

Common Helmet Design for Launch, Entry, & Abort and EVA Activities

A Discussion on the Design and Selection Process of Helmets for Future Manned Flight

Jamie Gil and David Graziosi
ILC Dover LP

Brian Daniel and Mark Dub
NASA Johnson Space Center

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ABSTRACT

Effective helmet performance is a critical component to achieving safe and efficient missions along the entire timeline; from launch and entry events to operations in a micro-gravity environment to exploration of a planetary surface, the helmet system is the capstone of the pressurized space suit assembly. Each phase of a mission requires uncompromising protection in the form of a robust pressure vessel and adequate protection from impact, both interior and exterior, all while remaining relatively comfortable and providing excellent visual interaction with the environment. Historically there have been large voids between these critical characteristics with the primary focus concerning the pressure vessel first and impact protection and crew comfort second.

ILC Dover, NASA-JSC, Gentex Corporation, and Hamilton Sundstrand formed an Integrated Product Team (IPT) and conducted a NASA funded study to research and evaluate new concepts in helmet design. This study conceptualized and planned the development of a common helmet system that will deliver a new generation of space flight helmets that incorporate three key features: a helmet system that is IVA/EVA capable, offers excellent acceleration and impact protection, and provides an openable visor feature. This study also discussed the methodology, design, and testing for impact protection in helmets

Throughout the course of the study, these three features guided the designs at both the component and system levels. Several families of helmet designs were evaluated and the best, most mature system is one that incorporates an elliptical, hemispherical bubble. It can easily be configured for a waist-entry soft upper torso (SUT) or a rear-entry SUT. The helmet can utilize an

adaptive element that allows the helmet to be installed to either SUT; depending on the ultimate suit architecture it could be made to fit both without additional hardware. A benefit of this geometry is the degree of freedom allowed in selecting the openable visor configuration. A rear-mounted hinge and strut arrangement allows for a very large & comfortable opening, while another solution replaces half of the hemispherical bubble with soft-goods to reduce system mass and provide a smaller operational volume. The following discussion is a synopsis of the design factors, approaches, and philosophies that the IPT underwent during the course of the study.

INTRODUCTION

The declaration of the new Vision for Space Exploration brought with it the need for new vehicles, new suits, and new technology to meet the challenges of traveling to the moon and the additional challenges of traveling beyond. The suit is essentially the smallest, yet most important space craft that astronauts will find themselves using during the exploration of our solar system. The suit, and by extension the helmet provides an environment where human physiology can survive when there is no environment to speak of: the frigid vacuum of space or the desolate, sun baked surface of a lifeless moon or neighboring planet. The helmet fulfills the critical role of providing the life-sustaining environment and also allows for interaction and contact with the surroundings via adequate fields-of-view and impact protection. The helmet contains the communication equipment, feed port, and protective solar visors without burdening the astronaut excessively while presenting an environment that is as comfortable as possible.

Previous flight systems were divided between launch and entry helmets and extravehicular helmets with each optimized for the primary task. The study asked for a helmet system that performs all phases of flight without the need for a separate system while minimizing helmet mass and volume impacts. Additionally, previous systems did not focus on crew protection to mitigate sudden accelerations or impacts, both internal and external. This study has three main focal points: a pressure vessel that can survive all environments from launch to terrestrial exploration, provide adequate levels of protection during all events, and provide a system that will be comfortable and easy to wear during all of these mission phases. A key component to providing a comfortable helmet is the inclusion of an openable visor on the helmet. Emerging flight operational concepts allow the crew members to be fully suited with the visor in the "up" or "opened" position in the final moments prior to a flight maneuver (launch, docking, EVA transfer, etc) to extend the comfort of "open-air" breathing as long as possible.

Each of the three focal points is well understood but this study marked the first time where all were included in one system. The intent of this study is to find a solution that answers these points with the least amount of compromise. Therein lies the challenge; comfort and occupant protection can often reflect opposite design philosophies and certainly mass and complexity run counter to protection and inclusion of an openable visor/helmet.

In addition to new concepts, the original Apollo helmet system, and the later Shuttle EMU system were carried along for the purpose of benchmarking as well as acknowledging the success of early designs. Despite the lack of an openable visor, the safety, visibility, and operational characteristics can not be ignored. The solid bubble concept remains a viable solution which can be used as both the LEA helmet and EVA helmet or just the EVA helmet if multiple helmet architecture is selected for future vehicles.

The first phase of the study was the evaluation of a helmet system that adapts to two different soft upper torso configurations; one SUT optimized for launch, entry, and abort scenarios (LEA) and the other for surface/planetary exploration. The difference in the two SUT systems is the angle at which the helmet attaches to the neck ring and is based on the critical field-of-view (FOV) requirements of each phase of the mission; 25 degrees for the LEA SUT and 50 degrees for the surface SUT. Additionally, the steeper angle on the surface SUT facilitates incorporation of a rear door donning configuration but works equally well with the traditional waist entry design. Current and historic flight helmets cannot reasonably be adapted to both configurations at the same time so a new approach must be found. Considering life cycle costs, logistical concerns, and added system complexity, multiple helmet solutions have been evaluated but are not recommended solutions for multiple SUT configurations.

Recognizing the impacts of a multiple helmet solution, the second task of the study was to develop a helmet system that is not limited by different SUT interfaces but still maintains optimization across the two separate operational scenarios. Several recommended solutions were found for the helmet design as well as various operational considerations to aid in the overall design and interfaces between crew member, suit, seat, and vehicle. The recommended designs and features can be incorporated into the suit architecture with very little impact. Several of the recommended designs are also based on current development efforts that have taken place in preparation for new suit design.

Where applicable, notes regarding how the requirements are applied to nominal and contingency operations are also given. A detailed description of vehicle dynamics and loads is coupled with a discussion of design and selection of occupant protection methods and materials. Finally, the recommended helmet systems are explained in detail.

A risk analysis effort was performed and was left as an ongoing activity throughout the design and selection process. The risk analysis focuses on the ability of a helmet system to perform in the likely operational scenarios and identifies critical failure modes of the recommended helmets.

STUDY APPROACH

The study began with a review of the focal points and attributes described by NASA. The concepts for the common helmet system were broken down around five basic functional areas:

- Pressure Containment
- Communications
- Acceleration Protection
- EVA Visor Assembly
- Suit Interfaces.

The five functional areas were broken down further into categories to aid brainstorming of each component (Figure 1).

This deconstruction allowed for the study of attributes that make for the best component solution without compromise or interference from other helmet components. Not surprising, sometimes the best solutions within a functional group directly conflicted with another area of the helmet design. Most notably, the ideal pressure vessel is an uninterrupted surface of revolution that is conformal to the crew member. This is the helmet geometry that was ultimately selected for the Apollo suits and the EMU suit. While performing as a pressure vessel flawlessly and providing nearly unlimited FOV, the helmet does not have an openable feature nor does it address acceleration or internal impact protection. It does offer a degree of external impact protection when the EVVA is installed, but it does not

Pressure Containment	Communications	Acceleration Protection	EVA Visor Assembly	Suit Interface System
Pressure Vessel	Configuration	Head Mounted	EVVA Configuration	Vent Initiation
Shell / Visor Materials	Hearing Protection	Helmet Mounted	Materials	Water Egress Protection
Openable Visor	Noise Avoidance	Suit Mounted	Coatings	Toxic Air Protection
PV Fittings	HUD / HMD	Materials - Impact		Lights and Camera
TMD		Materials - Comfort		Neck Ring Attachment

Figure 1 – Break down of functional development areas

offer much protection during off-nominal launch, entry, or abort events.

After creation of the five categories, components and concepts were generated and assigned to the groups. Often, the generation of concepts in one functional group would beget concepts in another. Another trend that was quickly noticed was the development of one concept or component would automatically pre-suppose a component in another group. It became apparent that the helmet geometry, crew protection, and openable visor feature were very inter-related and descriptions of these components relied heavily upon existing or historical examples of flight helmets.

All concepts were generated through team brainstorming activities, research of related historical information dealing with full pressure suits, and novel approaches and technologies from related commercial and military products. The study focused on Pressure Containment, Crew Protection, and Communications. It was quickly discovered that conceptualizing the EVA Visor and Suit Interfaces was too far along the design path for the initial brainstorming effort. Although critical to the performance of the system, these components will be driven by the overall design and are not considered primary drivers to the system architecture. These became secondary requirements that will be met at the system level of the whole helmet and will incorporate mature technologies.

Throughout the process of reviewing the requirements and generating concepts it was noted that deconstructing the helmet system into its constituent parts proved to be a very difficult exercise. It was a challenge to compare concepts in their base function without mention of other components. It was quickly discovered that the pressure vessel, visor assembly, and crew protection were inter-related to the point of affecting the team's ability to separately design these components.

Because the pressure vessel is the backbone of the helmet system, the system level concepts were grouped into families based on the helmet geometry: non-conformal, conformal, and hemispherical. These families generally contain two members with differing visor

concepts. All of the helmet systems were traded against each other as complete units; any shortcoming of a component was viewed as a shortcoming of the entire system. In this way, it was easier to eliminate ideas that conflicted with the overall goal of a compact, low mass, solution that adapts to multiple suit architectures.

During the evaluation of concepts and ideas, the top six requirements for helmet design were found to be head and neck protection, environmental survivability, TMD protection, comfort, head-borne mass, and comms. Throughout the study, these six criteria consistently anchored the discussion about what are the most critical and/or desirable features in a space suit helmet. This further reinforced the theme that these requirements are where the greatest design effort should occur.

An interesting, yet obvious discovery was made while discussing requirements for a space suit helmet: some of the features do not benefit from extra design effort or perceived margin. An example of this is the ultimate pressure requirement of 16psid for a manned suit. While not necessarily a trivial requirement in helmet design, it was discovered that surpassing this requirement did not benefit the intent of the helmet. In fact, purposefully designing a helmet that overshot this requirement most likely took margin away from other requirements like system size, mass, material selection, and cost. Especially considering that the ultimate pressure is already loaded with factors of safety for manned use, increasing the abilities of the helmet in this area detracts from the system. Another example of a requirement that does not benefit from increased effort is stowage volume. Designing a smaller, lighter helmet may be important to the overall vehicle design but it likely sacrifices much in the way of protection and functionality. Utilizing as much of the given stowage envelope as possible will instead allow for better overall helmet performance.

Additionally, these discussions showed some possible areas where requirements might be softened in case of conflict during the design. An example of this is the operational or usage envelope of the helmet. An eighteen inch diameter sphere centered on the head's center of gravity does not necessarily represent a "hard

value compared to the operational temperatures of space. In this case, it may be possible to get additional allowance beyond the stated requirement during the vehicle and seating design. Sizing presents another area where requirements drift might be considered. Accommodating all head sizes and variations is certainly possible, but some helmet geometries, such as conformal, will likewise require an increased number of helmets to span all sizes. Increasing the number of helmet sizes, spare parts, and servicing has a very negative impact on the life-cycle cost of a helmet system.

HELMET FUNCTIONAL GROUPS

In order to generate and evaluate valid concepts using the “clean sheet” approach, existing spaceflight helmets were deconstructed into the five basic functional groups. Assessing component roles at the elementary level provided clear operational concepts for the team allowing them to speak a common language during the design process. A thorough understanding of how a helmet performs in spaceflight paves the way for a successful helmet system; a motorcycle helmet or a saturation diving helmet are each perfectly suited to their specific task, but do not make adequate spaceflight helmets on their own. They certainly have features that are desirable in this study, impact protection and pressure retaining respectively, but these alone cannot perform in the challenging environment of space.

The most identifiable functional group of a helmet system is the pressure containing vessel or helmet shell. Visors, both openable and protective are readily identifiable as another functional group. Materials and coatings are the third functional group since they provide the building blocks and environmental resistance of the first two groups. Acceleration and impact attenuation and protection are not only a functional group of the helmet system, but also a topic of extreme interest. Crew survivability and comfort are given greater design consideration than ever before due to the length of new missions and the goals of exploration. Suits and helmets are going to be worn for missions that extend to weeks and months as the Vision for Space Exploration reaches maturity. The helmet must provide adequate protection from high energy vehicle dynamic loads (tower abort) to low energy accidental contact loads (falling

on the lunar surface). The final functional group is the collection of technologies that share communications and information between the suited astronaut and his environment or fellow crewmembers.

After the requirements were evaluated, criteria were established for each functional group. The criteria expanded upon the requirements and created attributes that applied directly to the functional groups. The criteria were tailored to each group and in several instances overlapping or conflicting criteria were recognized. No conscious effort was made to resolve these overlaps or conflicts as it was decided to let the design activity bear out the answer. For instance, an openable visor in the pressure vessel presents a decrease in safety, environmental resistance, and dust tolerance even though this is a major requirement of the helmet system. Conversely, the openable visor greatly increases crew comfort and can decrease don/doff time. It also provides an easily defined FOV and establishes vent initiation for the system. See Figure 2 for functional group requirements assignments. The gray boxes indicate the strongest correlation between the requirements and the functional groups.

It was decided early on that suit interfaces, while important to the overall function of the helmet, did not drive the geometry or configuration. All helmets require the same suit interfaces so optimizing helmet bulkhead fittings, feedports, and anti-suffocation valves did not benefit the intent of the study to deliver a new helmet system. These features can be studied or optimized further along the design cycle and can be focused on during the optimization of a chosen design. Even though they are an integral part of the helmet functional groups, there are really not enough features in each to perform a conceptual trade which is the stated purpose of this study.

IVA Helmet Requirements (Shall Provide)	Pressure Vessel	Visors	Acceleration & Impact	Comms	Suit Interfaces
Head & Neck Protection	X		X		
<4.0 lb Head-borne mass	X	X	X	X	
Ventilation Integration	X		X		X
Feedport (hydration/nutrition/medicine)	X	X			X
Stowage Volume ≤ 2200 in3	X	X			
Comfort	X	X	X	X	
Anti-suffocation	X	X			X
CAI				X	X
Openable visor	X	X			X
Ventilation Initiation		X			X
Environmental Survivability	X	X			
Defined FOV		X			
Anthropometry (sizing)	X	X	X	X	
Ultimate Pressure of 16psid	X				
Operation Volume ≤ 18" dia	X	X			
EVA Helmet Requirements (in addition to IVA shall provide)					
TMD	X	X	X		
Dust Protection	X	X			
EVVA - external visor(s)		X	X		X
Scratch Resistance / Hardness					

Figure 2 – Functional Group Requirement Mapping

PRESSURE VESSEL

The pressure containment vessel is the core of the helmet system. Its principle responsibility is to contain the head and neck of a crewmember in a life-sustaining environment. It defines what can and cannot be installed or included in the helmet system and certain configurations pre-select how other functional groups are integrated into the system. Discussion in this section refers only to the pressure containing shell; helmet, bubble, shell, and vessel are used interchangeably as terms to describe this sub-component of the pressure containment functional group.

Differences in helmet attachment planes pose a unique challenge to the helmet design. It is not possible to fit a single helmet to different SUTs and still encompass the head with adequate FOV, comfort, and safety without an adapter or multiple configurations. Yet, a single helmet is preferred due to storage and operational volumes and simplicity. In the interest of completeness, multiple helmet solutions were carried through the design process. The key requirements that direct the design and selection of the shell are fit and sizing, FOV, head borne mass, operational protection, ballistic protection, operation and stowage volumes, hardware integration, don/doff, TMD protection/resistance, and environmental performance. Given that any of the concepts must meet these critical features, the exercise is to determine which shell performs the best. This is where it was first noticed the conflicting/competing requirements.

The brainstorming of concepts began with a review of historical and current flight systems as well as existing military systems. The Shuttle ACES and EMU, Sokol, and MkIII / I-Suit helmets are all considered current spaceflight-ready helmets and were evaluated against the requirements matrix. The Apollo/Skylab and previous Shuttle helmets were reviewed and evaluated because of their previous success in manned spaceflight. The SR-71 helmet is an example of an existing military system and was also evaluated. From the review of

these systems, the team's brainstormed concepts could be classified into families by describing the geometry or shape: non-conformal, conformal, and bubble; see Figure 3 for this classification system. The accompanying descriptions of existing helmets are only to provide a reference for the system discussion. This is not meant to convey that modifications of existing systems will meet the goals of future manned flight, but rather, to ground the discussion within the classification system.

The non-conformal helmet family requires a two helmet system: one is the primary LEA helmet that can perform contingency EVAs at 0gs and the other is only for surface/planetary operations. The non-conformal LEA helmet has an openable visor that is either internally or externally mounted. The two helmet system allows for a simple, robust bubble for surface exploration. The two helmet system optimizes the requirements such that the complicated opening mechanism of the LEA helmet is not exposed to lunar dust yet the surface bubble provides un-paralleled visibility in all directions. Both helmets can be designed such that only one size is needed for each. Because of the large size of the helmets respective to other systems, don/doff is relatively easy and quick. When un-pressurized, the mass of the helmet is not directly carried by the head; it rests on the shoulders allowing for reduced head-borne mass.

There are many drawbacks to the multiple helmet approach; the greatest of which is the lifecycle cost of carrying two EVA capable systems. Because the pressure bubble is designed and optimized for the surface SUT, it cannot be adapted to the LEAS in case of contingency EVAs; further, the helmet might not be stowed in the same vehicle as the crew-members if such a need arose. The openable visor assembly also presents difficulty in designing a robust system to remain sealed at ultimate pressure. An externally mounted closure mechanism is constantly fighting the internal pressure of the helmet. The coefficient of thermal expansion (CTE) of the different materials used in the mechanism also needs to be taken under consideration when designing the LEA helmet to be EVA capable. The transfer between the IVA environment and the harsh

temperature extremes of space may cause the visor mechanism to fail at a critical time. Two separate EVA visors must also be carried through the selection process because the geometry differences preclude using the same cover for both helmets.

The large size of the non-conformal LEA helmet may not have

Task 1	Historic Architecture
1.1 LEA Composite Helmet (non-conformal) & Surface Bubble	ACES
1.2 LEA Composite Helmet (conformal) & Surface Bubble	S1030
1.3 Hemispherical Bubble & Wedge	I-Suit
1.4 Hemispherical Bubble, Wedge, & Rear Hinge	New Concept
1.5 Hemispherical 1/2 Bubble, Wedge, & Pivot Hinge	New Concept
Task 2	
2.1 Conformal Bubble	Apollo
2.2 Soft Helmet w/ Soft Fixed Visor	EIS
2.3 Soft Helmet w/ Rigid Visor	Sokol
2.4 Composite Helmet (non-conformal)	-
2.5 Composite Helmet (conformal)	-
2.6 Composite Helmet (clamshell)	Shuttle HGU-20P

Figure 3 – Pressure Vessel Classification and Description

