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A SPACE SUIT FOR LUNAR CONSTRUCTION AND EXPLORATION

Brand Norman Griffin*

ABSTRACT

A Command/Control Pressure Suit (CCPS) for lunar exploration and construction is described. The benefits of this design are detailed in terms of environmental, operational and vehicular interface conditions. An unconventional faceted helmet forms a seamless union with the upper torso creating The Rigid Upper Torso/Helmet (TRUTH) assembly. This configuration integrates external visibility with internal displays offering astronauts a portable command center for improved autonomy, safety, and productivity. Reliable, low-cost, in-helmet liquid crystal displays eliminate the conventional chest-mounted display and control module enlarging the prime work area. These displays provide direct viewing of checklists, diagrams, and video while allowing astronauts to keep both hands on the job.

The key features of the the CCPS are discussed. These include 1) internal displays, 2) integral torso/helmet assembly, 3) single point rear entry, and 4) modularity.

Development stages of the CCPS are presented showing concept drawings through subscale models to a full scale engineering test article.

INTRODUCTION

The Command/Control Pressure Suit (CCPS) is designed to be an integral part of the exploration infrastructure. (Figure 1) It is simple, rugged, and particularly suited for routine, long-life operation in the harsh lunar environment. A unique feature of the CCPS is the ability of serve as a command/control center for both the suit and attached systems. Astronauts use voice commands to status suit systems, determine time remaining in the mission, and code samples with time and location tags. Equally important, the CCPS is designed to display information on attached systems such as the lunar rover, lunar hopper, even another CCPS. In the case of a lunar hopper, this feature avoids the weight and complexity of a pressurized cab by enabling astronauts to be rigidly attached to the vehicle and connected to its data system. (Figure 2) Communication, navigation, flight information, and vehicle health are displayed within the CCPS, otherwise, flight control and other key vehicle functions remain a manual operation using hand controllers and switches on the flight deck.

Although appearing unconventional, the CCPS evolves from over thirty years of technical development producing a conservative, low-risk concept for lunar extravehicular activity (EVA). The CCPS design is an extension of proven systems in response to environmental and operational conditions. The following paper includes discussions on the response to environment and operations with a separate section addressing the attributes of the CCPS internal display.

*Project Manager, Advanced Civil Space Systems
Member AIAA

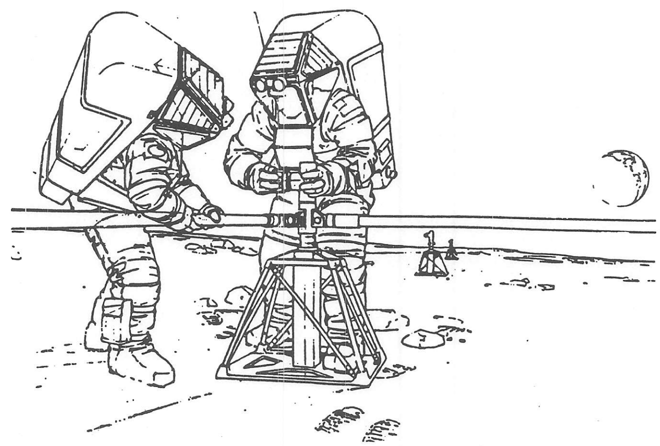


Figure 1 *Astronauts use the CCPS for lunar base construction*

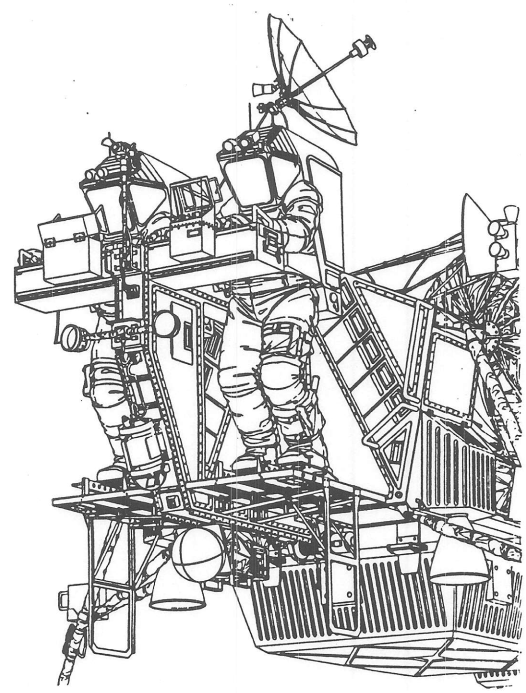


Figure 2 *Securely connected for the vehicle, astronauts stand to operate lunar hopper*

ENVIRONMENT

ATMOSPHERE/PRESSURE

The CCPS is designed to operate in a vacuum and even at the low Apollo lunar suit operating pressure of 25.9-kN/m^2 (3.75 psig) there is considerable stress on the suit's structural system. Zero prebreathe conditions more than double the pressure to 57.2-kN/m^2 (8.3 psig). This is significant because the repeated mating and de-mating of field-joints, such as the gloves and helmet, can lead to wear and leakage. By reducing the number of pressure connections made for each EVA the CCPS minimizes leak paths. (Figure 3) The CCPS avoids a neck ring connection with a seamless union of helmet and upper torso called The Rigid Upper Torso/Helmet (TRUTH) assembly. TRUTH combined with a single point rear entry and a policy of keeping gloves attached between EVAs minimizes the wear on joints. Long-life pressure integrity is expected by having a single-point connection at the backpack and by using memory metals such as Nitinol for the seal.

A major feature of the CCPS is a dust-resistant design. All displays are internal avoiding problems of dust buildup and except for the backpack, all pressure joints remain intact until servicing, minimizing exposure to dust. Sacraficial outer visors protect helmet glass from scratches and a replaceable, near-continous outer garment inhibits dust from reaching moving parts of the CCPS. Another feature which holds promise is a seal which mates directly to the module exterior allowing direct entry/exit without an airlock. This approach would not eliminate the airlock, but for routine operation, would avoid dust contamination.

GRAVITY

Like the Apollo lunar suit, the CCPS is designed to operate in weightlessness and a gravity field. Suit fit is key to astronaut performance and this is why posture and operating position played an important role in the design process. A range of postures and accelerations was considered (Figure 4) and two interesting observations surfaced; leg design should work like an inflatable column and the standing position is best for vehicle operation. Using the legs as columns, in some ways, violates perceived measures of good suit design. The problem is, that the low friction bearings that offer effortless mobility in weightlessness provide no support in a gravity field. This means that the entire weight of the suit is carried by the astronauts.

Virtually all operations of the Apollo program were conducted from the similar postures of standing or lying down. The Lunar Module was flown standing, the Command Module was flown from couches, and EVA was conducted standing. An important distinction concerning operating position is that in

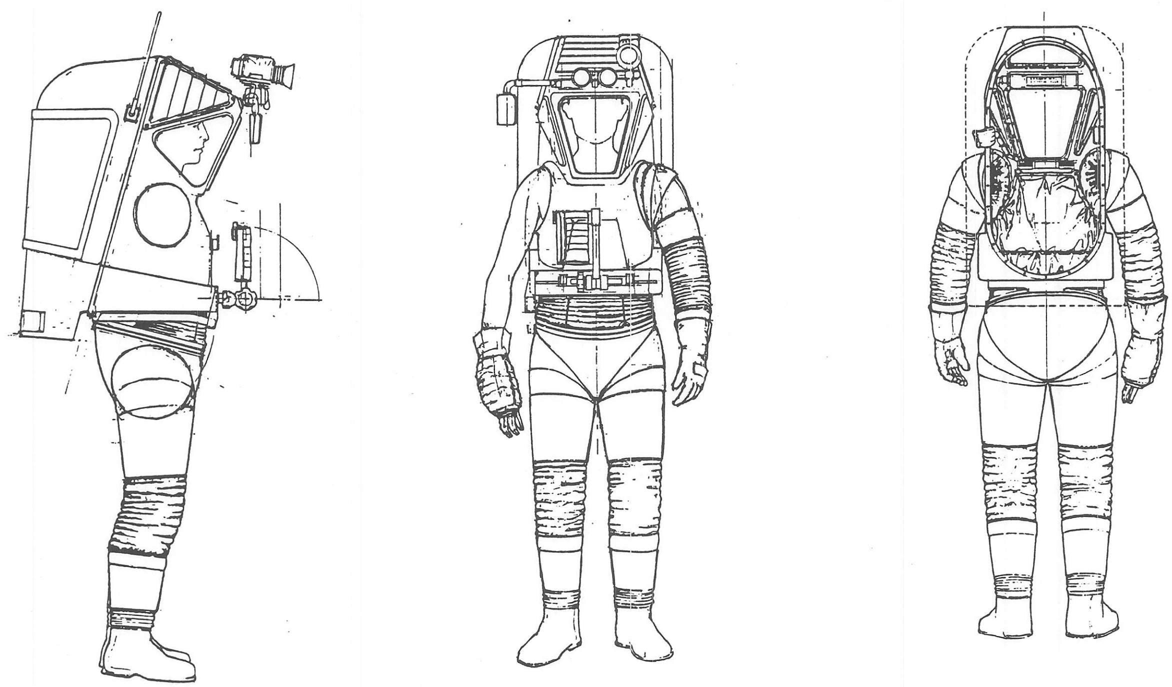


Figure 3 Three views of the CCPS pressure garment

DUST

The pervasive and abrasive dust will be a major problem for lunar EVA. Formed not by erosion like on Earth, lunar dust is the jagged by-product of 4 billion years of meteroid impacts. It has electrostatic properties and adheres to the suit. Removal is difficult and when brushed away usually scratches the surface. During the Apollo program, visibility of displays and performance of thermal coatings was impaired because of dust buildup. Furthermore, the process of getting in and out of the suit, brings the risk of contaminating both the breathable atmosphere and pressure seals to the suit, airlock, and habitat.

zero-g astronauts do not sit or stand in their suit, they float. However in a gravity field, astronauts actually sit within the ballooned suit adjusting the eye-point and sometimes compromising visibility.

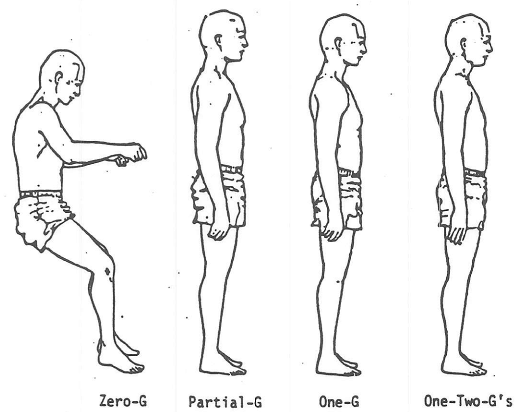


Figure 4 *Postural changes for different accelerations*

On the Earth, the advantage of operating from the seated position is that the feet no longer need to carry the body's weight and can be used for control, like accelerator, brakes or rudder. In a pressure suit, foot control would be imprecise and tiring, therefore Apollo astronauts seated in the lunar rover used a hand controller.

Another advantage of the standing position is that the legs serve as natural shock absorbers whereas when seated, the ride is rough, as confirmed by lunar rover astronauts.

To assist in operating from the standing position, the CCPS has two structural extensions at the mid torso. Astronauts secure suit structure to the vehicle flight deck then lock boots into conventional foot restraints for a rigid, four-point connection. This arrangement in conjunction with column-like legs minimizes the weight carried by the astronaut.

SUNLIGHT

Sunlight, and associated heat gain is controlled with louvers covering the upper three panes. (Figure 5) Astronauts can adjust each one individually depending upon the sun angle and desired visibility. The three lower panes are clear with thin replaceable protective visors. On the Moon, the sun will move only a little over four degrees during a typical eight hour EVA. With this stability in sun-angle, visors can be predictably tailored to the mission. A gold coated panel with high reflectivity are attached for daylight operations and only the protective scratch panel is used during a night EVA. Also, an option being studied to reduce glare is a dark collar made with multilayer insulation worn over the shoulders (Figure 6). Thermal analyses will determine the feasibility of this concept.

RADIATION

EVA astronauts are at an increased risk to radiation exposure. And unlike operations in low Earth orbit, being outside of the Earth's magnetic field, makes lunar EVA even a greater concern. The areas of potential protection being considered are use of metal matrix composites for TRUTH, thick leaded glass panes in the helmet-area and like the Zero Prebreathe Suit (ZPS), the use of tungsten in the thermal-micrometeroid over garment. Unlike bubble-shaped helmets, where thick glass creates a lens, tests have confirmed little to no distortion from the CCPS faceted geometry with 3/4-inch thick panes.

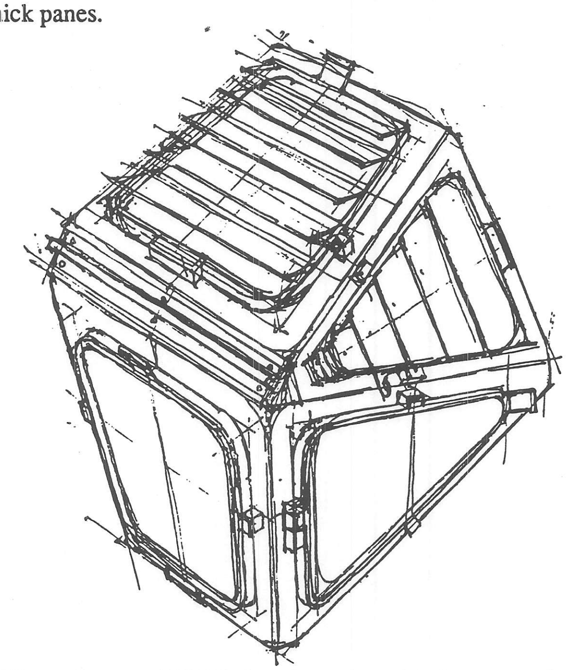


Figure 5 *CCPS helmet has adjustable louvers and protectivescratch guards*

OPERATIONS

ENTRY/EXIT

To complete an EVA, astronauts will enter the air lock, walk forward to the support stand, lock boots in the foot restraints and secure the structural/data connection at the front of the CCPS. Once procedures for shut-down are completed and pressure equalized, the astronaut will free the safety-catch on a release handle. The handle is then moved freeing the pins that secure the backpack to the CCPS. The backpack is then swung to the side allowing the astronaut to remove his arms, grab a bar overhead and pull himself out. No assistance is required either for entry or exit and all operations have direct visual confirmation. The simplicity in pressure seal geometry was an important reason for selection of this design. Other concepts were studied and two are shown in Figure 7.

BUDDY SYSTEM PROVISIONS

Standard buddy system practices will be used with CCPS EVA and all suits are equipped with an emergency umbilical. The umbilical is coiled up under the lower left side of TRUTH and connects to the suit's emergency oxygen and data systems. A corresponding receptacle for the umbilical is on the lower right side of each backpack. This offers ready access to the umbilical with an easy connection to the buddy's receptical and allows side by side walking while joined. The data connection allows one astronaut to access the other's data management system for diagnostic interrogation or system control. Shown in Figure 8 is an early concept of the receptacle.

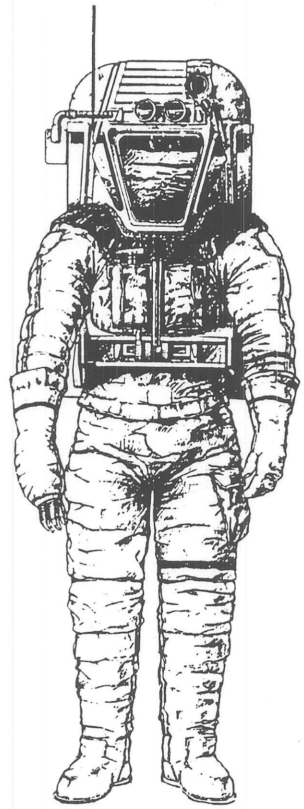


Figure 6 *CCPS Outer garmet offers provisions for glare reductions*

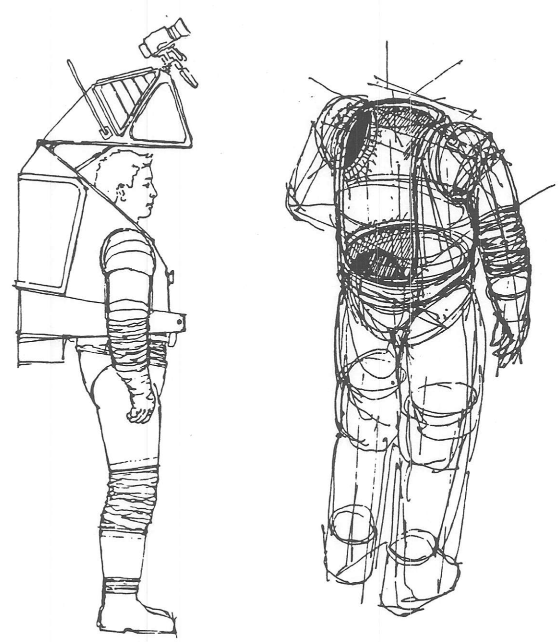


Figure 7 *Alternate entry/exit configurations*

MAINTENANCE

Because of the distance and shear effort required to get anything on the Moon, the CCPS is intended to be maintained in-situ. In order to promote reliability, CCPS systems are proven technologies. Rather than pioneer new technologies, the CCPS approach is to refine the integration of entire system adopting a test, test, retest and test again method of assuring high reliability and low-maintenance. Other measures included to reduce maintenance are to spend the time and effort necessary to make it simple and design a forgiving system with conservative margins.

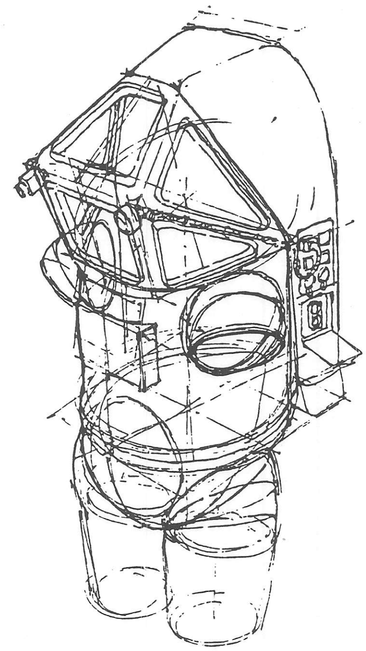


Figure 8 *Early development sketch of the CCPS*

A key feature of the CCPS which promotes easy maintenance is modularity. Backpacks are modular and interchangeable. (Figure 9) They range from a simple pressure cover with umbilical interface for tethered EVA to an autonomous extended-range portable life support system. The backpacks are easily removed for transport into a clean environment for servicing. Multiple, modular, and easily installed backpacks provide ready-access for EVA with one operational, one standing-by, and another being serviced.

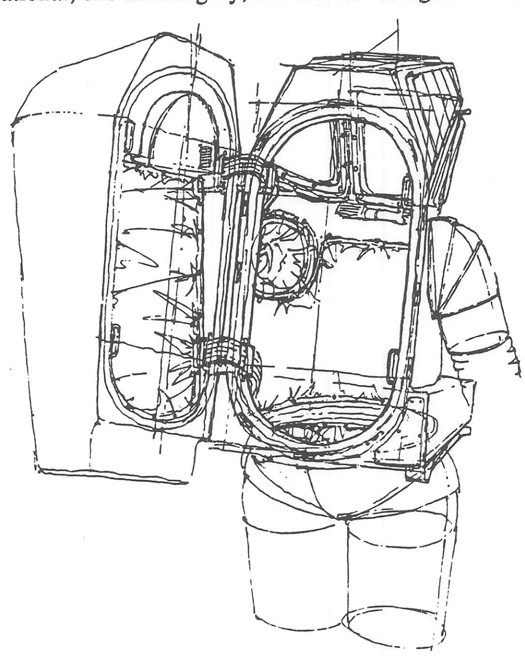


Figure 9 *The CCPS rear opening accommodates modular backpacks*

Modularity is extended to the gloves. For certain missions where tasks are well understood, repeated clamping may be required. This is a fatiguing operation using a pressurized glove and a reason for manipulator end-effectors that mate to the wrist seal. A number of concepts for pressure suit mechanical end-effectors have been developed. Using these manipulator options, provides the CCPS with a mechanical advantage and tireless clamping especially useful in construction.

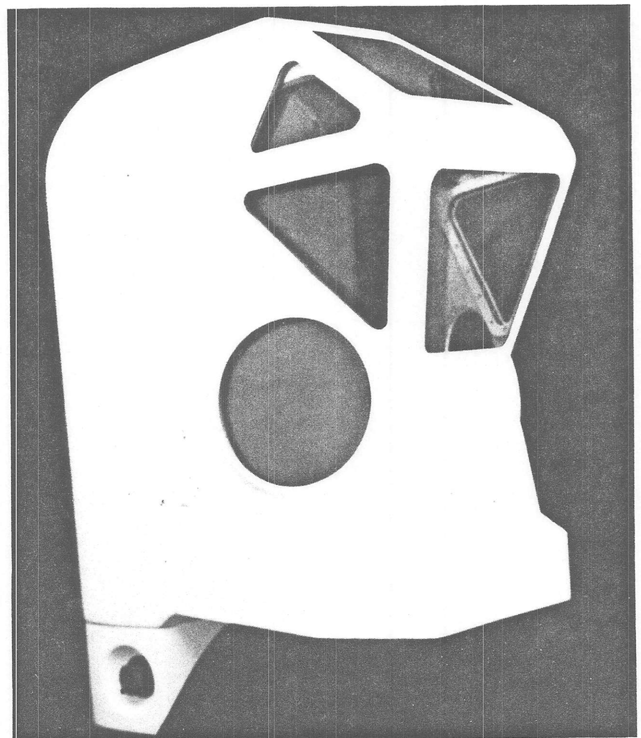
INTERNAL DISPLAYS

Most EVA has been performed for a specific task often rehearsed many times before the mission. This allows astronauts to become familiar with the hardware and refine procedures. To aid in these operations, cuff-mounted checklists have served as a useful reminder for corrective action and procedural instructions. There are deficiencies in the cuff checklist because the wrist is not always in the best position for reading and at least one hand is required for turning pages. Furthermore, information is limited to 3.25-inch by 4.5-inch pages which require a restraint to keep open.

EVA tasks will be less predictable for the longer missions and rotating crews of Space Station Freedom and a lunar outpost. Astronauts will be asked to inspect, repair, and service unfamiliar hardware and for these jobs, a cuff-mounted checklist is inadequate. Recognizing this problem, other means have been pursued. In 1986, a voice actived/voice synthesized system was developed and evaluated in a series of neutral buoyancy tests. In 1988, an external helmet-mounted display was delivered and tested under a NASA contract to the Hamilton Standard Division of United Technologies. The voice system was an improvement over the cuff-mounted checklist allowing both hands on-the-job but created a lot of disruptive "chatter" in the helmet. The Hamilton Standard external display removed the chatter problem, but is subject to the harsh lunar environment. Abrasive dust which obscured Apollo EVA displays will compromise legibility by collecting on the helmet visor and display surface. For these reasons, internal displays were favored and integrated into the CCPS helmet offering combined visibility of the outside while providing an unobscured view of useful, if not life-critical, information.

A common misconception is that because EVA helmets look somewhat like heads, they move like heads. In fact, the helmet is fixed in place and the astronaut turns his head within. This makes using a space suit much like operating from an aircraft cockpit.

The arrangement of glass, structure, and displays for TRUTH was determined by a process which first analyzed eye position and head movement with in the helmet. To confirm two dimensional decisions, a 10th scale model was evaluated which lead to a full scale formcore mockup. Improvements based on evaluations of this work have been incorporated into a full scale fiberglass engineering test article which is begin used to further analyze display characteristics, entry/exit procedures, visibility, form/fit and vehicle interface compatibility. (Figures 10 and 11)



Paul Hudson fabrication

Figure 10 *Full scale engineering test article for systems integration evaluation*

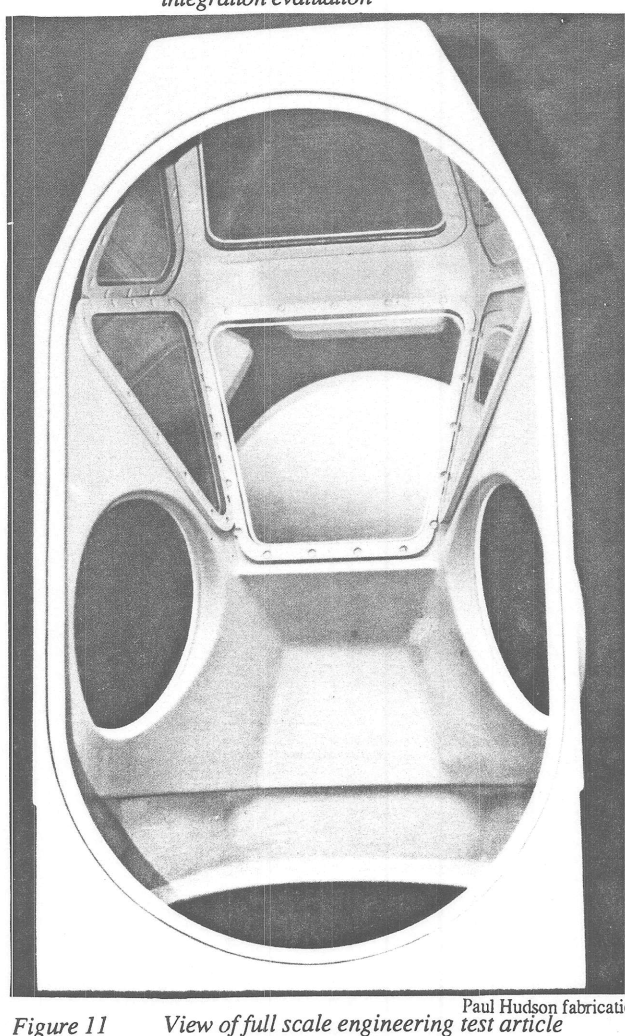


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Figure 11 *View of full scale engineering test article showing CCPS interior*

The prime work envelope in pressure suits is confined to a small area in front of the chest where the operator's cone of vision intersects both hands. (Figure 12) Traditionally, the space suit Display and Control Module (DCM) has been located in this zone. The CCPS relocates the DCM function into the helmet, enlarging the prime work envelope and improving display visibility. Figure 13 shows a lunar mini workstation in the CCPS prime work envelope.

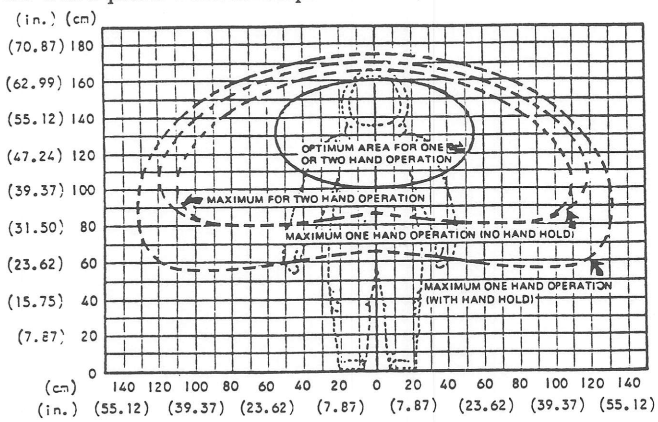


Figure 12 Prime work area for EVA astronauts

Lunar Suit Work Station

1. Backplate
2. Stowed Position
3. Thumb Lock
4. Position Handle
5. Full-Open Position
6. Tools (Clip-on)
7. Work Station Frame
8. Handle
9. Sample Bag
10. Parts Bin

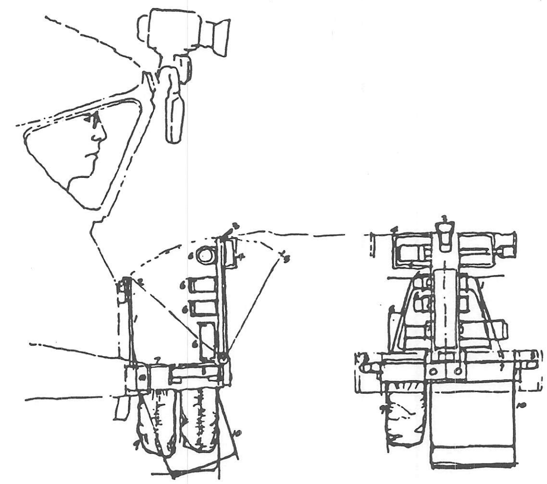
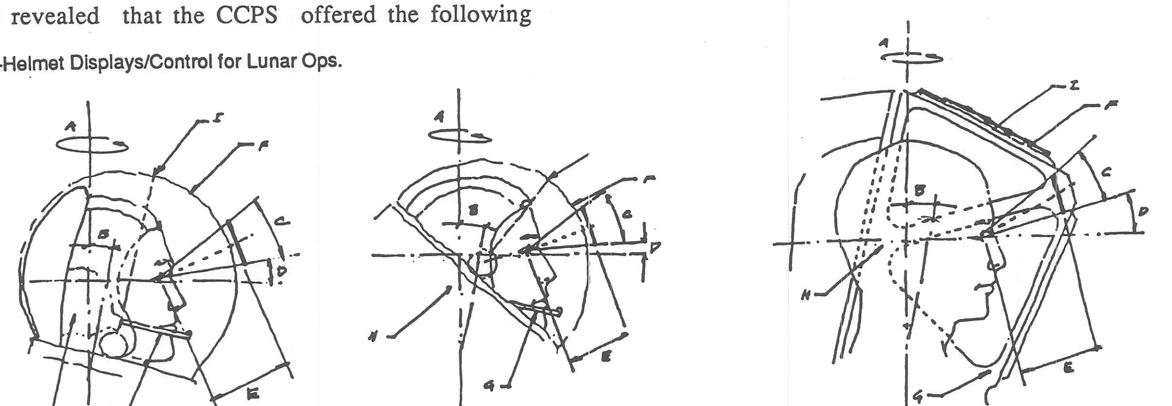


Figure 13 Removal of the chest mounted Display Control Module enlarges the prime work area

The display location for three types of suits was compared: the current Space Shuttle Extravehicular Mobility Unit (EMU), the planned Zero Prebreathe Suits (both ZPS and AX5) and the CCPS. (Figure 14) The bubble shaped helmets could not physically accommodate internal displays so an external configuration like the one developed by Hamilton Standard for the helmet mounted display contract was analyzed. The study revealed that the CCPS offered the following advantages: 1) displays are not blocked by the use of protective visors, 2) the legibility of information is not compromised by coatings or dust, 3) internal displays are less likely to get bumped and fail than protruding external configurations, 4) internal location offers a benign operating environment with longer equipment life, and 5) conventional flat rectangular displays are easily integrated.

In-Helmet Displays/Control for Lunar Ops.



EMU	ZPS/AX-5	CCPS
A = Head Rotation	Same	Same
B = Head Tilt Angle	Same	Improved
C = Field of View (Display)	Same	Improved - Internal, 8 Flat Improved
D = Display Location	Same	Improved - Overhead 4 Side Rails and Chin
E = Distance from Eye	Same	Same
F = Helmet Geometry/Coatings	Same (External)	Improved - Internal not subject to Dust and wash out by sun - No visual coatings to look through
G = Microphone	Same	Improved - Built in Microphone
H = Speakers	Same	Improved - Suit Mounted
I = Outer Vision	Same	Improved - Louvers rotate (Does not require clearance swept area as with visor)

Figure 14 Comparison of helmet displays for three space suits

Three identical, low-power, color, liquid crystal displays are used for video, graphic and alpha-numeric information. (Figure 15) Although the system is dual fault tolerant, allowing critical information to be displayed on any monitor, the two monitors in the brow location are generally used for system status and situational information. The monitor in the chin location is used for instructional information such as checklists. Four side bars, two positioned on either side of the front face plate and two overhead are discrete multi-function displays. The monitors display 1) map-type graphics for navigation, 2) video

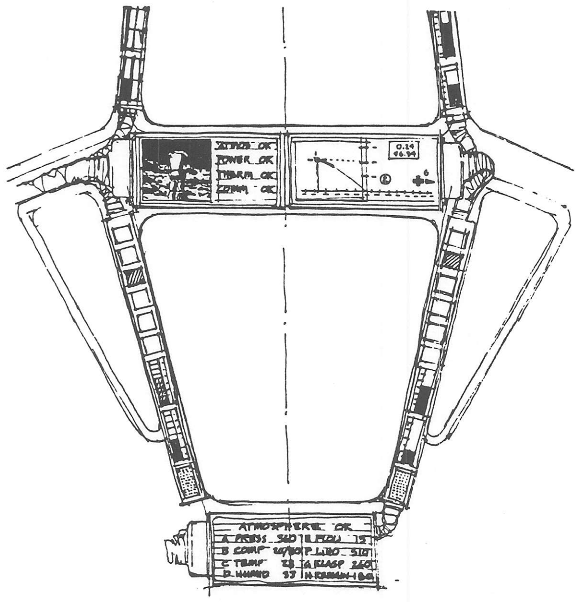


Figure 15 *Interior view of CCPS helmet describes display layout*

for prerecorded instructions and remote camera viewing, and 3) gauge readings for consumables.

SUMMARY

The CCPS gives astronauts improved safety, autonomy and productivity. It's unconventional faceted helmet and seamless upper torso are the result of integrating the attributes of internal displays with EVA operations in the harsh lunar environment. The CCPS takes a full-up systems approach using nature technologies and modular design to provide high reliability with easy maintenance. The CCPS has evolved from concept to full scale engineering test article with plans for continued development.

Acknowledgement
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