2006-01-2137

Crew Protection, Contingency EVA and the Crew Exploration Vehicle

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ABSTRACT

The proposed NASA Crew Exploration Vehicle (CEV) has been labeled "not as a repetition of Apollo, but instead what Apollo should have been." While this designation is certainly ripe for debate, there is no debating that the space suit community has, up to this point, had limited or no input into the on-going design of the CEV. However, it is important that the community take the opportunity to influence the configuration of the proposed CEV so as to optimize its orbital and planetary/lunar EVA capability, flexibility and safety. This "window of opportunity" will not remain open for long, as the CEV's configuration is rapidly congealing.

This paper covers:

1. Brief space suit configurations, employment and history.
2. Brief descriptions and comparisons of IVA, EVA and IEVA space suits.
3. How history can be a guide to optimize EVA for the Crew Exploration Vehicle.

INTRODUCTION

An oft used axiom is "those who ignore history are fated to repeat its mistakes." Unfortunately that old hackneyed aphorism holds as true today as ever. Perhaps with the benefit of a little hindsight, however, we can avoid a few of its pitfalls. As the space suit community begins its cycle of concept, design and development of a space suit for NASA's proposed CEV (Crew Exploration Vehicle), we need to carefully, and without bias, consider what worked well and what didn't work so well, in the past. The proposed CEV, being conceived roughly along the lines of the 1960's Apollo spacecraft (though larger), looks to still have a very cramped internal cabin, certainly in comparison to the present Space Shuttle Transportation System. This internal crew volume and stowage restriction will have a profound influence on the design drivers affecting any IVA/EVA systems employed. Still, it seems self-evident that some type of personal crew protect will be required on the CEV for launch, reentry and in cases of cabin atmosphere contamination. Moreover, some type of intravehicular space suit may have to be employed that has a contingency extravehicular function.

The configuration of space suit that is to be used as crew protection for the CEV, if any, has yet to be determined. Will the CEV use a purely IVA suit with only IVA design requirements? Or will it use an IVA suit only during launch, reentry, etc. and employ a separate EVA suit for activities outside the space vehicle? Or will the CEV use a suit system, as was utilized during Apollo, that performed both functions (IEVA)?

If this system (IVA/EVA/IEVA) is to be a purely, dedicated IVA suit, or a separate, dedicated EVA suit system, or a combination of the two, then we must determine this criteria very early in the program. We must also quantify and express this criteria while keeping in mind that space suit design is an endless series of engineering trade-offs (compromises) dictated by the launch vehicle and other related systems that the space suit community can often influence only indirectly.

Conventional space suit and pressure suit systems can be generally divided into three categories:

1. Intravehicular (IVA) – Intravehicular Activity, e.g. the Russian Sokol suit or David Clark Company ACES (Advanced Crew Escape Suit).

2. Extravehicular (EVA) – Extravehicular Activity, e.g. the American Shuttle EMU (Extravehicular Mobility Unit) or Russian Orlan series.

3. Intravehicular/Extravehicular Activity (IEVA), e.g. Apollo A7L/A7LB, Litton RX and AES, AiResearch EX-1A and AES series, or what the Russian refer to as a universal space suit.

IVA and EVA systems have a distinctive set of requirements and design drivers/solutions that, at the least, often conflict with one another, and at worst are at times mutually exclusive. Conventional intravehicular suit systems (what the Russians call emergency suits) are most often designed to be worn unpressurized and serve as only a back-up to the cabin pressure system of a high altitude aircraft or space vehicle. Such suits are only pressurized in cases of cabin pressure failure or cabin atmosphere contamination, or fire (vacuum supression). However, due to serving as only a backup to the cabin's main life support system, an intravehicular suit does not have, or need, the component redundancy required of an EVA space suit system. For example, the Russian Orlan EVA suit is equipped with two pressure bladders, a primary bladder and a hot standby (reserve). The Orlan pressure bladders are fabricated from light weight, moderate denier, Nylon. Bonded onto the Nylon are membrane/pressure barriers of thin Latex. If the outer pressure bladder is compromised then an aneroid valve automatically activates the inner "hot standby" bladder and pressure integrity is maintained during an EVA emergency. Even if both bladders are penetrated pressure can be nominally maintained in the Orlan, at least for a limited time. This is due to the hole in the inner bladder generally misaligning with the hole in the outer bladder during inner bladder inflation, thereby creating a short term seal. In contrast the Russian Sokol IVA emergency suit lacks this reserve "hot standby" bladder because the crew cabin serves in place of the primary bladder under normal circumstances. In the Russian Orlan and the American EMU, nearly all suit components are built to high redundancy standards.

Another area of distinct difference in an Intravehicular and an EVA suit system is in the area of mobility. An IVA suit requires only enough mobility to allow the pilot to effectively fly his or her aircraft or space vehicle. For example, no mobility is required in the ankles and only minimal mobility is needed in the knees, hips and waist of an IVA suit enclosure. The greatest mobility of an IVA system is needed in the wrists and elbows, to allow pilot control of avionics. Even the shoulder joints of an IVA suit require only limited rotation, adduction/abduction and lateral/medial motion. Minimal mobility is also designed into the IVA suit to enhance sitting comfort, as most of the time spent in an IVA suit is while lying in a spacecraft couch. As more mobility enhancing components are incorporated into an IVA suit its comfort decreases due to the hard points of contact against the astronaut's body caused by the folds of convolute joint fabric, webbing restraint straps, mobility anchor elements and suit connections, closures, etc. This is especially true in the area of the back, buttocks and posterior of the legs. Simplifying the IVA suit's mobility components also lessens its weigh and decreases its stowage penalty. Sizing range and sizing ability are also simplified. For example, in an EVA space suit straddle joints are often employed below the hip joints to contribute to a natural walking gate, comfortable sitting posture and increased mobility range, locomotion, etc. In contrast, and IVA suit, which needs no pressurized walking ability, can use a simplified hip section, and a sizing element (lacing, for example) in the same linear leg space that the straddle joint would otherwise occupy. This increased sizing range means that a greater number of individuals can be accommodated by a simplified IVA suit design without expensive modifications.

Another area of conflicting requirements between an IVA and an EVA suit enclosure is in suit geometry. A conventional IVA suit is manufactured in a sitting position. In the IVA suit's restraint and bladder fabric layers extra fabric relief is provided around the buttocks to allow the suit user to sit with reasonable comfort. This attention to comfort is important as the astronaut may spend hundreds of hours sitting in a simulator in a one gravity field during training. Indeed, far more time will be spent wearing a space suit (IVA or EVA) in training than in operational use. A suit constituent that might enhance mobility for an EVA system can, in contrast, be physically painful if incorporated into an IVA suit. To illustrate, a purely IVA suit has little need for a highly mobile waist joint, as the suit is already manufactured into a sitting position. The webbing restraint straps, tapes and fabric folds that make a fabric waist joint mobile can also become severely uncomfortable after an astronaut has lain on them in a spacecraft couch for a time. In comparison, an IEVA or EVA suit needs a comparatively flexible waist joint to allow the astronaut's helmet to not distend upward when sitting or bending at the waist, when the suit is pressurized.

In contrast, a dedicated EVA space suit must display acceptable mobility to perform task far in advance of simple avionics control. For instance, the design drivers of an orbital EVA system require it to have acceptable mobility range and low joint moment (torque) forces in the gloves, wrists, elbow and shoulder joints. Omni-directional motion is also required in the shoulders. To optimize omni-directional motion in the shoulder area a rotational scye bearing is employed in the American Shuttle EMU and Russian Orlan EVA suits. Scye bearings work reasonably well in a suit in which the astronaut is standing, but while sitting or lying in a cockpit couch rigid scye bearings become painful. Scye bearings were tried in early American military high altitude pressure suits of the 1950s and were abandoned, for this application, due to discomfort. It is very difficult to add enough padding into the shoulder area of an IVA/IEVA pressure suit to keep the scye bearing from pressing against the dorsal area of the shoulder while in a reclining position.

During the Apollo era this scye area mobility/comfort/bulk problem was never satisfactorily solved. In an effort to impart acceptable omni-directional range into the Apollo IEVA suit's shoulder area, and avoid the sitting discomfort of a scye bearing, the designers employed a cable assisted shoulder joint. The cable assisted shoulder concept, which dated back to the Army Air Force's MX-117 Program of the 1940's, used a Teflon coated steel cable running through a

Teflon lined metal tube (Fig.1). The cable assisted shoulder joint rendered good lateral/medial motion (picking the whole arm up and down), though as the arm was raised past the neutral point of the joint it tended to rapidly "pop" upward/downward as the cable passed the center or pressure. It also allowed a limited adduction/abduction motion (sweeping the shoulder fore and aft), though to perform this latter/medial function exacted a high metabolic price, as the cable and tube were a high friction area. This high friction equated to high torque and thus meant that the joint required considerable effort to initiate motion (Fig.2).

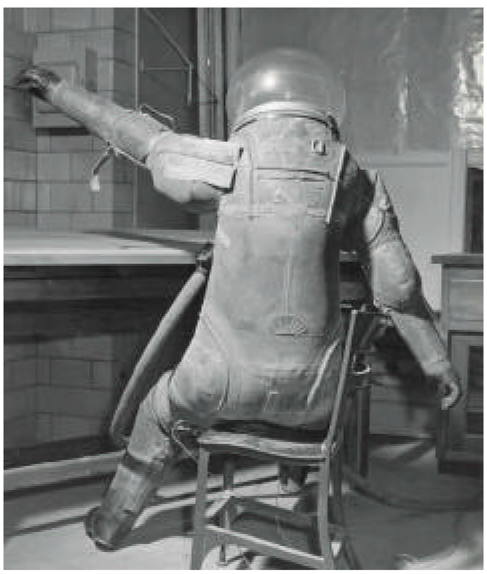

Figure-1 Goodyear Tire and Rubber Co. XH-3 prototype high altitude pressure suit (1943). Note: cable assisted shoulder joint.

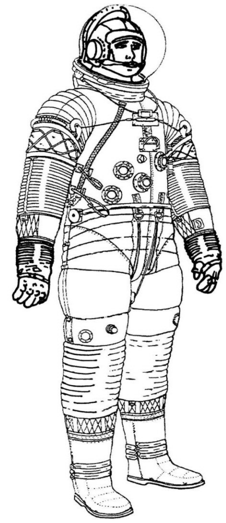

Figure-2 Apollo A7LB IEVA Suit.

Other difficulties with the Apollo cable assisted shoulder joint were that the cable's motion chaffed the restraint layer fabric and also abraded the inside of the metal tube. This abrasion made joint cycle life low and was one of the factors that contributed to the Apollo EVA suits being worn out after just hours of operation on the lunar surface. In fairness to the Apollo suit designers they had limited technical choices in the matter. Such circumscribed approaches emerged because the United States was racing the old Soviet Union to the moon. This "flags and footprints" type of engineering mission meant that time was a severely limiting factor when it came to exploring technical choices. It has been wisely pointed out to these Authors that "now that we plan to go back to the moon to work and stay for extended durations, compromises to EVA design have a much greater negative impact [than they did during Apollo]".

The Apollo suit designers had to struggle to fit three fully suited crew-members into a very cramped vehicle that had already been designed before the space suit problem was fully considered. The space suit community, or to be more exact for those years, the aviation pressure suit community, had very limited input into the initial concept/design phase of the Apollo vehicle system. Which brings us to the point of this paper, it appears that we are getting ready to make the same mistake again.

It is common knowledge that during the Apollo era the Apollo Command Module was essentially designed from the outside in. That is, the external geometry was frozen early in the program by designers at NASA Langley. The folks at Langley had only limited choices in their design architecture for the Apollo spacecraft due to payload weight, diameter limitations of the ServiceModule and thermo/aerodynamic loads that were projected for the Apollo Command Module. However, designing the vehicle from-the-outside-in forced all other contractors to "wedge" their equipment into the extremely constricted space of the Command Module. The result was that the space suits for Apollo could not be dedicated IVA and or EVA suits, but instead had to be a combination of the two; in other words a dual function suit system (IEVA).

Choosing a space suit for Apollo that had a dual function (IVA and EVA) meant that the optimization of either function was compromised. In other words the Apollo suits performed neither function to a high standard. The following points illustrate this compromise.

1. In order to meet the requirements of an IVA role, the Apollo IEVA suits could not employ a more desirable/highly mobile scye bearing and so had to compromise on a cable assisted shoulder joint.

2. Because the Apollo suits were IEVA (IVA and EVA), they had to use a separate backpack life support system (LSS). This choice dictated a suit with external hoses for life support gas, coolant water, etc. These external hoses were vulnerable, a leak source and a fouling hazard.

3. Due to the Apollo suit being an IVA suit employed in an EVA role (or if you desire, an EVA suit in an IVA role), the backpack was attached "rucksack" fashion, which allowed it to shift around during walking, bending, etc. This shifting changed the suit's CG (center of gravity) and astronaut/suit walking thrust vector. Vector and CG motion contributed to making locomotion/translation clumsy.

4. Because a separate LSS pack had to be employed, the Apollo suit's center of gravity was high and non-coincident with the desired natural CG range of the astronaut's body and thrust vector of his legs. This non-coincident, high CG was one of the main factors that contributed to the unnatural, exaggerated side-to-side loping gate of the lunar astronauts.

5. Due to the EVA requirements placed upon the Apollo suit, the Integrated ITMG (Integrated Thermal Micrometeroid Garment) was worn with the suit during launch and reentry. Even without the ITMG the astronauts lay shoulder-upon-shoulder in their couches. Only 23 inches width was allowed for couch shoulder diameter. This diameter was barely adequate for an unsuited crewmember, would have been marginal for an astronaut wearing a light IVA suit (something along the lines of the Russian Sokol emergency suit), but was very cramped in the extreme for an individual wearing an EVA suit with bulky shoulder joints and an ITMG.

6. Due to its IEVA role, the Apollo suits had to use less reliable (for that time) slide fasteners and zippers as suit closures (though in fairness, newer materials and assembly techniques have greatly enhanced the robustness of these components). It is very difficult to design a mechanical suit don/doff closure (though a dual planar closure may be able to meet this requirement) that is comfortable while lying on a spacecraft couch.

7. A dual function IEVA suit severely limits optimal helmet choice. During the Mercury and Gemini Programs the helmets employed were evolved derivatives of the old Air Force MA-1 helmet. This choice was dictated by the fact that the only suits in existence in the late 1950's/early 60s had evolved from high altitude, military aviation pressure suits. The Mercury suit, for example, was a modified Navy Mk-IV and the Gemini G-3C was an evolved A/P22S-2 that came out of the Air Force's X-15 Program. Pilots seem to prefer IVA headgear that allows them to open (flip-up) the face pressure visor. Nevertheless movable visors tend to create additional failure modes in an already complex system, e.g. opening and closing mechanisms, visor seal and the increased possibility of leakage (Stahl 1998). Accordingly, these faults probably preclude the use of flip-up visors on modern EVA helmets. Many engineers feel that the optimal EVA helmet is a hemispherical design (half bubble – such as NASA's "H" Suit), or a derivative of this concept, for example, an oval half bubble (as is used on the ILC "I" Suit). The advantage of a hemispherical design, other than its optimal equalization of pressure and excellent optics, is that if the seeing area is scratched or mired, the astronaut simply need rotate it around to a clear part of the hemisphere. This makes it excellent for planetary use. That said, it might be possible to employ a universal disconnect neck ring to accommodate one type of helmet for IVA and a separate bubble helmet for EVA purposes. Apollo A7L/LB used an egg shaped bubble with a vent valve.

The Russians, in comparison, when they chose a space suit configuration for their manned lunar landing (N-1/L-3) program chose to employ no IVA suit for launch/reentry but to use a dedicated, pure EVA suit for exploration of the lunar surface (the Krechet-94 and Orlan EVA suits). Latter however, after fatalities during the Soyuz-11/Salyut -1 flight, due to reentry module depressurization, they adopted a simple, lightweight IVA suit (Sokol- a modification of an earlier military pressure suit of the same name). This demarcation of the IVA - EVA function was deemed necessary by the Russian engineers at Zvezda in order to avoid compromising the utility of both suits. This decision has proven to be a wise one and the Sokol and Orlan suits are both still in use. To be fair here NASA eventually demarcated the function of their space suits for Shuttle as well. Indeed, the Orlan has gone through a number of iterations (Kretchet, Orlan, Orlan-D, DM, DMA and M) and has shown itself to be highly adaptable to orbital space station basing even after nearly 40 years.

Again in fairness, almost a year before the Kennedy challenge to place a man on the moon, NASA studied a vehicle concept for Apollo that preceded, and was very similar to, the Soyuz vehicle. This early 1961 General Electric feasibility study (Fig.3) used an orbital airlock/stowage module and a reentry vehicle startlingly similar to what Soyuz eventually became. The NASA Langley design staff rejected the General Electric concept for time and simplicity reasons.

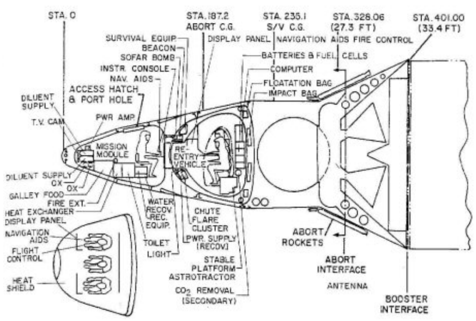

Figure-3 General Electric Apollo feasibility study.

What has all this got to do with the present NASA Crew Exploration Vehicle? Simply this: What made possible the Russian decision to demarcate the function of their space suits, and thereby optimize the capability of both suit types, was that the Soyuz space vehicle had/has an airlock attached to the front of the command module, though the Russians call this airlock an “Orbital Module.” The Soyuz spacecraft, like Orlan, also evolved out of the old Russian manned lunar program. The addition of an airlock onto the front of the Soyuz vehicle allowed enough room to stow two EVA suits. One for the pilot of the lunar lander and another for the mission commander, who was to remain behind in the lunar orbiter. It was necessary to stow EVA suits on the lunar vehicles as the Russians wanted to avoid the complex hydraulic plumbing and connections required when docking two pressurized vehicles. They chose instead to use a simple mechanical pegboard docking grab, accompanied by EVA ship-to-ship transfer.

While it would be nice to think that this fortuitous Soyuz design came about due to farsighted engineering, in reality it emerged as much due to serendipity as anything. As originally designed, the Soyuz command module cockpit could not be depressurized as it still used vacuum tubes for its avionics (thus necessitating a separate airlock module). Vacuum tubes rely on air circulation for cooling and without it will quickly burn out. In contrast, American space vehicles, like Gemini and Apollo, used solid state circuitry which were unaffected by vacuum. This meant that the Apollo command module cabin could be depressurized, and that it didn’t need a separate airlock module. Accordingly, due to this and the resultant stowage restrictions Apollo used a space suit that had IVA and EVA dual use function (IEVA).

If NASA develops a CEV with no airlock or stowage module, as it now appears it might, then they will have no choice but to develop for the CEV a space suit that is an IEVA configuration, thereby compromising its capabilities. In essence they will build a suit that is only a contingency system. It will be neither an ideal IVA suit nor an optimized EVA system. The space suit community will be back where it started 40 years ago trying to wedge a number of astronauts into too small a space, into a space vehicle built from-the-outside-in, designed with only tertiary consideration for the capabilities of the EVA system.

Conclusions

Why does this matter, and how can it be fixed, or at least alleviated? We think that the following comments are pertinent:

1. EVA has become the centerpiece of the Shuttle System. While the shuttle was originally designed without EVA as a prime design driver (the original specifications were that it “would be

designed in such a manner so as not to preclude EVA."), EVA has, nevertheless, become central to why the STS is orbited, e.g. Hubble mission, space station construction, etc. It stands to reason that orbital EVA will become as important to the CEV as it is to Shuttle.

2. The Shuttle EMU was also originally designed as only a "contingency system." It was initially meant to be only used to close the payload bay doors if automatic systems failed and to cast off a jammed satellite. This compromise has made the EMU less than optimal.

3. If a lightweight, dedicated IVA suit is used for the CEV the crew will have more cabin room, greater comfort and less on-board stowage problems. Something simple, along the lines of the Russian Sokol or the old Gemini G5C (which had a fabric helmet), though much improved, would suffice (Fig.4).

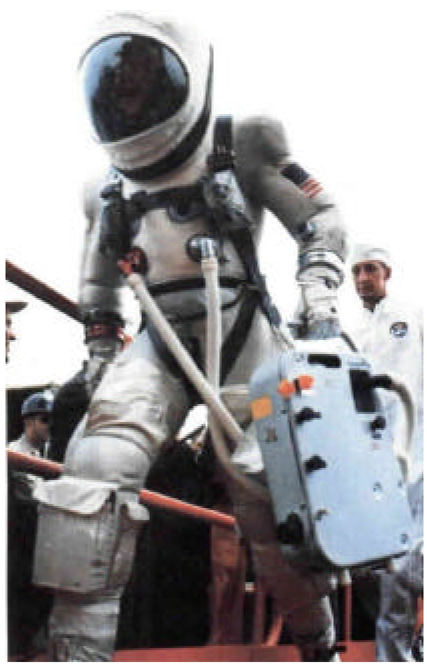

Figure-4 Gemini G5C IVA Suit

4. The addition of an airlock module to the CEV launch package would allow for stowage of dedicated, separate EVA suits optimized for orbital and or planetary use. Of course for lunar operations EVA suits would be carried in the lunar lander and no orbital module would be required on such missions. For orbital operations, an airlock/stowage module would also keep the crew from having to depressurize the crew cabin for contingency EVA, thus exposing the entire crew to the inordinate danger of vacuum. Moreover, the CEV is projected to initially have up to four crewmembers with six crewmembers eventually to be accommodated (in a follow-on "Block" vehicle). It is uncommon, but not without precedent, that a pressure suit can experience difficulty in "taking seal." (achieving pressure integrity) in preparation for EVA. This suggests that if any one crewmembers experiences difficulty getting a seal on his or her pressure suit, prior to crew cabin depress, that a contingency or emergency EVA might not be possible. An airlock/stowage (orbital) module could be launched with the CEV and then docked, in much the same manner that the Apollo command vehicle docked with the LM (Lunar Module). If the CEV booster's payload lifting capacity is sufficient, then an orbital module may be possible. For example, less propellant tankage is needed for orbital missions than for a lunar mission. A CEV variant might be able to carry an airlock/stowage orbital module in place of the smaller tankage (Fig.5). The module could be carried into orbit much the same as the LM was carried on the Apollo/Saturn launcher, i.e., nestled aft of the Command/Service Modules

in an aeroshell. Such a module might also be an inflatable structure, with aerobeam stiffeners, if space is limited in the booster shroud/aeroshell.

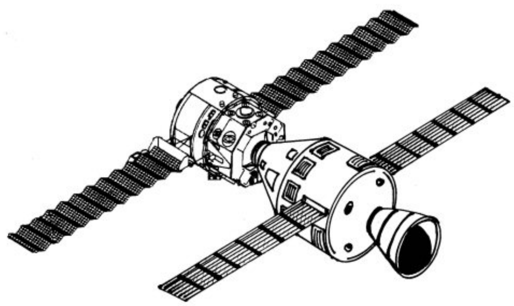

Figure-5 Proposed CEV Orbital Module

5. Barring the use of an airlock/stowage module, crew size must be reduced during EVA missions so that separate, dedicated EVA suits may be stowed. If crew couches and their accompanying emergency life support are modularized, they too can be removed before EVA missions to allow extra stowage room. But this is a less than ideal choice.
6. A dedicated EVA suit developed for the CEV can have planetary capabilities (a walking suit, for example). Thus helping to share and spread out development costs over several programs (CEV, Moon-Mars).
7. A dedicated EVA suit carried on CEV will be far superior to any contingency IEVA system in mobility, comfort, safety, and favorable mass distribution, etc. It will also help to advance the state- of-the art for the moon-Mars program.
8. Lastly, the CEV needs to also be designed from the inside-out, with the interior needs and EVA function of the vehicle taken into equal consideration with the need for proper external aero/thermodynamic considerations, etc. The space suit community must keep talking to the launcher/vehicle design community, and both must educate the other to its needs, capabilities and limitations.

References

Harris, Gary L., The Origins and Technology of the Advanced Extravehicular Space Suit. AAS History Series, Vol. 24, Univelt Publishers, San Diego, CA 2001.

ILC Dover Inc., M-Suit Final Report [called I-Suit by NASA], Dover, Delaware, 1999.

Manager, Apollo Program Office/ILC Industries, ILLUSTRATED PARTS BREAKDOWN, Model

A7LB, Apollo Skylab & ASTP Space Suits. NAS 9-6100, 1973.

McBarron, James W., Charles E. Whitsett, Guy I. Severin and Isask P. Abramov. Space Biology and Medicine: Life Support and Habitability II, Chapter-14, Individual Systems for Crewmember Life Support and Extravehicular Activity. AAS, 1994.

Severin, G.I., I.P. Abramov and V.I. Svertshek. Main Phases of The EVA Space Suits Development. The 46th International Astronautical Congress, Oslo, Norway. IAA-95-IAA.10.1.01, 1995

Stahl, Robert M. Director, High Flight Element, Air Force Flight Test Center, Physiology Support Flight, 95th AMDS/SGPT, Edwards Air Force Base, CA. Discussions concerning high altitude crew protection. March 1998.

Wilde, Richard C., Isaak P. Abramov and James W. McBarron II, Extravehicular Individual Life Support: A Comparison of American and Russian Systems. The 23rd ICES, Colorado Springs, CO, SAE 932223, July 1993.