONGERONS

OPERATOR COMPARTMENT

PARTITION

144, 9 + 12, 5 + 7, 243, 10

+ 11

648

15, 0

TRANSLATION

X-AXIS

Y-AXIS

143, 17 + 8, 244, 5

+ 6

5

I - 8

10 LBS

9 - 12

5 LBS

4 Work Station Capsule Inboard Profile - Top view

5 Propulsion Nozzle Arrangement
6 Docking Arrangement

TRANSIT -
DOORS CLOSED

WORKING -
DOORS OPEN
ATTACHMENT ARMS EXTENDED

7 Work Station Capsule in Action
8 Work Station Capsule in an Air Lock of a Space Station

9 Pressure/Time Plot for a Pressurization Emergency.