ILC Space Suits
& Related Products

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This report was written through the volunteer efforts of ILC employees, retirees and friends. Additionally, this report would not have been possible without the efforts of Ken Thomas at Hamilton Sundstrand who truly realizes the significance of preserving the history of US space suit development. The information has been compiled to the best of the participant's abilities given the volunteer nature of this effort. Any errors are unintentional and will be corrected once identified and verified. If there are any questions regarding any detail of this report, please call (302) 335-3911 Ext. 248. The production of this report does not imply ILC Dover agrees with or is responsible for the contents therein. This report has been compiled from information in the public domain and poses no export licensing issues.

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ACRONYMS USED WITHIN THIS PUBLICATION

AHAFS	-	Advanced High Altitude Flying Suit
ASTP	-	Apollo Soyuz Test Program
CEI	-	Contract End Item
CMP	-	Command Module Pilot
CPV	-	Combination Purge Valve
DCM	-	Display and Control Module
DIDB	-	Disposable In-suit Drink Bag
EIS	-	Emergency Intra-vehicular Suit
EMU	-	Extra-vehicular Mobility Unit
EVA	-	Extra-Vehicular Activity
EVVA	-	Extra-Vehicular Visor Assembly
FCS	-	Fecal Containment System
HS	-	Hamilton Standard, later changed to Hamilton Sundstrand
HUT	-	Hard Upper Torso
IDB	-	In-suit Drink Bag
I/EVA	-	Intra/Extra-Vehicular Activity
ILC	-	International Latex Corporation later changed to ILC Dover
ISS	-	International Space Station
ISSA	-	Intra-Vehicular Space Suit Assembly
KPa	-	Kilo-Pascals
ITMG	-	Integrated Thermal Micrometeorite Garment
IVA	-	Intra-Vehicular Activity
LCG	-	Liquid Cooling Garment
LCVG	-	Liquid Cooling and Ventilating Garment
LEVA	-	Lunar Extra-vehicular Visor Assembly
LITMG	-	Lunar Integrated Thermal Micrometeorite Garment
LM	-	Lunar Module
LMP	-	Lunar Module Pilot
LSS	-	Life Support System
LTA	-	Lower Torso Assembly
MOL	-	Manned Orbital Laboratory
MWC	-	Multiple Water Connector
MSC	-	Manned Spaceflight Center
OES	-	Orbital Extra-vehicular Suit
RFP	-	Request For Proposal
PGA	-	Pressure Garment Assembly
PLSS	-	Primary Life Support System
PSI	-	Pounds per Square Inch
PRE	-	Personal Rescue Enclosure
SOA	-	State-Of-the-Art
SPD	-	Specialty Products Division
SSA	-	Space Suit Assembly
SUT	-	Soft Upper Torso
TMG	-	Thermal Micrometeorite Garment
UCTA	-	Urine Collection and Transfer Assembly
WLVTA	-	Water Line Vent Tube Assembly
ZPS	-	Zero Pre-breath Suit

Chapter 1 The Path Leading To Space

ILC Dover prides itself on being the world's leader in engineered softgoods products. ILC designs and fabricates a wide variety of softgoods systems including powder containment solutions for the pharmaceutical industry, airships that fly over sporting events and airbags that have landed robotic explorers on Mars, to name a few. Although the nature of ILC's business today is very diverse, the company's beginnings are rooted in one significant product line which played a major part in forming this nation's history in manned space exploration.

International Latex Corporation (ILC) was founded in Dover, Delaware in 1937 by Mr. Abram Nathaniel (A.N.) Spanel and quickly grew to become a diverse corporation. Mr. Spanel started ILC in order to produce many of his inventions that included baby's diapers and other products using latex rubber. It was the company's expertise in developing these latex rubber goods that aided in the design and fabrication of flexible joints that ultimately made it possible to work inside of the pressure suits that would allow man to walk on the Moon.

In 1947, International Latex separated into four distinct divisions. ILC's lineage stems from the division that was initially named the Metals Division. This segment of the company was organized to fabricate the metal display stands that held the Playtex bras and girdles in stores. In a strange sort of twist, this division soon after started producing high altitude helmets for the Air Force. By 1955, this division had grown and attracted talent from American industry to become the Specialty Products Division involved in many technically challenging areas including high-altitude pressure suit systems. The talent recruited to support that growth included personnel already skilled in high altitude pressure suit development.

While International Latex underwent many changes and mergers, the Specialty Products Division grew to become the space suit supplier for the Apollo Extravehicular Mobility Unit (EMU or "space suit"). In January 1969, the parent corporation made the Specialty Products Division a separate organization named ILC Industries and sold 30% of its holdings to the public. ILC stayed in the Dover, Delaware area supporting the U.S. space program without interruption. In 1982, the parent corporation sold the remaining holdings of ILC to a private individual who still oversees its operations today.

The XMC-2-ILC X-15 Competition Prototype (1957)

In the early 1950s, ILC's Specialty Products Division developed a molded rubber convolute joint that appeared to offer greater mobility with lower bending effort than the other concepts then in use in the industry. For the X-15 pressure suit competition, ILC took the next step and developed its first complete pressure suit using a number of these molded convolutes in critical flex areas. This suit was the XMC-2-ILC prototype.

In 1954, the National Advisory Committee on Aeronautics (NACA) had joined the U.S. Air Force (USAF) and US Navy in a joint experimental aircraft/spacecraft named the X-15 that was contracted to North American Aviation. The X-15 program's mission was to expand significantly the horizons of aerospace research. Operating as an aircraft, the X-15 ultimately reached Mach 6.72. However, the X-15 was designed to resist the heat and friction of sub orbital atmospheric reentry. Powered by rocket engines that were not dependent on air for propulsion, the X-15 was also intended to be a sub-orbital space-plane. Thus, X-15 pressure suits were also intra-vehicular activity (IVA) space suits.

Development and selection of X-15 suits started when the USAF invited several companies to provide pressure suit designs for consideration. Prototypes from International Latex Corporation (now ILC Dover), Rand Corporation and David Clark Company were among the suits funded by and evaluated at Wright Paterson Air Force Base in Ohio in 1957.

This evaluation saw the debut of ILC as a pressure suit design and fabricating organization. A curious feature of the XMC-2-ILC prototype (Fig. 1.1) was that it was not equipped with pressure gloves. This was due to the X-15 evaluation being a competition for mobility. Providing pressure gloves with the suit prototype was not a requirement.

Fig. 1.1 The 1957 ILC XMC Suit

While ILC did not win the competition, the XMC-2-ILC prototype demonstrated to the fledgling space community that ILC had become a recognized competitor. A reflection of this is the fact that ILC would be invited to compete for the Mercury space suit contract in 1959.

The SPD-117 Mercury Competition Prototype (1959)

Fig. 1.2 ILC SPD-117 Mercury Competition Suit
(Courtesy Mr. Gary Harris)

In reaction to the launch of Sputnik I, the U.S. created the National Aeronautics and Space Administration (NASA). NASA's first manned exploration program was Project Mercury. The Mercury program did not have a formal pressure suit competition by later contracting standards. At the time, 16 separate contractors fabricated suits for the Mercury Program; however NASA selected suits from only three contractors for consideration. They were ILC, B. F. Goodrich and David Clark Corporation.

ILC's prototype was designated SPD-117 (ref. Fig. 1.2) by ILC to denote it being the Specialty Products Division's one hundred and seventeenth design. Unfortunately, this provides no insight into ILC's proactive suit developments as most of the preceding designs were for commercial applications related to products other than pressure suits.

The Mercury pressure suit contract was awarded in July 1959 to another contractor whose design was already certified for high altitude aviation service. However, the SPD-117 suit had proven to be competitive and would play a role in the activities leading to ILC's next NASA competition. The competition was for Apollo.

Chapter 2 The Journey To The Moon (1960-72)

ILC's preparation for what would be the Apollo Space Suit Assembly competition started without hesitation following the end of the Mercury competition in 1959. ILC knew NASA would need an extra-vehicular activity (EVA) capacity and looked for opportunities to demonstrate its vision to meet that need (ref. Fig. 2.1).

Fig. 2.1 ILC's George Durney & ILC SPD-117 Suit
In A 1959 or 1960 Promotional Picture

On May 25, 1961, President John Fitzgerald Kennedy announced the goal to go to the moon by the end of the decade. This gave NASA a program schedule. NASA would call the program Apollo. The 1962 Apollo suit competition was for a Space Suit Assembly (SSA) that would serve as both a launch/entry suit (intra-vehicular activity or IVA) and as a lunar exploration system (extra-vehicular activity or EVA). This contract was to provide an adaptable Pressure Garment Assembly (PGA), a Portable Life Support System (PLSS), an Emergency Oxygen System (EOS) and Extra-Vehicular Activity (EVA) accessories in the form of an integrated and developed system. The contract originally included suits for all Apollo flights and proposals were submitted in March, 1962.

This contract would later be split by NASA in October 1964 into Block I for early missions that required an IVA only SSA and Block II system to support missions with both IVA and EVA. In November 1964, NASA's Manned Spaceflight Center (MSC) Engineering Director Dr. Maxime "Max" Faget renamed the Apollo Block II SSA the Extravehicular Mobility Unit (EMU).

<u>ILC Developments & Prototype Suits Leading To The Apollo Contract (1960-62)</u>

ILC's preparation had two parallel paths. The first was pressure suit development. In 1961, the Crew Systems Division of the Manned Spacecraft Center in Houston (now the Johnson Space Center) and the U. S. Air Force jointly funded Apollo pressure garment preliminary studies that were to result in evaluation suits. In September, NASA issued the study contracts that started on 1 October, 1961 to ILC and a limited number of competitors. As the studies did not fund any development, ILC elected to supplement its efforts with internal research and development budgets. NASA called the ILC study suit the "SOA-ILC" suit. "SOA" stood for "State of the Art" and it would continue to be used by ILC and ultimately reflected the pride in their product. It was almost routinely applied to its latest pressure suit prototype from 1959 to 1965. Figure 2.2 shows the SOA-ILC suit. Also in 1961, ILC added Republic Aviation to its team to gain Republic's pressure suit anthropomorphic experience and access to its suit man-testing facilities.

Fig. 2.2 ILC's 1960 SOA Suit (George Durney in suit)

The second development path stemmed from ILC's recognition that to be an EVA suit-system provider required being able to offer a life support capacity. In 1959 or 1960, ILC had started working with Garrett's AiReseach Division on a space suit joint venture focused on lunar exploration. In 1961, ILC changed to team with Westinghouse (and Republic Aviation) with ILC being the prime contractor.

Competitive proposals for the Apollo SSA were submitted in March 1962. The ILC proposal acknowledged that the period of performance, which was ten months, precluded extensive pressure suit mobility development. ILC proposed that the requirements could be met by refining their existing suit technology to obtain the mobility in specific directions to meet the mission's requirements.

Westinghouse proposed a four hour maximum life support system using cryogenic oxygen for breathing gas replenishment, primary heat removal and ventilation power. Boiling gas was expected to drive a turbine to power ventilation. The concept included a water boiler for additional heat removal.

The ILC/Westinghouse/Republic proposal was submitted on 28 March, 1962. A complete suit-system mockup was provided that included a full pressure garment with separately donnable mockup backpack life support and cover garments (ref. Figs. 2.3 & 2.4). An interesting feature of the ILC suit was that the torso with the helmet removed left a soft garment that could be worn for days with acceptable comfort (ref. Fig. 2.4left). The proposal claimed that the pressure suit could be consistently donned without assistance in less than three minutes in a volume comparable to that needed for donning a conventional pair of coveralls. While ILC also called ILC's proposal pressure suit the SOA suit, NASA assigned it the designation of AX1L.

Fig. 2.3 1962 ILC AX1L Suit with Westinghouse PLSS Mockup (Courtesy Gary Harris)

Fig. 2.4 ILC's Apollo Proposal Suit-System (George Durney – left)

The principal competitors to the International Latex / Republic / Westinghouse team were:

- Hamilton Standard / David Clark Company
- North American Aviation
- Ling Temco Vought (LTV)
- Northrop Corporation's Space Laboratory
- Bendix Corporation's Eclipse-Pioneer Division of Litton Systems
- General Electric / B. F. Goodrich
- Grumman Aircraft / AiResearch Division of Garrett Corporation

After NASA's evaluation of the proposal hardware, NASA preferred the Hamilton Standard (HS, now Hamilton Sundstrand) PLSS and government contract management experience but the ILC AX1L competition prototype suit. Based on HS and ILC indicating that they could work together, NASA announced on 29 April, 1962 it would award the contract to HS with the stipulation that ILC be the PGA provider. NASA's decision to split two contractor teams and taking portions of each to form another has been described by most who participated as a "shot-gun wedding".

The negotiations between HS and ILC were hard fought. It took until August for ILC management and HS to complete working agreements and until October to be under contact. During the HS/ILC negotiation period, NASA needed Apollo configuration pressure suits to support preliminary design efforts. To fill that need, NASA issued a direct contract to ILC for a very limited quantity of production versions of the ILC AX1L competition suit (ref. Fig 2.5).

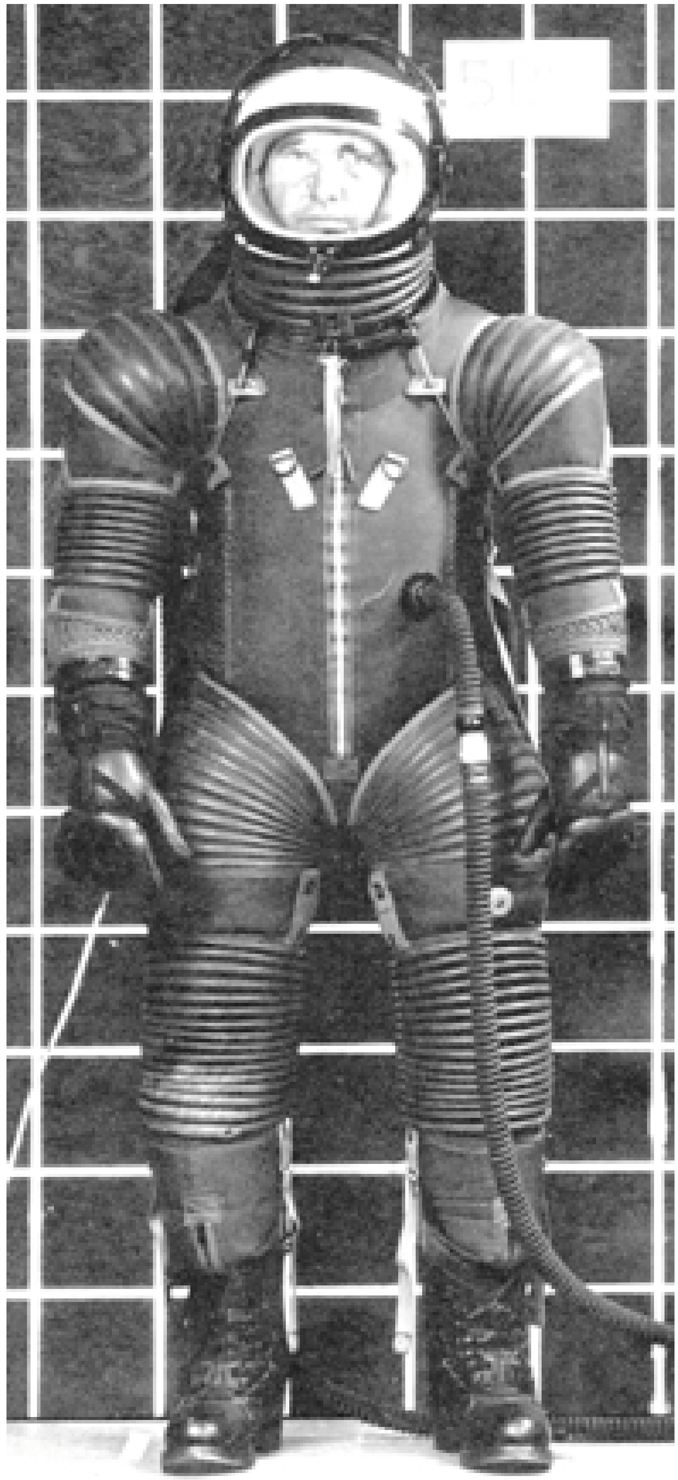

Fig. 2.5 ILC's Apollo Proposal Suit-System

SPD-143 Training Suits

In September, SPD-143 training suit production was directed by Hamilton to ILC in advance of the formal contract award that followed in October. SPD-143 suits (ref. Fig. 2.6) were essentially production models of ILC's pre-HS contract prototype suit designated AX1L (ref. Figs 2.3 & 2.5) but with NASA specified changes. The changes most likely were the result of NASA testing the ILC competition prototype and at least two other AX1L suits that were sold by ILC directly to NASA during Hamilton / ILC contract negotiations.

Fig. 2.6 The ILC Apollo SPD-143 Training Suit (George Durney in suit)

In the SPD-143 series, the helmets were designation SPD-143-1. The glove sets were SPD-143-2. The torso assemblies (SPD-143-3) were olive in color with black convoluted joints. Torso circumference sizing adjustment was provided by one set of loop-tape and lacing running down the middle of the back and adjustment straps on the arms and legs.

The SPD-143 suits initially differed from the AX1L suit in at least two ways.

- The SPD-143s gained 3 restraints running around the torso that provided secondary restraint against pressure load on the entry zippers and a set of torso adjustment restraints over the shoulders
- SPD-143 helmets lacked a tinted (not gold plated) sun visor.

The SPD-143 production started with AX1L type gloves and by the summer of 1963 had gained the new Apollo design gloves that would be used in Apollo suits until 1965.

There were twenty SPD-143 suits delivered. The first eight NASA delivered AX1L based suits delivered were used to verify 5th to 95th percentile male population sizing. This group of suits also supported mockup backpack and other suit to life support system interface evaluations that were conducted from Oct. 1962 to April 1963 (ref. Fig. 2.7). The first Apollo Thermal Meteoroid Garment (TMG) was made by ILC for an SPD-143 suit and was delivered to HS in April of 1963 (ref. Fig. 2.8) with more prototypes that followed to support Apollo preliminary suit design. Until 1967, the Apollo program had planned for the TMG to be a separate garment that would be donned over the pressure suit like a ski suit.

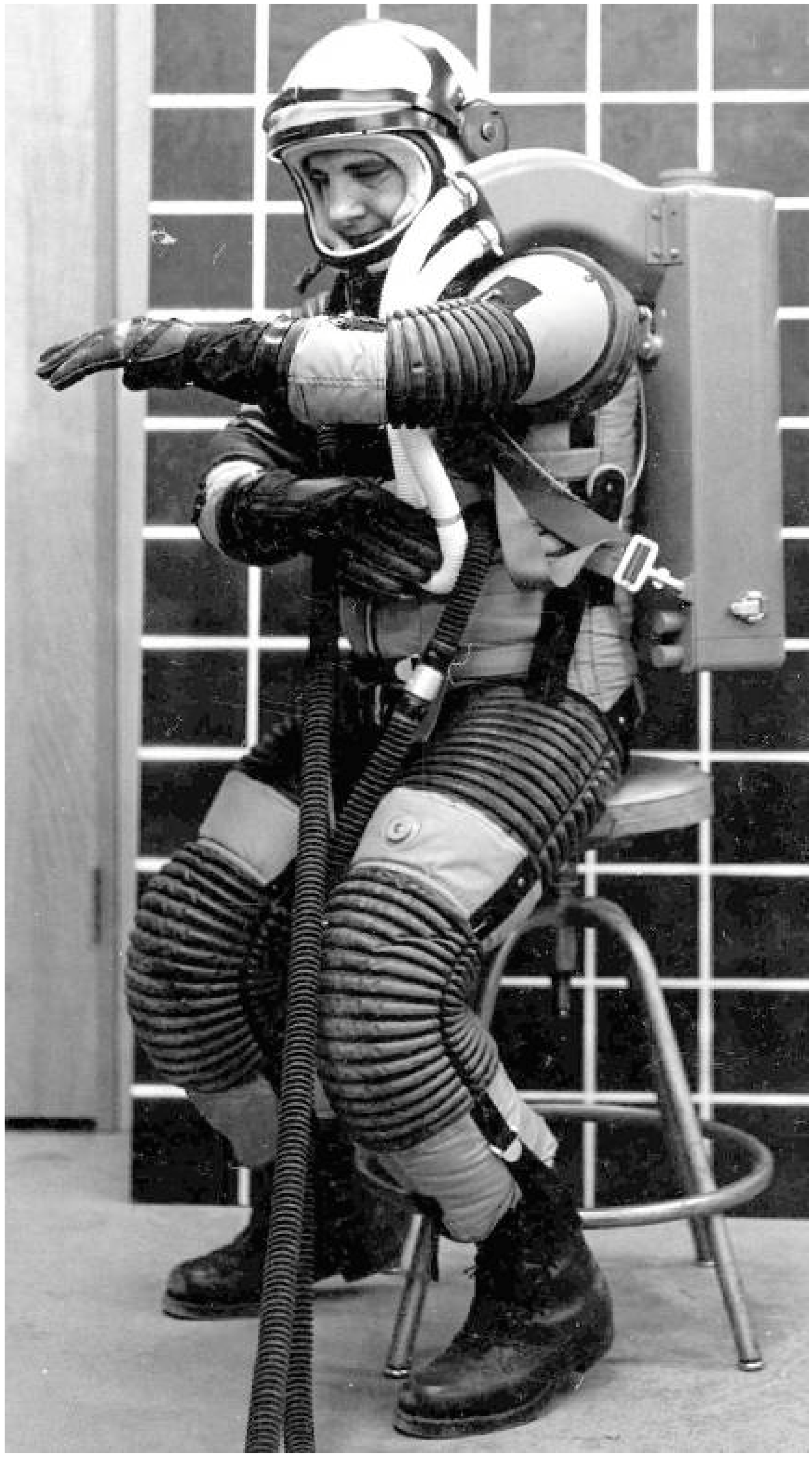

Fig. 2.7 ILC's George Durney Evaluating Possible Life Support Attachments (George Durney in suit)

Fig. 2.8 The First Apollo Thermal Meteoroid Garment (Courtesy Hamilton Sundstrand)

<u>Glove Development For Apollo And The World (1962-Present)</u>

For effective lunar exploration, NASA recognized that a highly mobile and reliable pressure glove had to be developed. This challenge was part of the Apollo SSA (later EMU) program. Under the Apollo contract, ILC designed an entirely new glove. This was accomplished in iterative design-steps. An intermediate design had been accomplished to the prototype level by December 1962. This evolved into the design that appeared in SPD-143 Training Suit production in the spring of 1963 (ref. Figs. 2.6 & 2.9). For this design, a new durable glove bladder was created by a woven nylon tricot glove-shaped sock being dip impregnated and coated with a neoprene/natural rubber mixture. In the fingers, the bladders were also the restraint mechanism. Also, the fingers had easement (extra material) formed into the backs of the fingers for lower effort when grasping tools and controls.

Fig. 2.9 ILC's 1963 To Early 1965 Apollo Glove

The glove restraint system had a fingerless outer restraint assembly. The part of this restraint assembly that covered the palm/back-hand area was essentially a leather outer glove. This attached to a wrist bearing via a metallic cable that anchored on the both ends of the cable. The metallic cable ran through a stainless steel conduit that extended from the wrist/hand interface at the thumb, across the palm and down to the wrist/hand interface on the opposite(pinkie finger) side. The conduit doubled as the rigid, palm-side-part of the palm bar. The wrist portion of the glove outer restraint assembly featured a convoluted, constant volume joint. This system provided previously unparalleled wrist mobility.

For this glove system, ILC developed techniques for dip molding fabric-and-cord-reinforced gloves over forms that ultimately created repetitively accurate moldings from hand casts of the individual Apollo astronauts.

This bladder and restraint technology provided the basis for all ILC gloves from 1963 to 1978. ILC would make improvements with the ILC AX5L in 1965 (ref. Fig 2.10). Hamilton Standard also would make gloves based on this ILC design between 1964 and 1967. The principal differences between these and the later HS gloves and ILC 1965-78 gloves were different wrist joints and palm-bars. While the historical trail is still unclear, it appears that in 1971, the Soviet Union's space suit manufacturer, Factory 53 (now Zvezda), acquired a pair of ILC Apollo A7L gloves. The AL7 gloves were reverse-engineered to provide the glove (with minor changes) that started service on Russian space suits in 1973 (ref. Fig. 2.11). In the 1990s, China acquired two Sokol KV-2 suits for training purposes. The Chinese reported that they had designed and manufactured Shenzhou 5 space suits used on their first manned spaceflight in 2003. This is interesting as the suit appeared to be identical to a Russian Sokol KV-2 space suit, including its gloves. While the Chinese have made noticeable improvements to the torsos of their space suits in recent years, the gloves appear to be unchanged. Thus the gloves ILC originally designed for Apollo SPD-143 Training Suits has continued with minor changes to not only be used on all man's explorations of the moon but continues to see service in the present Russian and Chinese space programs.

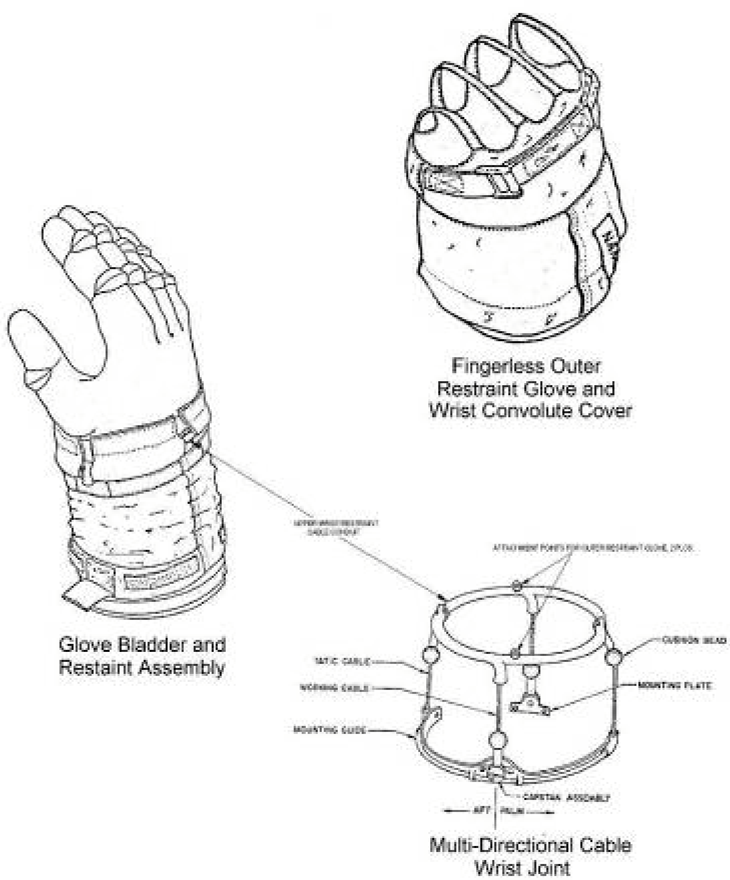

Fig. 2.10 ILC's 1965 Apollo Improvements For The First Gloves To Be Used On The Moon

Fig. 2.11 The Russian Sokol KV-2 Space Suit With ILC Apollo-Like Gloves

AX1H - The First New Design Of The Apollo Program

The AX1H design was developed by using an already existing SPD-143 suit and incrementally replacing and comparatively testing the various mobility elements one at a time to evaluate the improvements (ref. Fig. 2.12). Upon completion, this incrementally retrofitted suit was delivered to Hamilton Standard for evaluation and then retained for manned systems testing. Once the retrofit prototype was accepted, ILC manufactured the AX1H-021 suit (ref. Fig. 2.13).

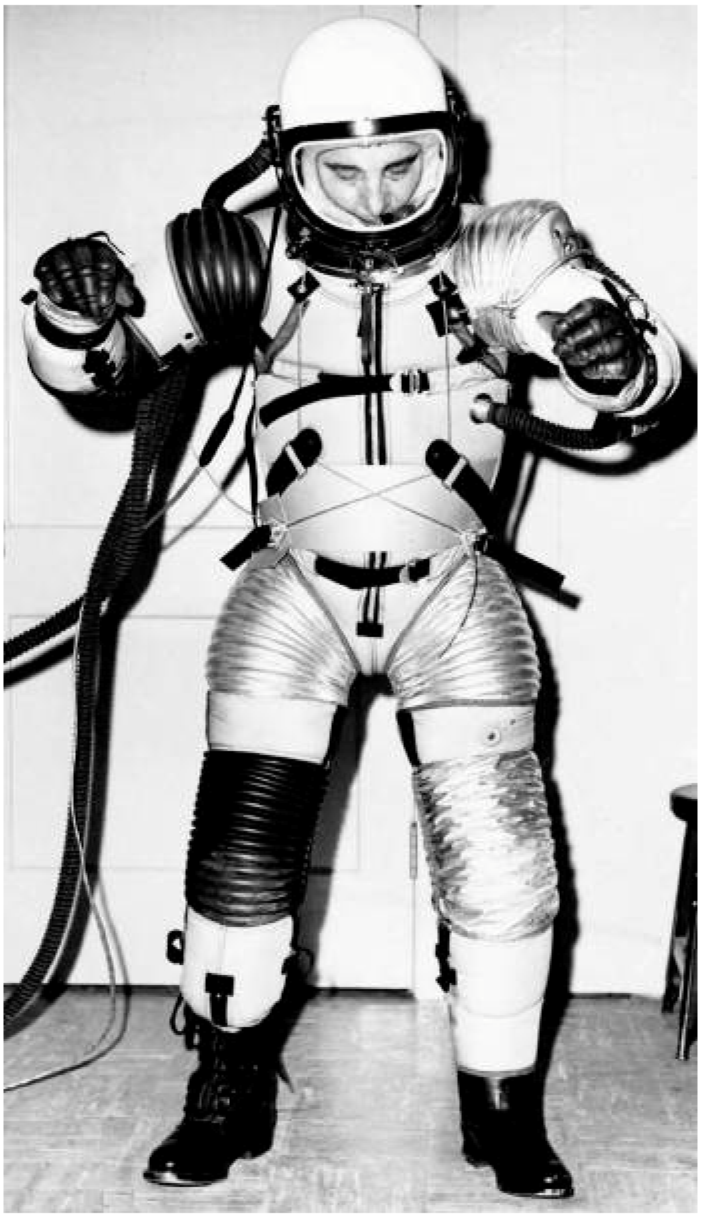

Fig. 2.12 The Incremental Development Of The Apollo AX1H (George Durney in suit)

Fig. 2.13 First New-Design Apollo Space Suit, The ILC AX1H

The AX1H-021 term was a NASA-assigned designation. It meant A = Apollo program, X = Experimental prototype (dash or nothing meant production unit), 1H = first design of the Hamilton-to-NASA contract, 021 = 21st suit under that HS Apollo contract. The AX1H configuration had significance as it:

- Incorporated a two cable assisted shoulder joint to provide flexion-extension and adduction-abduction.
- Featured ILC designed and manufactured torso assembly with aluminized coating to the boots, torso and gloves to permit thermal evaluation. Ability to bend (as in sitting) was provided by a torso compression strap that had cables attaching to suit side helmet disconnect. Non-lacing, slip in (leather) boots were added for improved don/doff. The sizing adjustment loop-tape on the back was increased to 3 sets.
- Used a new ILC designed and manufactured helmet with novel features that included the acrylic pressure visor which retracted inside the helmet shell when not in use for protection. In addition, it had the ability to drop down and move out to meet the helmet shell when deployed so that the pressure load helped seal the visor against the shell. That sealing against the shell also offered greater safety than other helmets of the time because other helmets depended on the dropping and raising mechanism to hold back the pressure. The failure of one item in such mechanisms could result in loss of life.

The evaluations of the AX1H-021 suit illustrated the difficulties with early lack of established requirements within the Apollo Program. The incremental development approach of the AX1H systems should have assured unquestionable agreement that the AX1H design was a significant advancement in mobility. Hamilton Standard subsequently performed comparative testing of the AX1H (or the retrofit AX1H prototype) against a SPD-143 Training Suit and judged that there was no improvement in range or reduction in effort with the AX1H. In the NASA testing that followed, NASA objected to an un-natural stance but had no issues with mobility. Part of the disparity in customer evaluation was that there were no quantitative Apollo mobility requirements until 1964. The findings from suit evaluators were subjective. However, the effort required to overcome the friction of the cables sliding (or not sliding) through their stainless steel conduits was an underlying mobility factor. Another factor was that the base design had very good mobility (for the time) in specific directions. Skilled suit users used combinations of shoulder and elbow movements to reach various points. Naturally, ILC users were the most skilled in that art because of their experience.

The AX1H shoulder width was beyond the specified limit of 23” maximum. During development, it was expected that the specification would be relaxed. However, the discovery of a design error precluded allowing greater volume and a revision of the requirement.

An interesting feature of the AX1H-021 helmet (ref. Fig. 2.13) was its accompanying opaque sun visor prototype. The “visor” portion was made of spun aluminum that was trimmed into the proposed visor’s dimensions. This permitted attachment and dimensional evaluations via a technology that was readily available within ILC’s Dover facility.

AX2H Suits (Sept. 1963 & Oct. 1963)

There were two AX2H suits made (A-2H-022 and A-2H-023). The neck-ring restraint cable attachments and the torso compression strap were revised into separate assemblies as part of the suit stance change from the A-1H-021 evaluation. Each assembly attached directly to the torso. The outer fabrics of the A-2H-022 (ref. Fig. 2.14) were aluminized to support thermal testing. The A-2H-023 was covered with more durable white nylon for training. The AX2H helmet embodied a minor change from the AX1H design in that the pressure visor latch was changed from stainless steel to anodized aluminum to reduce weight.

Fig. 2.14 ILC Apollo AX1H-022 Suit

The A-2H-023 suit was delivered on 7 September, 1963. On 21 November 1963, the A-2H-022 suit was delivered. In subsequent evaluations, NASA judged mobility improvements were not adequate and issued a failure to meet contract requirements against Hamilton. The NASA reliability system formally required identification of cause and recommendations for corrective action. It was accepted by all that the challenges of mobility development had been greater than anticipated. The corrective actions Hamilton Standard offered and NASA accepted were that Hamilton should offer engineering aid to ILC in suit mobility development and that Hamilton Standard should develop the next Apollo helmet to permit ILC greater resources for pressure suit development. This complicated relations within the Apollo program since ILC saw this move as Hamilton Standard's desire to take the helmet business away from them although Hamilton Standard felt they had the resources to perform this task and free-up time for ILC to focus on suit improvements. On 21 January, 1964, an Astronaut's inability to get up from an on-back position during a partial-G test caused the differing views on corrective actions to become even more entrenched. Being able to rise from an on-back position was one of the few critical program mobility requirements. However, it was not entirely clear if it was due to suit mobility. NASA compressed the front to back dimension of the space suit to aid Grumman in meeting its (then) Lunar Excursion Module design requirements. This forced Hamilton to redesign the Apollo portable life support system (PLSS) envelope twice. Each front to back dimension reduction caused the PLSS shape to become less helpful in rising from being on the back position.

The AX3H Suit (2/64-5/64)

As cost had been a significant issue with NASA in issuing a contract for the first fleet of new - design Apollo training suits, ILC had looked for ways of decreasing costs while offering potential design improvements to the program. One ILC internally funded effort developed a system where the life support systems (LSS) connection/disconnection would be located in the umbilical being attached to the suit by a short hose. At the time, the Apollo program was using custom-designed LSS connectors that were very expensive. The ILC concept was expected to reduce program costs by allowing the potential use of off-the-shelf commercial connectors. Additionally, this new connector would permit the astronaut to see the connector better because it would now be in the line of sight. The original configuration of the AX3H prototype was the first suit to be delivered with such a connector system.

Fig. 2.15 The Original Configuration Of The AX3H-023 Suit

On 20 February, 1964 the A-3H-024 prototype suit was delivered to HS for testing (ref. Fig. 2.15). The features of the A-3H-024 also included:

- Improvements to torso compression strap attachment capacity were made.
- Torso sizing loop-tape sets increased to 9 (2 on front, 7 on back).
- First Apollo prototype suit to have a TMG as part of original manufacture.

On 23 March, 1964, the A-3H-024 suit was demonstrated at a NASA/Grumman Lunar Module progress review held at Grumman. The astronaut and contractor evaluation was unfavorable. The A-3H-024 suit was immediately returned to Hamilton for a community evaluation and to ILC for modifications. ILC worked with Hamilton and NASA to resolve all issues. What resulted was the “Revised AX3H” that is discussed later.

Costs & The Apollo A-2L Suits (1/64-4/64)

In September of 1963, NASA requested a proposal for 38 training suits to be based on the AX2H design. These were to be made under flight quality control requirements with each suit having a complete set of thermal outer garments. The resulting Hamilton/ILC proposal proved higher than NASA had expected. This coupled with AX2H suit mobility issues caused NASA to cancel the proposal request.

ILC felt that it could offer better value by NASA directly contracting with ILC. On 3 January, 1964, NASA submitted a revised request for 14 training suits. ILC won, resulting in A-2L training suits (ref. Fig. 2.16). The first three A-2L suits were to support a Human Engineering Criteria Mobility Analysis Review (HECMAR) being conducted at North American Aerospace in March of that year.

Fig. 2.16 An ILC A-2L Suit (on right) In A NASA Evaluation

<u>1963-64 Research & Development</u>

In parallel to Apollo contract activities, ILC continued company private research and development (R&D). As such activities are company funded, the resources are channeled into test hardware rather than reports and historical trail. However, such activities do leave a trail. In 1963, evaluation feedback indicated astronaut-users preferred the simplicity of the rear entry of Gemini suits to the Apollo front entry system of the time. Additionally, ILC recognized possible safety issues with front entry zippers losing capacity when forced into tight folds like those experienced when the torso was pulled into a sitting or bent-over position with the torso draw strap. In November 1963, ILC unsuccessfully tried to convince HS to fund exploration of rear entry. As ILC's early explorations used AX1L and SPD-143 based garments (ref. Fig. 2.17), it appears rear entry R&D started in 1963 and was temporarily sidelined to permit response to program developments.

Fig. 2.17 Preliminary ILC Rear Entry Development (ILC Employee Earl Williams)

In late 1963, the costs associated with manufacture appeared to be the principal constraint to the creation of a fleet of latest configuration Apollo training suits to replace SPD-143s. ILC built a precursor prototype to the AX3H to validate the umbilical with commercial life support connector concept.

Probably in an immediate response to feedback from March 1964 evaluations of the AX3H, ILC produced an AX3H similar suit but with more compact shoulders and a revised umbilical with commercial connector concept that was less likely to catch on objects (ref. Fig. 2.18).

A NASA request was most likely the genesis for ILC's creation of an A-2L suit derivation that featured Gemini style boots (ref. Fig. 2.19). The suit's shoulder abrasion patches being smaller than the subsequent remanufactured AX3H and A-4H training suits (ref. Fig. 2.19) successfully places this suit in the April-May 1964 period.

Fig. 2.18 A Compact Shoulder Revised Umbilical R&D Alternative To The AX3H (Courtesy James McBarron II)

Fig. 2.19 An ILC A-2L Equipped With Gemini Boots

The Revised AX3H - Prototype To A-4H Training Suits (5/64)

Following the March 1964 evaluations at Grumman, ILC expended every effort in working with its customer to regain their satisfaction. On 4 June, 1964, the revised A-3H-024 suit was delivered to NASA (ref. Fig. 2.20). While the revised configuration embodied scores of improvements, the most noticeable changes from its original design was the conversion to Gemini program life support connectors, abrasion patches being added to the shoulders, and the use of a non-ILC Apollo helmet.

The revisions addressed customer concerns and the general reaction was positive and NASA directed that the revised AX3H configuration should be used as the basis of the immediate production of an A-4H training suit fleet. The AX3H suit was later used in manned testing with Astronaut Walter Cunningham in a simulated lunar terrain in Big Bend Oregon (ref. Fig. 2.21).

Fig. 2.20 NASA Engineer Jim O'Kane Demonstrating The Revised AX3H-024 Suit

Fig. 2.21 NASA Suit-System Evaluations In An Analog Lunar Terrain (Courtesy NASA)

“Early” A-4H Training Suits (Sept. 1964- Jan. 1965)

NASA ordered fourteen training suits of this model. Twelve suits were ultimately delivered. During the production run the configuration was revised but the program model identifier remained the same producing noticeably different “early” (serial numbers 025 to 029) and “late” (serial numbers 030 to 036) versions of the same “model”. The early A-4H suits differed from the revised AX3H in that they featured aluminized outer fabrics (ref. Fig. 2.22).

Fig. 2.22 An Early A-4H Suit

The first two suits were AX4H-025 and AX4H-026 that were delivered in September 1964. The “A4H” training suits that followed used the A-4H prefix. Through both the early and late A-4H production run, the life support system (LSS) connectors optionally varied between one or two Air-Lock designed “Dual Port” Apollo LSS connectors that were similar to those of the A-1H and the A-2H suits but revised for improved ease of attachment. The other option was the one or two pair of single Gemini style (separate inlet and outlet) LSS connectors with the inlet being anodized blue and outlet being anodized red).

Langley & Ames Research Center Suits (1964)

In 1962-63, ILC had started building the space suit manufacturing capability that would provide100 suits a year during the Apollo program. However, there were significant portions of 1964 and early 1965 when this expanding capability was idled due to the growing pains being experienced on the Apollo program. To retain personnel, ILC explored space suit sales opportunities outside the Apollo contract. Traces of these efforts can be found in Langley Research Center (LARC) reports issued in 1965 and 1966. In the 1960s, NASA's LARC located in Hampton, Virginia conducted research in support of NASA's manned exploration programs. To support this research, LARC needed current configuration space suits. Consequently many LARC reports showed suits that appeared to be early A-4H training suits except for the use of original configuration AX3H style helmets.

With the demise of the USAF X-20 program, there was interest in the space community to continue some of the research being conducted by the program. NASA-Ames had the interest and in 1964 gained access of the X-20 technical data and equipment. ILC won a contract to provide suit prototypes to support the study. The suit (ref Fig. 2.23) gained the nickname "clam shell" from the hard back-section developed to support the ejection mechanism. While the program is but a historical memory, the Ames Research Center has retained the suit, which is now in the process of being donated to the Smithsonian Air & Space Museum.

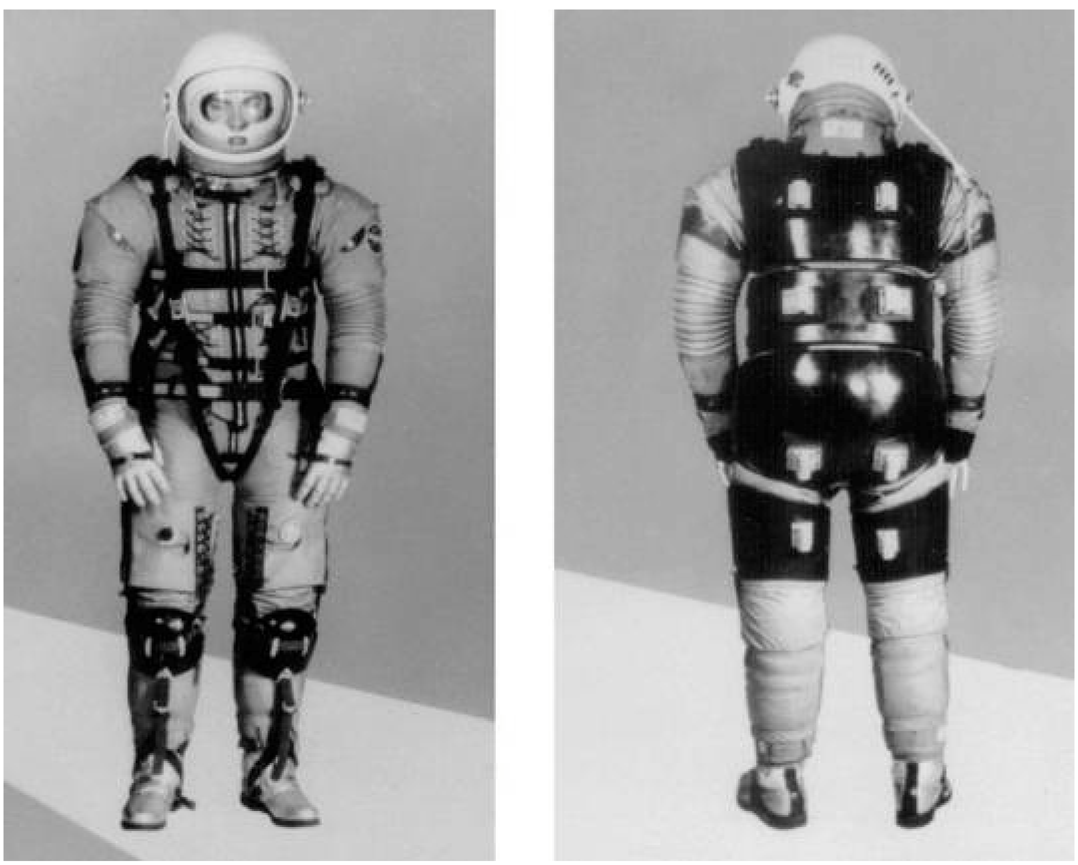

Fig. 2.23 The 1964 ILC Clam Shell Suit

Dr. Finkelstein, & The ILC Playsuit, S.O.A. Suit, "ILC Suit" November Prototypes

Reflecting the level of ILC's commitment to the success of the Apollo Program, ILC recruited Dr. Nission Ascher "Art" Finkelstein in June 1964 to lead ILC's Apollo suit development program. Art was a Harvard and M.I.T graduate who had headed significant and successful research and development efforts in industry during the two years before joining ILC. While his presence did not immediately cause a flurry of resulting developments, November 1964 would be significant in that ILC delivered three prototypes featuring advanced developments with one prototype being retrofitted for other potential systems and being returned within the month.

Another complication to Dr. Finkelstein's "getting up to speed" would be that during the first week of October 1964, NASA announced that the suit portion of the Apollo EMU contract would be divided into two blocks. Block I would be for the early flights that did not plan EVAs. Block I was awarded to the David Clark Company without competition. Block II would be for the Apollo flights that involved EVA. The suit portion of Block II Apollo would be competed in 1965 (later established to be 15 June, 1965).

In November 1964, ILC would deliver three prototype suits to the Apollo program. The first was the ILC Play-suit. The ILC Play-suit was an A-4H like pressure suit similar in configuration to an early A-4H suit that provided a test-bed for upper torso mobility systems by replacing the shoulders and arms. First delivered for customer evaluation on 12 November, 1964, the ILC Play-suit first featured a customer requested concept that included tapered convolute shoulders. While the shoulder breadth was only 23 inches and arms had good fit in the down position, these elements did not provide the needed mobility or reach. The suit was soon returned to ILC to be equipped with different shoulders for additional concept evaluations. By 25 November, 1964, the ILC Play-suit had been returned to the customer for yet another evaluation. This time it was equipped with different versions of the ILC soft cone bellows shoulder (ref. Fig. 2.24), which showed promise.

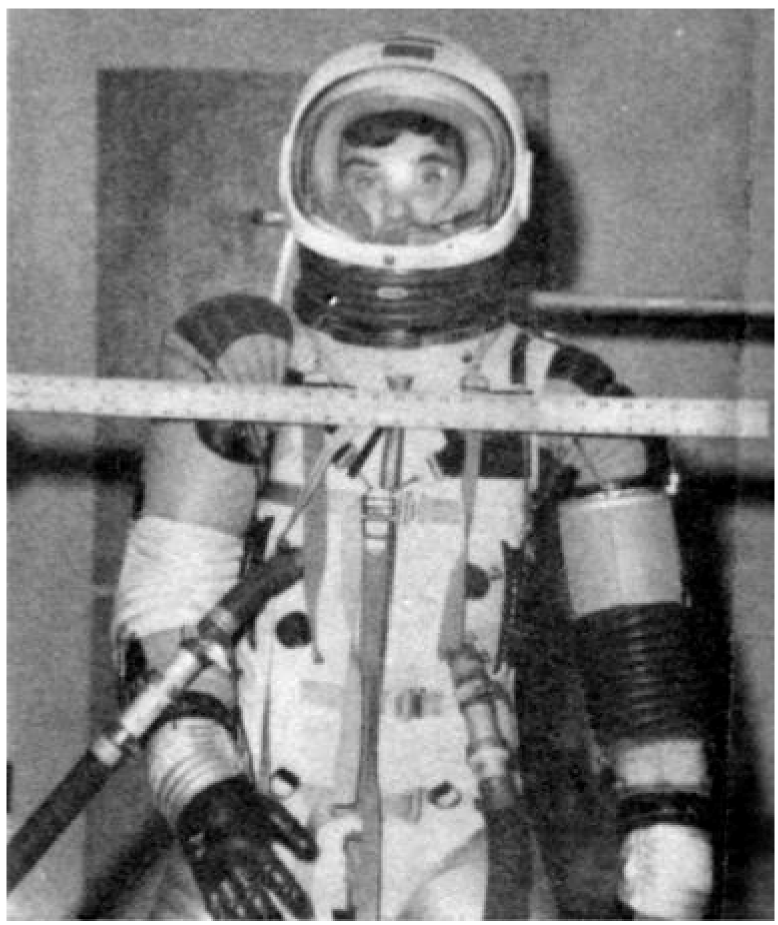

Fig. 2.24 The "ILC Play-suit" ILC Shoulder Developments

On or slightly before 20 November, 1964, ILC also delivered its second prototype of November, the S.O.A. (State Of the Art) Suit for program evaluation. This was an Apollo program style front entry garment but featured the latest ILC designed thigh and brief section (ref. Fig. 2.25). While it was not yet fully refined, this was a fore-runner of the brief system of the competition winning AX5L, which with some minor improvements, would see service on the Moon and Skylab (ref. Figs. 2.35 & 2.36).

The third prototype was the "ILC Suit", which was an evaluation prototype to demonstrate that, if NASA selected the BFG XN-20 shoulders for the A5H training suit design, ILC would be capable of the pressure suit manufacture. This garment (ref. Fig. 2.26) was delivered to HS on or soon after 25 November, 1964. By similarity of performance in comparative testing against the BFG XN-20 suit of the time, the ILC Suit successfully verified that ILC could produce the A5H series if the BFG shoulder were selected. This was the last complete prototype pressure suit from ILC under the HS Apollo contract.

While the ILC Play-suit and S.O.A. Suit both embodied significant technical advances, developments had continued elsewhere in the Apollo program and the ILC concepts were judged to be not yet sufficiently developed to be selected for the Apollo A5H design. Undaunted, ILC's personnel went back to the drawing board on a very winding road to the Apollo Block II (and ultimately Block I) victory.

Fig. 2.25 The November 1964 ILC S.O.A. Suit

Fig. 2.26 The "ILC Suit" Demonstrating Versatility In Manufacture

“Late” A4H Training Suits (3/65-6/65)

The late A-4H training suits are most frequently identified as A4H in surviving documents because by the end of 1964, NASA was looking to end Apollo suit development and proceed exclusively with “production”, thus eliminating the need for “X” and “-“designations to differentiate prototype from production models. The last seven A-4H or A4H training suits were the “late” version (S/Ns 030-036). Also called the “030 Series”, these were delivered between December 1964 and June 1965. These suits used:

- Larger neck-rings and a new “fixed type” program supplied helmet.
- Lower (front) attachments for the backpack straps that were revised to facilitate handling while pressurized.
- Three less sets of sizing-adjustment loop-tape (deleted from the lower rear of the suits)

The late A4H suits came in two versions. One was a basic training model with white nylon cover garment (ref. Fig. 2.27). The other featured aluminized outer coverings (ref. Fig. 2.28) to permit thermal testing that would replicate later flight units.

Fig. 2.27 A Late A4H With Natural (White) Nylon Covers (Courtesy Smithsonian National Air & Space Museum)

Fig. 2.28 A Late A4H With Aluminized Outer Fabrics

The A4H series enjoyed a reputation for durability and quality, which reflects a portion of the considerable progress made in the first two years of the Apollo program. A4H supported many critical preliminary development efforts such as the Lunar Roving Vehicle or "Rover" (ref. Fig. 2.29).

Fig. 2.29 An A4H Supporting 1965 Rover development At Boeing

The A4H contract deliveries included Apollo Extravehicular Thermal Meteoroid Garments (ref. Fig. 2.30), which reflected the state of protective over-garment development. These deliveries came on the eve of NASA relaxing the particle impingement requirements allowing thinner and more conformal garments. This was even more important at this point in the Apollo Program as the Extravehicular Thermal Meteoroid Garments was still to be donned as a separate coverall.

Fig. 2.30 An A4H Demonstrating The 1964 Thermal Micrometeoroid Garment Design

The Rear-Entry SOA Prototype (2/65)

In the first week of December 1964, Hamilton Standard announced that the competitive testing of mobility designs from ILC, B. F. Goodrich, David Clark Company and Hamilton Standard indicated that a non-ILC design would be used as the basis of the next generation of training suits, the model A5H. Hamilton directed ILC to continue development efforts for an upcoming final selection of a Hamilton/ILC Block II competition suit design. It was a matter of pride that this prototype would be an ILC design and ILC's space suit organization arose to the occasion. What resulted was a rear-entry prototype that represented a milestone in pressure suit development. ILC called this prototype, like so many before it, the "State Of the Art" (SOA) Suit (ref. Fig. 2.31). As this featured a rear entry system, this suit may have began under ILC internal funding prior to the start of December 1964. When it was completed is also unknown. However, ILC allowing the suit to be used as a demonstration vehicle for a helmet provides a date.

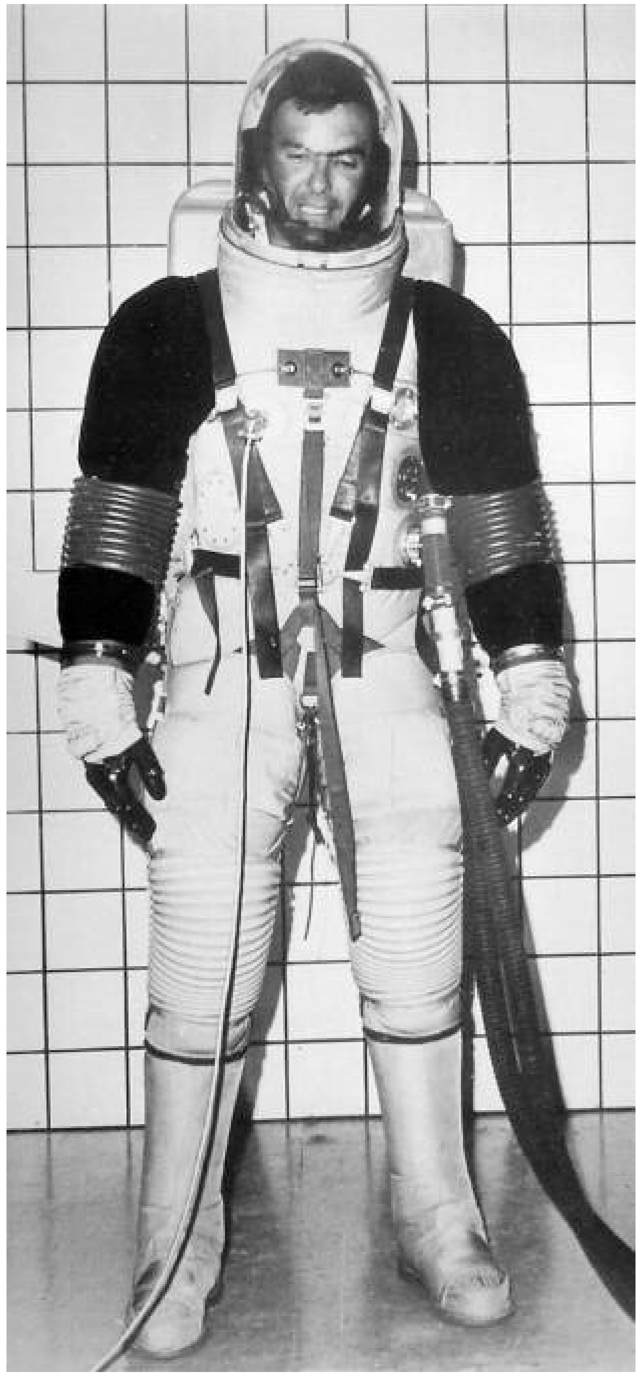

Fig. 2.31 ILC's Rear-Entry SOA Suit

In 1964, NASA engineers James "Jim" O'Kane and Dr. Robert L. Jones started NASA development of a full Polycarbonate bubble that attached directly to the neck-ring eliminating the intermediate fiberglass shell. On 11 February, 1965, O'Kane was at ILC overseeing the evaluation of the latest helmet prototype on ILC's rear-entry SOA (ref. Fig. 2.32). It is known that ILC's rear-entry SOA suit was completed before a previous O'Kane trip where O'Kane took measurements for the manufacturing of this latest NASA helmet prototype. So, ILC's rear-entry SOA suit was completed by the beginning of February 1965.

Most of the surviving pictures of the State Of The Art Suit (ref. Fig. 2.31) have the arm details blocked out to keep proprietary details from competitors. This also obscured the technical details for the historical record. However, a picture that had been identified through the years as the AX5L clearly shows a black rubber molded elbow convolute (ref. Fig. 2.32). As the elbow rubber of the AX5L was dyed a light blue to match the outer fabrics, the suit shown in Figure 2.32 confirms that the rear-entry SOA (probably the retroactively designated "AX4L") had an arm/shoulder architecture identical to the AX5L including the pressure sealing bearings in the upper arms.

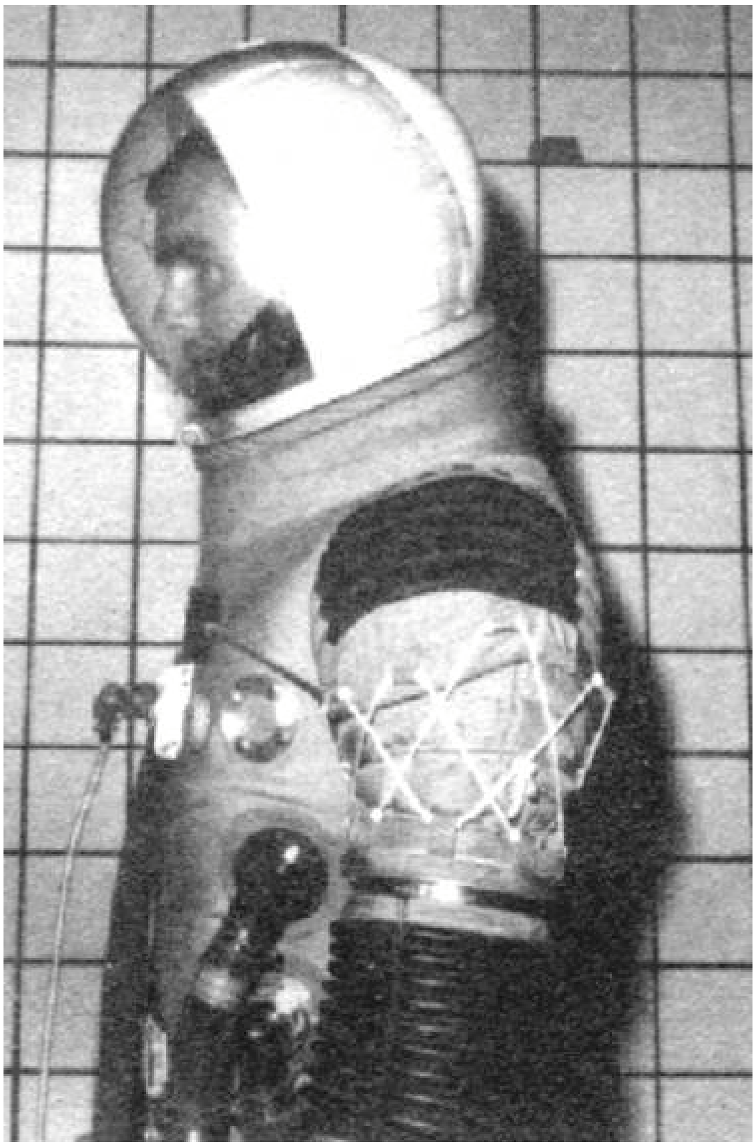

Fig. 2.32 Side Close-Up Of ILC (Rear-Entry) SOA Suit

The rear-entry SOA suit also provided yet another refining iteration of the ILC (George Durney) invented walking brief prior to the Apollo Block II pressure suit competition. This brief system would not only be a standard in all ILC space suit production through 1975 but would be imitated, with minor derivations, by competitors.

One feature the rear-entry SOA probably did not have, that the AX5L did have, was a pressure sealing zipper in its entry system. The pressure sealing zipper was a non-ILC development that probably was not available before March 1965. Without a pressure sealing zipper, it is unknown if the lengthy rear-entry zipper of the SOA suit met Apollo suit leakage requirements.

The ILC - Hamilton Separation (3/65)

From 1962 to early 1965 there were really two stories that were intertwined. One story was of businesses attempting to work together while the other was the story of technical development. Hamilton Standard and International Latex management never formed an effective working relationship. Many of the ILC management decisions were being made from the New York headquarters by the corporation's President W. O. "Wally" Heinze.

In the first week of December 1964 when Hamilton announced the selection of a non-ILC design for the A5H training suits, ILC protested the decision. Hamilton directed ILC to continue development efforts, which reflected the pattern of the 1962-64 Apollo business relations. Hamilton and NASA expected the next resulting ILC prototype, which was being called the Composite Mockup suit, to be another ILC attempt at the Block II competition suit.

For whatever reason, International Latex management elected to make a Composite Mockup Suit delivery during the week of January 18, 1965 that consisted of an incomplete garment comprised of only a torso and legs. While this caught both Hamilton and NASA by surprise, which may have been the intent, it also drew negative reactions. Hamilton immediately issued a stop-work on all ILC Apollo development activities and campaigned for NASA to not fund ILC directly for development. The "Composite Mockup Suit" delivery also triggered Hamilton to actively start working to replace ILC with B. F. Goodrich as the Apollo suit manufacturer. While it is unknown what ILC management knew of these reactions, it is clear that this was not visible to the ILC space suit workforce. The International Latex management elected not to demonstrate the rear-entry SOA suit to Hamilton. On 3 March, 1965 with ten weeks to the Block II suit competition, Hamilton Standard gained NASA permission to switch to B. F. Goodrich for subsequent Apollo suit manufacturing and notified ILC that the Apollo development contract was formally ended and to complete A4H production.

The ILC "AX3L"& "AX4L" Apollo Configurations

In the Gemini and Apollo programs, the assigning of NASA designations to suit configurations was not a formal configuration management system directed by NASA headquarters but rather an informal function that was provided by a NASA engineer named George Lutz. It helped to provide a trail and commonly accepted identifiers to what otherwise would have been chaos. Going into the Apollo Block II competition, ILC management felt that their development work was under represented within the existing NASA designations. At the time of the submittal of ILC's Block II competition suit, a presentation was made to Lutz advocating that two preceding ILC configurations had been significant to the Apollo program and should be recognized. The presentation was successful. In assigning AX5L to the ILC Apollo Block II competition suit, NASA recognized two preceding ILC configurations as AX3L and AX4L.

The ILC Funded AX5L Competition Suit & Apollo Block II Win (June, 1965-July, 1965)

The AX5L Block II Competition prototype is a globally historic space suit that almost did not happen. International Latex headquarters was reluctant to accept that external funding sources were unavailable. By the time headquarters approved internal funding, it was technically too late to fabricate the prototype and deliver it in time to be eligible for the competition. ILC proceeded on the gamble that a late entry would be allowed.

The 1965 Apollo suit re-competition for the Block II EVA suit contract was held at the Manned Spacecraft Center in Houston. The competition began on June 15, 1965. The suits present at the beginning were the David Clark Company AX1C Suit and the Hamilton Standard / B. F. Goodrich AX6H Suit. The ILC AX5L (ref. Figs. 2.33 & 2.34) arrived two weeks after the start of the competition but was accepted by NASA.

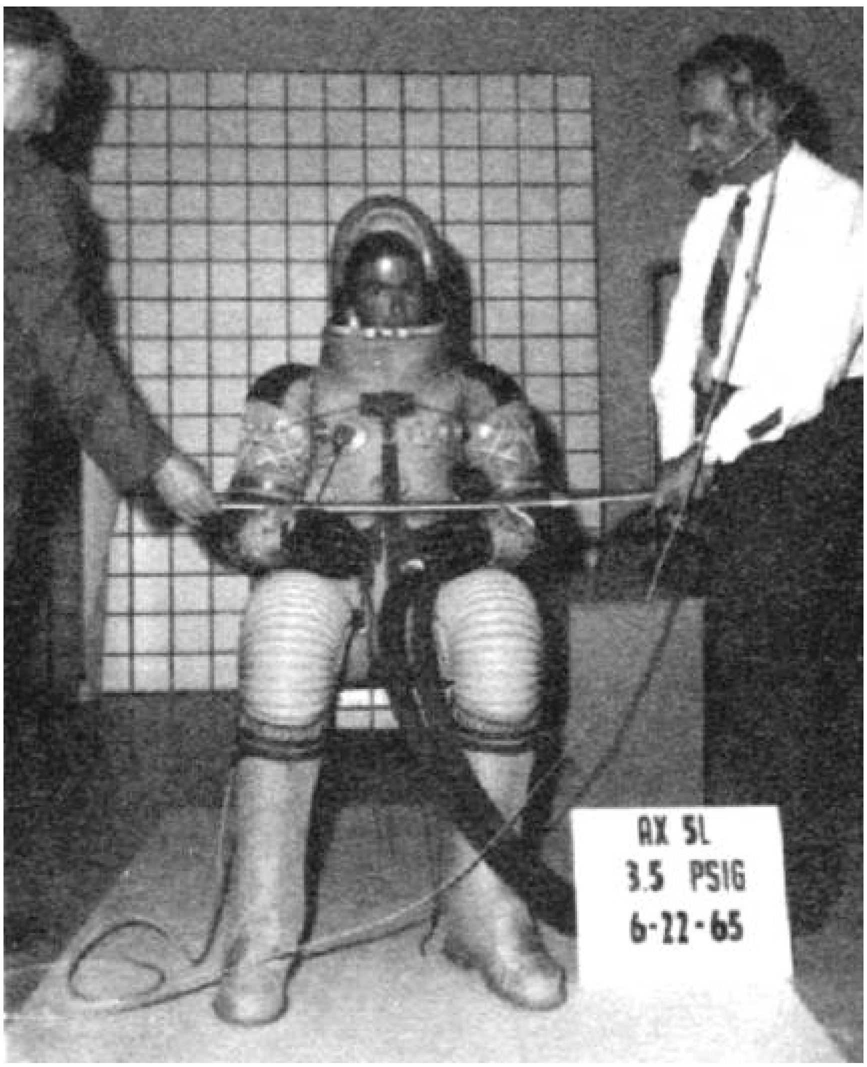

Fig. 2.33 The Completed AX5L Being Prepared At ILC For The Competition
(Len Shepard on right, Richard Ellis is suit subject. Individual on left is unknown)

The AX5L reflected ILC's study and understanding of potential systems conceived in the industry, coupled with invention and the capacity to take concepts and turn them into a well functioning system. Specifically, the AX5L featured:

- Arm bearings in the upper arms adjacent to bi-axial (near) constant volume elbow joints
- Walking brief / thigh restraint system (inventor George P. Durney, Patent No. 3,699,589)
- Rear entry reducing the potential hazards associated with draw-strap systems used in conjunction with zipper front entry
- A BFG rubber pressure sealing zipper that resulted in the AX5L having the best gas retention of the suits in the competition
- Revised pressure glove with improved, steel cable, multi-directional wrist joint (ref. Fig. 2.10)
- The use of a NASA O'Kane/Jones helmet and visor assembly.

Not only was the Apollo suit required to perform long walks on the lunar surface, but it also needed to allow the astronaut to descend/ascend the LM ladder. The Durney invention of the walking brief and thigh restraint system was significant because a non-bearing brief has an inherent difficulty bending in the waist or being able to move the legs in different directions as is required in a normal walking stride.

Fig. 2.34 The Block II EVA Suit Competition Winning ILC AX5L Prototype

There is a need for the legs outer restraint cables to bend at approximately the same location as the hip socket of the suit user but the inner restraints that traditionally attach under the crotch would not permit it. The user had to expend significant effort to overcome pressure loading to walk in an unsuited manner. ILC's George Durney devised a system to allow the inner restraints to pivot around the same arc as the outer restraints. The system used on the AX5L and subsequent A5L training suits is shown in Figures 2.35 & 2.36. This system was further refined. Figure 2.36 shows the lower torque system used on the A6L, A7L and A7LB pressure suits that was achieved by bearing-pulleys riding on the brief cables.

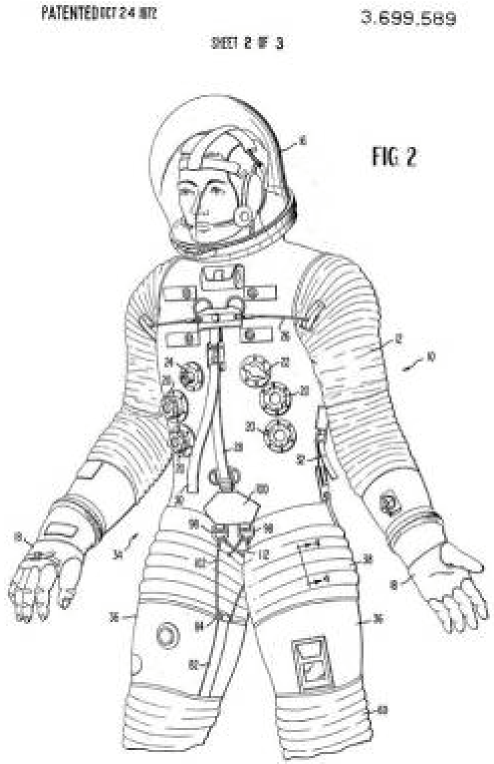

Fig. 2.35 The AX5L & A5L Walking Brief & Thigh System

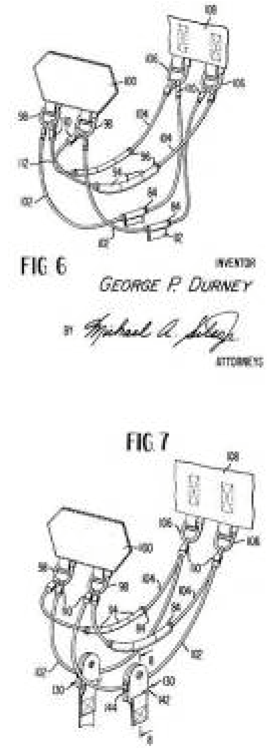

Fig. 2.36 The A6L, A7L & A7LB Walking Brief & Thigh System

Credit: US Patent Office

The ILC AX5L won the 1965 Block II competition on the basis of superior performance. Specifically, the AX5L was:

- The most mobile. The Air Lock arm bearing coupled to the ILC constant volume joint allowed mobility around an approximately 330 degree range. This resulted in lower effort in arm motions and greater range of arm movement than the HS and DCC competitors.
- The most pressure tight of the three suits. The winning ILC design included an inner pressure sealing zipper and pressure sealed arm bearings. The pressure sealing zipper (of BFG design and manufacture) resulted in the AX5L having the least leakage of the suits tested.
- Best at retaining shape under pressure.

NASA announced ILC the winner at the end of July. In September 1965, NASA functionally became the integrator of the Apollo EMU program with ILC and Hamilton being NASA's pressure suit and life support providers respectively.

There were many challenges facing ILC in terms of getting up to speed in such disciplines as Systems Engineering and Configuration Management. In the previous contract these issues were handled by Hamilton Standard. In order to bring on trained individuals almost immediately, ILC turned to the Ling Tempco Vaught (LTV) Company of Dallas, Texas for manpower assistance. Within weeks, ILC set up offices for LTV Configuration Management experts as well as others who specialized in areas where ILC was weak. These individuals called ILC and the Dover area their home for many months and in some cases, years that followed. Without the help of LTV personnel, the start for ILC on the Apollo contract would have been very shaky. Later in the program, ILC would use the services of LTV for the fabrication of the Lunar Extra-Vehicular Visor Assembly (LEVA).

<u>A5L Training Suits (1965-66)</u>

In September 1965, NASA ordered A-5L Training Suits on the basis of the Apollo Block II competition results (ref. Fig. 2.37). This configuration started appearing before the end of 1965. The A5L featured patterning, restraint, and convolute improvements over the AX5L. As NASA was still having difficultly developing an optical quality polycarbonate full bubble helmet, ILC developed a ¾ Bubble Helmet to allow deliveries (ref. Fig. 2.38).

Fig. 2.37 The Apollo A5L Training Suit (Richard Ellis)

Fig. 2.38 An ILC A5L Supporting Advanced Life Support Development

There are 14 known A5L suits made.

<u>Intravehicular Or High-Performance Aircraft Simple Soft Suit System (1965)</u>

This suit (ref. Fig. 2.39) was designed by ILC to function as a "shirtsleeve" environment in high-performance aircraft or space vehicles while affording short term pressure protection when required. The soft helmet folded down in the un-pressurized mode and could easily be pulled up and zipped closed when the need arose for pressurization. The suit assembly included a long sleeve coverall for warmth (below right). This system was developed under the guidance of Mr. Don Wolgemuth who came to ILC from BF Goodrich after ILC had won the Apollo contest with the AX5L suit. Mr. Wolgemuth was restricted from working on the Apollo suit due to protests from BF Goodrich over intellectual rights.

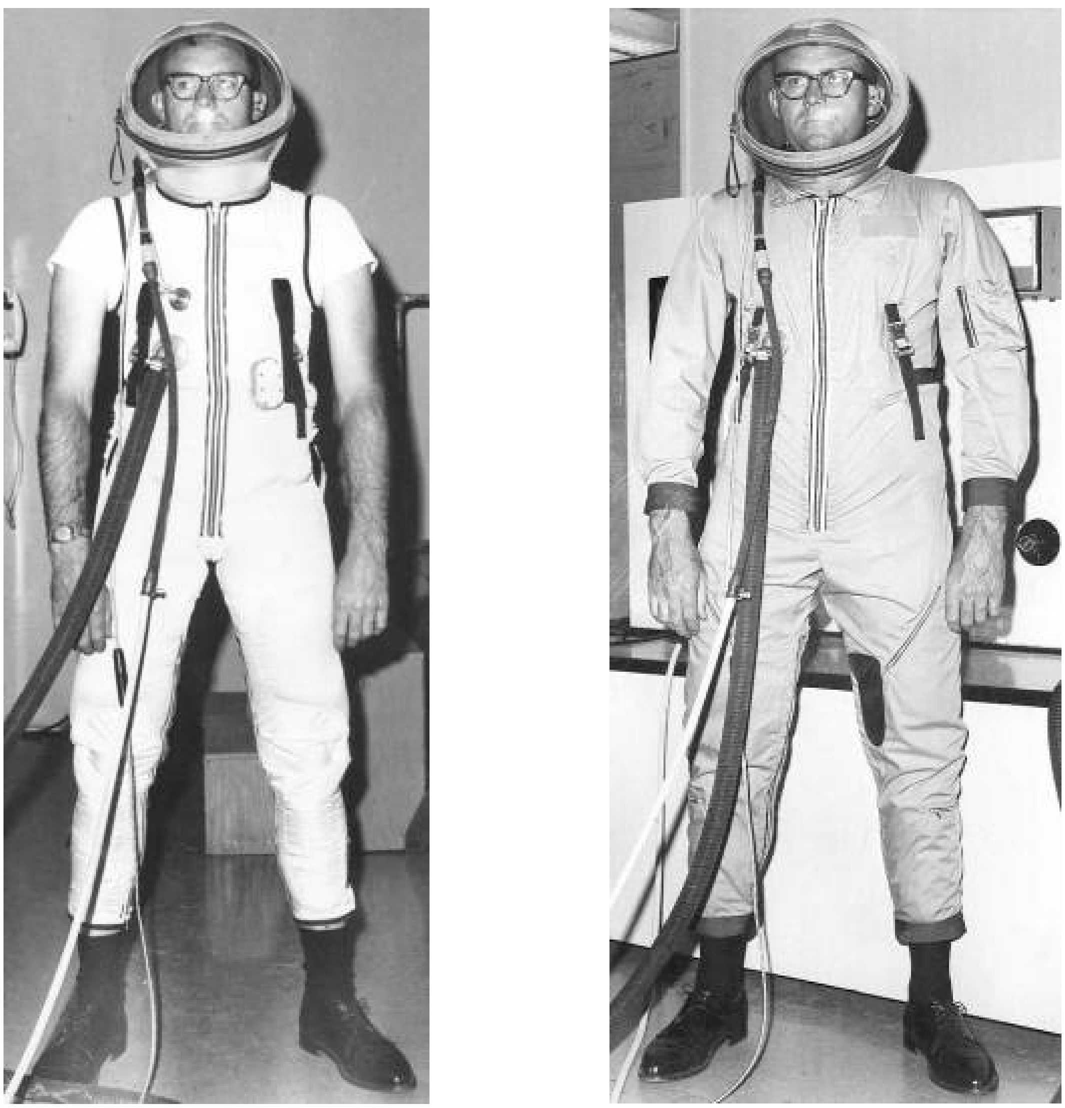

Fig. 2.39 The ILC Partial Pressure Suit Prototype

A6L Flight Configuration Suits (1966)

The A6L suit model (ref. Fig. 2.40) was more of an evolution period than a configuration. The A-6L Pressure Garment Assembly (PGA) configuration started in 1966. It essentially started as the flight-qualified version of the A5L. At the start of the A6L, the External Thermal/Meteoroid Garment (ETMG) was essentially a removable jacket and pants set (ref. Fig. 2.41). The ETMG was designed to be donned over the intravehicular pressure suit before EVAs. The ETMG pants incorporated suspenders, and had longitudinal zippers to assist donning over a pressurized suit. The ETMG jacket had apertures for the passage of the life support hoses, and like the pants, had flaps to minimize heat exchange through closures.

In 1966, thermal testing identified shortcomings in the NASA designed LEVA. ILC was given the opportunity to develop a NASA-LEVA based derivation that would see service on Apollo 9 and 10 (ref. Figs. 2.49).

The original ETMG had a Nomex outer layer for fire and abrasion resistance. Under the Nomex were seven layers of perforated aluminized Mylar separated by seven layers of Dacron scrim for thermal protection. Inside the Mylar were two layers of neoprene-coated nylon, which served to enhance micrometeoroid protection. Of note is the fact that the thermal layers were all nested, with butted and taped seams to minimize heat transfer through each layer. The perforations in the Mylar were required to ensure a vacuum between each layer as pressure equalized in the TMG upon exiting the vehicle. Kapton Tape was applied to the Mylar at various intervals to act as a rip-stop.

Fig. 2.40 The A6L Pressure Garment Assembly

Fig. 2.41 The 1966 Apollo EMU

The Apollo 204 fire (later called Apollo 1) prompted a complete revision of the Apollo space suit assembly. It was found that the pure oxygen atmosphere in the Command Module would support combustion of such materials as Nomex. Therefore, the decision was made to always have the cover garment attached to the pressure garment resulting in an Integrated Thermal/Meteoroid Garment (ITMG), and to change the composition of the TMG to make it fireproof--as opposed to fire-resistant. These changes were proposed to ensure that the astronauts would be protected during any capsule fire.

The ITMG was altered to assure that the outer layers would protect the interior from flame. Following significant development work conducted by NASA and Owens Corning Corporation, a material was finally chosen for the outer layer which consisted of woven glass fibers. This material was called Beta Fabric. Because the Beta Fabric was made of glass, it would not combust, and would only melt at temperatures substantially above the burning temperature of most of the materials in the capsule (1200 degrees F). To enhance the flame protection of the TMG, the outer two layers of Mylar were replaced by two layers of Kapton sandwiched with layers of Beta Fabric marquisette.

The remainder of the ITMG consisted of five layers of aluminized Mylar sandwiched with Dacron scrim, and one layer of neoprene-coated nylon. Again, the layers were all nested, and were permanently attached to the underlying pressure garment.

The lunar over-boots contained the Thermal/Meteoroid Garment (TMG) and flexible walking sole. These over-boots were not pressure tight, and were fastened over the suits pressure boot much like a pair of galoshes. The over-boot's TMG was different from that on the rest of the SSA. It consisted of seven layers of aluminized Mylar sandwiched with Dacron, six layers of Kapton sandwiched with Beta marquisette, two layers of Nomex felt, and a covering of Chromel-R which was a woven fabric consisting of chromium steel fibers to protect against potential abrasions with rocks. Chromel-R was also used on the glove TMG. The RTV silicone rubber sole extended over the toe area, and gave the boot the appearance of a sneaker when the overshoe was in place. This sole provided abrasion resistance, traction, enhanced insulation, and had ridges that fit the rungs of the Lunar Module's ladder. The lunar over-boots were provided in only two sizes.

Considering the amount of time spent in the suits, there was always a need for waste collection devices. During the A6L model, the suit’s waste collection devices progressed from preliminary development units to certified items. The Apollo missions used a Urine Collection and Transfer Assembly (UCTA) and a Fecal Containment System (FCS). The UCTA provided for the hygienic collection, storage and eventual transfer of urine. The design of the UCTA did not require any manual adjustment by the crewmember. The UCTA was attached using a roll-on, condom-like cuff and had a flapper valve that would only allow fluid to flow one way. This design worked quite well and was carried over for use in the early years of the Shuttle EMU.

The FCS provided for emergency containment of solid waste matter when the spacecraft facilities were not available for use as in the case of an emergency situation such as capsule depressurization when the crewmembers had to remain pressurized in their suits for up to several days until their return to earth. The item consisted of a pair of elasticized underwear shorts with an absorbent liner. To prevent the skin from drying out or itching, a protective ointment was applied to the skin. The material of the FCS allowed the moisture to be absorbed by the liner and evaporate into the suit atmosphere. There was a cutout in the front of the FCS to allow for the UCTA to be attached.

Thus, the last A6L suits differed little from the suits that allowed the first humans to walk on the Moon. At least 25 A6L PGA’s were delivered to the Apollo program.

The "100 Series" Apollo 7-14 A7L Suits (1968-70)

The A7L was a versatile system having a base configuration (ref. Fig. 2.42) that supported launch and reentry intra-vehicular activity (IVA) and by donning extra-vehicular activity (EVA) accessories (ref. Fig. 2.43) supported walking on the Moon. The A7L's rear entry pressure suit (ref. Figs. 2.44 & 2.45) featured only evolutionary changes from ILC's 1965 AX5L prototype (ref. Fig. 2.34).

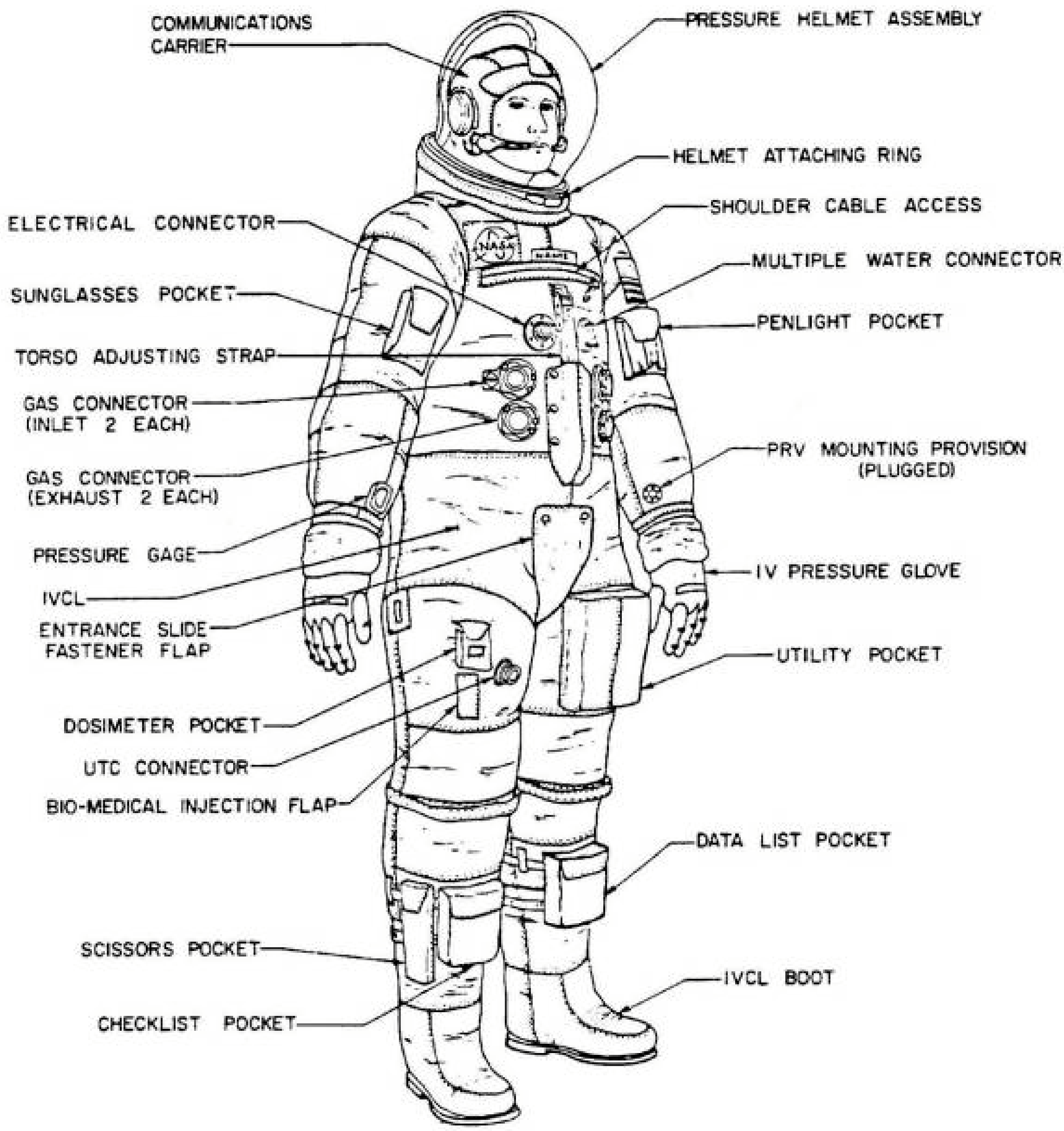

Fig. 2.42 Features Of A7L Ready For IVA

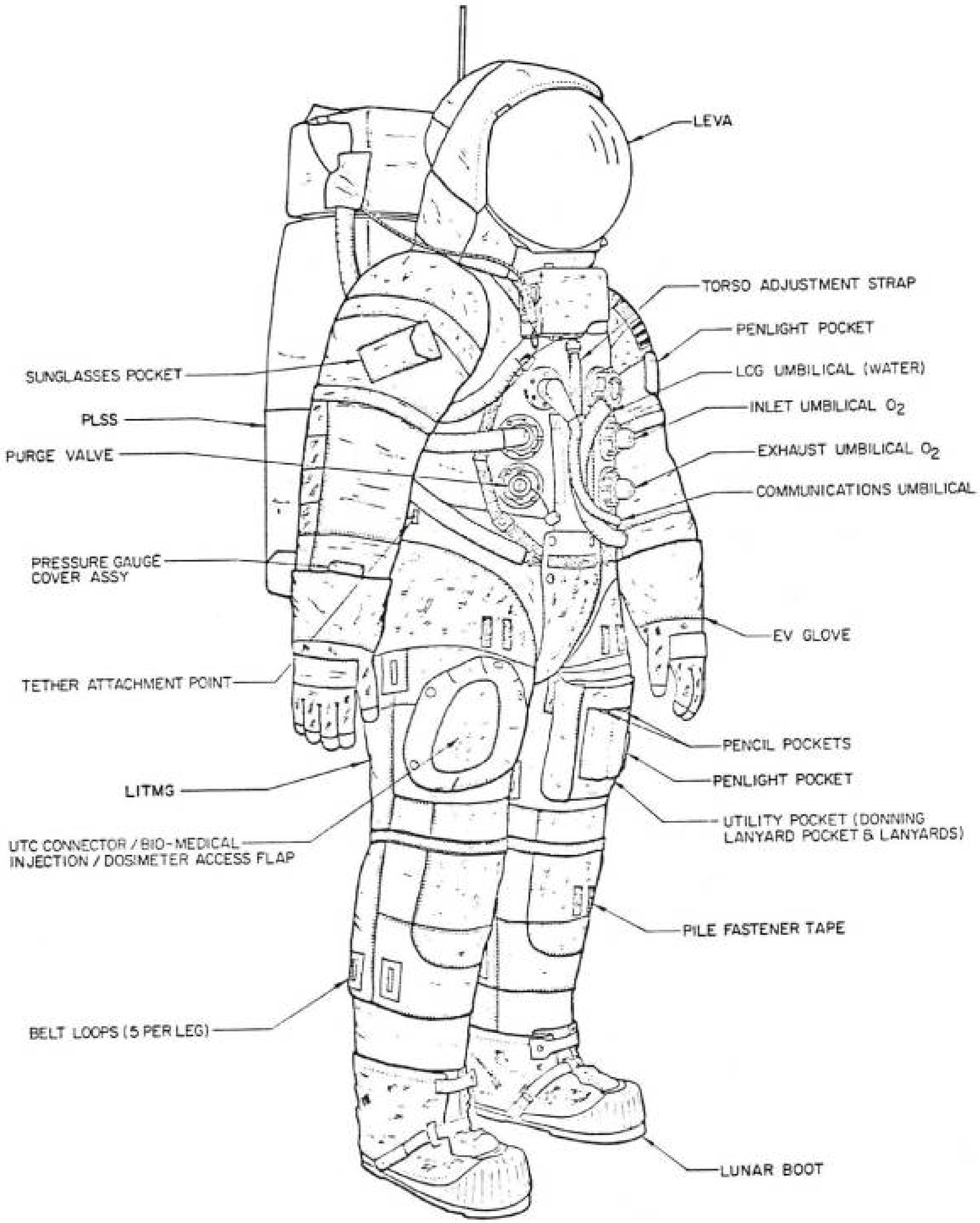

Fig. 2.43 Features With EVA Accessories (Apollo 11-13 Version Shown)

Fig. 2.44 A7L Pressure Suit Without Integrated Thermal/Meteoroid Garment

Fig. 2.45 A7L Pressure Suit's Rear-Entry System

The A7L had two configurations, which were the Extra-Vehicular (EV) and the Intra-vehicular (IV) Command Module Pilot (CMP) versions. The EV configuration was supplied to the Lunar Module crewmembers. This was the clear descendant of the AX5L. The most significant features of the A7L EV were two sets of life support system (LSS) connectors on the front of the torso and arm bearings in the upper arms (ref. Fig 2.46). The two sets of LSS connectors were needed to permit staying on the Lunar Module (LM) life support while attaching the Portable Life Support Systems (PLSS) and verifying it was fully operational before disconnecting from the LM and going EVA.

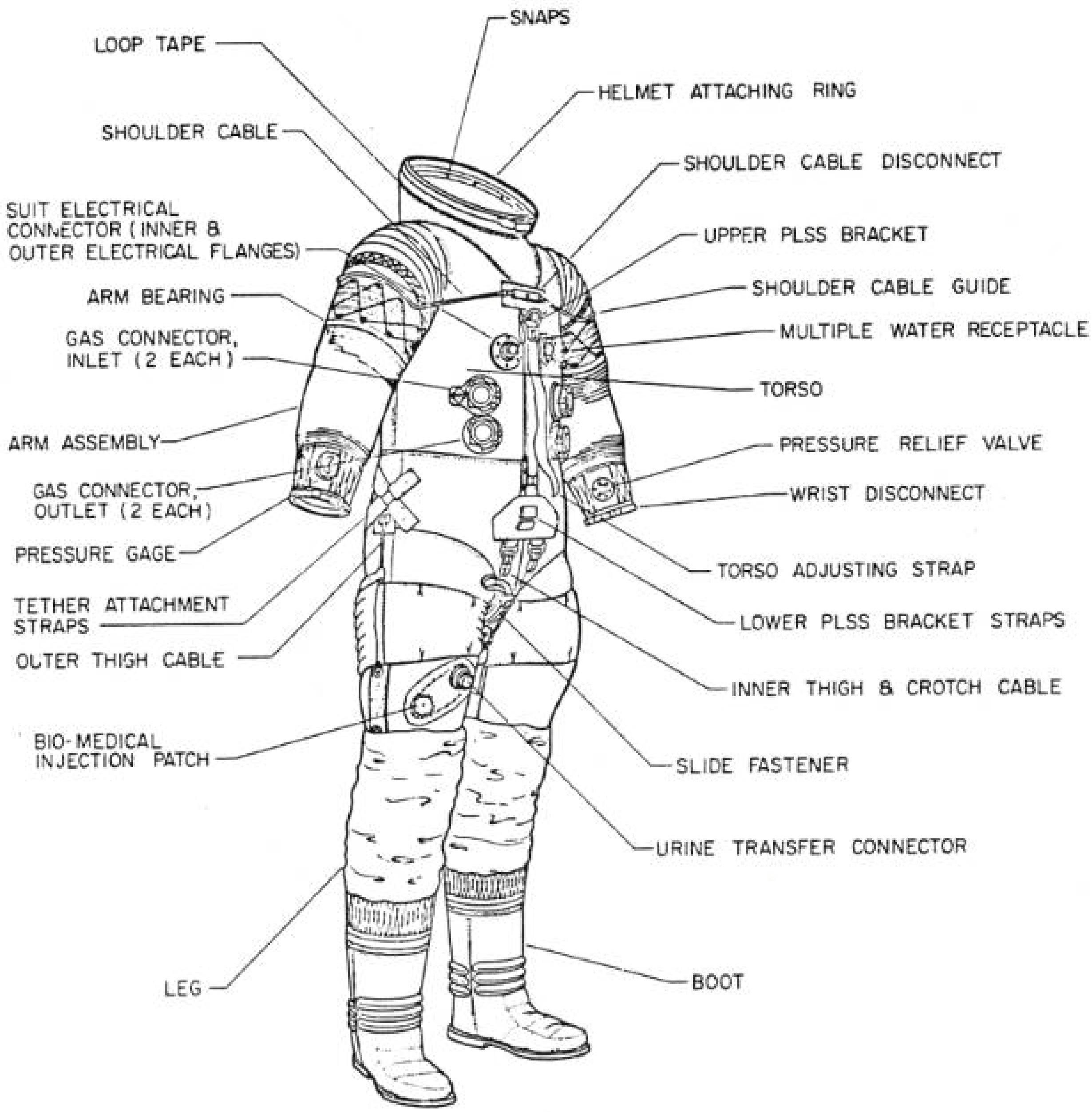

Fig. 2.46 A7L EV Torso Features

The other A7L configuration was the Intra-vehicular Command Module Pilot (CMP) suit. The A7L CMP configuration lacked arm bearings and had only one pair of LSS connectors (ref. Fig 2.47). The lack of arm bearings provided a small amount of additional shoulder room within the Command Module. As the CMP was never expected to use a PLSS, additional pair of LSS connectors added cost without serving a mission purpose.

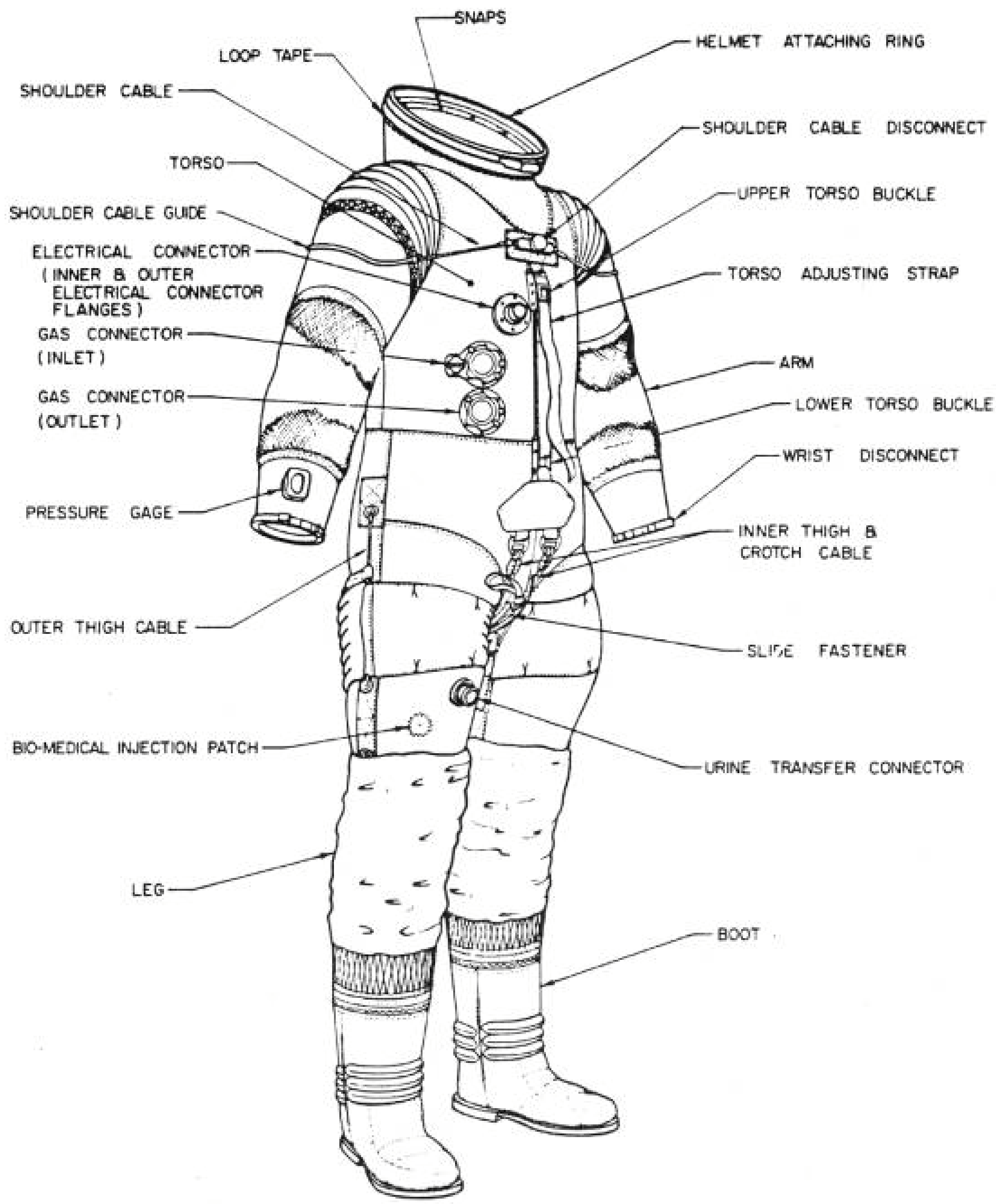

Fig. 2.47 A7L CMP Torso Features

Between Apollo 7 and Apollo 14, there were minor changes. On Apollo missions 7 and 8, the crews were not provided with EVA accessories because EVA was not part of the mission evaluations.

The Lunar Extra-vehicular Visor Assembly (LEVA) was developed to protect the astronauts from the harsh radiant energy of the sun during their EVA. It included a gold coated visor and later included sun shades. For Apollo 9 and 10, the LEVA was an ILC design derivation of a 1965 NASA design (ref. Figs. 2.48 & 2.49). Minor frost and condensation inside the helmet was experienced during the EVA on Apollo 9. This resulted in redesign of the LEVA for Apollo 11 (ref. Fig. 2.48).

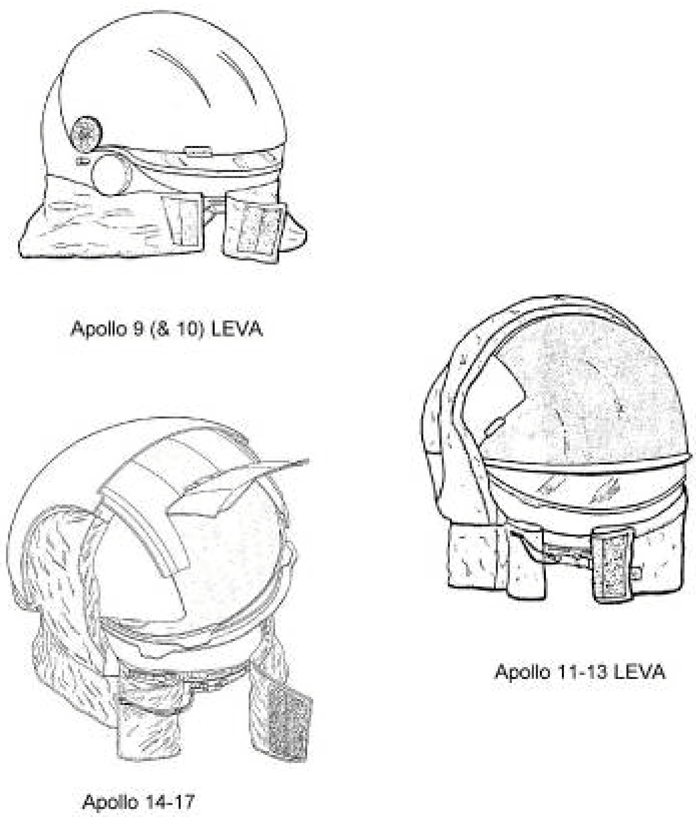

Fig. 2.48 Lunar Extra-vehicular Visor Assembly (LEVA) Configurations

The ITMG utilized in Apollo 7 through Apollo 9 had a Beta Fabric outer layer that had an extremely limited life because the glass fibers would break and degrade. The outer layer of Beta Fabric was, therefore, coated with Teflon to improve its service life. Also, the Beta marquisette was bonded to the Kapton to retard breakage of the Beta insulation.

A special intravehicular suit was developed for Apollo 8. This suit had three layers of protection that replaced the TMG of the previous suit. It was not designed for EVA, and would be used only to protect the occupant while inside the capsule. The outer layer of this garment was a new material called Super Beta. Super Beta was a further attempt to extend the life of the Teflon-coated Beta by coating the glass fibers with Teflon before weaving. The intravehicular suit was used by all of the astronauts during Apollo 8, and by the center couch occupant (CM pilot) for the remainder of the Apollo missions. The Super Beta replaced Teflon-coated Beta cloth as the outer material on Apollo 10 and subsequent ITMGs.

Fig. 2.49 The Apollo 9 LEVA In Apollo 9 Use

Reflective glare inside the helmet that was experienced on Apollo missions 11 (ref. Fig. 2.48) and 12 caused yet another LEVA revision. A "baseball cap" center opaque sun shade with flip-up front panel was added (ref. Fig. 2.48). This configuration of LEVA was used on the Apollo 14 and subsequent missions.

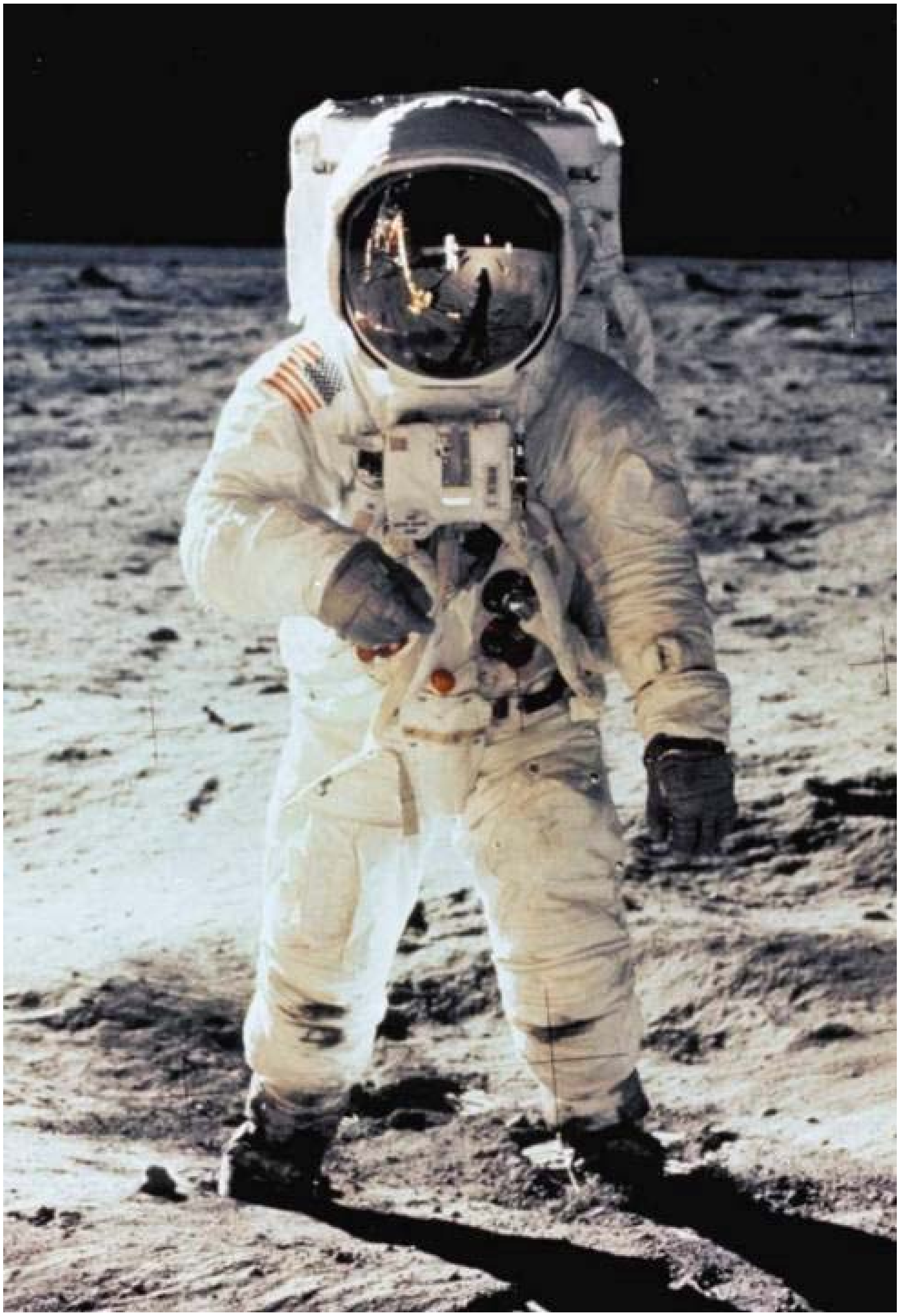

Fig. 2.50 The Apollo 11-13 LEVA In Use In Apollo 11 (Photo courtesy NASA)

There were at least 105 A7L PGA's delivered, some of which would be retrofitted to A7LB CMP configuration. A7L suit systems could support both launch/entry and EVA through the addition and removal of EVA accessories.

One Giant Step To Moonwalker Road & Autonomy (1968-69)

Throughout Apollo, the ILC pressure suits were manufactured in their 350 Pear Street facility located in Dover, Delaware. However by 1968, more floor space was needed. As a result, a section of the factory was relocated to a leased facility in Frederica, Delaware where the Apollo ITMG was fabricated. Figure 2.51 shows a lunar boot being made in the Dover facility.

Fig. 2.51 ILC Personnel Manufacturing Apollo Space Suits Circa 1968

In NASA's patent of the A7L Apollo pressure suit (ref. No. 3,751,727), NASA acknowledged ILC employees for their contributions to the Apollo Effort. Specifically, Lenard F. Shepard, George P. Durney, Melvin C. Case, A. J. Kenneway, Robert C. Wise, Dixie Rinehart, Ronald J. Bessette, and Richard C. Pulling were listed as A7L inventors in recognition of their technical contributions in the areas of integration and mobility system development.

By 1969, International Latex had been acquired by a larger corporation that merged with yet another. In January 1969, the parent corporation spun-off the Specialty Products Division into a separate organization named ILC Industries and sold 30% of its holdings to the public

<u>The "200 Series" A8L Concept & The Omega Project (1968-69)</u>

The base AX5L to A7L configuration was "locked-in" in 1965, not because it was considered an ideal, but rather because it was the best at the time and the Apollo program had to progress to training and flight. The technical personnel intimate with the suit system recognized there were opportunities for improvement, especially in the areas of ease of donning, bending over and visibility in the seated position.

No one remembers exactly who was responsible for the idea that many called the "Omega Project". It seems to have germinated in the ranks of NASA or ILC engineering some time in very late 1967 or early 1968. The first known activity appears to have been a very informal study conducted by NASA and ILC field personnel. This "study" permitted a closer look at entry concepts. This was accomplished by taking several obsolete A5L and/or A6L suits and sewing on zippers to represent proposed entry configurations. Then ILC technicians cut the pressure garment along the opening plain of the zipper to evaluate these various concepts. This effort ultimately produced two configurations that were called the "A8L" and "A9L." While it was proposed under the name Omega Project to build A8L and A9L prototypes to permit competitively evaluating the concepts, the funding was never approved.

The NASA/ILC technical teams were obliged to propose one prototype (ref. Figs. 2.52). This concept was re-identified A7LB. The concept that was selected was the former "A9L" configuration and would ultimately be named the A7LB EV configuration (discussed in the next topic). Because the A7LB EV serial numbers started at 301, it appears that the 201 and subsequent serial numbers had been set aside for "A8L" prototype(s) that were never funded and built. It is also possible that the 200 S/N suits were a series of DVT or development suits.

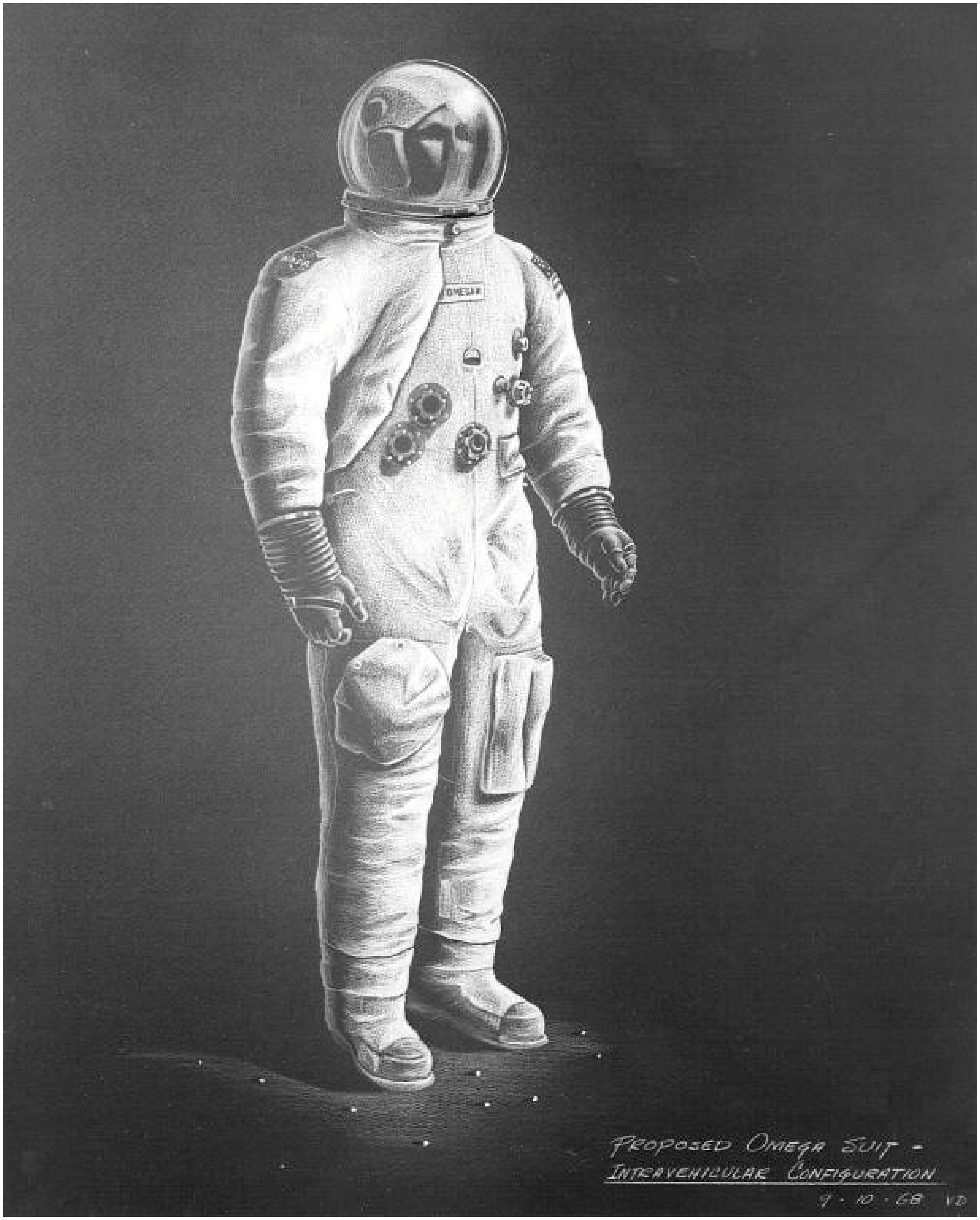

Fig. 2.52 The Omega Suit Concept

Apollo 15-17 (300 Series) A7LB Extra-Vehicular (EV) Suits (1968-72)

With the beginning of 1968, there were strong indications that 1969 and later years would be financially less favorable for Apollo. As a result, ILC tried to find low-cost ways of improving mobility and don/doff of the existing Apollo pressure suit. What resulted was the EV version of the A7LB (ref. Figs. 2.53 & 2.54). The EV version was for the Lunar Module crew that consisted of the Lunar Module Pilot and the mission Commander. The A7LB EV changes consisted of:

- Side entry
- Neck-ring orientation revised
- Neck and waist joints added
- Brief revised for improved walking performance
- Torso Draw Strap dropped
- Gloves revised to reduce manufacturing costs and to enhance durability
- A newer style of lower profile arm bearings for the A7LB suits were developed and manufactured by ILC.

Fig. 2.53 Features Of The A7LB EV Torso

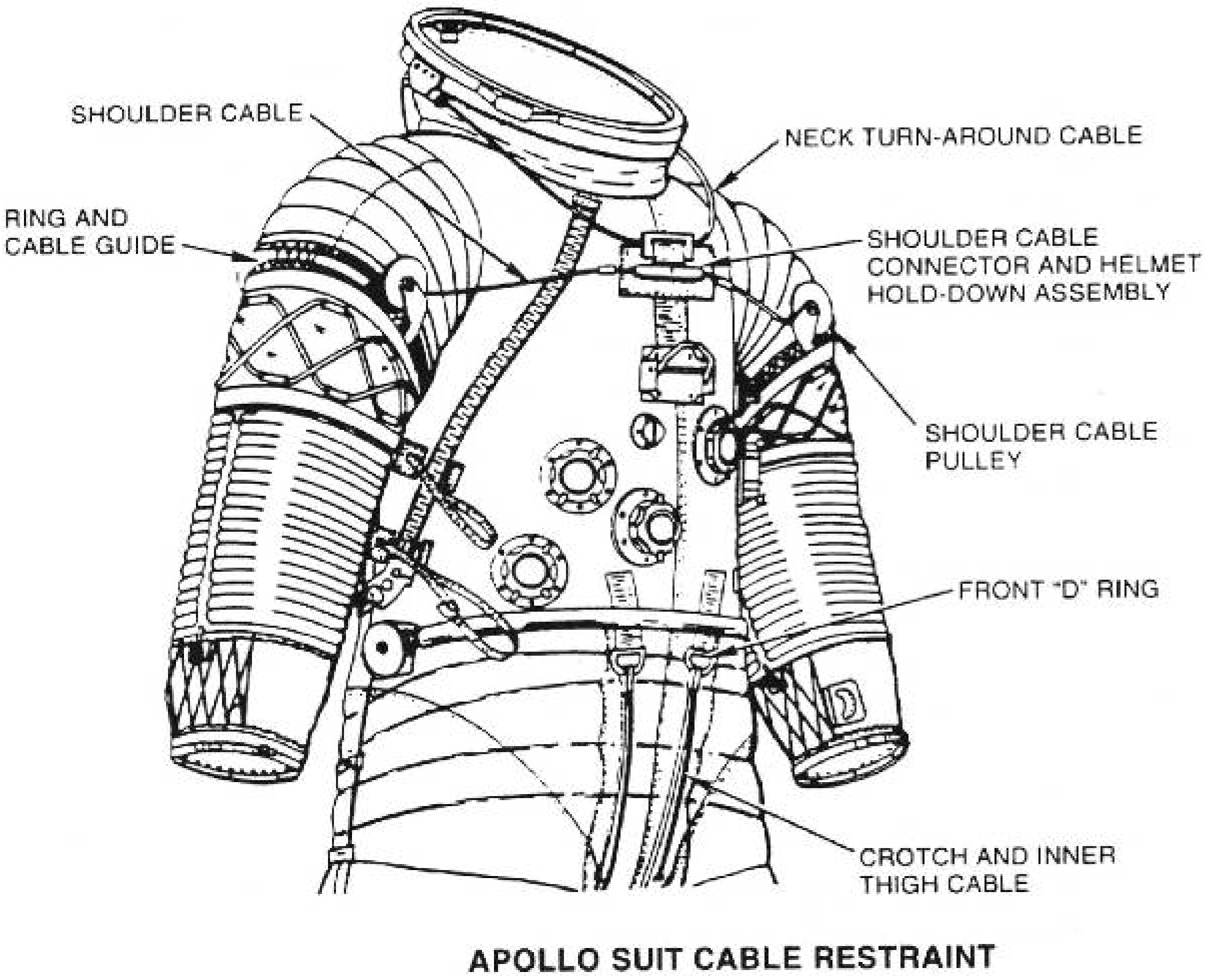

Fig. 2.54 The A7LB EV Pressure Suit Assembly

For A7LB, the fingerless outer restraint glove / wrist convolute cover assembly was revised to a dipped assembly to facilitate manufacture (ref. Figs. 2.53 & 2.56). The A7LB gloves used in late Apollo and Skylab appears to have almost exclusively used 4 inch disconnects but the glove system retained an option for 3.5 inch disconnects.

The A7LB EV suits served reliably and with distinction in the Apollo 15 through 17 "Rover missions" (ref. Fig. 2.55)

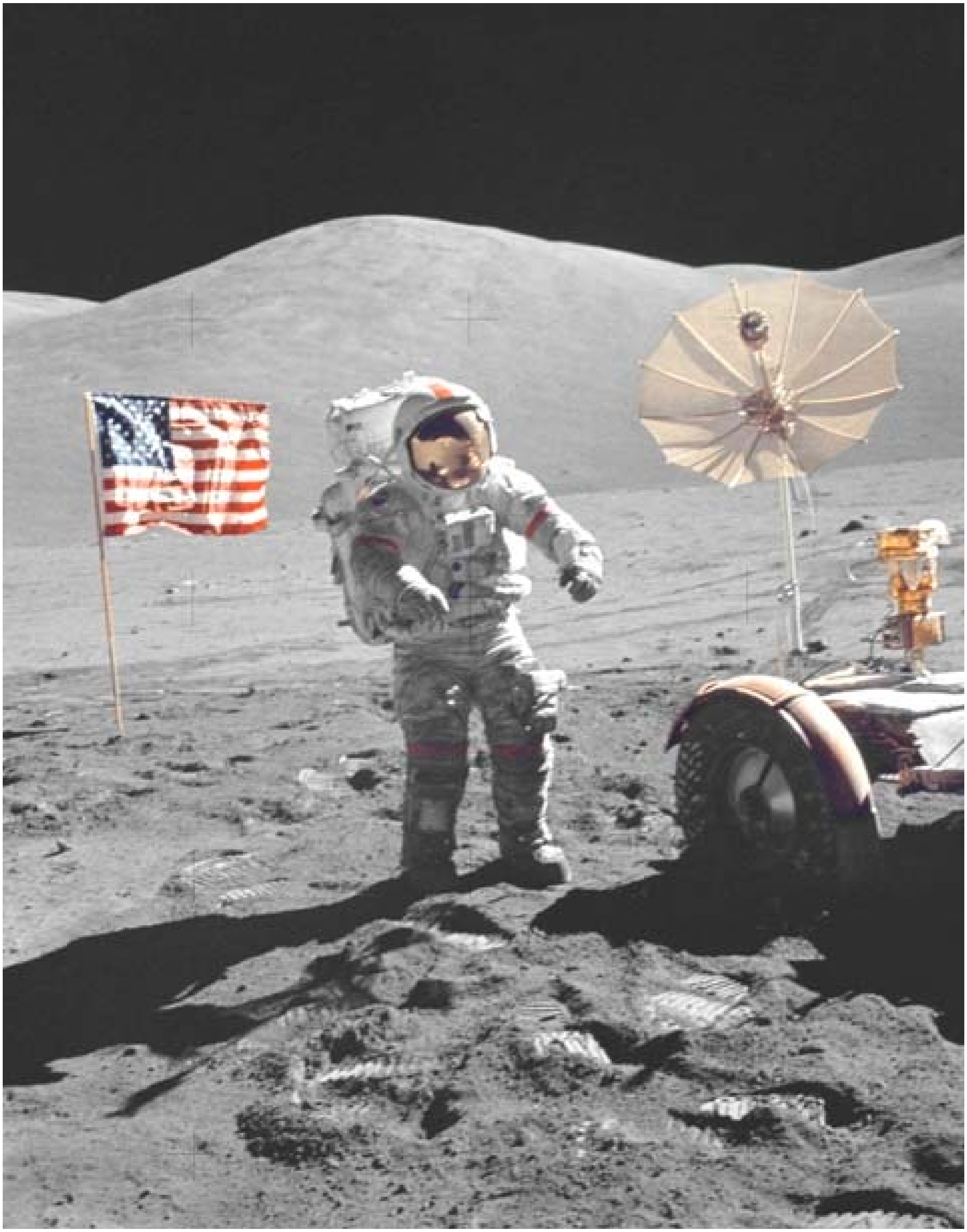

Fig. 2.55 An ILC A7LB EV Supporting Apollo 17 (Courtesy NASA)

Apollo 15-17 (400 Series) A7LB Command Module Pilot (CMP) Suits (1968-72)

Starting in 1969, NASA's budgets were reduced. Apollo missions 18-21 were cancelled. There was not the funding for PGA quantities like those ordered for the A7L model. To meet the needs of Apollo 15-17, only the Lunar Module crewmembers would be provided the new EV configuration of A7LB.

Except for 4 known new build 400 series pressure suits to support Apollo 17, all of the remaining A7LB CMP suits were retrofitted A7L PSA inventory (ref Fig. 2.56). The retrofit consisted of replacing the Multiple Water Connector (MWC) with a plate like plug, providing a new ITMG without MWC hole, supplying A7LB gloves and not supplying a Liquid Cooling Garment (LCG).

The new build 400 series suits were identical to the retrofitted A7LB CMP except that the 400 series A7LB CMP suits lacked the plate filling the MWC hole.

The ILC A7LB CMP pressure suits have the distinction of supporting the world's only deep space EVAs. On Apollo 15-17, the Command Module Pilots were afforded the opportunity to leave the Command Module early on the return trip and traverse outside the spacecraft to the Scientific Instrument Module bay built into the side of the Service Module to retrieve film packages and experiments. Unlike Earth orbital EVAs, there was no radiation protection provided from the Earth's Van Allen belt. During the return voyage on December 17, 1972, Command Module Pilot Ronald Evans performed a 1 hour and 7 minute EVA that is man's last deep space EVA to date (Figure 2.57).

Fig. 2.56 The A7LB CMP Pressure Suit Assembly

Fig. 2.57 An ILC A7LB CMP Suit Making Man's Last Deep Space EVAs Possible (Courtesy NASA)

Chapter 3 The U.S. Air Force Manned Orbiting Laboratory (MOL)

In the late 1950s / early 1960s, the U.S. Air Force (USAF) had a variety of active satellite and flight efforts, such as the X-15 program, that were reaching the edge of space. The Soviet space program being principally military based, coupled with the Eisenhower administration mandate that NASA be a "civilian" space agency resulted in parallel defense department space activity. In 1963, the Kennedy administration decided to have the USAF develop a defense oriented space program. This was named the Manned Orbiting Laboratory (MOL). In 1969, the Nixon administration cancelled MOL. However, ILC provided some interesting suit contributions to this short-lived piece of history.

Softgoods For A Primate Suit (1964-65)

In late 1964, Hamilton Standard was still attempting to maintain an effective working relationship with ILC. In parallel, Hamilton wished to initiate a "chimp suit" to attract USAF interest in Hamilton being a possible systems and life support provider for MOL. To that end, Hamilton funded ILC to design and fabricate the coverall assembly for their suit concept (ref. Fig. 3.1).

The suit system essentially consisted of a chimpanzee sized/shaped helmet with simple fabric coverall (torso assembly) to help hold the helmet in place on the suit subject. The coverall assembly featured a bushy synthetic material on the inside of the chest area and padded, thumb-less mittens to discourage the primate test subject from removing bio-medical monitors. The helmet had accommodations for inlet/outlet hoses, and captured the atmosphere via a neck dam. The ILC coverall has survived and is in Hamilton Sundstrand's Space Heritage Hardware collection.

Fig. 3.1 The MOL Chimp Suit Concept (Courtesy Hamilton Sundstrand)

MOL SOA Evaluation Suits (1966)

In 1966, ILC was fresh from the Apollo contract win. It is believed that in 1966, the USAF purchased a limited quantity of State Of the Art (SOA) suits from ILC to allow MOL evaluators to gain familiarity with the Apollo based suit in advance of the MOL suit competition the next year. There is a suit in the National Air and Space Museum preservation collection which has yet to be positively identified (ref. Fig. 3.2). However, it is a 1966 ILC manufactured, Apollo A5L or A6L like garment. Furthermore, the one remaining life support system connector is Defense Department type, not NASA style. This suit is serial number 007 indicating that if this is an ILC MOL SOA evaluation suit, then the USAF purchased at least seven from ILC.

Fig. 3.2 Probable ILC MOL SOA Evaluation Suit In The Smithsonian (Courtesy Smithsonian National Air & Space Museum)

It is currently unknown what sorts of helmets were delivered with the ILC MOL evaluation suits of 1966. By the neck-ring on the suit, it is certain that it was a conventional early Apollo style helmet probably like the A5L and A6L of the period (ref. Figs 2.35, 2.36 & 3.3).

Fig. 3.3 Probable MOL SOA Evaluation Suit Configuration With & Without Cover Garments
(Courtesy Hamilton Sundstrand)

<u>The ILC MOL Competition Suit (1966)</u>

In late 1966, ILC produced their Competition Suit for MOL that was held at Wright-Paterson Air Force Base in January 1967. ILC's Competition Suit was based on their Apollo A5L design but featured a novel elliptical hemisphere removable pressure visor in place of the traditional helmet (ref. Figs. 3.4 & 3.5).

Fig. 3.4 ILC's 1966 MOL Competition Suit (Donald Wolgemouth in suit)

Fig. 3.5 ILC's 1966 MOL Competition Suit

ILC did not win the competition for the MOL suit, which was a dual-purpose launch, reentry, and contingency EVA pressure suit. However, it did generate respect from a competitor that would play into NASA's Shuttle and subsequent EVA suit competitions.

Chapter 4 The Mix Of Skylab, Apollo-Soyuz & Early Shuttle (1968-75)

The Presidential election of 1968 would have a profound effect on the Apollo program and NASA's vision going forward. In November 1968, it was confirmed that the administration-elect's vision was for a reduced Apollo program and cost-effective transition to new space exploration goals that in the coming months would become the Skylab space station. This created a period of change. Many corporations that provided space suit competition saw reduced sales potential and elected to withdraw from the business. However, ILC had a commitment to space suit development and saw this period of change as an opportunity, as illustrated in the topics that follow.

Given the experiences of Gemini and Apollo, ILC recognized the limitations of the IEVA (intra & extra-vehicular activity, i.e. dual purpose) suit approach and saw that future business opportunities might lie in the use of two separate systems. Being proactive, ILC would demonstrate its ability to be cost effective and to develop the technological approaches that provided the foundation for space suits of the future

The Intravehicular Space Suit Assembly (ISSA) "Briefcase Suit" (1969-70)

A 1970 ILC advertisement justifiably boasted "The ability to move is the secret that keeps ILC industries ahead of its competition and the ISSA Suit (Intravehicular Space Suit Assembly) is real proof of that fact. Hardware speaks louder than words' is another fact and the ISSA Suit has been recognized." The hardware being referred to was the internally funded 1969-70 prototype development of the "Briefcase Suit" (ref. Fig. 4.1). The Briefcase Suit or ISSA offered lightweight, compact stowage ability and an extremely high level of technical readiness as it was a derivation of a design already certified for space flight, the Apollo A7LB. In a period when new vehicle trade studies were facing great weight and volume challenges and NASA had extremely limited budgets, the compact storage and low weight of this "ready for certification" design might mean the difference between a system being able to provide emergency pressure or not.


Fig. 4.1 ILC's 1969-70 ISSA "Briefcase Suit" Prototype

This first ISSA or Briefcase Suit weighed only 10.2 pounds including boots, gloves, helmet and two arm bearings and featured a stowage volume of 0.5 cubic feet, which could be reduced to 0.22 cubic feet if the suit was vacuum packed. The pressurized mobility and range were equal to or greater than the Apollo Space Suit. Un-pressurized, the mobility and range was greater than the Apollo Space Suit offering shirt-sleeve mobility equal to that of the nude body.

While the Briefcase Suit came at a time when there was not a specific program need for such a suit, the proactive effort positioned ILC well for entry into an evaluation series for a competition that would soon follow. For it seems that an ILC competitor caused NASA to take interest in "flat pattern" mobility elements and then quit space suits due to poor sales and profits forecasts. Unlike other suit providers of the time, ILC recognized the potential benefits of the technology and elected to champion the development of flat pattern mobility joints (ref. Fig. 4.2), which would be key to space suit systems of the future. The first step down that historic path was NASA funding ILC for an evaluation prototype to be competed for a possible future intra-vehicular suit system. ILC would also name this next prototype the ISSA.

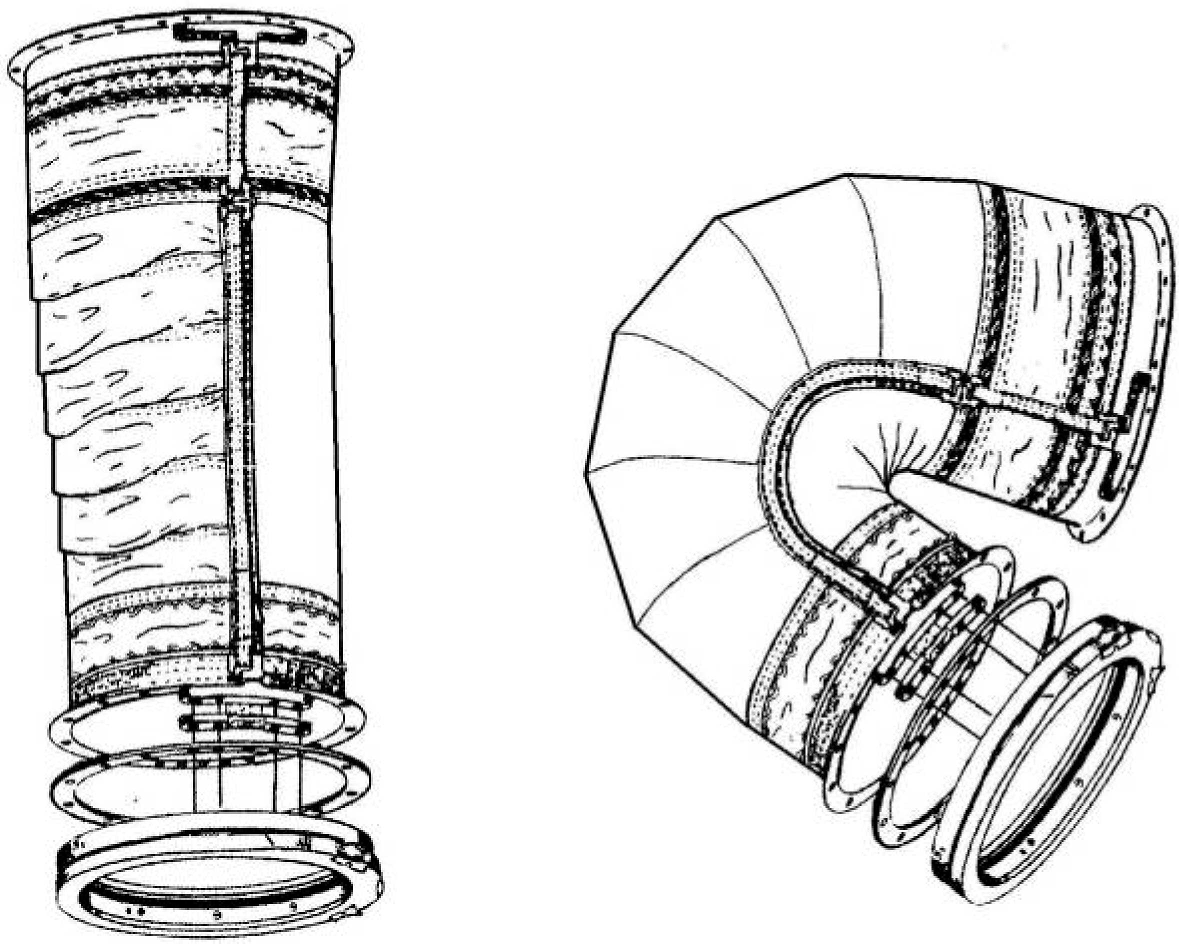

Fig. 4.2 A Typical ILC Flat pattern Joint

The 500 Series A7LB Pressure Suit Configuration

Currently there is no known surviving ILC space suit with a serial number of 501 (or later) or records that would identify the 500 series configuration. The 500 series probably consisted of one prototype serial number 501.

NASA Funded ISSA Prototype (1970-71)

In 1970, ILC was one of two organizations to be funded to produce an advanced technology, next generation intra-vehicular activity (IVA) prototype for a competitive evaluation. The contract specified the 3.75 psi IVA prototypes being delivered in May 1971. The attributes in this competition would be minimum weight, minimum storage volume, and maximum mobility. ILC also named this next prototype the Intravehicular Space Suit Assembly (ISSA). ILC delivered this advanced prototype (ref. Fig. 4.3) on time and the evaluation was successful.

While the 1971 ISSA flat pattern joint prototype defeated its "tucked fabric" joint competitor, the perceived requirements would significantly change. In June 1971, A Russian (Soyuz 11) spacecraft experienced a loss of internal pressure during reentry resulting in loss of the crew. While the Soyuz crew were not provided IVA space suits, if they had been provided 3.75 psi IVA suits, injury or possible loss of life due to decompression sickness may not have occurred NASA medical experts judged that a safe, minimum, operating pressure for an IVA suit would be 8 psi. This was arrived at by the NASA medical experts who felt that the human body could function at this lower pressure without experiencing decompression sickness. At the same time, it was agreed by NASA engineers and designers that the 8 PSI suit operating pressure was obtainable without severely impacting mobility although it was understood by all that some loss could be expected. On the basis of the 1971 IVA competition results, ILC would be awarded another development contract for an 8 psi prototype. This would be named the Emergency Intravehicular Suit.

Fig. 4.3 ILC's 1971 ISSA Prototype (NASA's Joe Kosmo in Suit)

The 8 PSI Emergency Intravehicular Suit (1973)

In 1972, NASA funded ILC for another emergency IVA prototype that would feature a safer, more reliable, faster closing and lower leakage entry/closure system and also support reasonably rapid decompression from a 14.7 psi (1 atm) cabin pressure without risk of decompression sickness. This resulted in ILC's next IVA prototype (ref. Fig. 4.4), the Emergency Intravehicular Suit (EIS). This was designed to operate at 8.0 psi (55 kPa). The EIS was fabricated in 1973 and was all soft except for a circular waist entry disconnect, helmet disconnect, and arm bearings. Sizing was by laced and zipper take-up of restraint elements. The helmet was fabric with an integralvisor. The EIS weighed 21 pounds and suit leakage was so low that it was difficult to measure.

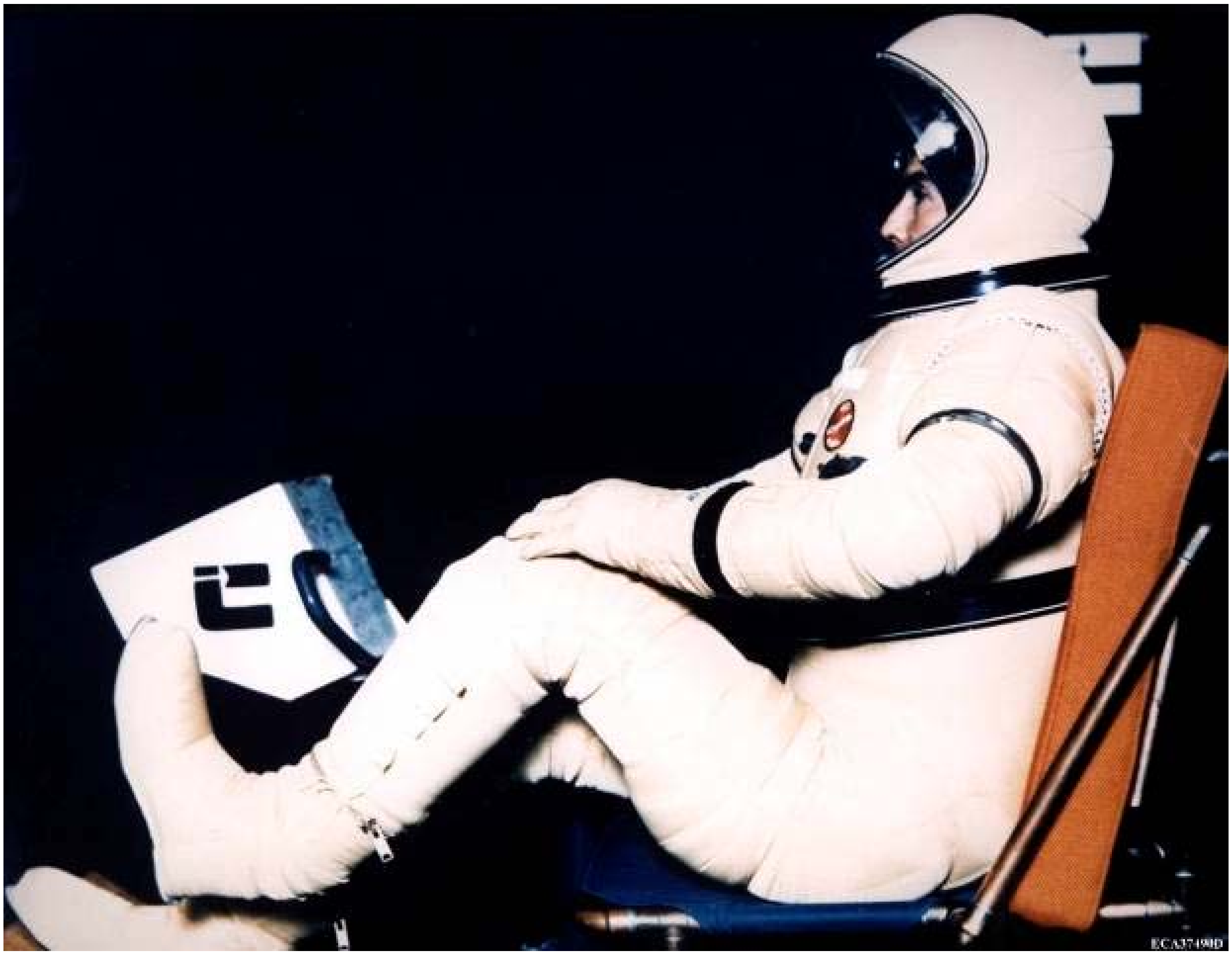

Fig. 4.4 ILC's 1973 Emergency Intravehicular Suit (EIS) (ILC Engineer Mel Case in suit)

While NASA's evaluation of the ILC EIS was highly favorable, NASA had extensive experience at lower operating pressures. Coupled with budget; weight and volume constraints in the planned Shuttle program NASA ultimately elected to implement a 4.0 psi extra-vehicular suit system. In addition, they did not include a launch/reentry/escape system in the Shuttle once it became fully operational. Thus, the EIS became a historical benchmark.

Skylab (600 Series) A7LB Pressure Suit Assembly (1969-73)

Between the U.S. Apollo missions 14 and 15, the Soviet Union launched their Salyut I space station. Salyut I failed to make orbit. This Soviet setback put the U.S. into contention for a world's first space station race. On 4/3/73, the Soviets launched Salyut II. Salyut II was damaged on launch and while docking was achieved, it never saw manned entry or habitation. The Soviets heralded Salyut I as the world's first space station. The U.S. elected not to recognize Salyut I or II as neither was successfully manned and both were rendezvous space-vehicle sized craft that had about one quarter the launch weight of Skylab. Additionally, Salyut II was placed in extremely low Earth orbit such that it reentered the atmosphere and burned up in six months.

On 5/14/73, The U.S. launched the Skylab assembly. Skylab was 118 feet long, 21 feet in diameter and weighed almost 100 tons. Skylab consisted of a two level workshop, living quarters (including a shower), a docking module, an airlock module with EVA capability, a space telescope and a solar observatory.

Due to declining budgets, NASA decided to continue use of the ILC Apollo A7LB EV suit system with only minor modifications in the Pressure Suit Assembly (PSA).

Differences from the Apollo A7LB EV and the Skylab A7LB (ref. Fig. 4.5) were:

- Upper and lower PLSS strap attachment buckles were removed and replaced with ALSA compatible attachment brackets
- Lunar Boots were deleted and the pressure garment boots modified to provide zero gravity Skylab foot restraint interface compatibility. A "Z" shaped plate was added at the front inside portion of the heel, and a conformal plate was added to the back of the heel.
- The LEVA was replaced with a lighter weight and less expensive Skylab Extra-Visor Assembly (SEVA). The thermal cover was deleted and replaced with only a polycarbonate shell having a thermal coating on the inside surface. The design also provided an easy capability for in-flight removal and replacement of the sun and protective visor subassembly.
- The Lunar ITMG was replaced with a lighter weight and less expensive Skylab ITMG. The materials cross-section incorporated fewer layers, and the design was changed to allow cross-section sewn-through seams in lieu of the individual layer, taped adhesive seams used for the Lunar ITMG.
- The Apollo suit maintenance kit was replaced with a Skylab suit maintenance kit that provided 25 EVA's capability. New features included a syringe and ampoules containing anti-fog solution and additional hardware seals and bladder repair patches.
- In addition, a light weight helmet stowage bag was developed and provided for in-flight stowage of each crewman's helmet, EVVA, and EVA Gloves.

There were at least 35 each 600 series Skylab A7LB suits made. These were delivered to NASA, which was the suit system integrator. NASA married the ILC suits to an umbilical life support system made by Allied Signal to create the Skylab Extravehicular Mobility Unit (EMU, ref. Fig. 4.6).

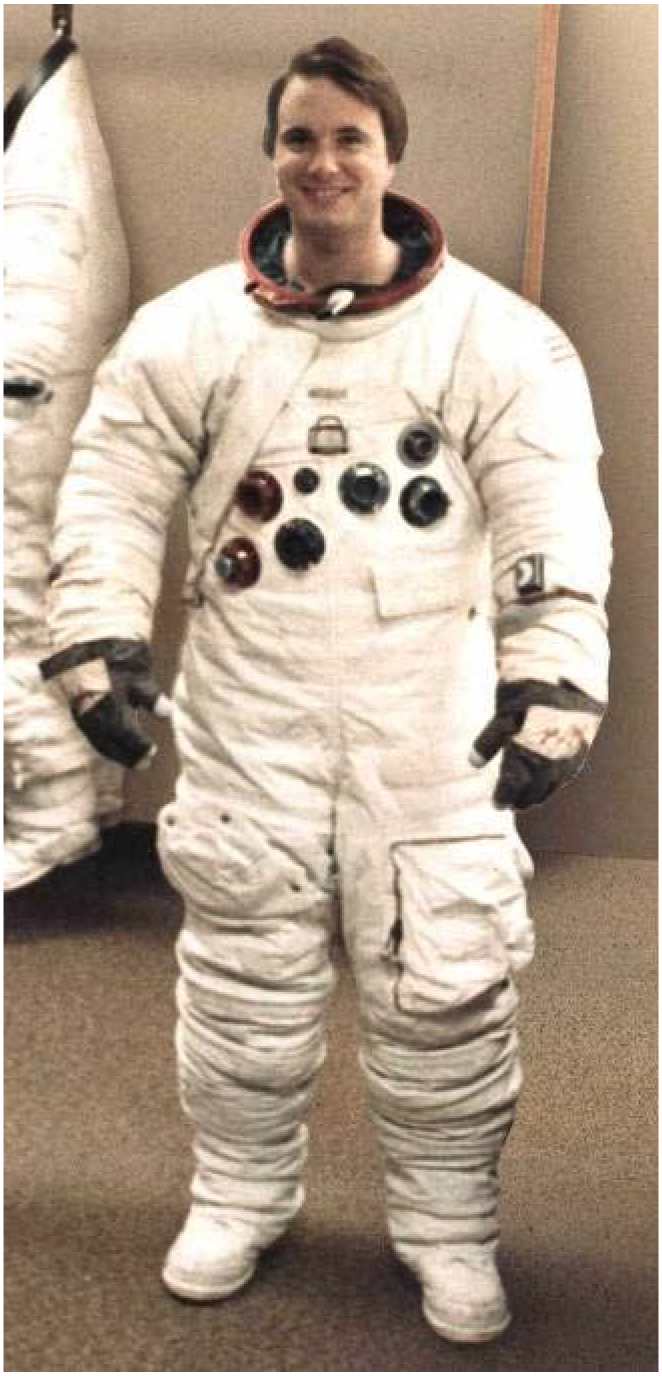

Fig. 4.5 The Skylab A7LB Suit

However, ILC's key role in Skylab was not limited to pressure suits. The unmanned launch of the Station (Skylab I) resulted in damage including loss of one (of two) solar arrays and loss of a thermal shield. The surviving solar array was unable to be automatically deployed. If left un-repaired, Skylab would have been irreparably damaged by heat build-up in weeks.

The Skylab 2 with crew was to have launched a couple of days later to open house but that had changed. Skylab 2 had become a repair mission. In support, ILC sent two engineers and a fabricator to Houston to quickly develop and fabricate what ultimately turned out to be a parasol that was deployed over the Skylab module. In nine days, a makeshift thermal cover was designed, the cover and all the tools were made, the crew trained and the mission successfully launched. The internal temperatures were reduced from 125 deg to 80 deg almost immediately following its deployment. The cover was made out of aluminized Mylar laminated to a lightweight orange nylon rip-stop. In addition, ILC engineers developed a special pair of cover gloves made out of a material identified as PRD-49. These special gloves protected the EV gloves from the suspected sharp edges of metal around the damaged surfaces of Skylab.

The Skylab 2 crew launched and successfully performed the EVAs needed to free the solar array and installed the thermal cover (ref. Figs. 4.7). The station became operational and the crew set a new space duration record of 28 days. With Skylab 3 launched in July, EVAs permitted further repairs (ref. Figs. 4.8), which allowed an extension of the world record to 59 days. This also set the stage for the Skylab 4 scientific-focused mission that extended the record yet-again to 84 days and included many zero-gravity experiments.

Fig. 4.6 The Skylab Extravehicular Mobility Unit (EMU)

Fig. 4.7 The Repaired Skylab Starting Its Journey Into History (Courtesy NASA)

Fig. 4.8 Skylab 3 Astronaut Al Bean Working In Space Thanks To An ILC A7LB Suit (Courtesy NASA)

The Flat Pattern EVA Suit (1973)

In parallel to the Skylab program activities and development of the 8 PSI Emergency Intravehicular Suit, ILC had an eye on the potential requirements for the planned Space Shuttle. In 1972, there was strong support within NASA that a Shuttle space suit should be an intra and extra vehicular activity (IEVA) suit like Apollo but less labor intensive and thus less expensive. To demonstrate that the latest mobility technology could be infused into the A7LB configuration to produce a more mobile and less labor intensive pressure suit, ILC internally funded a flat-pattern EVA prototype in 1973 (ref. Fig. 4.9).

Fig. 4.9 ILC's 1973 Flat Pattern EVA Prototype

Currently there is no known surviving ILC space suit with a 701 or subsequent serial number and no records that would definitely identify ILC's 700 series configuration. The lack of such trace may support the fact that the "700 series" consisted of one prototype serial number 701. The Flat Pattern EVA Suit was funded to show that the A7LB design could be spun-off to support the next generation of vehicle system and the timing of its creation falls between the start of the 600 series Skylab and Apollo-Soyuz Test Project 800 Series A7LB suits.

However, in 1973, NASA's advanced development started focusing on one suit for the operational Shuttle, and that would be an exclusively EVA system. Since NASA was very impressed with the mobility of the ILC Flat Pattern EVA Suit, ILC was funded for another suit prototyping effort that was named the Orbital Extravehicular Suit (OES).

Orbital Extravehicular Suit (OES) Prototypes (1971-73)

The OES effort consisted of two prototypes. For the first prototype, NASA provided a "left over" Hard Upper Torso (HUT) to speed exploration of flat pattern technology in an exclusively EVA configuration (ref. Fig. 4.10). The results were encouraging and a second prototype was funded by NASA. This has been known as the ILC EOS.

The second EOS prototype was "built-from-scratch" by ILC (ref. Fig. 4.11). This second prototype featured the use of Kevlar as the restraint fabric and ILC's first HUT. Kevlar, first marketed by DuPont in 1971, was considered as the key ingredient to making new state-of-the-art space suits. Tests showed however that many formulations of Kevlar knit would prematurely fail in areas of repeated flex. As a result, ILC discontinued the pursuit of using Kevlar as a suit restraint material.

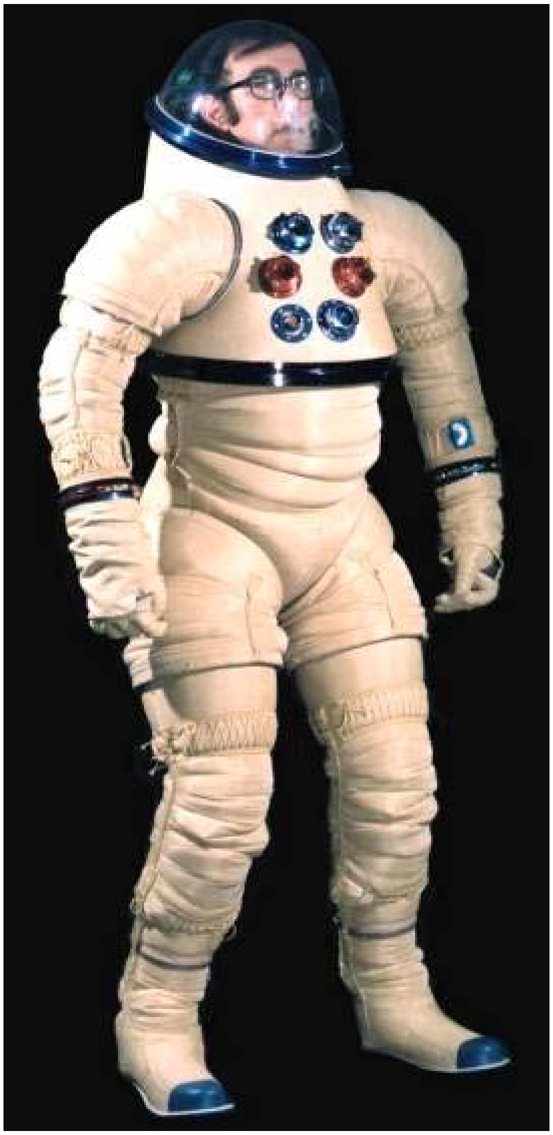

Fig. 4.10 The First Prototype
In The EOS Effort

Fig. 4.11 The (Second)
ILC EOS Prototype

<u>The Apollo-Soyuz Test Project (ASTP) A7LB (800 Series) Suits (1972-75)</u>

The Apollo Soyuz Test Project (ASTP) attempted to build cooperation with the Soviet Union, which was still a philosophical and potential military adversary. ASTP had practical technical motives for linking up the two predominant space-faring nations in the first international manned spaceflight. Developing the ability for rendezvous and docking between American and Soviet spacecraft could allow rescue by one nation of a spacecraft crew from the other nation that was in danger or distress. While this capacity was not subsequently sustained or used, it previewed the path taken for the development of the International Space Station docking systems over a quarter century later.

There were formidable challenges to this endeavor. Aside from the politically adversarial positions of the two nations, there were language and geographical barriers, plus radically different approaches to life support and vehicle design. Potential ASTP related EVA was considered until 1974.

The ASTP crew of Stafford, Slayton and Brand utilized slightly modified Apollo A7LB CMP suits for the mission (Fig. 4.12). Since there was no EVA, the suits were modified to reduce weight and cost. The normal outer cover layer of Teflon Beta cloth with under layers of aluminized Kapton with nylon spacers was replaced with Teflon Beta polybenzimidazole (PBI) fabric, which increased its durability. Also, extravehicular gloves, the suit positive pressure relief valve, the extravehicular visor, and the connectors for the liquid cooling garment and emergency oxygen system were removed for this flight. The helmets and boots were of the Skylab variety. There were at least 9 “800” series ASTP A7LB PSA made.

Fig. 4.12 The ILC ASTP A7LB Suit
(Astronaut Donald “Deke” Slayton in suit)
Courtesy NASA

The single ASTP mission launched on July 15, 1975 marked the successful debut of the first international cooperation in manned spaceflight through the linkup of the Russian and American vehicles.

ILC stayed in the Dover, Delaware area supporting the Apollo, Skylab and ASTP space program without interruption. However, in July 1975, ILC closed the doors to their Dover facility and moved key personnel and resources to their Frederica plant.

Chapter 5 Space suit Spin-Offs (1976-Present)

With space suits, ILC gained a technical capacity in structural fabrics that placed it as a world leader in a variety of products both terrestrial and extraterrestrial. Some of these products are highlighted in the topics that follow.

Protective Suits (1976-Present)

In 1976, the U.S. Army's Chemical Systems Laboratory surveyed the United States for an off-the-shelf, positive pressure, totally encapsulating suit for use by maintenance personnel at a chemical weapons site. Since the suit was to be used in one of the most toxic chemical environments known, the requirements for reliability, impermeability, chemical resistance, and durability-plus personnel mobility and comfort-were most stringent. After verifying that no existing product met these requirements, the Army asked ILC to develop a special garment for this application.

ILC pooled its space pressure suit experience and appreciation for working in hazardous environments where there is no room for error to develop a very low leakage and low cost suit named the Demilitarization Protective Ensemble (DPE, ref. Fig. 5.1). In September 1979, the DPE made its initial entry into a chemically "hot" environment at Tooele Army Depot in Utah.

In 1979, ILC surveyed the industrial chemical protective suit market and decided that they could market an industrial version of the DPE garment at a competitive price. Beyond changing the color from white to blue, ILC added a unique extruded plastic closure assembly, a ventilation system, and wrist rings. This new system, named the Chemturion™, went to market in August of 1979. The Chemturion™ (ref. Fig. 5.2) is now being used by the Environmental protection Agency, NIOSH, the Atlanta Center for Disease Control, and many companies such as DuPont, Dow, Georgia Pacific and Eli Lilly.

Fig. 5.1 The Demilitarization Protective Ensemble (DPE)

Fig. 5.2 ILC Industrial "Chemturion™" Protective Suit with the Shuttle SSA

The Child’s Mobile Biological Isolation System (1977)

A boy named David Vetter was born in 1971 with a rare genetic birth defect that left him without any immunity to disease. Until 1977, David spent his life in relatively small, sterilized enclosures, never able to go outside like other children. This situation was televised and saddened many, including some who worked in the space industry. NASA spearheaded an effort to provide assistance in the form of a custom suit and life support system. This was officially titled the Mobile Biological Isolation System (MBIS).

The MBIS (ref. Fig. 5.3) was a mobile, 4 hour maximum, low- pressure umbilical-purge life support suit-system. The “suit” portion of the MBIS was produced by ILC. For use, the sterile suit was entered from the rear, through a long, circular tunnel that attached to the child’s suit. Once inside the suit, the tunnel was twisted into a tether to provide ventilation from a filtered air supply. It was re-deployed for exit and return to the enclosure. The BioLife Support System (BLSS) provided sterile input atmosphere. The BLSS consisted of biological contaminant filtration cartridges and a fan system. The power and ventilation systems were totally redundant, and the entire assembly, including a seat, was mounted on a rugged industrial power lawnmower frame. The outlet of the umbilical system was restricted to assure positive pressure in the event of a tear in the suit. The mobile platform and battery system was a unique group effort in simplicity and reliability.

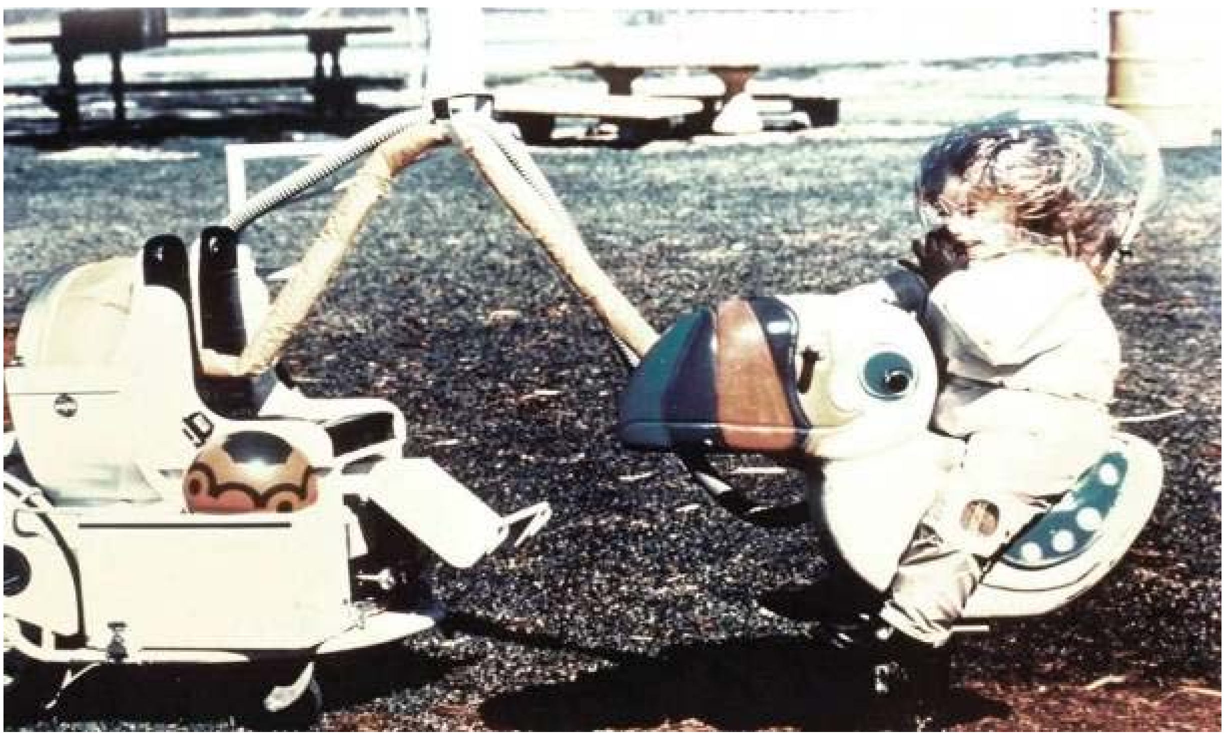

Fig. 5.3 David Vetter Suited Up For Play (Courtesy NASA)

With this suit system, David was able to hug his Mother, play with his sister, draw with school supplies and play outside for the first time in his life. A second MBIS was built (with spares) and sent to NASA's Jet Propulsion Laboratory in California for use by the Children's Hospital of Los Angeles. David Vetter's life was short (1971-1984), but if not for this effort, David would never have experienced some of life’s everyday activities that most take for granted.

The ILC Cool Suit & Commercial Cooling Garments (1979-Present)

In 1966, as part of the Apollo Block II win, ILC utilized the Apollo Liquid Cooling Garment (LCG) to provide comfort within the space suit. A commercial spin-off of the space LCG was the "Cool Suit" (ref. Fig. 5.4). With a dry system weight of only 4.5 pounds and 7 pounds of ice for cooling, the suit circulated 5.5 pounds of water to remove 600 btu per hour to keep people comfortable in most environments. In addition, several models of a cool suit were made for NASCAR drivers (ref. Figs. 5.5 & 6).

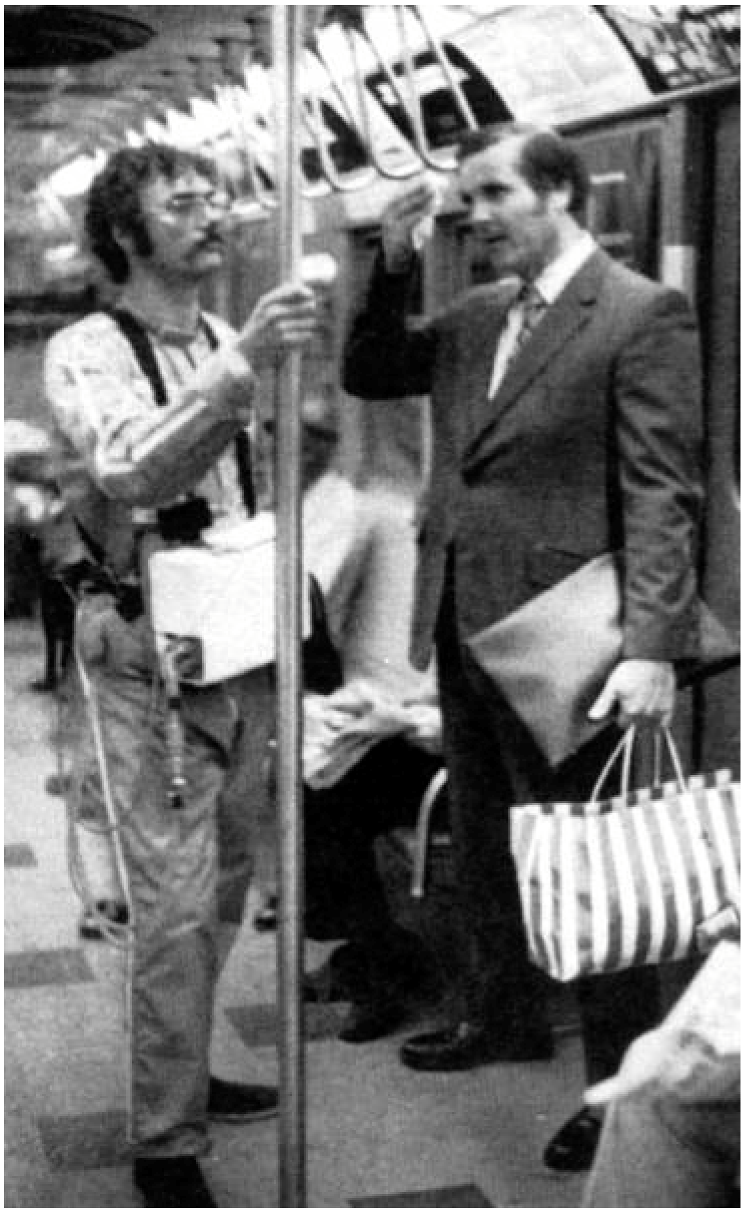

Fig. 5.4 ILC's (Commercial) Cool Suit

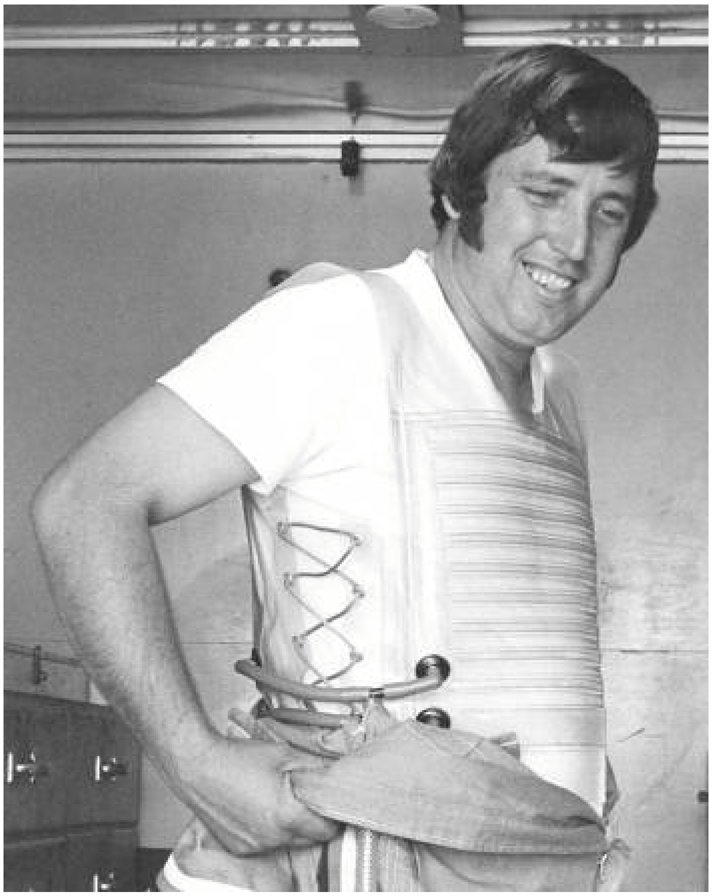

Fig. 5.5 ILC's NASCAR Cool Suit Being Donned

Fig. 5.6 ILC's NASCAR Cool Suit Ready To Support Racing

TR-1 Prototype Pressure Suit; 1980

This prototype full pressure suit (ref. Fig. 5.7) was manufactured under a contract to the US Air Force for the TR-1 aircraft. It contained a cable restraint system as well as a torso webbing pull-down strap similar to that found on the A7L Apollo suits. It is unknown how many of these suits were made.

Fig. 5.7 The TR1 Suit Full Pressure

Propellant Handlers Ensemble (1981-85)

Starting in 1981, under contract to NASA, ILC designed and manufactured a new Propellant Handlers Ensemble (PHE) suit to be used by ground crews for both fueling and de-fueling the Shuttle orbiters. At the time, the Shuttle used deadly hypergolic fuels for its steering control systems. Hundreds of various sized suits (ref. Fig. 5.8) were manufactured during the period and were supplied with a self-contained liquid air breathing system made by ILC subcontractor, ARO.

Fig. 5.8 ILC's Propellant Handlers Ensemble (PHE)

Advanced Protective System (APS) (1986)

Under a contract to Northrop Corp, ILC completed a Phase I, II and III program to design, fabricate and deliver an aircrew protective system for advanced aircraft applications. This system (ref. Fig. 5.9) consisted of a pressure helmet and partial pressure suit; a composite assembly to provide breathing and pressurization air; a microclimate cooling and heating system to provide conditioned vent air to the suit while outside of the aircraft; test equipment to verify system operation prior to flight and prototype evaluation equipment which allowed testing of the system in a laboratory environment. Two complete systems were delivered under this contract.

Fig. 5.9 The APS F22 Suit

The USAF High Altitude Flying Outfit (HAFO, 1986)

The High Altitude Flying Outfit (HAFO) was manufactured by ILC Dover under a contract to Brooks AFB in 1986. This was a prototype 5.0 psig full pressure garment complete with convoluted joints and a continuous cable restraint system at the shoulder based on the Apollo suit design (ref. Fig. 5.10). It included a thermal barrier along with chemical defense, anti-G and immersion protection.

Fig. 5.10 The HAFO (ILC Engineer Don Johnson in suit)

High Altitude Pressure Suits

Technical evolution tends to loop back upon itself in the course of time. A classic example is ILC's advanced high altitude pressure suit efforts. High altitude pressure suit technology provided the basis of space suit development in the late 1950s and early 1960s. Space suits took that technology to a new level in the 1980s,

Advanced High-Altitude Flight Suit (1988):

A total of three Advanced High-Altitude Flight Suit (AHAFS) were made for the US Air Force under a Wright Patterson AFB contract. This consisted of a systems study of a high internal operating pressure flight suit which eliminated the need for pre-breathe prior to operational use. The design (ref. Figs. 5.11 & 5.12) effort focused on reducing bulk and improving joint mobility and materials.

Fig. 5.11 ILC's AHAFS with Cover Garments

Fig. 5.12 The AHAFS In Mobility Testing

Space Inflatables/Deployable Structures (1988-Present)

Combining its years of experience with space suits and large Aerostats/Airships/Blimps inflatable structures, ILC re-applied it to the development of inflatable gossamer structures for use in numerous applications for satellite and planetary applications. This class of space inflatable structures ranges from human-rated habitat structures to ultra-lightweight gossamer structures such as solar sails. Space inflatable structures generally are deployed via inflation and become rigid once deployed to eliminate the reliance on the inflation gas to maintain geometry and structural stiffness over the life of the component. Of this diverse family of products, the two areas that have gained the most public attention have been space entry/landing systems and inflatable space habitats.

ILC has developed several airbag and ballute systems for the protection of spacecraft or launch vehicle components for their safe landing on the surface of Mars or earth. The best known of these inflatables is the Mars Pathfinder impact attenuation airbag system (ref. Fig. 5.13). Advanced materials and design practices were developed by ILC to enable the Mars Pathfinder and Mars Exploratory Rover (MER) missions.

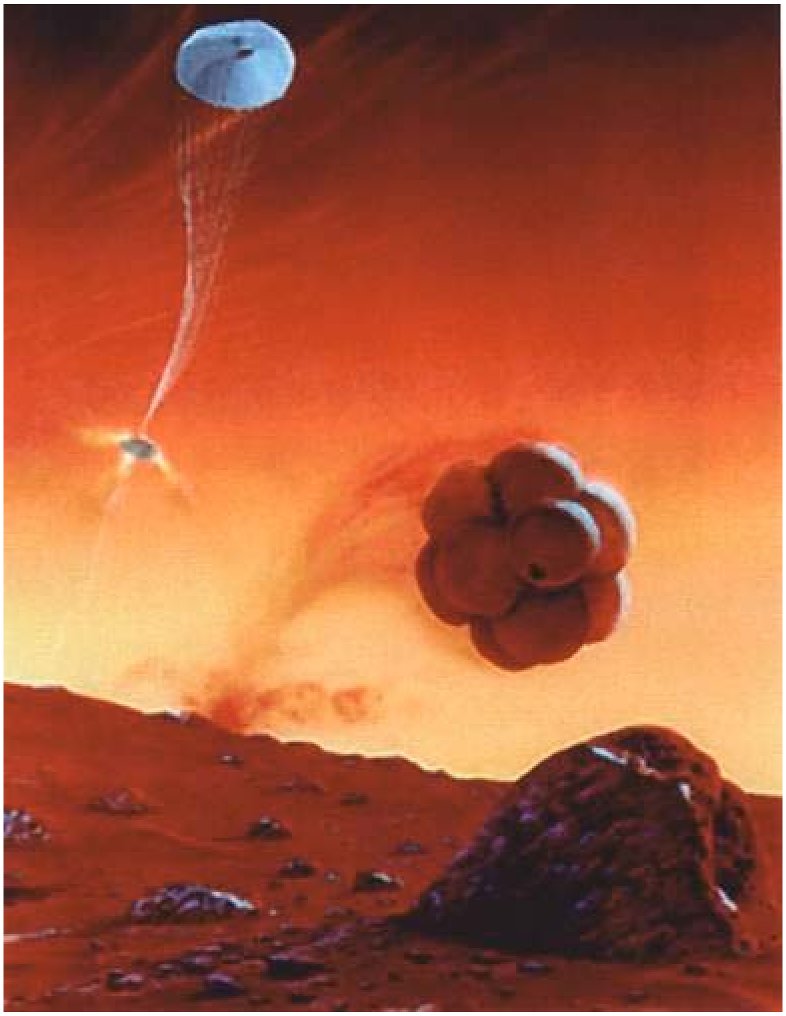

Fig. 5.13 The Mars Pathfinder
Impact Attenuation Airbag System (Courtesy NASA)

To place large structures in orbit or place them on distant bodies such as the Moon or Mars has immense challenges from mass and volume constraints. ILC has pioneered a novel solution with the design of man-rated inflatable habitats for use in orbit, during transit to other planets, and on planetary surfaces. These systems utilize layers of robust material to provide thermal, hypervelocity particle impact, and radiation protection while maintaining a safe and comfortable environment for its inhabitants. The use of inflatable structures in habitat design enables large volumetric structures to be packaged into small volumes for launch. ILC has worked on numerous studies of inflatable habitats over the past decades including the Lawrence Livermore inflatable space station, inflatable lunar habitats and the Mars Trans-hab (ref. Fig. 5.14) that was also considered for use on International Space Station.

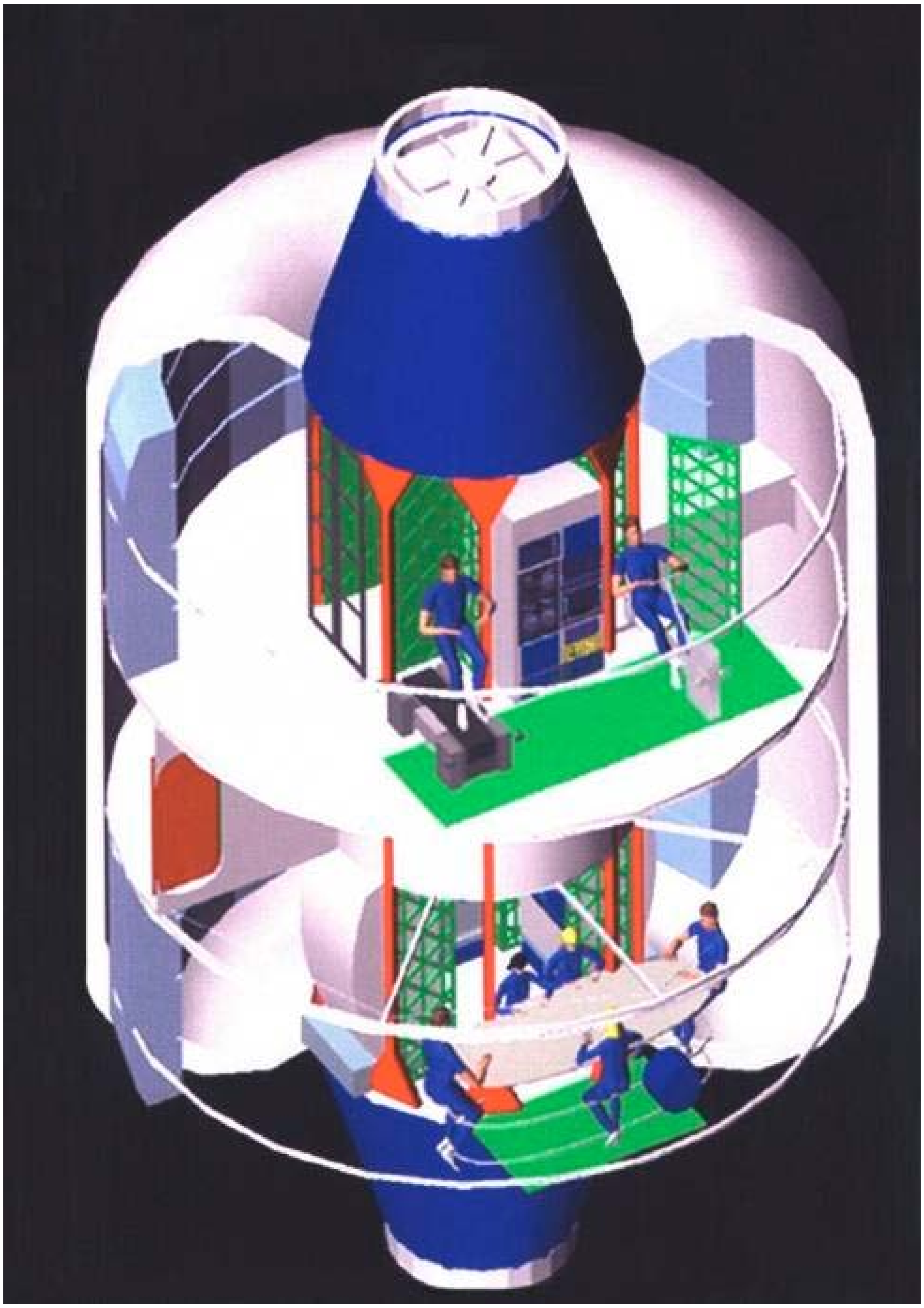

Fig. 5.14   The Mars Trans-hab Concept (Courtesy NASA)

In November, 2007, ILC unveiled the inflatable Antarctic Habitat (figure 5.15). This structure began service at McMurdo Station in the Antarctic in January, 2008. This project was funded by NASA in partnership with the National Science Foundation (NSF) who manages McMurdo Station. The habitat has an inflatable wall structure to provide rigidity and includes a spacious interior with 384 square feet of floor space and an 8-foot clearance in the center. The walls also contain insulation to help maintain comfort within. In addition, the structure is equipped with numerous temperature and pressure sensors to track the performance of the structure in one of the harshest environments on Earth. Data from the performance of the habitat will be shared by NASA, the NSF and ILC Dover to provide a better understanding of the performance requirements for an eventual Lunar or Mars based structure that will provide protection for future astronauts. The goal during the design and manufacture of this structure was to provide a system that was lightweight for transportation purposes and easy to erect. Materials had to be selected that could withstand the extremely harsh environment. The outside of the habitat includes numerous fan patches to provide a tie-down capability to assure that the structure would stay in place with wind speeds up to 100 mph.

Figure 5.15

Chapter 6 The Shuttle Era Efforts (1975-Present)

The Shuttle Extravehicular Mobility Unit (EMU) was conceived to be a reusable space suit for the Space Shuttle. To that end, it was designed as an integrated suit system that would be more robust, compact, mobile, maintainable and universally sizable than any preceding flight EVA system.

Since a design process starts with identifying the requirements a system must satisfy, the Shuttle EMU design started in 1971. This was ten years before the first Shuttle flight and thirteen years before the first Shuttle EVA.

The development of the Shuttle EMU appears to have been in three phases. The first phase lasted from 1971 to about 1974. Here, the requirements had not yet been established. NASA was searching for the best technical options. As illustrated by the numerous development suit efforts in Chapter 4, ILC was the most prolific supporter of NASA's vision towards the future.

By 1974-75, the process entered a second phase. The requirements had been (for the most part) established. Following the conclusion of the Apollo program, six ILC employees were retained under a six-month contract to develop the specifications and Manufacturing, Quality and Configuration Management process improvements for the Shuttle program. Many of these recommendations were adapted by NASA for the Shuttle suit program. Budget constraints within NASA had become a significant influence in defining the Shuttle EMU requirements. In this time, the competing teams formed and conducted preliminary designs in preparation for the time when NASA would issue the request for proposals for the Shuttle EMU. This would come in February, 1976.

ILC's teaming for the Shuttle EMU would provide an interesting twist. For Apollo, Hamilton Standard (HS) and ILC had been forced together in 1962. This was a period of great friction between the managements of HS and ILC (then International Latex). By the start of 1965, the two organizations were space pressure-suit design rivals. In 1965, ILC won the Apollo EVA suit in competition against HS and the David Clark Company (DCC). In 1967, HS defeated ILC (and DCC) for the Manned Orbiting Laboratory suit. Ironically, this provided a foundation of mutual HS/ILC respect. In 1969, International Latex spun-off ILC into a separate business entity removing International Latex as an influence. Through the years of the Apollo 9 to 17 missions, HS and ILC personnel worked together on a daily basis, which further enhanced mutual respect and formed lasting personal friendships. By 1975, the ILC and HS relationship had changed. In 1975, ILC voluntarily joined with HS to pursue the Shuttle EMU contract. The theme of this teaming was "Best of Apollo, United for Shuttle."

The third phase started in 1975 with NASA competing Shuttle related contracts. During this period ILC won key crew survival and escape systems, which provided a prelude to winning the Space Suit Assembly of the Shuttle EMU.

Exploration of Shuttle Crew Survival & Escape Systems

In 1975, NASA started implementation of a crew survival system to permit in-space rescue and survival (ref. Fig. 6.1). NASA explored two concepts. The concepts were built around the use of the Shuttle's compact Portable Oxygen Subsystem that was being developed in parallel and two options of enclosure. ILC would have key roles in both concepts.

Fig. 6.1 EVA Astronaut Ferrying A Crewmember Inside A PRE "Rescue Ball" (Courtesy NASA)

The Personal Rescue Enclosure (1977-80)

Space Shuttles originally planned to fly only two full pressure suits (EMUs) on board. To provide emergency life support for the non-EVA crewmembers in the event of an in-flight emergency requiring depressurization, protection from toxic chemicals in the atmosphere, or transfer to another vehicle (ref. Fig. 6.1), another space suit system was devised by the HS/ILC team. This protection system was the Personal Rescue Enclosure (PRE) or "Rescue Ball". The life support during PRE use was supplied by either the Portable Oxygen Subsystem or the Shuttle's Environmental Control and Life Support System and required the external support of astronauts using EMUs.

ILC won the contract for the PRE in 1975. The PRE (ref. Fig. 6.2) was a 30-inch diameter fabric sphere developed and manufactured by ILC. HS support to ILC consisted of requirements and interface definitions. To don the PRE (ref. Fig 6.3), a non-EVA crewmember would open the zipper and enter wearing a Portable Oxygen System. Another crewmember would zip the PRE closed. The PRE had optional connection features to permit pressure and oxygen supply from the Shuttle until the Portable Oxygen System was needed. By carrying five highly compact PREs, three more Portable Oxygen Systems and using the two EVA suits, an emergency environmental haven could be provided for all crewmembers. In the event that a Shuttle was stranded in space, a second Shuttle could be launched and the EVA crewmembers could ferry PRE-enclosed colleagues to the rescue vehicle for return to Earth.

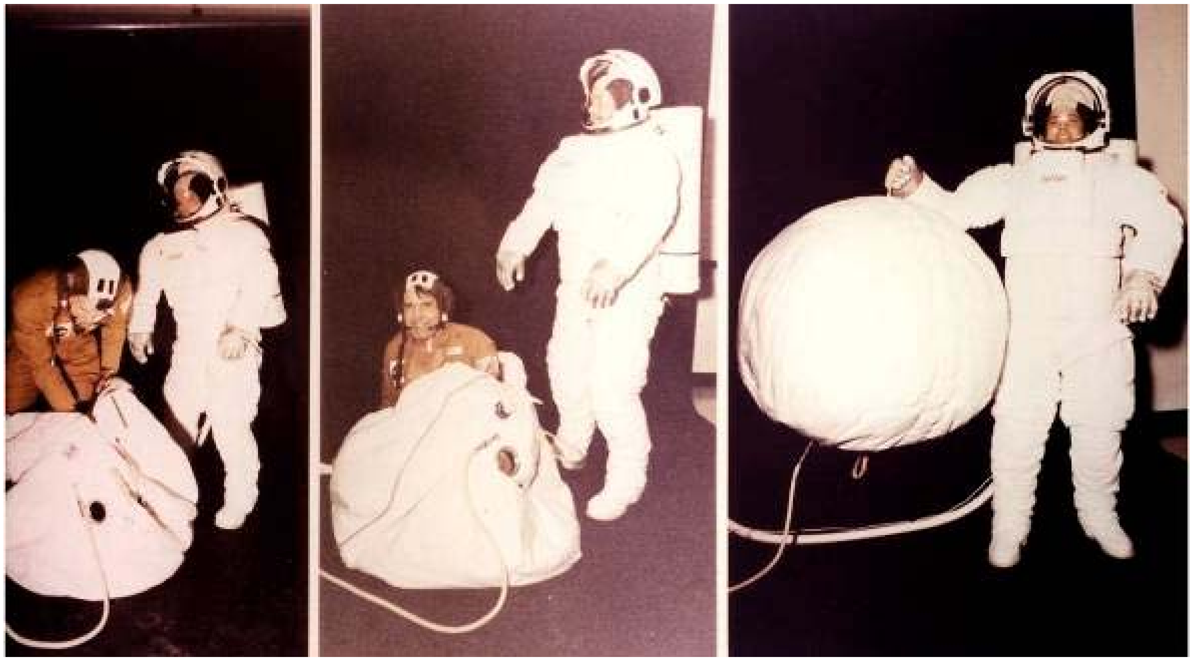

Fig. 6.2 Personal Rescue Enclosure (PRE) Demo

Fig. 6.3 Astronaut In A PRE Volumetric Mockup

However, the transfer option required a second Shuttle ready to launch. NASA accepted that such a contingency was not logistically feasible. The PRE did not reach flight. However, the PRE remains part of the astronaut candidate screening process.

Anthropomorphic Rescue Garment (1976-77)

An alternative to the PRE was also explored briefly with the Anthropomorphic Rescue Garment (ARG). Crewmembers wearing a Portable Oxygen System could don the ARG and perform some level of self-help tasks during emergency, rescue or transfer operations. NASA funded ARG prototypes from ILC (ref. Fig. 6.4) and a competitor. NASA carried out evaluations of both prototypes. Before the Shuttles became operational, this overall rescue concept was found not to be practical. Thus, the ARG quickly became relegated to history.

Fig. 6.4 ILC's Anthropomorphic Rescue Garment Prototype (Courtesy Gary Harris)

The SX-1 Prototype & The Competition Win (1976)

In NASA's Request For Proposal (RFP) for the Shuttle EMU, NASA requested that the proposals be based on an EMU system that would be a compact, robust, reusable and cost effective. Additionally, it would provide standardized sizing that could support 5th percentile female to 95th percentile male users. The EMU would be re-usable and would have a 6 year useful life and a 7 hour capacity with a 30 minute backup. A 33% reduction in the maximum front-to-back dimension from the Apollo EMU was needed for egress through all Shuttle Orbiter hatches. The EMU was not to use zippers for entry or metal cables as restraint systems. To minimize technical challenge and cost, NASA requested that the proposal be based on:

- The use of existing/certified technology (where possible)
- A small increase in EMU operating pressure (from 3.7 to 4.0 psi or 25.5 to 28 kPa)
- Use of the Apollo/Skylab helmet and neck-ring
- Use of flat-pattern joint mobility elements as a highly-desirable approach

On the basis that the system was to be based on existing technology to the extent possible, NASA did not fund the creation of demonstration space suit systems for the competition.

The HS/ILC team offered one proposal that met all of NASA's requirements. Although proposal submittals for the Shuttle EMU did not require accompanying proof-of-concept prototypes, the HS/ILC team elected to submit a suit system prototype (designation SX-1 for Shuttle EXperimental #1). The SX-1 (ref. Figs. 6.5 to 6.10) featured flat pattern joints, a

Fig. 6.5 SX-1 Prototype From HS/ILC Shuttle EMU Proposal (ILC's Tom Sylvester in suit)

waist bearing to allow torso rotation, compact front-to-back envelope and a full scale volumetric mockup of the Shuttle Obiter's decks and hatches. This permitted HS/ILC to demonstrate the ability to meet all Shuttle requirements by demonstration and subsequent NASA evaluation.

Fig. 6.6 Preparing To Don SX-1 (note original Display and Controls Module concept)

Fig. 6.7 Don SX-1 LTA

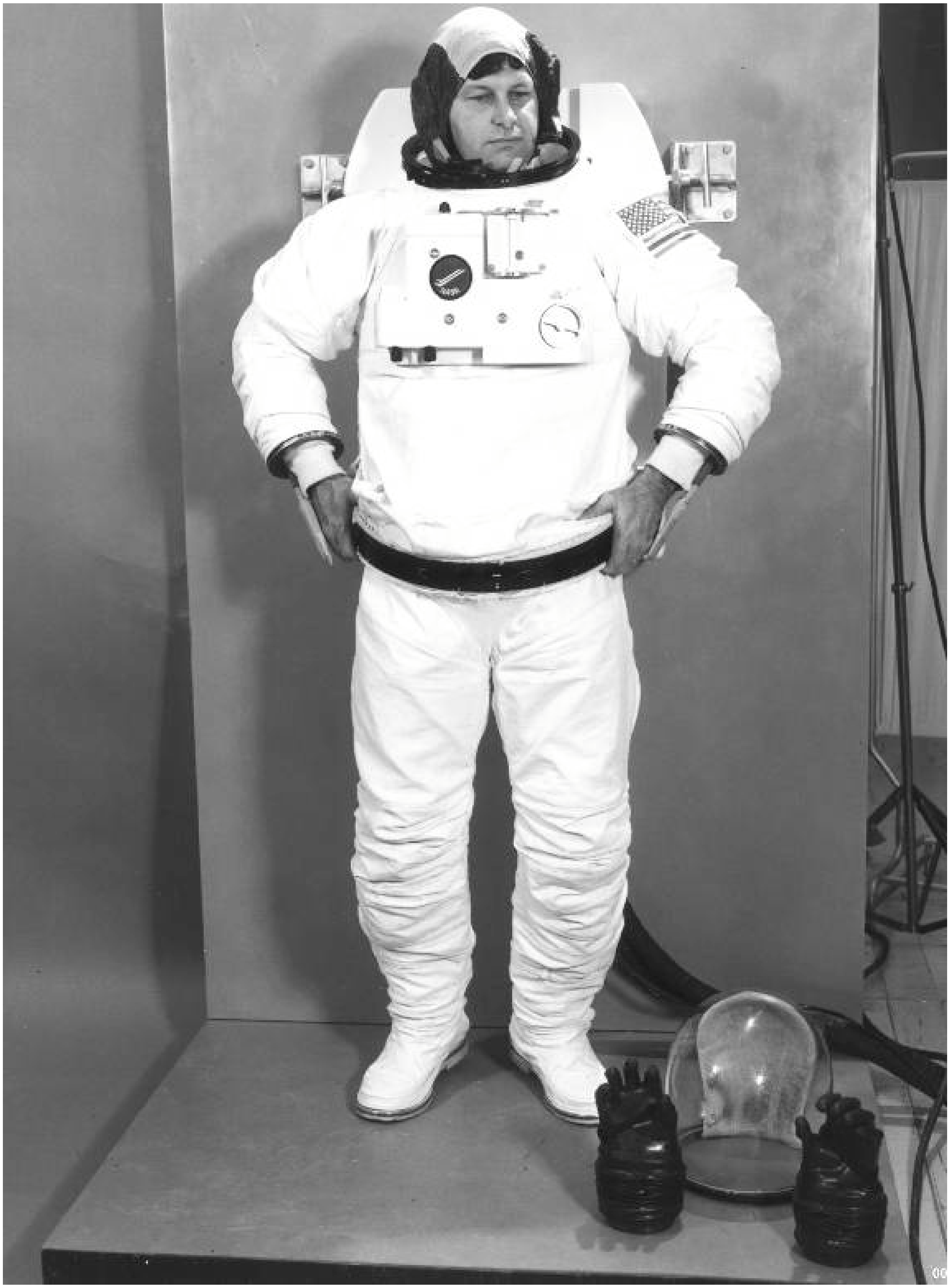

Fig. 6.8 Closing the Body Seal Closure / Waist Bearing

Fig. 6.9 Waist Bearing Permitting Torso Rotation

Fig. 6.10 The SX Series Torso Assembly

The competition was held in February 1976. The HS/ILC team won the contract. The contract was formally awarded in January, 1977.

<u>The Shuttle Extravehicular Mobility Unit (EMU)</u>

The Shuttle EMU (ref. Fig 6.11) has always been a modular system. By using combinations of various parts, literally thousands of sizing variations can be achieved. The modules are produced in limited quantities. To minimize inventory, NASA purchases Shuttle EMU modules called Contract End Items (CEIs). CEIs (ref. Fig 6.12) have life spans and some also have refurbishment cycles, which provide opportunities to make changes at minimum cost. Because NASA has taken advantage of this to make improvements, the Shuttle EMU has been a slowly evolving system. Now the designation "Baseline EMU" refers to the Shuttle EMU configurations that existed before 1990. The decision to further evolve the EMU (via "Enhancements") to meet the needs of the Space Station Freedom, (now International Space Station) resulted in the "Enhanced EMU" that is addressed later in this report.

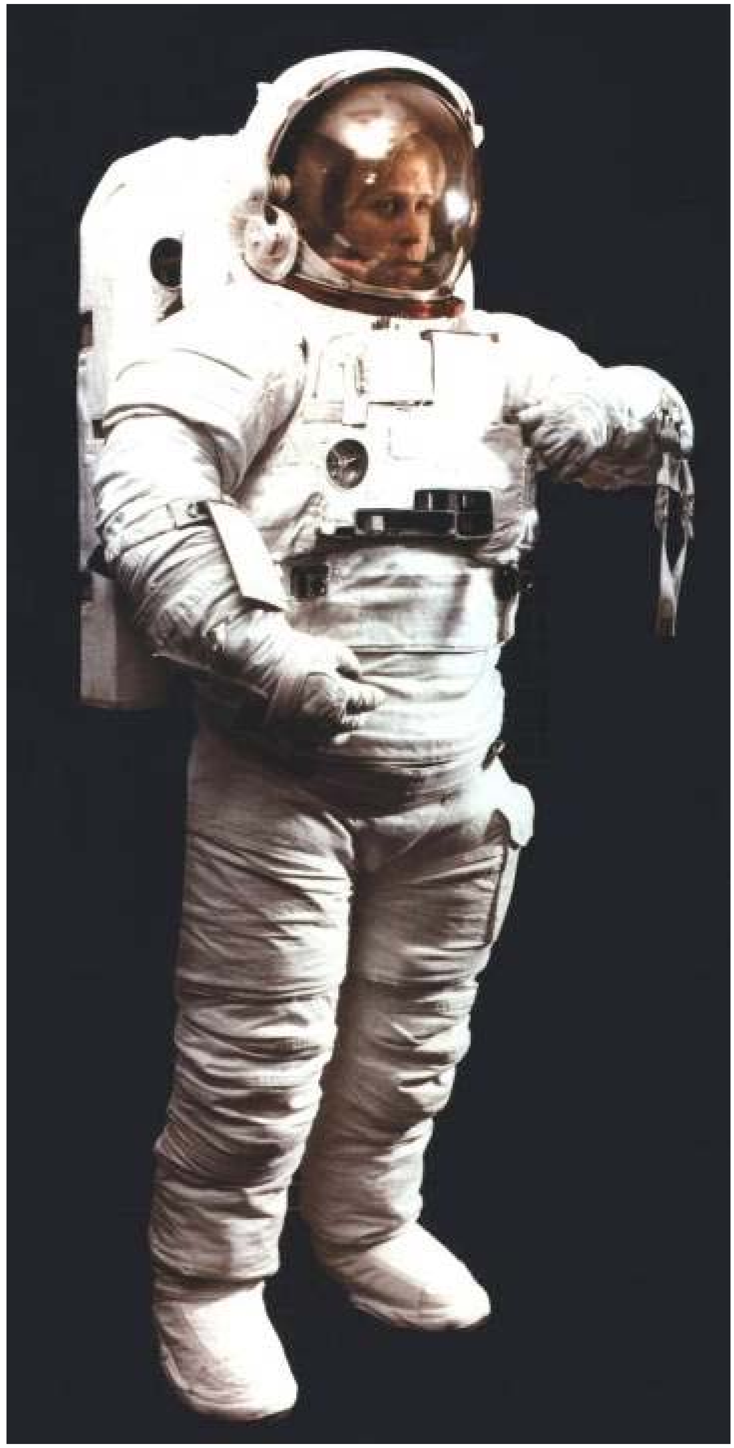

Fig. 6.11 "Baseline" Production EMU

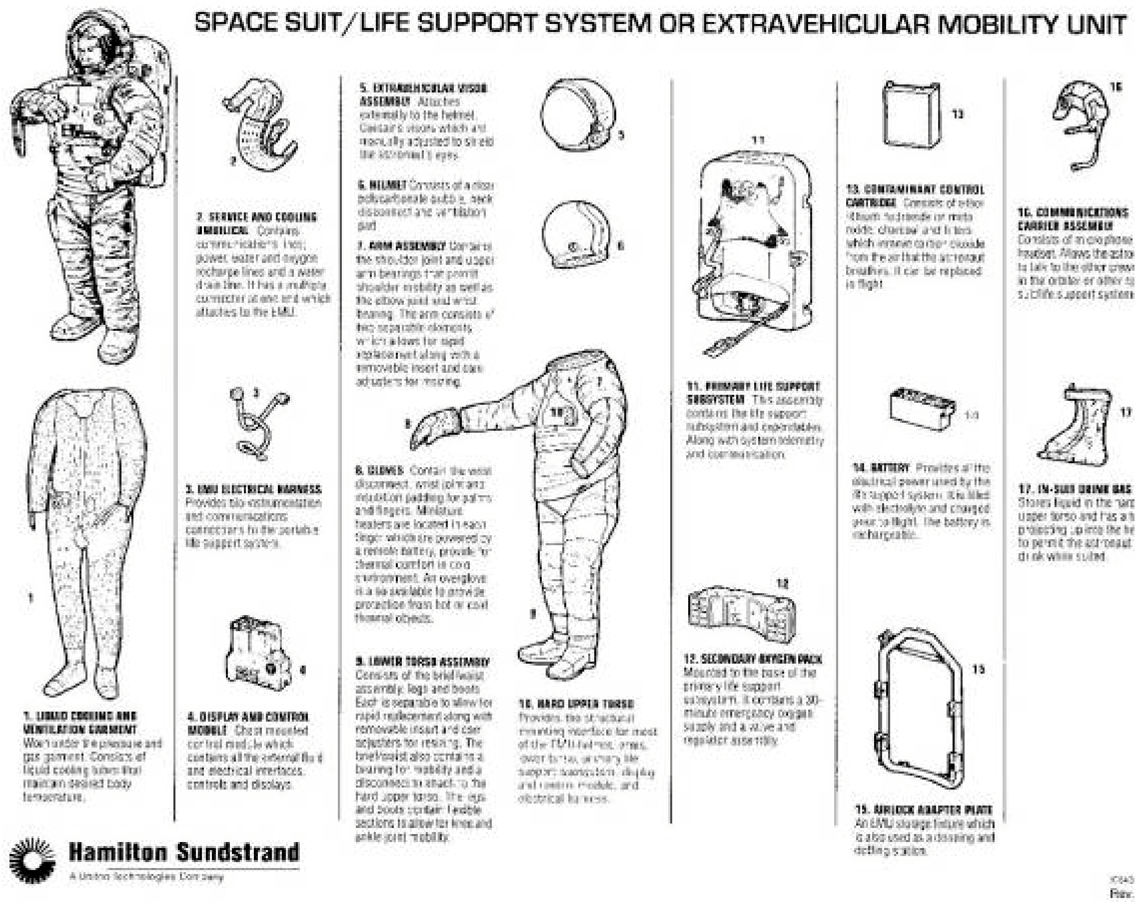

Fig. 6.12 EMU Modules Information

ILC is the integrator of the Space Suit Assembly (SSA). The SSA is the pressure-suit side of the EMU system. Being the SSA integrator has many roles: ILC is the system designer, designer/manufacturer of the mobility systems and softgoods (i.e. fabric portions of the EMU), as well as the organization responsible for SSA quality, cost and on-time delivery of all SSA modules CEIs.

Changes & Refinements Creating The "Baseline" Configuration (1977-79)

NASA's 1977-79 evaluations of SX-1-based EMU prototypes resulted in the refinement of the mid-entry closure, and waist bearing plus the incorporation of more sizing options. During this period, ILC developed a new glove system for the Shuttle EMU. Adding to the changes, in 1979, NASA increased the operating pressure requirement from 4.0 to 4.3 psi (27 to 30 kPa) and all SSA restraint systems were made redundant. This caused another redesign of the EMU's SSA. By 1980, these changes resulted in a transformation from the SX-1 level to the Shuttle EMU (ref. Figs. 6.13 to 6.17) design.

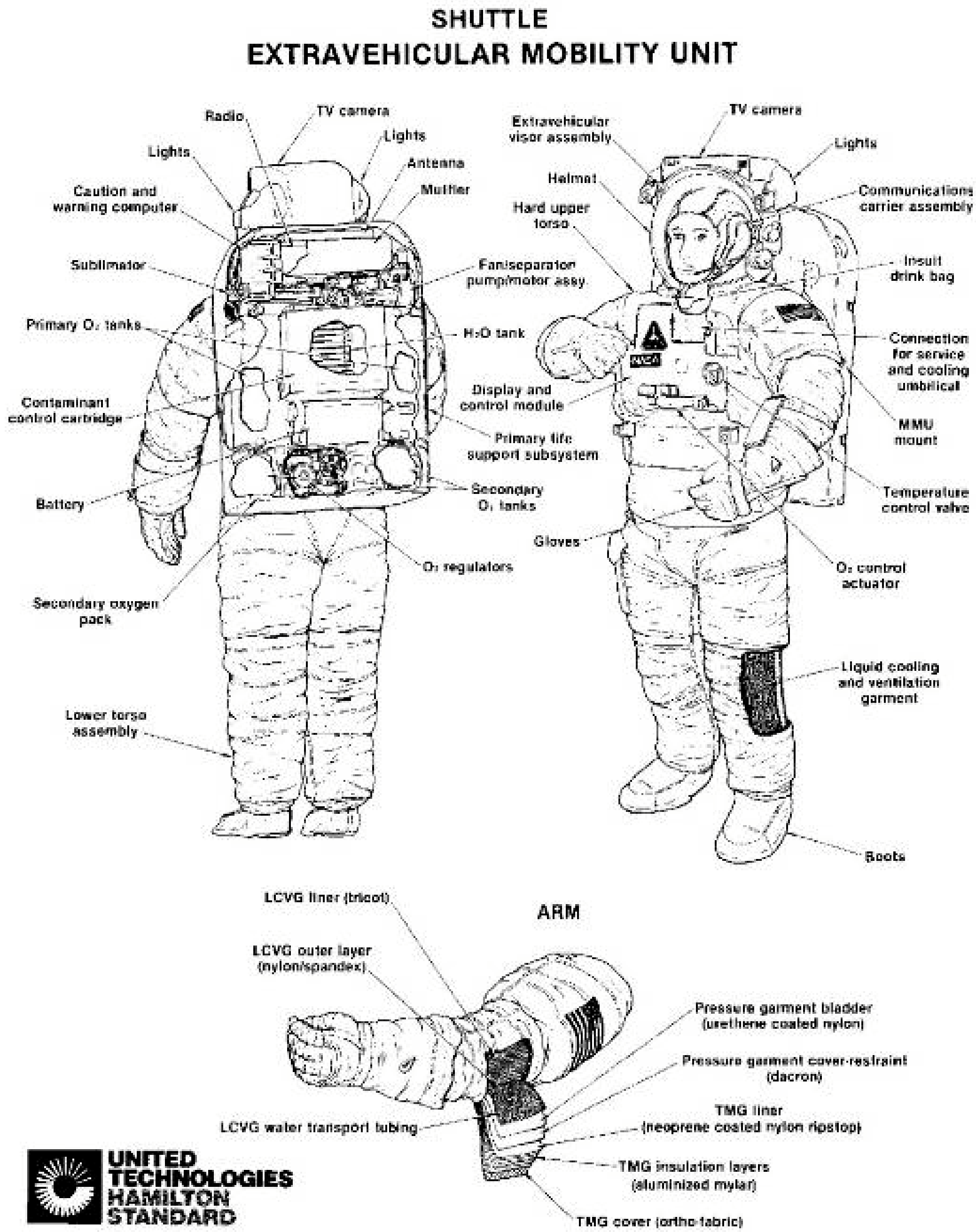

Fig. 6.13 EMU Explanation Diagram

Fig. 6.14 Shuttle EMU – Donning LTA (Courtesy Hamilton Sundstrand)

Fig. 6.15 Shuttle EMU – Donning HUT (Courtesy Hamilton Sundstrand)

Fig. 6.16 Shuttle EMU – Connecting LCVG (Courtesy Hamilton Sundstrand)

Fig. 6.17 Shuttle EMU – Reach Check Before Leaving Donning Station (Courtesy Hamilton Sundstrand)

The Resulting "Baseline" EMU Space Suit Assembly Items (1980-1983)

The Shuttle EMU CEI or modules that ILC provides have item number designations. The SSA items that supported the first EMU EVA are as follows:

Item 101 - Communications Carrier Assembly (CCA)

The CCA or "Snoopy Cap" (ref. Fig. 6.18) serves to ensure that the headset microphone, ear-cups and associated cables remain secure and comfortably positioned during EVA. ILC is the designer and manufacturer of the CCA softgoods.

Fig. 6.18 Communications Carrier Assembly

Item 102 - Hard Upper Torso (HUT)

The HUT (ref. Fig. 6.19) provides the structural mounting interface for the Primary Life Support System (PLSS), Display and Controls Module (DCM), Helmet, Arms, Lower Torso Assembly (LTA) and the EMU electrical Harness.

Development and production of the fiberglass HUT was and is a team effort. HS provides ILC with the Hard Torso Shell and EMU Electrical Harness. ILC purchases the HUT-side helmet disconnect, the HUT-side Body Seal Closure, the Multiple Water Connector (MWC) and Water Line Vent Tube Assembly (WLVTA) clamps and fittings. The MWC/WLVTA provides the connection between the HUT and the Liquid Cooling and Ventilation Garment. ILC manufactures the softgoods such as the Thermal and Micrometeoroid Garments (TMG), shoulder harness system and flexible vent for the WLVTA, plus a variety of smaller yet key items. ILC assembles the HUT, performs acceptance testing and provides delivery.

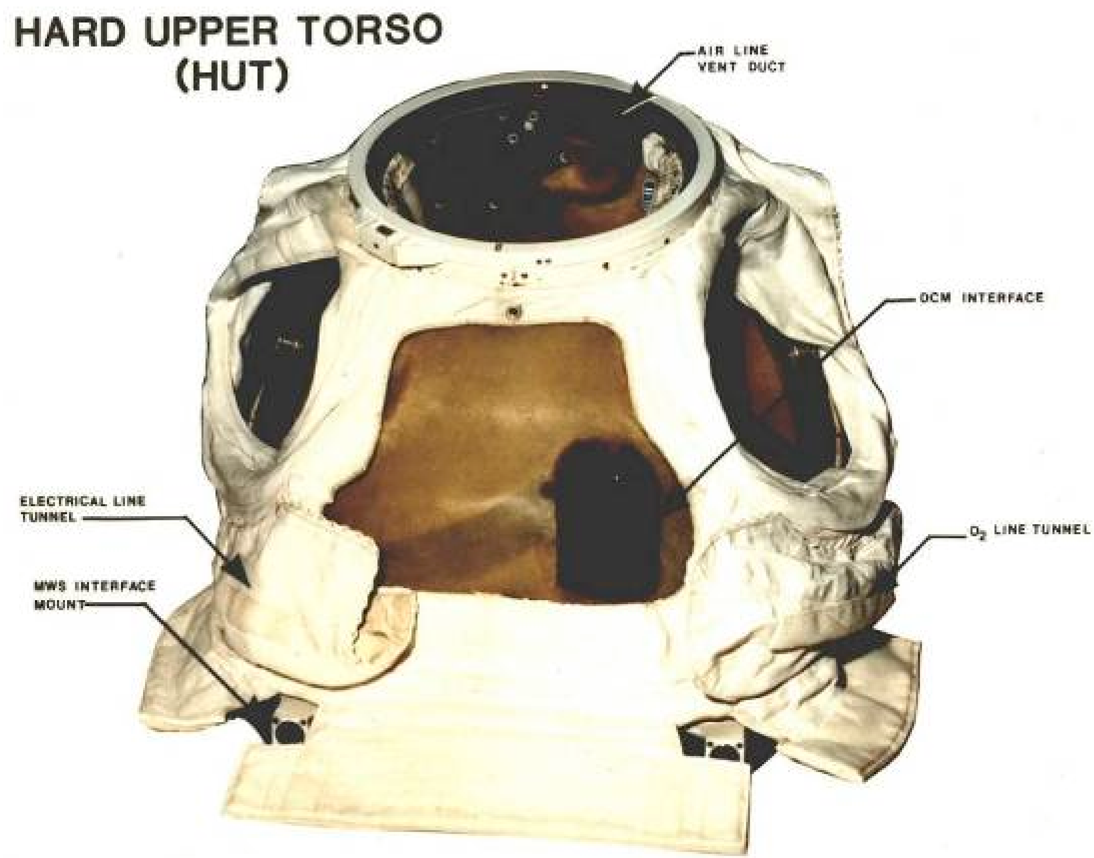

Fig. 6.19 Hard Upper Torso (HUT)

Item 103 - Arm Assembly

The Arm Assembly (ref. Fig. 6.20) consists of the Upper Arm Restraint and Bladder Assembly, the Lower Arm Restraint and Bladder Assembly, the SCYE and Arm Bearings, the Wrist Disconnect and the Thermal and Micrometeoroid Garment (TMG). ILC purchases the hardware to meet their requirements and manufactures the softgoods. ILC assembles, performs acceptance testing and provides delivery.

Fig. 6.20 Arm Assemblies Installed In HUT (HUT is less TMG)

Item 104 - Lower Torso Assembly (LTA)

The Lower Torso Assembly (ref. Fig. 6.21) consists of the Waist, Brief, Leg and Boot assemblies and contains a waist bearing that permits torso rotation and mobility joints at the hip, knees and ankles. ILC purchases the hardware to meet their requirements and manufactures the softgoods. ILC assembles, performs acceptance testing and provides delivery.

Fig. 6.21 Lower Torso Assembly (LTA)

<u>Item 105 – Helmet Assembly</u>

The Helmet (ref. Fig. 6.22) consists of a clear polycarbonate bubble, neck disconnect, ventilation pad and Combination Purge Valve (CPV). The Helmet provides visibility, pressure retention, impact protection and emergency purge capability for a crew member using the SSA in an EVA configuration. This is the helmet (less vent duct headrest pad) that was developed and furnished by AirLock for the Apollo program. This is principally a purchased assembly manufactured to meet ILC requirements. ILC performs acceptance testing and provides delivery.

Fig. 6.22 Helmet

<u>Item 106 – Glove Assemblies (1000 Series</u>

Gloves are the active interface between the crewmember and the work being performed. The gloves provide an effective degree of hand mobility along with a protective barrier against the natural environment, as well as work place hazards. The ILC Apollo glove functioned exceptionally well for the single-mission life of an Apollo suit. However, a new design was needed for the Shuttle EMU due to:

- Life (age and cycle) limitations of Apollo glove materials
- Assembly of the Apollo wrist joint and pressure glove was extremely labor, time and skill intensive.
- Higher operating pressure for Shuttle

The goals of the Shuttle glove development program were to produce a reusable glove within a system of standardized sizing, while retaining or enhancing the mobility of the A7LB glove. This goal was made more difficult to achieve because the Shuttle SSA was designed to operate ultimately at 4.0 psi (27 kPa) and was revised in 1979 to operate at 4.3 psi (30 kPa), where the Apollo/Skylab SSA operated at 3.75 psi (24 kPa). Since glove mobility normally decreases with an increase in pressure, many features of the A7LB glove were not adaptable to meet the new requirements.

The first Shuttle glove was the 1000 Series. This glove featured a one-piece urethane bladder, a separate polyester restraint layer and a nominally attached but removable Thermal and Micrometeoroid Garment (TMG) over-glove. The pressure glove incorporated a gimbaled wrist joint (ref. Fig. 6.23) for improved, multi-directional movement and polyester-reinforced, thimble-shaped, fine Polyester (later replace by Kevlar) mesh finger-tip caps for improved pressure glove tactility.

During the development of the 1000 series, the EMU operating pressure was increased from 4.0 to 4.3 psi (27 to 30 kPa) and requirements for redundant (secondary in addition to primary) restraints were added. This resulted in many changes; the most noticeable of which were the wrist gimbals and glove disconnects becoming a more robust structure (ref. Fig. 6.24). The new disconnect featured a flange clamp which facilitates glove bladder and restraint assembly replacements.

On the Apollo/Skylab series glove TMGs, the finger and hand areas were covered with Chromel-R and the gauntlets covered in Beta cloth. Chromel-R was a metallic cloth that had very poor cycle life and was very expensive ($1500/yd. circa 1966). Beta cloth was a fiberglass fabric that was very fragile. The Shuttle TMG (ref. Fig. 6.25) incorporated Kevlar-reinforced RTV fingertips, silicone-coated Kevlar on the palm and the fingers, three layers of aluminized Mylar interspaced with three layers of non-woven polyester for insulation and Teflon fabric as an outer layer on the back of the hand and on the wrist gauntlet.

Additionally, 1000 series TMGs had other improvements. The length of the gauntlets was revised to cover a greater portion of the forearm for increased thermal protection. And although the 1000 series TMGs still featured the ILC-invented RTV finger caps like the earlier Apollo, the Shuttle units were smaller to aid in tactility.

An optional slipover with Velcro attachment type mittens provided capability to support extreme cold or abrasive environments (ref. Fig. 6.26).

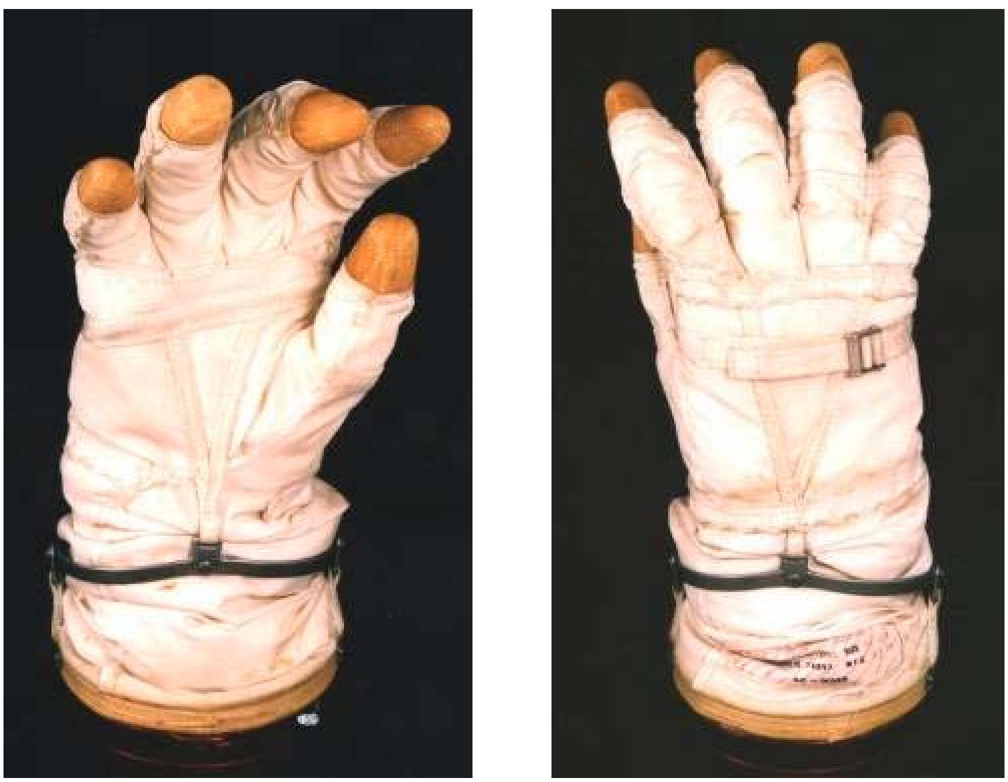

Fig. 6.23 The Original 1000 Series Pressure Glove

Fig. 6.24 1000 Series Glove Made For 4.3 Psi Operation

Fig. 6.25 1980-85 Glove Thermal Micrometeoroid Garment (TMG)

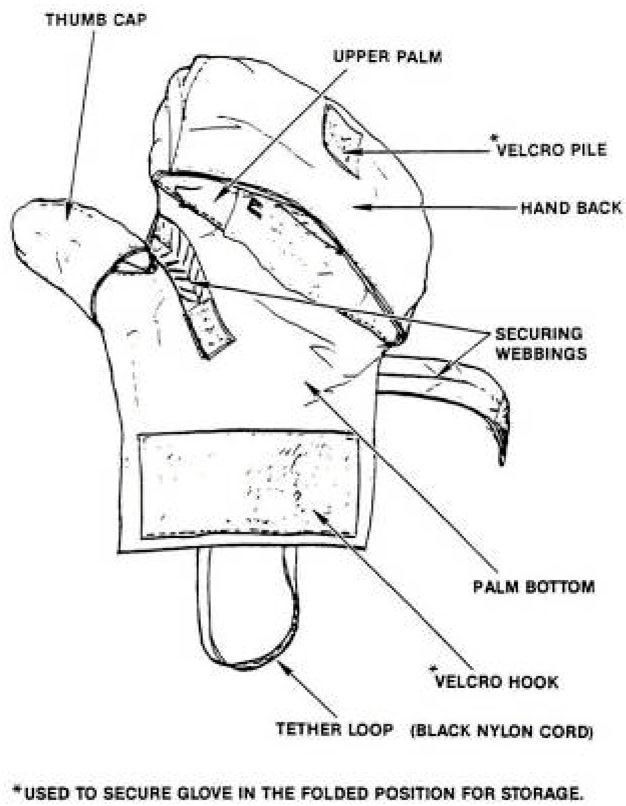

Fig. 6.26 Optional Thermal Mitten

Item 107 - Liquid Cooling and Ventilation Garment (LCVG)

The LCVG (ref. Fig. 6.27) assembly is a form-fitting, stretchable undergarment that provides cooling and the return ventilation from the pressure suit to the PLSS. The LCVG consists of a Liner Assembly, the Restraint Assembly, the Vent Plenum Assembly and the Multiple Water Connector (MWC). The Liner Assembly is made of a lightweight nylon tricot material and aids in both donning and doffing while providing a comfort layer between the tubing and the crewmember's skin. The Restraint Assembly is made from a nylon spandex mesh, which supports the weave-through flexible water line tubing and holds the tubing firmly against the crewmember's body. The Vent Plenum Assembly is a flexible vent system returning ventilation gas from the arms and legs. The MWC is the make-and-break connector for the cooling and vent systems. ILC purchases the hardware for the LCVG to meet ILC requirements and manufactures the softgoods. ILC assembles, performs acceptance testing and provides delivery.

Fig. 6.27 Shuttle EMU LCVG

Item 108 – Extra-Vehicular Visor Assembly (EVVA)

Extra-Vehicular Visor Assembly (EVVA, ref. Fig. 6.28) is a heat and light-attenuating device (via the visors and eyeshades) that attaches to and covers the Helmet. It provides micrometeoroid protection and protects the helmet from accidental impact damage. The outer sun visor has a high reflective and emittance thermal optical coating that protects against excessive solar radiation from entering the helmet and onto the facial surface and eyes. The inner protective visor has a low emittance thermal optical coating that prevents excessive heat loss outwards and prevents icing and fogging on the helmet interior visual surface area when facing towards the environment of deep space.

Fig. 6.28 Helmet With Extra-Vehicular Visor Assembly (EVVA)

The EVVA contains the Shell, TMG, center and side Eyeshades, Sun Visor and Protective Visor. While it is principally a purchased assembly, it is manufactured to meet ILC requirements. ILC provides the EVVA's Thermal Micrometeoroid Garment (TMG) or outer softgoods cover for completion. ILC is responsible for acceptance and provides delivery.

Item 109 - In-Suit Drinking Bag (IDB)

The baseline era IDB (ref. Fig. 6.29) was a sealed bag assembly that stores water in the Hard Upper Torso, consisting of a bladder, inlet valve, outlet valve, drink tube and Velcro attachments. It was attached to the front interior of the HUT and served to supply drinking water to the crewmember during EVA. During the baseline era, the IDB was available only in a 21 ounce size. In the mid-1990s, an optional 32 ounce capacity IDB was introduced. The IDB was replaced by the Disposable In-suit Drink Bag (DIDB) in the late 1990s. These come in a 32 ounce capacity and are made from a heat-sealable film. (ref. fig. 6.30)

Fig. 6.29 The Original In-Suit Drinking Bag (IDB)

Fig. 6.30 Disposable In-suit Drink Bag (DIDB)

The EMU Improvements during the Baseline Era (1983-2002)

While next generation systems were being explored in the Zero Pre-breathe Suit and Space Station Freedom Advanced EMU, the Shuttle EMU was undergoing a mild evolution in parallel. This was facilitated in-part by the modular architecture of the Shuttle EMU allowing sub-system upgrades at scheduled replacements and servicings that would be invisible to the system as a whole. The following are examples of these improvements.

ILC's 2000/3000 Series Gloves (1984-86)

Lack of adjustability in the 1000 Series glove system resulted in the need for custom gloves. To alleviate this condition, development of the 2000 Series (ref Fig. 6.31) started in 1983. The 2000 Series attempted to:

- Enhance sizing adjustability by introducing Finger length adjustability
- Provide an adjustable two-position palm-bar system.
- Improve dexterity/tactility further via a lighter, more flexible nylon/polyester pressure glove restraint assembly.
- Increased bladder life by reformulation of bladder material.

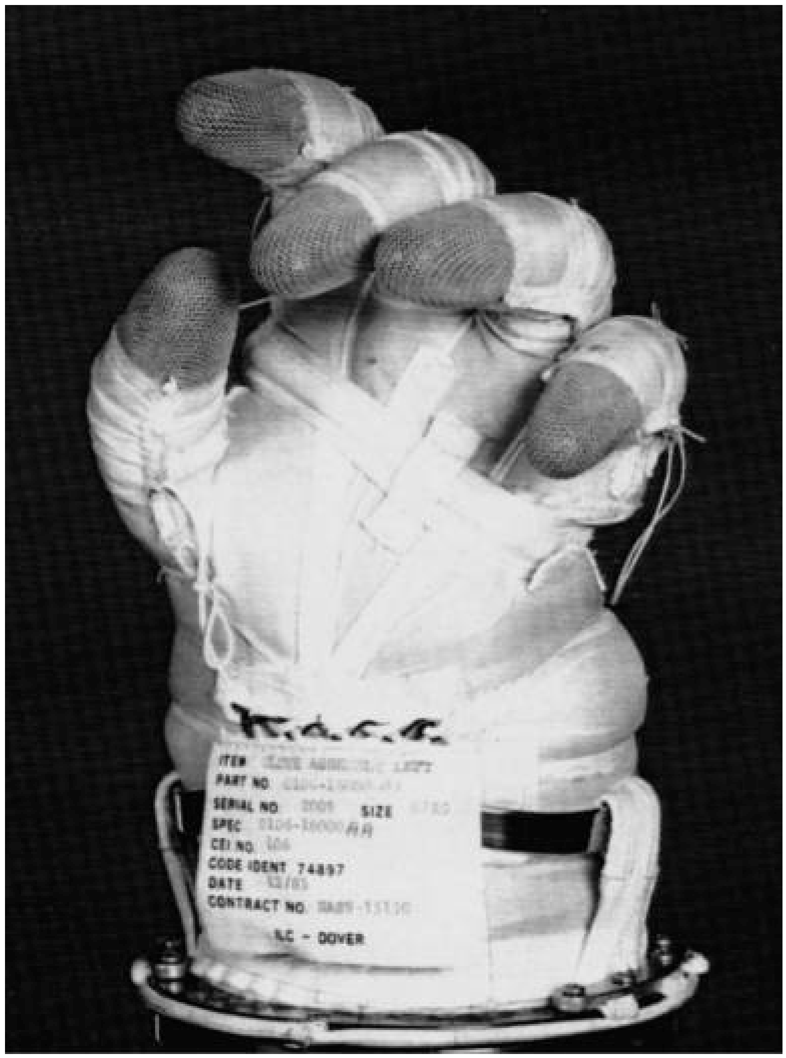

Fig. 6.31 2000 Series Pressure Glove

Before the 2000 Series reached flight service, training usage illustrated areas for potential improvements including a three-position palm-bar adjustment system. The incorporation of these improvements resulted in the 3000 Series, which reached flight service in 1984.

The 3000 Series kept the same wrist disconnects and wrist gimbal rings as the late 1000 Series. To minimize the cost of introduction, pre-existing gloves were cannibalized to provide disconnects and gimbals for 3000 Series units. During the service life of the 3000 Series, the glove featured evolutionary improvements in the bladder, restraint, TMG and mitten assemblies. The TMGs specifically gained a more durable/serviceable Silicon palm and palm-side finger covering in 1985 (ref. Fig. 6.32).

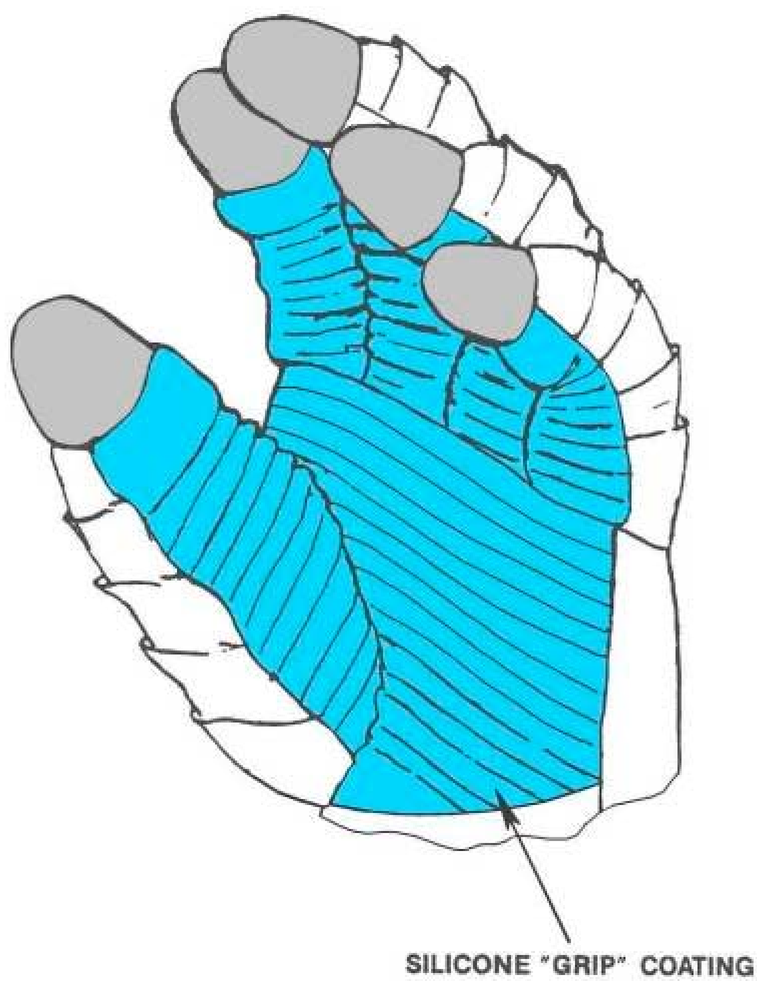

Fig. 6.32 1985 & Later Glove TMG Palm Area

ILC's 4000 Series Gloves (1986-2001)

The next Shuttle glove development was the 4000 Series glove (ref. Fig. 6.33). Development of the 4000 Series started in 1986 to reduce bladder bunching and improve fit and mobility. With the introduction of the 4000 Series glove, the 3000 Series was removed from service principally through attrition. The metallic "hard" parts from the 3000 Series were recycled into the 4000 Series to minimize expense. Many 3000 Series gloves saw training service into the late 1990s. The 4000 Series glove has the distinction of being the longest used model of EVA glove in the history of U. S. space exploration, seeing service until the phase-in of the Phase VI gloves as part of the "Enhanced EMU".

Fig. 6.33 Shuttle EMU 4000 Series Pressure Glove

Baseline EMU Entry Into Flight Service

The EMU went into flight service on 4/12/81. The first Extra-Vehicular Activity (EVA) for the Shuttle EMU was on 4/6/83 (ref. Fig. 6.34). In the production of the original Shuttle series, 57 EMU space suit assemblies (52 for NASA-JSC) were made accumulating over 26,000 hours of manned pressurized time as of the end of 1997. Only 15 EMU (space type) life support systems were required to complete the flight inventory, which supported almost 100 missions (ref. Figs. 6.35 to 6.40).

Fig. 6.34 Shuttle EMU First EVA On 4/6/83 (Courtesy NASA)

Fig. 6.35 Proving EMU Operation From The Robotic Arm (1984) (Courtesy NASA)

Fig. 6.36 McChandless MMU on First Flight (2/7/84) (Courtesy NASA)

Fig. 6.37 MMU Retrieving Satellite (Courtesy NASA)

Fig. 6.38 STS-49, Manual Retrieval EVA of Intelsat (Courtesy NASA)

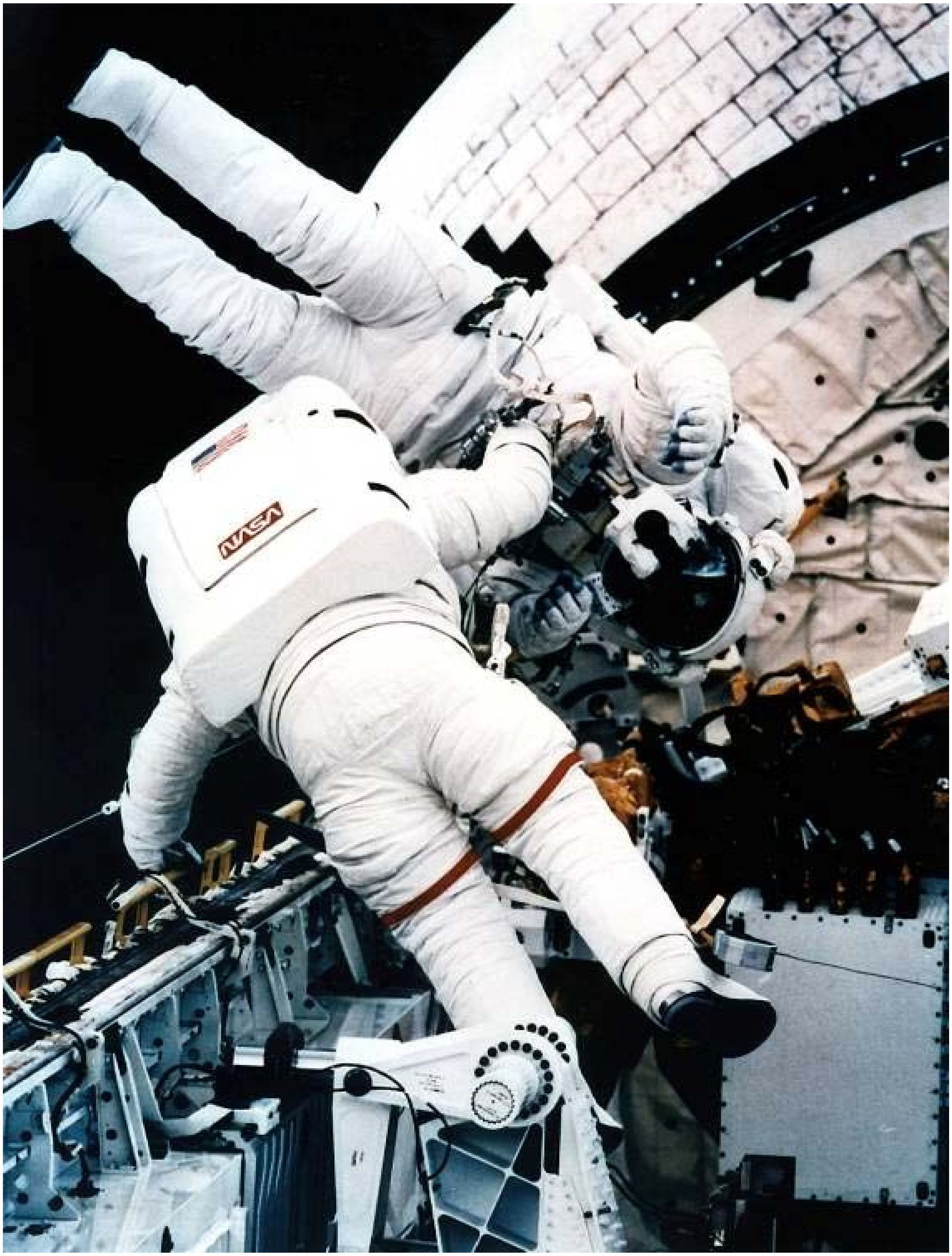

Fig. 6.39 EVA Astronauts Floating (Courtesy NASA)

Fig. 6.40 STS-61, The First Hubble Servicing Mission (Courtesy NASA)

Chasing The Moving Target

The beginning development of the next generation space suit is usually years or decades away from actual use. The mission that the next space suit might have to support is ever changing until it is finally defined in a competition request for quote. ILC's commitment to "Creating what's next" means that it has produced many suits which have not reached flight and are now a part of U.S. history. However, in doing so, ILC has refined and improved its ability through the decades to respond to customer needs. While the suit systems in the next two topics never reached flight, they had influences on the Enhanced Shuttle EMU and continue to influence the next generation suit development.

The Zero Pre-Breathe Efforts (1983-85)

At the Johnson Space Center in the late 1970s, there was support by many for planned improvements to the Shuttle EMU, including operating at the higher pressure of 8 psi, to be accomplished by incremental modular upgrades (ref. Fig. 6.41). Higher operating pressures (above the current 4.3 psi) are desired because astronauts would not have to spend costly time pre-breathing pure oxygen to remove nitrogen from the body. The Ames Research Center (ARC) space suit development personnel shared the interest with JSC for the development of a higher operating pressure EVA space suit system. This led to the NASA Centers joining forces for the Zero Pre-Breath Suit (ZPS) effort, which is outlined in this section.

Fig. 6.41 1979 EMU Evolution Concepts Including Zero Pre-Breathe Capability

Thanks to NASA centers combining efforts, ZPS became a funded activity in 1980. The two centers brought a variety of supporting organizations together. NASA-JSC had the lead for management of the various fabrication tasks and for systems testing. NASA-ARC supplied the initial design layout for most of the joint concepts and many potential manufacturing technologies. The approach was to bring various technology elements together to be evaluated on one prototype tested pressure suit. Those combined activities are the ZPS effort.

The over-all effort to evolve the Shuttle EMU into an advanced suit-system better able to support Shuttle and the future-planned Space Station extended beyond pressure suit mobility joints and gloves (ref Fig. 6.42). NASA additionally explored improvements to life support and less conventional approaches to working in space.

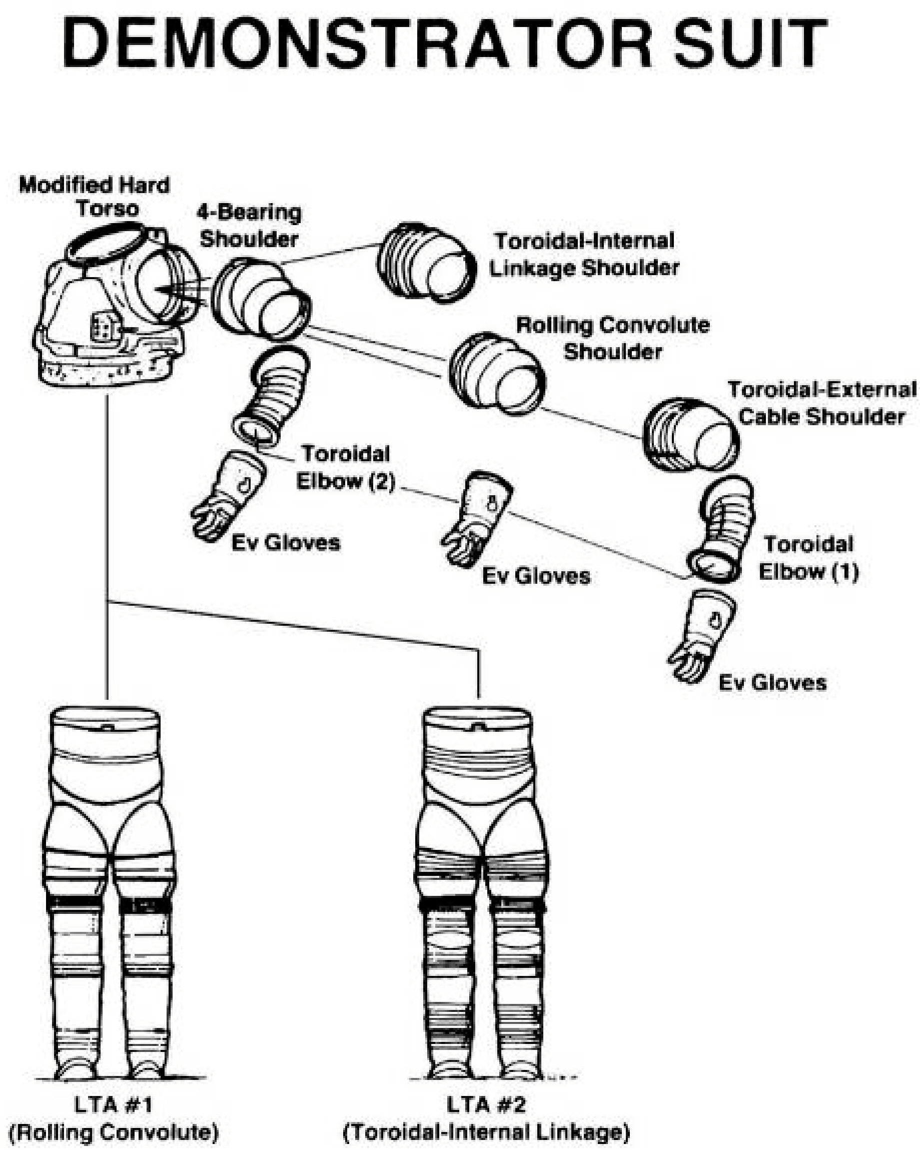

Fig. 6.42 The ZPS Options Diagram

The goals of the ZPS program were to develop an improved high pressure (zero pre-breathe) space suit utilizing the latest joint technology as well as materials and processes, which were to be consistent with the space environment and suit production techniques. Other development objectives included: longer life, lower joint torques with increased ranges, lowest effort restraints, lower torque bearings, improved reproducibility and reliability, re-sizing ability and increased overall performance capability when compared to the present Shuttle Orbiter Space suit at the higher pressures.

The ground rules for this ZPS effort included:

- The ZPS EMU interfaces had to remain the same as the baseline EMU so that ZPS modules could be introduced incrementally.
- A ZPS HUT must be able to be created by retrofit of a baseline 4.3 psi (30 kPa) HUT to an 8.3 psi (57 kPa) configuration. This offered the capacity to use existing HUTs as higher pressure training units, keeping risks and costs minimal.

In support of this effort, most of the various shoulders, elbows, waists, briefs and knees plus a single supply of sizing elements, ankles, and boots, were manufactured by ILC. ILC and two other contractors provided glove concepts that were evaluated. The resulting ZPS effort (ref. Figs. 6.43 & 6.44) demonstrated that the EMU was capable of evolving to a higher operating pressure with gloves needing the most improvement. The need to develop an entirely new EMU for Space Station Freedom relegated ZPS to history.

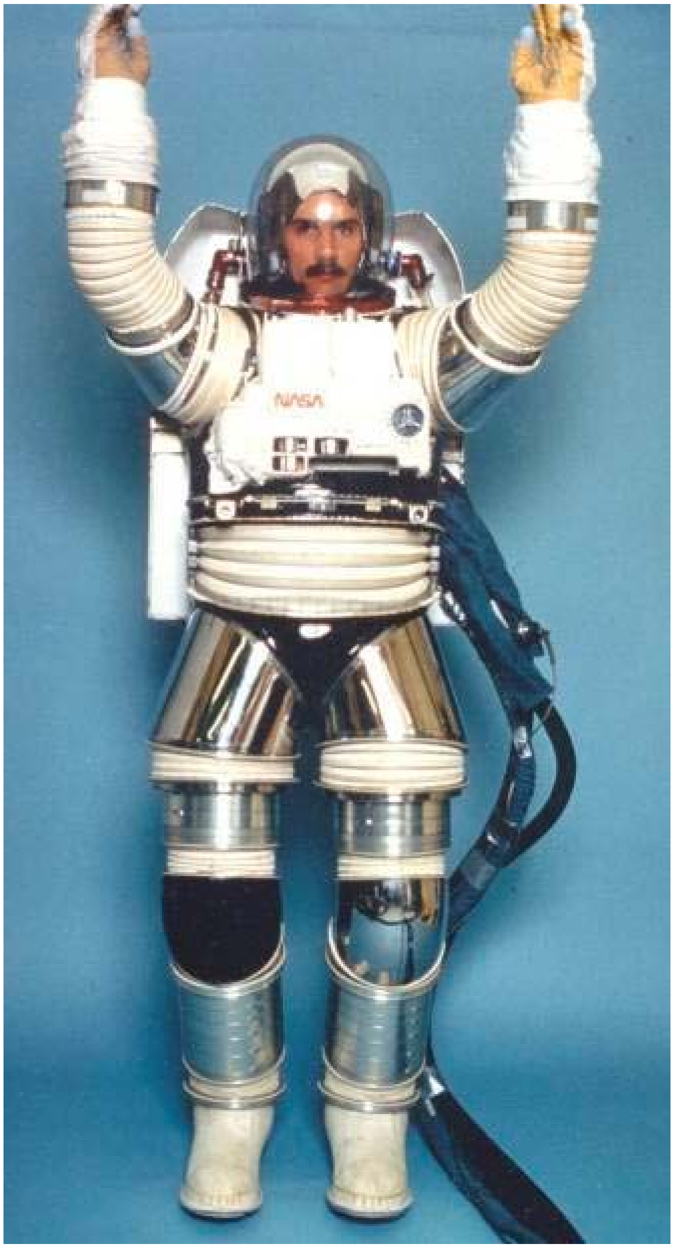

Fig. 6.43 Zero Pre-breathe Suit (ZPS or Mk. I) (ILC employee Richard Bork in suit)

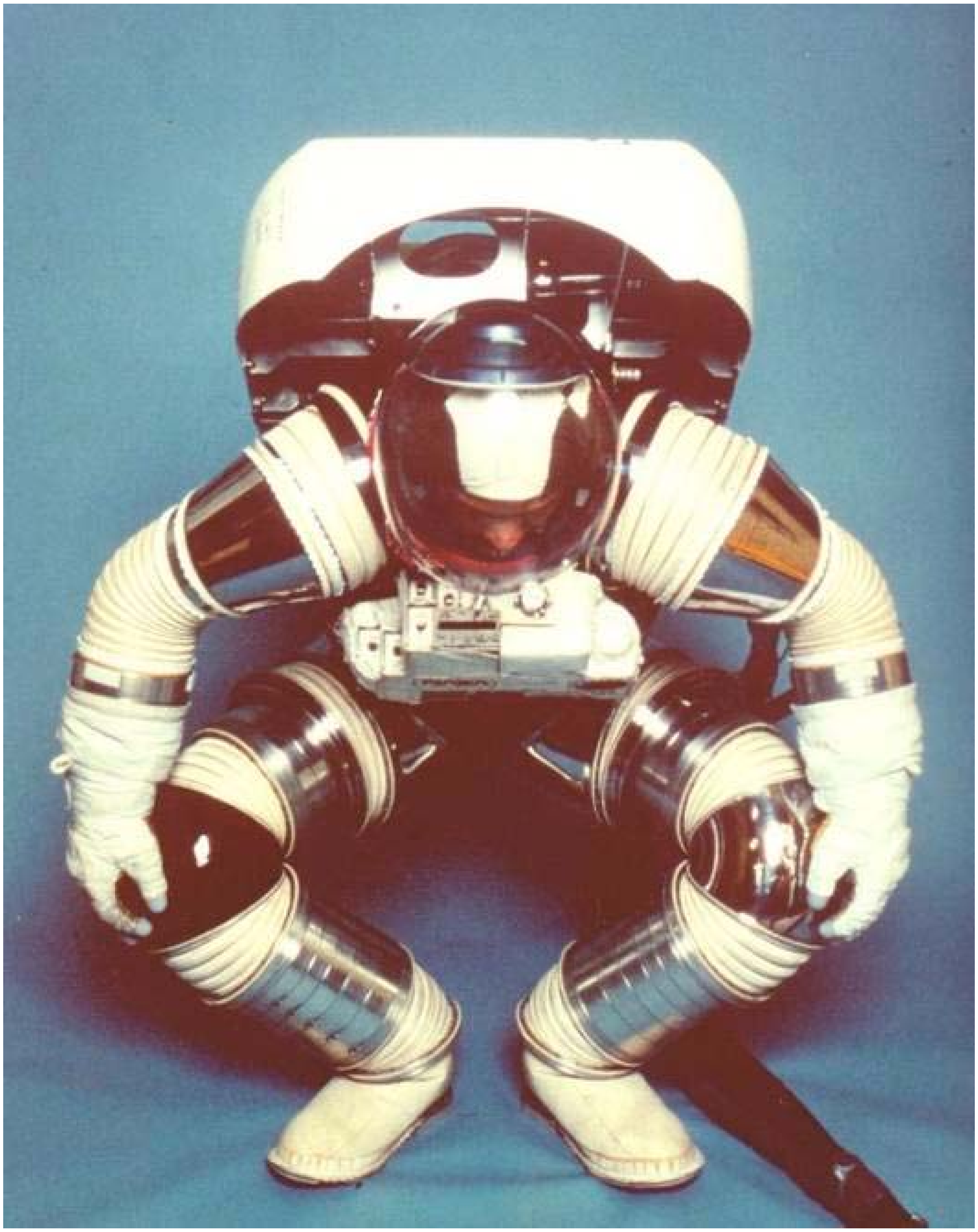

Fig. 6.44 ZPS / Mk. I Squatting

There were two ILC 8 psi (55 kPa) glove efforts under this project. The first explored a NASA requested approach in glove technology (ref. Figs. 6.45 & 6.46) that had been championed by a competitor that had subsequently gone out of the space suit business. In crafting this glove prototype, ILC demonstrated that it could understand conceptual approaches of others and then design and manufacture the concept into a successful prototype.

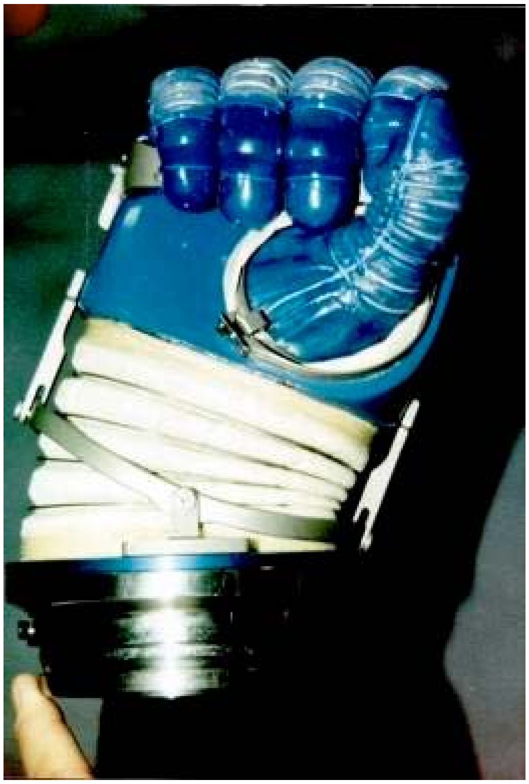

Fig. 6.45 1982 ILC 8 psi Glove
(grasping, palm-side view)

Fig. 6.46 1982 ILC 8 psi Glove
(side view showing metacarpal joint)

The second glove system (ref. Fig. 6.47) was produced as a follow-on in the overall, ZPS-related effort. This glove system design was principally based on ILC's 2000 Series Shuttle glove but redesigned for significantly higher pressure loads. One new feature of the glove was an ILC designed multi-gimbal wrist joint.

Fig. 6.47 1983 ILC 8 Psi Glove With Multi-Gimbal Wrist Joint (right)

Also during this period (1983-86), ILC was a key supporter of the Power Assisted Glove-end Effector (PAGE) study. Gripping power tools and repetitively actuating controls in pressurized gloves over many hours of EVA presents significant challenges. The PAGE effort was to find an alternative solution.

With having the tool attach directly to the glove disconnect, the ungloved hand would grip the tool controls in a pressure chamber portion of the tool. The one tool would have changeable end-drives for socket-drive, drilling, or saber-saw. This concept provided unsuited-like activation and control free from pressure glove encumbrance. An ILC prototyped concept was having a trigger mechanism built into the pressure glove with a connection provided that would accommodate a variety of power tools (ref. Fig. 6.48). Another ILC concept was to include a Velcro/strap restrain system so the hand would grasp the tool without effort being required by the Astronaut (ref. Fig. 6.49).

Fig. 6.48 The ILC Page Trigger Glove Prototype

Fig. 6.49 The ILC Page Trigger Glove Prototype with Velcro clasp.

The Advanced EMU For Station (1985-90)

In 1980, President Regan presented a new space program concept to the U.S. Congress. This was Space Station Freedom (SSF). NASA set about developing an Advanced EMU by first developing key technologies desired in a new SSF EMU. ILC won contracts to develop the key technologies. The SSF Advanced EMU started with NASA identification and funding of technology development for a fully regenerable, zero prebreathe suit (ZPS) for potentially supporting daily-working-in-space.

The ILC "Mark III" Pressure Suit (1985-90)

In 1985, NASA wished to determine the conceptual direction of higher pressure (8.3 psi or 576 kPa, zero pre-breathe) Advanced Suit development and to build a complete prototype suit for SSF. NASA issued a RFP. ILC's proposal won. In this proposal, HS supported ILC as the HUT subcontractor. One objective of this effort was to determine the optimum entry concept. The other was to determine the base suit concept. The competing base concepts at the time were the all-hard suit, such as the AX-5, a hard/soft hybrid, like the Shuttle EMU, or a soft suit like the Shuttle Launch Entry Suit and the Mercury through Skylab suits.

The effort started with NASA (JSC) review of all known entry concepts. After evaluation, two concepts emerged. These two concepts were the Dual Plane and the Rear Entry. Under contract to ILC, Hamilton Standard developed and built a 1.0 psi (7 kPa) concept mockup Hard Upper Torso (HUT) of each in fiberglass. These were subsequently used in zero-G evaluations. This resulted in NASA's selecting the Rear Entry HUT as the best advanced suit entry concept. This was incorporated into the HS design that created the "milled aluminum" HUT that was subsequently used in the Mk. III prototype.

In 1987, NASA and ILC were ready to progress with the manufacture of a second complete Mk. III pressure suit prototype. To reflect the extensive effort expended in the 1985-87 studies and evaluations of potential architectures, the study efforts became referred to as Mk. II (although no "Mk. II" suit was ever built). The Mk. III embodied NASA historical knowledge and ILC technical capabilities (ref. Fig. 6.50 & 6.51).

Fig. 6.50 Mk. III Pressure Suit (front view) (ILC Engineer Mel Case in suit)

Fig. 6.51 Mk. III Pressure Suit (side view)

One of the technological milestones in the Mk. III prototype was ILC's 8.3 psi (57 kPa) gloves with multi-gimbaled, rolling convolute wrist joint (ref. Fig. 6.52). The restraint layer incorporated simpler, flat pattern fingertips as compared to the Shuttle EMU Kevlar mesh-reinforced finger caps. An interesting feature of this glove was a multi-directional thumb joint using a sliding mesh technology.

Fig. 6.52 ILC's MK. III 8.3 PSI Glove

While the Mark III glove did not make production as NASA elected to not implement the Space Station Freedom Advanced EMU for budgetary reasons, a derivation of this glove continued in the 5000 series glove of the "Enhanced EMU" effort. The SSF Advanced EMU program was terminated in February 1990 while the Advanced EMU SSA prototype (ref. Fig 6.53) was in initial evaluations. While there was consideration of marrying the Mk. III SSA to the existing Shuttle EMU life support system for station use, the principal legacy of the effort would be the many influences it would have on the Enhanced Shuttle EMU as described in the discussions that follow.

Fig. 6.53 The Results of Advanced EMU Development at Program's End

The Enhanced Shuttle EMU (1990-Present)

International Space Station (ISS) poses significant challenges. The number of spacewalks necessary for ISS construction will be greater than all the space walks previously conducted in the history of the world's space programs. The financial constraints of proceeding with the U. S. portion of the ISS are formidable, especially while attempting to continue NASA advances in aviation and other space arenas. In 1990, NASA elected to implement evolutionary improvements (enhancements) to the Shuttle EMU, rather than develop an all new suit-system, to more cost effectively meet Space Station needs.

While the "Enhanced EMU" for joint ISS / Shuttle activities shows only subtle external changes, almost every subassembly of the EMU has been revised and improved. These improvement efforts combined with those that follow will provide an EVA system to support the needs of Shuttle and the International Space Station into the 21st century.

ILC 5000 Series Gloves (1989-1993)

In 1989, there was an attempt to bring developments from the Space Station Freedom Advanced (SSF) EMU glove research into the Shuttle EMU in the form of the 5000 series glove (ref. Fig. 6.54). There was little difference between the Mark III and initial 5000 series gloves. The post-development 5000 series featured a more durable "low torque" pressure glove thumb and TMG over glove. The goals of the 5000 series were to:

- Provide a more durable glove, optionally upgradeable to higher operating pressures.
- Reduce the effort required for manual working in space.
- Minimize finger bulk to improve grasp.

Fig. 6.54 5000 Series Pressure Glove

Notable among the developmental departures from the 1000-4000 Shuttle pressure gloves were the two-gimbal wrist joints, the restraint assembly no longer had the Kevlar mesh fingertips and a bladder with convolutes at the finger and thumb joints to reduce grasping effort.

The 5000 Series glove was flown on Shuttle mission STS-37 (in April 1991) in response to a Detailed Test Objective (DTO). While the 5000 series did not reach continued flight service, hybrid 4000/5000 series options were discussed. One by-product of the 5000 series that came to fruition was the optional use of the more flexible and tactile Low Torque glove TMG with the 4000 series pressure glove. This was first flown in May 1992 (STS-49) and later became a crewmember option for all 4000 Series flight gloves (ref. Fig. 6.55).

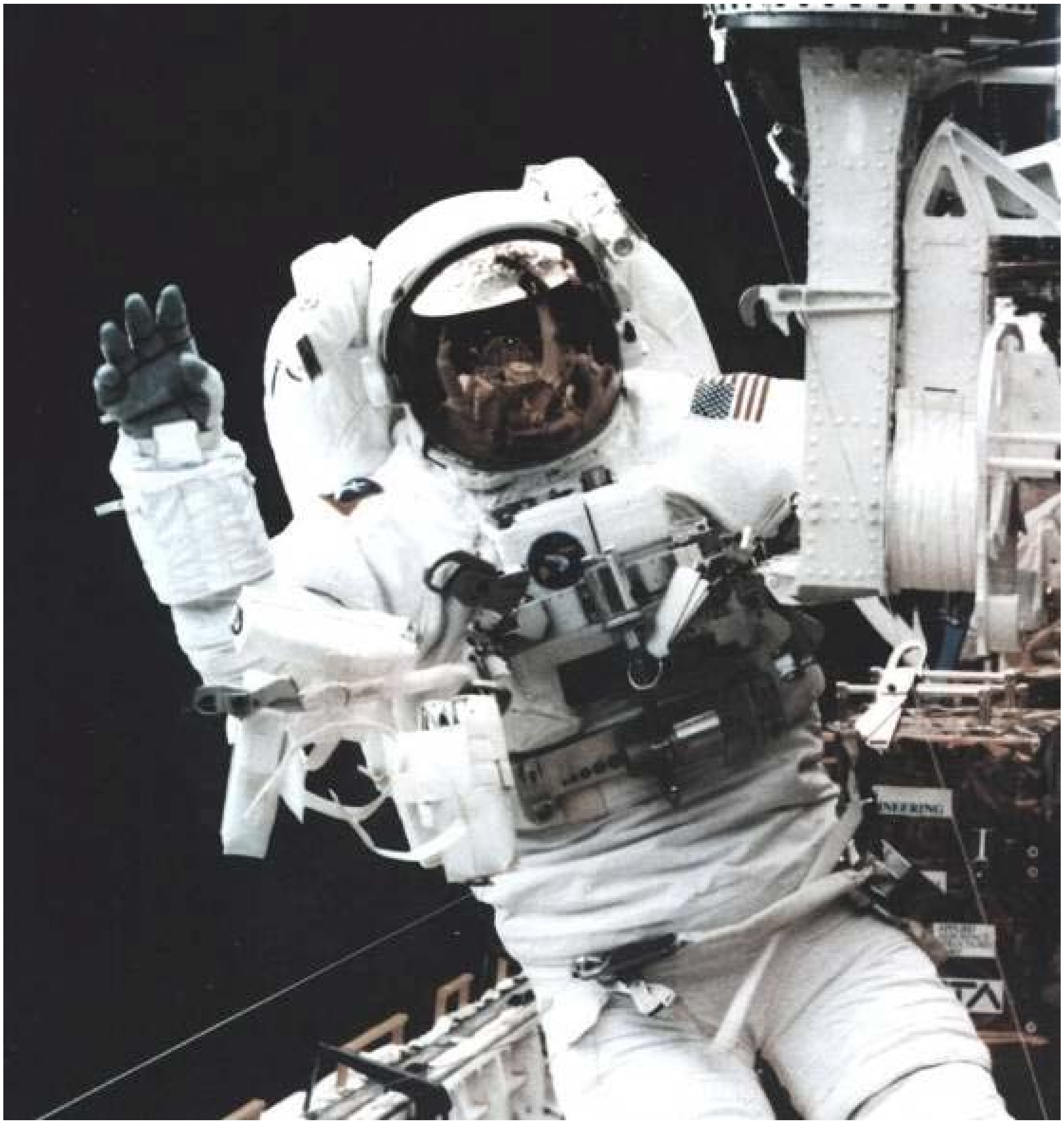

Fig. 6.55 Low Torque Glove TMG In Use (Courtesy NASA)

"Planar" Hard Upper Torso Development (1992-Present)

The "Pivoted" Hard Upper Torso (HUT) of the "Baseline" EMU was designed in 1978 for a 6-year useful life. By 1994, HUT life extension testing had been conducted and the useful life had been extended to 14 years. In parallel, the development of a less expensive and more robust HUT was pursued. After evaluation of many concepts including cast and milled aluminum shells, a longer life fiberglass shell with fixed arm apertures was selected.

During development of what became the "Planar HUT" (ref. Fig. 6.56), another consideration was added to the program. This was On-orbit Replaceable Units (ORU) (ref. Fig. 6.57). ORU was to permit the changing of a backpack (Primary Life Support System or PLSS), the front Display Control Module (DCM), or change to a different size HUT while on the Shuttle or Station. ORU attachment also went through a prototyping and evaluation process resulting in a redundant system with "Lock-Lock" safety features and "Trailer Hitch" lower PLSS mounts (ref. Fig. 6.58).

Fig. 6.56 "Planar" HUT With ORU Features (front view, no TMG)

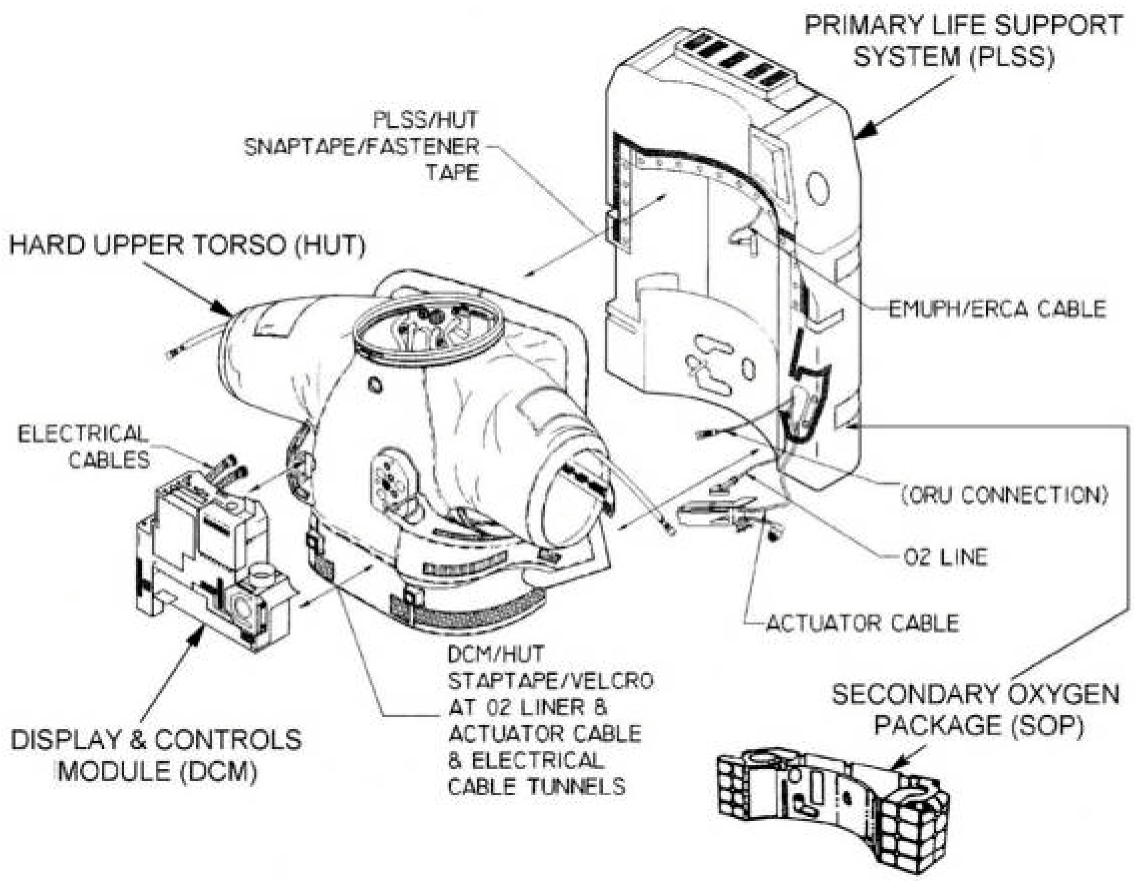

Fig. 6.57 On-orbit Replaceable Unit (ORU) Concept

The production Planar HUTs were delivered in March 1996. The first Class I (cert unit) was delivered on October 1996. The first Class I flight unit followed in December of that year. Planar HUTs entered flight service with mission STS-89 in January 1998 and are now supporting International Space Station assembly.

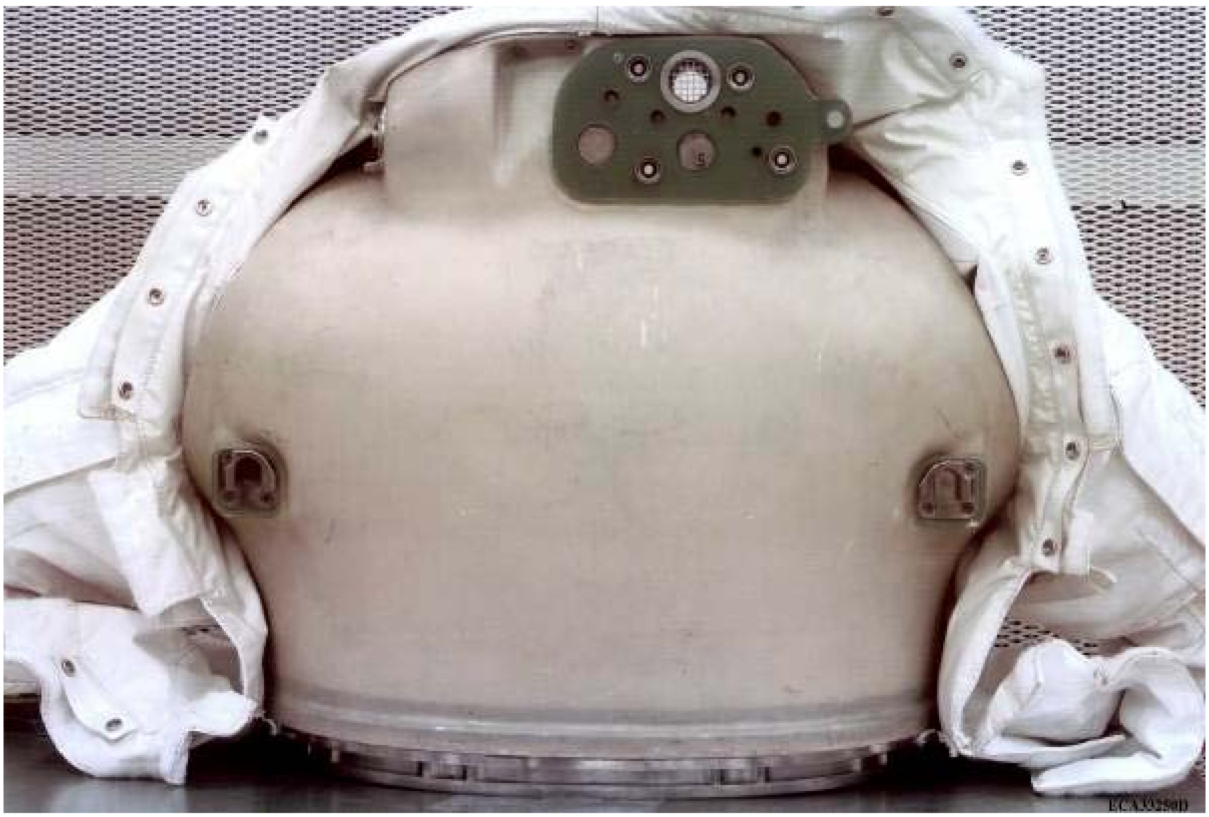

Fig. 6.58 ORU Planar HUT (rear view with TMG)

ILC Heated Gloves (1994-Present)

From 1979 to 1994, the method of controlling object handling in extreme cold was the use of thermal over-mittens. In space, without physical contact with another object, all heat gain or loss is through radiation. In direct sun light, exposed areas of objects absorb energy and expand. In shade, objects cool and contract. To maintain dimension control, orbital satellite maintenance and International Space Station (ISS) assembly procedures have increasingly been performed in shade or during the "night-side" of orbits where temperatures can reach minus 140 degrees F. Performing assembly operations with bulky over-mittens was not feasible.

In recognition of this, ILC developed a Heated Glove prototype (under internal funding) during the summer of 1994. This prototype featured heating elements attached to the glove finger tips with a switch located on the glove. This permitted crew members to manually turn the heating elements on and off. The power source was from batteries mounted on the back-side of the gloves.

A proof of concept glove was further developed and tested under NASA funding in 1994-95. The Detailed Test Object (DTO) utilized off-the-shelf components to reduce development costs. HS contributed aviation heater experience and electrical engineering support to this effort. The DTO glove successfully completed chamber runs at NASA/JSC and performed flawlessly during a DTO evaluation on flight STS-69 in September 1995.

The disadvantage of this system was battery-pack bulk affecting wrist mobility. Thus, the glove-mounted batteries were eliminated in favor of a (suit location) Space Suit Assembly Power Harness (SSAPH). The SSAPH (ref. Fig. 6.59) moved the power source for the heating elements from the back of the glove to the main structure of the EMU.

Fig. 6.59 Heated Gloves

ILC Enhanced Lower Torso Assembly & Arms (1993-Present)

In 1990, the Advanced (Space Station) EMU was terminated in favor of evolutionary enhancements of the Shuttle EMU. The Space Suit Assembly (SSA) side of this effort started with three goals. The first and principal goal was to enhance on-ground and in-orbit sizing changes. This was to be accomplished by removable sizing rings and adjustable brackets (ref. Figs. 6.60 to 6.62).

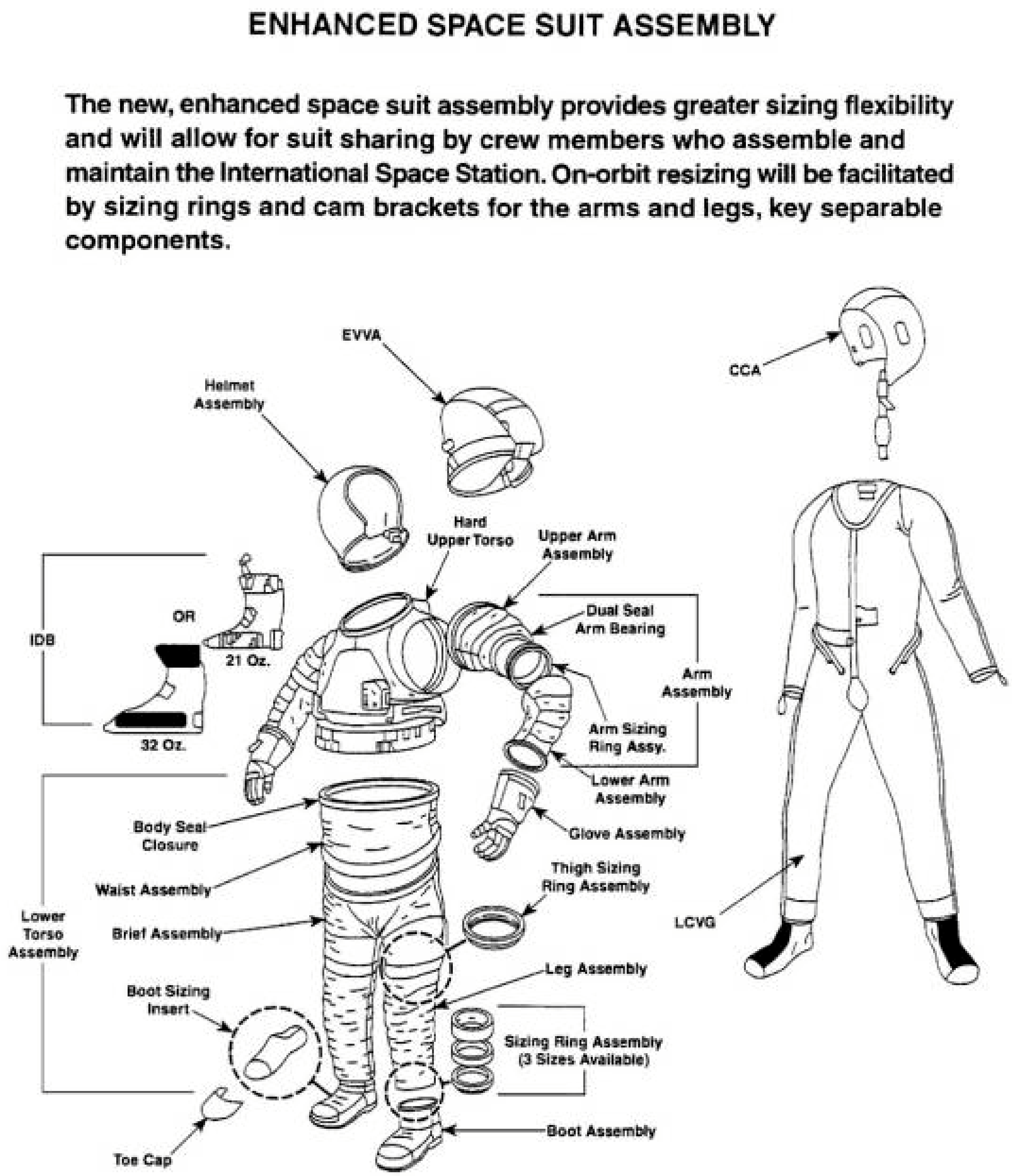

Fig. 6.60 Enhanced EMU/SSA Diagram

Fig. 6.61 Pressure Suit Comparison, Enhanced (left) To Baseline (right)

Fig. 6.62 Enhanced Arm (w/out TMGs)

The second goal was to reduce torque in the elbow and knee joints. This was to be accomplished by reducing the bearing torque and modifying the softgoods with Spectra webbing and improved patterning.

The third goal was to reduce bearing pressure seal criticality (Crit) from 1/1 to 2/1R. A “Crit 1/1” means that a failure results in the loss of a crewmember. Crit 2/1R is when an independent back-up system exists to perform the function of the primary system in the event of a failure. Loss of the backup system would result in loss of life. The goal of reducing criticality was accomplished by adding a second pressure seal in the bearings of the EMU.

Also in 1993-94, redesign of seals and bladders were added to the enhancement process. The life of polyester/polyurethane pressure seals in disconnects and bearings were successfully increased from 3 to 8 years by a chemical enhancement process. Arm and LTA bladders were extended from 6 to 8 years with the exception of the waist assembly of the LTA. This area is limited to 6 years due to cemented reinforcement flanges and tapes.

The first flight of EMUs featuring enhancements was STS-79 in September 1996. The first on-orbit use of the re-sizing capability came in February 1997 with STS-82.

ILC Phase VI Gloves (1994-Present)

After the EMU program had elected to not implement the 5000 series glove, ILC continued development of the system in the belief that it was needed to facilitate ISS assembly. The glove that would ultimately result from this continuation would be the "Phase VI" (ref. Fig. 6.63). The name was derived from the glove's configuration which represented the sixth phase in this continued effort.

Fig. 6.63 ISS EMU Phase VI Pressure Glove

The Phase VI glove principally differed from the 4000 and 5000 series in that it:

- Is the first EVA glove to be developed completely with computer aided design. This results in:
    - A faster development cycle, higher accuracy and lower cost. An ILC developed laser scan process provides a 3D data of crewmembers hands, which can quickly and inexpensively produce molds for conformal fit. The 3D model can easily be adjusted to obtain optimum fit. Conformal fit provides minimum volume, thus reduced effort to perform work.
    - designed to be anthropomorphically correct to the crewmember's hand. Utilizing pleated, lightweight polyester fabric, the fingers and thumb mobility joints are designed as all fabric assemblies to decrease torque and increase fingertip tactility
- Uses a one-piece urethane bladder design that exhibits little to no wrinkling when integrated into the glove; thus significantly improves the fit and performance
- Features a lower torque wrist bearing and an enhanced rolling convolute wrist joint using a two gimbal ring system that:
    - Is tightly integrated to the wrist softgoods for reduced effort in use.
    - Has improved reproducibility through reduced wrist complexity of design as compared to the 5000 Series wrist.
- Utilizes a revised attachment method for rapid change out of the TMG on orbit.

Under the Phase VI implementation, EVA crewmembers named for flight are fit-checked in "close-fit" gloves that have been customized for other crewmembers. As was expected, excellent fits have been achieved, eliminating the need to create a custom glove for many.

<u>Adjustable Protective Mitten Assembly (APMA). (2007 – present)</u>

Following the final EVA of crewmember Robert Curbeam on mission STS 116, it was discovered that the thermal cover layer of his Phase VI glove had cut-related damage after coming into contact with a sharp object while performing assembly work on the International Space Station. Although every effort was made by NASA to avoid the risk of sharp objects, it was apparent that something unknown had caused this cut. Work immediately began between NASA and ILC Engineers to come up with an interim solution to avoid the possibility of further cuts to the gloves. The interim solution was the Adjustable Protective Mitten Assembly or APMA (figures 6.64 & 6.65). This mitten was first used on Shuttle mission STS 120. Until NASA can identify the specific causes of the cuts to the gloves or a long term glove design solution can be implemented, crew members were instructed to wear this APMA during particular phases of the EVA such as translating between work areas where there was reason for concern. The mitten could be removed during other phases of the EVA when close work was being performed. Initial comments from crewmembers that used the APMA were that they did not even know they were wearing them.

Fig. 6.64. The Adjustable Protective Mitten Assembly (APMA)

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Fig. 6.65. APMA as flown on the International Space Station, November, 2007 (Courtesy NASA)

On-orbit Replacement Units (1995-Present)

In 1993, a study was conducted on ways to meet space station EMU provisioning needs. The report noted that a malfunction of a Primary life Support System (PLSS), Secondary Oxygen Package (SOP), Display Control Module (DCM), Hard Upper Torso (HUT) or Arm could remove an entire EMU from service. This would multiply the number of spares needed to be inventoried on station to support EVA activity. The report concluded the EMU needed the capacity to replace malfunctioning subsystems on-orbit. This capacity is named On-orbit Replacement Units (ORU).

The objective of system-level ORU was to design, manufacture, certify and deliver hardware to support effective on-orbit changeout of PLSS, DCM, HUT, or SOP (ref. Fig. 6.57). Many factors made this a formidable task. The orbital change-out would have to be performed without specialized tools and fixtures that are common to field processing. PLSS to DCM cables and harnesses that are routed outside the HUT and under the TMGs provided additional complications.

The ORU effort was coordinated with the Planar HUT, Heated Glove implementation and NASA's Space Suit Assembly Power Harness (SSAPH). ORU certification was complete in October 1998. The first flight for the ORU system was STS-99 in February 2000.

International Space Station Assembly

The culmination of the enhancements to the Shuttle EMU was the first EVAs (ref. Figs. 6.66 & 6.67) that assembled Zarya and Unity First, which were the first two modules (ref. Fig. 6.68) of the International Space Station (ISS). As the EVAs have continued (ref. Fig. 6.69) thanks to quality, reliability, durability and mobility of the Shuttle EMU's SSA, ISS has correspondingly grown (ref. Fig. 6.70).

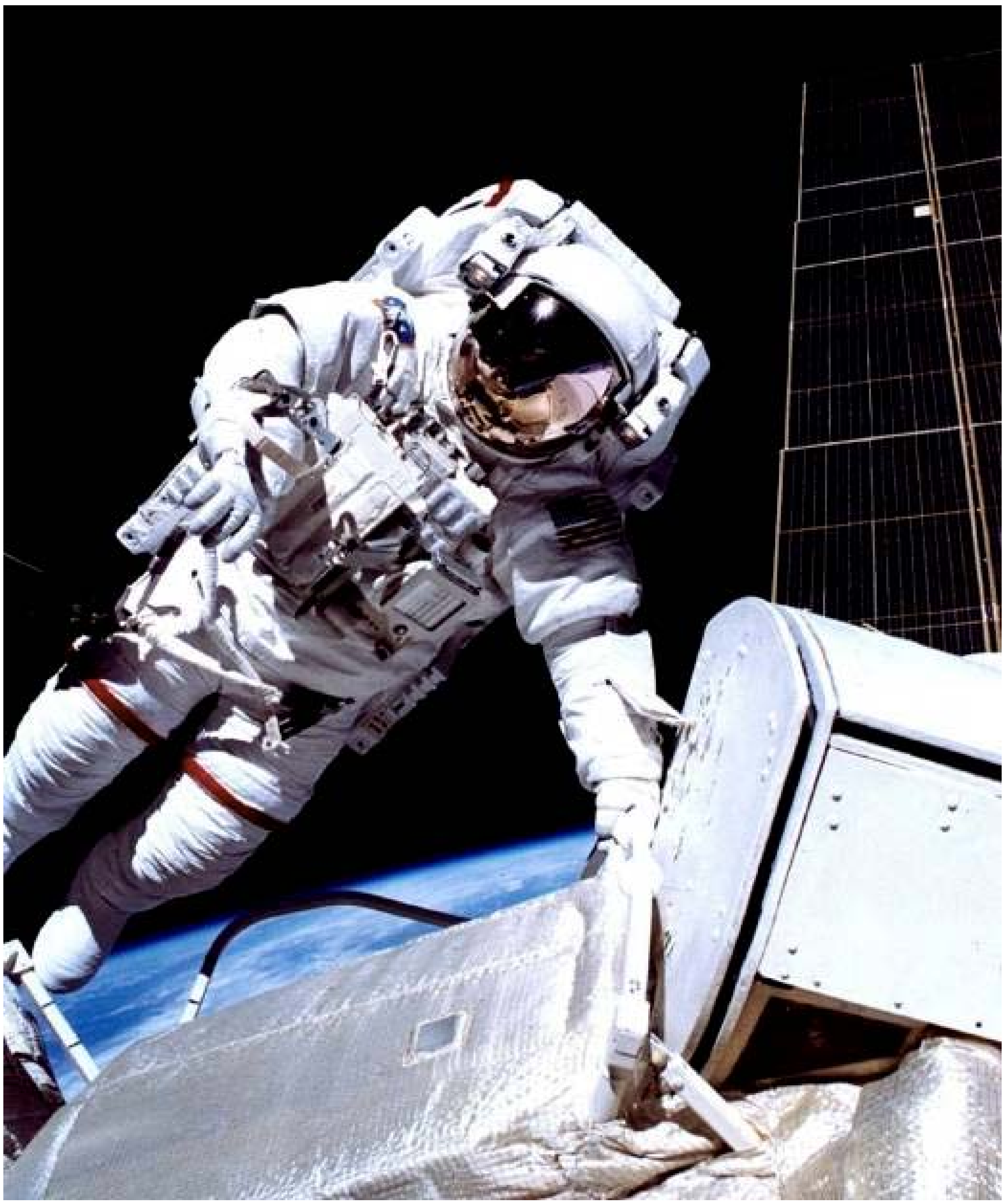

Fig. 6.66 EMU in Unity Assembly EVA (Courtesy NASA)

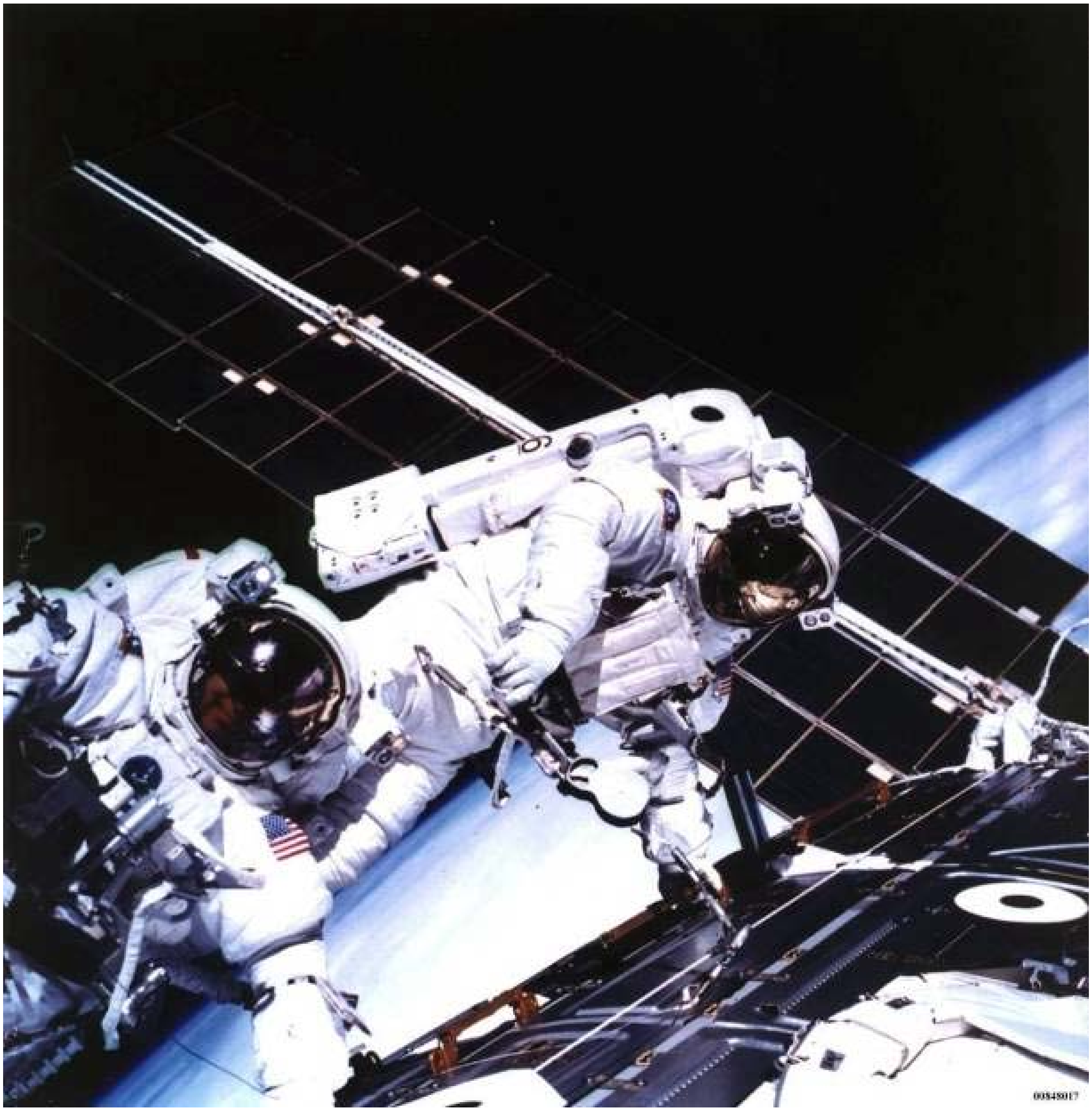

Fig. 6.67   EMUs in Unity Assembly EVA (Courtesy NASA)

Fig. 6.68 Zarya & Unity – The Beginning of ISS (Courtesy NASA)

Fig. 6.69 STS-113 EMU Helping To Build A Station (Courtesy NASA)

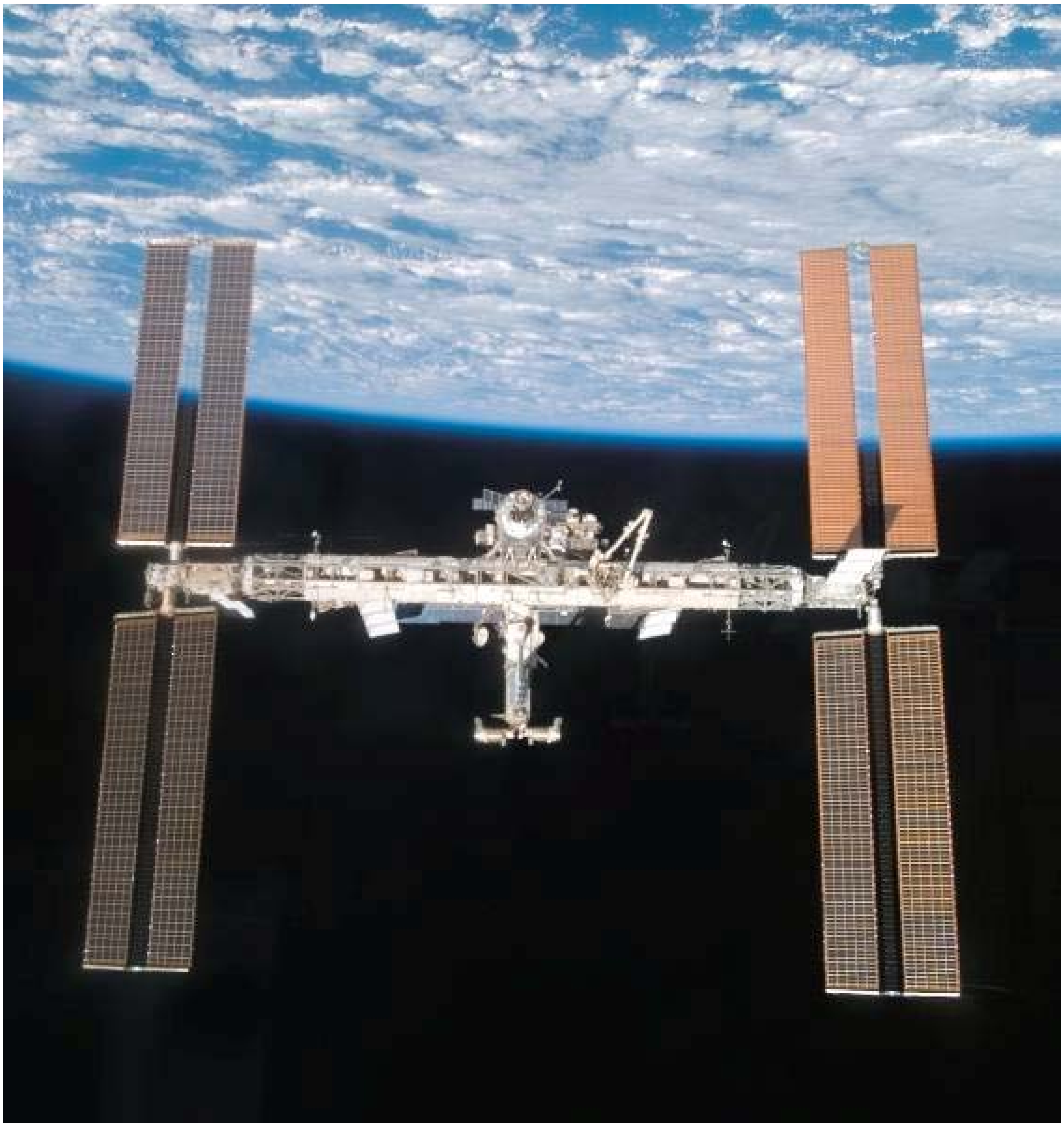

Fig. 6.70 A Growing ISS (As Of July 2005) (Courtesy NASA)

Chapter 7 The Journey Back-To-The-Moon & Mars

As the role of man's working in space continues to expand, the space suit system community endeavors to continue development to support that expanded role. This manifested itself in the early 1990s with a resurgence of NASA Back-To-The-Moon and Mars (ref. Figs. 7.1 & 7.2) studies, which were the expected precursors to next space suit system developments. To that end NASA and ILC responded to that direction. The following topics outlined in this section reflect that response.

Fig. 7.1   In-situ Resource Processing On The Moon (Courtesy NASA)

Fig. 7.2 In-situ Resource Processing On Mars (Courtesy NASA)

This report hopefully illustrates that space suit system development is iterative. Unlike most other engineering applications, there are no textbooks with empirical tables to allow the selecting of materials, system architectures and volumetric/mass attributes to effectively design, certify and produce an effective space suit system for any application with minimal development.

NASA's efforts during this period were essentially two pronged. One was exploring the possibility of making the Space Station Freedom Mk. III suit light enough to support Lunar/Mars exploration mobility requirements. This effort was captured in NASA's “Hybrid Suit” or “H Suit” effort. The other direction was funding “soft suit” research. The first EVA space suits were lighter, simpler and less expensive (per unit) and also supported launch/entry. This research was to see if lightweight fabric pressure suits could be made mobile, durable and reliable enough for planetary exploration. In 1997, NASA funded two prototypes, designation “I Suit” and “D Suit” manufactured by ILC Industries (ILC) and a competitor respectively. While these prototypes would be the last NASA would fund before the start of the Orion program, this was not an end to ILC space suit development but rather a jumping off point for continued ILC proactivity.

In 2006, NASA's goal of Back-To-The-Moon and Mars received the program name, Constellation, and a time table for implementation. The first of possibly one, two or three Constellation space suit competitions will occur in 2007 with an award slated for mid 2008. Since guarding intellectual property is of primary concern as ILC and the space suit community heads into the first of these historic competitions, what can be shared is more limited. The following topics are what are currently available in the public domain, but rest assured, ILC is continuing to do more.

NASA/ILC Hybrid "H" Suit Effort (1994-2000)

Starting in 1990, ILC has worked with NASA to explore the use of potential advanced composite materials in space suits. Using NASA's advanced prototype Mk. III suit, as the test-bed, a mixture of materials have been selected and introduced to evaluate applicability. The resulting hybrid Mk. III was re-designated the "H Suit" (ref. Fig 7.3). This evolution to a lighter system was aimed at operation in a gravitational environment such as Mars. In this evolution, metallic components were systematically replaced by advanced composite graphite-fiber equivalents and a waist bearing was added. These graphite fiber substitutions included an AirLock made graphite fiber/honeycomb filled Hard Upper Torso and ILC manufactured Lower Torso Assembly elements.

Fig. 7.3 Side & Front Views Of The 1997 NASA/ILC H Suit

In 1998, the H-Suit was extensively evaluated (ref. Figs. 7.3 against the two NASA-funded advanced I and D "soft suits". An interesting element of this evaluation is how NASA creates lunar and Martian gravity in Earth. NASA devised a specially equipped aircraft with an open interior to provide a laboratory. The aircraft travels to its maximum altitude and then goes into a finely controlled dive that creates precisely either a lunar or Martian gravity in which experiments can be performed. While such conditions can be maintained for generally less than a minute, it is sufficient to allow evaluations of space suits. See figure 7.4.

Fig. 7.4 The I-Suit Running in Simulated Martian Gravity.

The H Suit continues to provide NASA with distinguished service as a field test item (ref. Fig. 7.5) and tested to the present.

Fig. 7.5 The H Suit In Earth Gravity & Martian Type Terrain Evaluations (Photo courtesy NASA)

<u>The Original I-Suit (1997-98)</u>

During the period of its creation, this suit has been known as the "I-Suit", the "C-Suit" and the M-Suit". The official designation finally became “I-Suit”. The I-Suit (ref. Figs. 7.6 & 7.7) was primarily a soft suit, yet it incorporated a number of bearings at the shoulder, upper arm, upper hip and upper leg (2 bearings on each side of hip). The suit was mid-entry (like the Shuttle EMU) but featured a Soft Upper Torso (SUT) in place of the hard, fiberglass equivalent.

Fig. 7.6 & 7.7 Side & Front Views Of The NASA/ILC (First Generation) I-Suit

ILC's I-Suit continues to develop to meet the roles of tomorrow. In 2000, ILC devised an innovative interface between suit and life support. This interface additionally introduced a departure from the Apollo helmet and neck-ring with a derivation of ILC's Manned Orbiting Laboratory helmet design.

The Second Generation (Mid-Entry) I Suit (2000-05)

In 2001, ILC internally funded the creation of a second generation I-Suit (ref. Fig. 7.8). For this prototype, the helmet, boots, and waist/brief softgoods were enhanced. The helmet became elliptical shaped and was angled with a composite wedge element to improve visibility. The boot restraints became integrated into the boots and the brief became a separate component connected with a clamping ring. The air, water, and communications have been integrated into the wedge element. Speakers were mounted in the composite wedge element and a microphone array system was located at the helmet neck ring. Also for this creation, the suits mobility and sizing systems saw proprietary improvements.

Fig. 7.8 ILC's Proactive Second Generation I-Suit

The composite wedge element permitted the interfacing of this I-Suit with Shuttle EMU (Extravehicular Mobility Unit) training life support systems. This supported NASA's consideration of this configuration for use in space as a flight experiment and a possible next EVA (extra-vehicular activity) space suit. While this did not come to pass, this suit would see further evaluation applicable to the program that would be called Constellation.

The Rear-Entry (Third Generation) I-Suit (2005-Present)

The 2005 rear entry configuration is the latest evolution in ILC's I-Suit effort (ref. Figs. 7.9 & 7.10) that can be shared with the public. To create this configuration, ILC has used their 2000 internal prototype LTA and retrofitted it with a planetary type soft upper torso (SUT). Like the I-Suit configurations that preceded it, this is primarily a soft suit that incorporates a limited number of bearings at the shoulder, upper arm, upper hip, and upper leg (2 bearing hip) joint.

Fig. 7.9 Third Generation Rear-Entry I Suit In A Simulated Martian Terrain

Fig. 7.10 Side & Front Views Of The Rear-Entry I Suit (ILC Engineer Keith Splawn in suit)

ILC developed a soft rear entry door with the goal of designing a lightweight rear entry suit system (ref. Fig. 7.11). The lower torso assembly (LTA) is the same one used on the waist entry I-suit with the addition of Superfabric kneepads. In order to eliminate as much weight as possible, the material in the lower 2/3rds of the door were removed and replaced with a bladder and restraint Superfabric. Low profile donning brackets have been added to both sides of the rear entry closure to secure the suit during donning and doffing.

Fig. 7.11 Rear View Showing Entry & Design Features

Like the H-Suit and proceeding iterations of I-Suit, the ILC Rear-Entry I-Suit has the distinction of seeing service as the test-bed in NASA's prestigious "Desert Rats" Martian terrain evaluations (ref. Fig. 7.9) and in vehicle interface evaluations (ref. Fig. 7.12). For the Rear-Entry I-suit, this event occurred in 2006. NASA reported the evaluation results were favorable.

Fig. 7.12 Third Generation Rear-Entry I Suit With NASA's Rover Test-bed

Chapter 8 Concluding Remarks

Since winning the original Apollo contract in 1962, ILC has continued non-stop in the development and production of the space suits for this Nation's manned missions. In order to sustain this effort, ILC has maintained a staff of highly skilled employees who have gained their knowledge from the talented individuals before them and further build on these talents using the latest production facilities and materials available. To the typical layman, it appears simple to sew materials together to form a space suit. However, once the complexity of the system is revealed, it becomes apparent why ILC takes pride in the design and manufacture of such a complex marriage of softgoods and hardware that must conform to the human body in motion.

A special acknowledgment goes out to all of the past ILC employees who developed the Apollo space suit. This group of individuals blazed a trail into the history books starting in the late 1950's by developing systems that were at the time far removed from others capable of sustaining life in an environment as hostile as the Moon. By the time Neil Armstrong set foot on the moon in 1969, a relatively short 8 years had passed since President Kennedy's challenge and ILC's start at providing the suit system necessary to meet that daunting challenge.

Today's ILC employees continue to look towards the future of space suit development and the challenges associated with meeting America's future mission requirements in space. The hope is that further chapters will be added to this document that highlight the significant contributions ILC continues to make towards the successful future of manned missions to the Moon and then on to Mars.