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Phase VI Advanced EVA Glove Development and Certification for the International Space Station

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ABSTRACT

Since the early 1980's, the Shuttle Extra Vehicular Activity (EVA) glove design has evolved to meet the challenge of space based tasks. These tasks have typically been satellite retrieval and repair or EVA based flight experiments. With the start of the International Space Station (ISS) assembly, the number of EVA based missions is increasing far beyond what has been required in the past; this has commonly been referred to as the "Wall of EVA's".

To meet this challenge, it was determined that the evolution of the current glove design would not meet future mission objectives. Instead, a revolution in glove design was needed to create a high performance tool that would effectively increase crewmember mission efficiency.

The results of this effort have led to the design, certification and implementation of the Phase VI EVA glove into the Shuttle flight program.

INTRODUCTION

The success of astronauts in performing Extra-Vehicular Activity (EVA) is highly dependent on the performance of the space suit gloves they are wearing. Since the beginning of the Space Shuttle Program, one basic glove design has been evolving. The Shuttle EVA glove started with the 1000 Series glove and has evolved to the 4000 Series glove which is flying today. Through these generations, material changes were the primary focus of the evolution. These material changes did help to produce a better glove, but basic design, hardware and patterning philosophy did not change significantly.

By the early nineties, this 4000 Series glove and its performance had evolved as far as the basic design would allow. In an attempt to make a revolutionary step in glove design for International Space Station (ISS) assembly, a completely new glove was developed retaining little of the previous design except for some of the materials technology. This new design incorporated materials technology lessons learned from the 4000 Series glove program, but otherwise attempted and made quantum improvements in glove design.

The Phase VI glove is the first EVA glove to be developed completely with computer aided design. Phase VI glove sizes are being developed as custom gloves for International Space Station (ISS) Extravehicular (EV) Crewmembers. The previous glove designs were based on a standard sizing system that was modified, if necessary, for a particular crewmember. As with previous designs, the custom size development process starts with a hand cast but beyond that the Phase VI processes departs drastically from those of the previous design. The Phase VI glove design includes laser scanning technology, 3D computer modeling, stereo lithography, laser cutting technology and CNC machining. It is through the use of these advanced technologies that a higher performance Phase VI custom glove size can be developed faster, with higher accuracy and at a lower cost than previous glove designs.

GLOVE DEVELOPMENT HISTORY

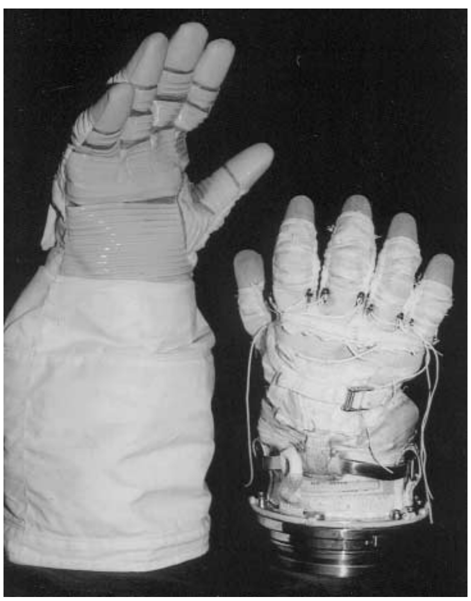
Fundamentally, all glove development to date has included the following three elements. From the hand outward, the first layer of the glove is the bladder. This layer is designed to retain the pressurized environment of the glove. The next layer of the glove is the restraint; this component of softgoods is responsible for carrying all pressure and man-induced loads during operational use. The final, outer layer, is the thermal and micrometeoroid garment (TMG). The function of this layer is to provide a buffer from thermal swings and to guard against the impact of hyper-velocity, micrometeoroid particles.

4000 SERIES GLOVE

The current EMU glove is the 4000 series glove. It was introduced into the flight program in 1985 as an evolution of the 3000 series glove. Based upon nine standard hand sizes, the 4000 program provides a "closest fit" glove sizing capability. Subsequent development of the 4000 series gloves included customization for crewmembers that did not adequately fit into a standard size. The fundamental approach remains the same in the 4000 series glove today.

A handcast of the subject is taken; from this, measurements are gathered and compared to the standard sizes of gloves. If no fit is possible within the standard size range, a custom glove is needed. Tooling is prepared using epoxy resin and handcrafted methods. This relies heavily on "old world" craftsmanship to create consistency among different glove sizes. For the restraint and TMG, the flat patterns are selected from the closest size. These patterns are modified to provide appropriate finger lengths and circumferences, and incorporate other changes deemed necessary to promote an adequate fit. This pattern making includes mostly hand-generated patterns and limited CAD assisted design, but for manufacturing, all fabric parts are hand cut from the paper pattern templates.

Based upon the standard size selected, whether it is to be a standard or "modified" custom, one of three wrist sizes follow through. The configuration of the wrist remains the same through the three sizes, but key, size related dimensions increase as the basic hand size increases. The wrist design utilizes a single gimbal ring and webbing restraint lines to provide wrist adduction/abduction and flexion/extension. The softgoods of this wrist is simply a compressed cylinder; its overall length is designed to provide the desired range of motion for effective EVA use.



4000 Series Glove Assembly
Figure 1

Unfortunately, because the softgoods and gimbal system are only locally indexed, this design can result in instability of the wrist. During use of the glove, it has been found that unexpected shifts in the volume of the joint cause a "cam-over" effect in the wrist. Typically the 4000 series wrist has three neutral positions in both flexion/extension and adduction/abduction: -45°, 0°, +45°.

After the introduction of the 4000 series glove, the development effort was focused on creating a new, high performance glove design to support future space exploration. From these programs, incremental improvements trickled into the 4000 series glove program as design improvements. However, the true intent of these efforts was to create a higher standard for glove performance. The Phase VI glove program represents the culmination of glove development efforts at ILC Dover over the last 14 years. It includes the follow-on effort of the Phase IV and 5000 series glove programs, the Laserscan process development and the Phase V glove program.

PHASE IV GLOVE

The Phase IV glove was developed as an 8.3 psi "zero-prebreathe" glove. It was decided at the time that eliminating long duration pre-breathe was essential to ISS to maximize the available EVA time. From the 4000 series glove, the Phase IV glove sought to improve glove fit by deriving the hand bladder mold and restraint shape directly from a handcast of the crewmember. This was done by still utilizing handcrafted tooling, but to create them directly from the handcasting of the subject. For this project, crewmember Jerry Ross was selected as the "customization" subject.

In addition to the new bladder changes, new restraint layer patterning was needed to meet the increased fit requirements; included in this was the development of full fabric fingers and improved seam configuration to better reproduce the desired inflated shape. In addition, the glove hand design included a custom formed, high strength palm bar and a segmented palm plate to form the palm of the pressurized glove to the natural shape of the hand. This provided a more conformal fit and still allowed some flexibility in this area due to the palm plate segmentation. The wrist of the Phase IV glove was developed as a four ring rolling convolute joint; this configuration provided a nearly constant volume during manipulation of the joint, promoting a low torque, stable motion. The Phase IV TMG remained basically unchanged from the 4000 series glove. However, tactility of the fingertips was improved due to the refinements of the Phase IV bladder and restraint designs.

5000 SERIES GLOVE

The 5000 series glove was a continuation of Phase IV, enhancing the design to allow it to be flown as a DTO glove on STS-37 for crewmember Ross. Improvements of the previous design included enhancements to the rolling convolute wrist and strength improvements due to the latest satellite/man-load requirements from the flight program. The new wrist was extremely low torque, and tracked very well to the movement of the user. However, the use of bearings in the pivot locations lead to complexity of the design and was perceived to increase the susceptibility to damage from a side impact. In addition, due to the use of many steel components, the wrist joint was a relatively heavy component of the glove.

LASERSCAN PROCESS DEVELOPMENT

After the 5000 series program, the Laserscan Process Development effort was underway. This program investigated advanced technologies such as laserscanning and stereolithography and methods to apply them to the design of an advanced EVA glove. For this program, these processes were used to develop the hand portion of a 5000 series style glove. The subject handcast was laserscanned and the resulting data set was developed into a rough bladder mold model. This model was then solid rendered using stereolithography apparatus (SLA). Subsequent model making of the SLA parts created the finished tooling for use in bladder production. With this advancement, the reproducibility of the glove design was greatly enhanced.

Also from this 3-dimensional computer model, flat patterning methods were derived to create glove restraint patterns that more accurately represent the shape of the human hand. It was this initial work that laid the foundation for the advanced technologies that are fundamental to the design of the Phase VI glove program today.

PHASE V GLOVE

The Phase V program represents the further refinement of the technologies and approaches carried through from the 5000 series glove. For this program, crewmember Story Musgrave was chosen as the customization subject. Again, a handcast was taken and laserscanned. With advances in laserscan technology, more accurate scanning was possible and data output became more readily useable by advancing computer aided design (CAD) software. Marked improvements to the 3-dimensional modeling were made possible with recent advances in CAD Non-Uniform Rational B-Spline (NURBS) capabilities. More complex surface models were possible, allowing more “electronic” modeling with less, subsequent handcraft modeling for the creation of production tooling.

With this advanced capability, significant effort was placed in determining minimum easements for the construction of the glove. This translated into lower volume in the glove and therefore less expended user effort when compared to existing designs. During this program, a minimum easement bladder/restraint system was developed. This resulted in an integrated bladder that exhibited virtually no wrinkles and provides a very comfortable, conformal glove. The palmbar and palm plate were also carried along to Phase V. However, the palm plate was changed in favor of a one-piece composite plate. This reduced the complexity of the plate and also reduced the bulk in the palm of the glove.

For the wrist, the extensive use of titanium and graphite/epoxy composite materials reduced weight in the rolling convolute. To reduce complexity of the wrist, the secondary pivots were redesigned and bearings were replaced with pin and bushing assemblies.
Included in Phase V was also the development of a new, on-orbit replaceable unit (ORU) TMG. It was manufactured from a knit fabric palm that was molded to the shape of the bladder-restraint system; this reduced the number of seams in the TMG and reduced bulk in the palm. The ORU feature provided attachment points between the restraint and TMG that would allow the easy removal and installation of the glove TMG while on orbit.

PHASE VI GLOVE DEVELOPMENT

Following the Phase V design, a new focus was placed on improving the cost/performance ratio of the advanced glove effort. The NASA community had decided that the EMU would operate at 4.3 psi for the foreseeable future. With this change in philosophy, the need for a hard wrist joint waned; the lower operating pressure would result in lower torque during operation, to the point that a softgoods joint approach could easily meet the high level of glove performance established by the advanced programs.

The Phase VI program consolidates all of the advanced technologies of the advanced glove programs with the development of a new, advanced softgoods wrist. It’s purpose is to provide custom fit gloves that promote improved dexterity, reduced fatigue and a high level of user comfort compared to current and previous glove designs.

At the start of the Phase VI program, investigation into a new constant volume soft wrist with minimal hardware was undertaken at ILC. For the initial development effort the Musgrave 5000 series glove was used as the foundation for the new glove. The rolling convolute wrist was to be replaced with the candidate soft wrist when development was complete. Borrowing from ILC’s Apollo experience, development of a convolute wrist joint began. It was felt that this joint design could provide exceptional range and low torque during its operation.

In January 1996, crewmember Greg Harbaugh was chosen as the first EVA astronaut to receive Phase VI gloves. By mid-summer 1996, his training gloves were delivered in preparation for his December 1996 flight on STS-82; his flight gloves were delivered in early fall. Unfortunately, just prior to STS-82 launch, a Phase VI glove production issue surfaced that could not be resolved in time for the flight. The gloves were pulled from the flight and the effort progressed to revise the production process.

Following the Harbaugh customization, crewmember Jerry Ross was selected to receive a Phase VI customization. His flight was the first ISS assembly flight, STS-88 (1A), and was scheduled for launch in 1998. Under an advanced development contract, this second customization provided the opportunity to incorporate more refined tooling and streamline the design process even further. Additional design improvements were developed and incorporated into the glove, including a revised TMG design with ORU capability and improved fit, improved bladder assembly and a maintenance free hardware assembly. Delivery of training gloves and flight gloves followed in early-mid 1998. In December 1998, Phase VI gloves were flown on their first mission with very successful results. While on orbit, Ross commented that the glove performance was superior to the 4000 series glove design.

Follow-on effort for Phase VI has been the certification for flight and the implementation of Phase VI into the flight program.

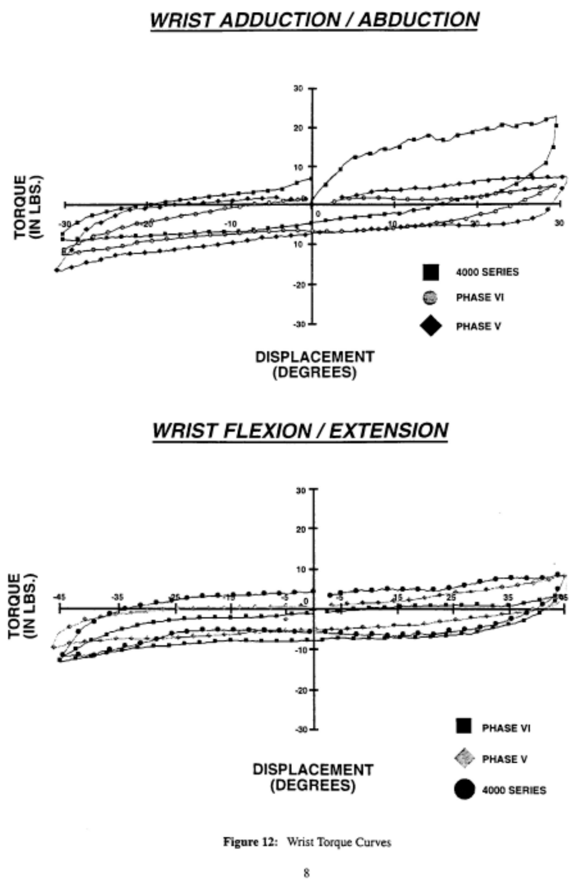
Phase VI Glove Assembly
Figure 2

WRIST RESTRAINT DESIGN

The new Phase VI wrist is designed using a two gimbal ring system that is tightly integrated to the wrist softgoods. The two-ring design isolates the flexion/extension of the wrist from the abduction/adduction of the wrist. This promotes a smoother wrist movement and better controls the shape of the softgoods joint. Several ring configurations were evaluated to determine the appropriate size and shape. This evaluation included fitchecks with crewmember Greg Harbaugh to down-select to the preferred geometry. Upon selection, a finite element analysis was performed to support the final design and reveal any deficiency prior to manufacture of the first design verification units. Currently, the wrist has been developed as a one size “system.” For all customizations, this standard wrist is applied directly to the glove design.

The current Phase VI configuration consists of an upper ring that is oval in shape; this mimics the cross-section of the human wrist and enhances the tracking of the glove to the hand. The lower ring is circular, with differential pivot heights; this geometry follows the design of the softgoods wrist and the pivot placement allows for efficient load transfer, which results in smooth gimbal operation. Between the rings and the wrist disconnect, swivel and webbing assemblies are used to allow smooth operation and support operational and satellite/manloads. In addition, the use of flexible webbing eliminates the potential for side impact failure of the gimbal system. Borrowed from the 4000 series glove, the swivels are modified to utilize a special self-lubricating hard coating. This feature allows the pivot points to be maintenance free for the operational life of the glove system. Currently, the 4000 series system must undergo pivot maintenance for every 40 hours of pressurized use. For the current push of ORU gear and on-orbit self-sufficiency, this represents a great stride in glove design.

The convolute wrist softgoods are designed as a three pattern convolute for the flexion/extension and two pattern convolute for abduction/adduction. Through optimization of the size and shape of the convolutes in the wrist, the required range of motion was achieved with very low torque and excellent stability. To bring the softgoods and gimbal system together, a configuration of lacing is used to tightly integrate the two systems together. By doing so, the joint shape is more tightly controlled when it is flexed and as the convolutes are compressed and expanded, the volume of the joint remains nearly constant. As part of the development of the wrist, torque to range of motion was evaluated and compared to existing glove designs. The following graphs show the hysteresis curves for the Adduction/Abduction and Flexion/Extension wrist torque for Phase VI, Phase V rolling convolute, and 4000 series wrists.



Glove Wrist Torque Data
Figure 3

As can be seen, with Phase VI, the joint torque has been decreased throughout the range of motion compared to 4000 series. The spike in the right hand side of the 4000 series adduction/abduction curve indicates the unstable nature of the wrist. It was also found that the Phase VI wrist closely tracks, and even out performs the Phase V wrist. The flatter and narrower the torque curve, the more stable the joint is through the range of motion.

Aside from the basic design approach, another contributor to increased wrist performance has been the change of hardware manufacture. For Phase VI hardware, the transition from casting and hand machining to the exclusive use of CNC machined pivot and bracket hardware has yielded higher quality parts. Since the hardware can be held to tighter tolerance and acceptance criteria, swivel and gimbal hardware performance exceeds earlier hardware design. Because of this, the current 4000 series glove has also adopted this approach for its gimbal system. In addition to improved performance, time and cost to manufacture is greatly reduced due to reduced scrap rate of parts.

The last component of the wrist restraint is the glove side disconnect. The Phase VI glove utilizes a low torque, dual seal bearing and standard Shuttle EMU disconnect hardware for attachment to the arms.

PHASE VI RESTRAINT HAND DESIGN

The Phase VI hand is designed to be anthropomorphicaly 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. By closely fitting the hand, finger and thumb joint torque is reduced and overall comfort is achieved.

For the hand section, the groundwork laid with the Laserscan and Phase V glove efforts was refined to increase repeatability, manufacturability and accuracy. During the Ross customization, bladder tooling and restraint patterns were optimized to promote a better fit for the hand. This included developing new anthropometrically based algorithms to reposition the thumb to promote better handgrip.

The stainless steel palmbar of the Phase VI glove is developed to provide palm control when the metacarpal-phalangial joint of the hand is flexed. By placing this in the crease of the hand, the comfort and effectiveness of the bar are greatly increased. The palm plate position has also been improved to prevent ballooning of the palm during pressurized use. By optimizing the perimeter shape to the hand, the curvature of the plate presents minimal bulk in the palm while providing significant improvement in grip.

BLADDER DESIGN

Mimicking the shape of the restraint, the bladder provides the conformal pressure-retaining layer of the glove. For Phase VI, a one-piece urethane bladder was designed that exhibits little to no wrinkling when integrated into the glove; this significantly improves the fit and performance. To reduce finger torque, convolute ridges are incorporated to provide additional material run length for flexion.

For abrasion protection, the Phase VI bladder includes a fabric liner in the wrist. This liner serves as a buffer between the crewmember's arm or liquid cooling/ventilation garment (LCVG) and the urethane bladder. By cycle testing this configuration, it was determined that this approach virtually eliminated all wear on the bladder during its entire cycle life.

The bladder also incorporates a one-piece fabric reinforced flange. This is used to prevent bolt hole tear-out during installation and removal of the glove disconnect.

TMG DESIGN

TMG design has typically resulted in a significant increase of finger and wrist joint torque. The Phase VI TMG design includes characteristics to help minimize this effect. To begin, TMG is sized to provide a very conformal fit. Its shape is defined by the restraint layer of the glove and is oversized only to prevent pressure load transfer from the restraint to the TMG.

The fabric used in the palm of the TMG was developed as a specially woven knit fabric, to allow stretch of the garment at the flex points on the palm of the hand. This also allows the fabrication of a one-piece palm; removing seams from this area greatly reduced the bulk from the working area of the glove.

This knit fabric is then molded to the shape of the subject's hand using TMG tooling derived from the laserscan process. As with the 4000 series glove, room temperature vulcanized rubber (RTV) is used on the palm of the TMG. The RTV is applied to the 3-dimensional palm to form pads. These pads provide and excellent insulative standoff for thermal protection and provide a high grip surface for work use. By shaping the pads to the geometry of the subject's hand, torque has also been reduced. In addition, selectively placed break-lines provide local areas of reduced torque and minimize the degradation in glove performance.

In order to meet the thermal challenges of ISS assembly, the Phase VI glove has also been designed to include improved insulation and an active heating system. Utilizing the geometry of the subject's hand, felt insulation has been placed in areas of prime surface contact. This includes selective areas of the palm and the fingertips. By reducing unneeded insulation, overall TMG performance has been further increased. In recent cooperative NASA/Zvesda redesign efforts, the Russian Orlan glove TMG has been modified to include similar insulation configuration to replicate Phase VI thermal performance.

The Phase VI glove incorporates and active heating system that consists of resistive element heaters located at the fingertips. This system originated as a 3-volt system designed to operate off a remotely located battery pack. A recent battery re-design has resulted in the evolvement of the heater system to a 12-volt design. The heating system is actuated with a toggle switch located on the gauntlet of the TMG. This switch indicates the On or OFF position to serve as a visual cue for the EVA crewmember. By cycling the heaters on and off, local heating at the fingertips reduces the likelihood of cold hands.

For ISS, ORU function is a requirement for the entire EMU; the Phase VI glove TMG has incorporated this feature to allow on-orbit replacement of a damaged or worn out TMG. The design consists two main components. The first is a set of small brackets, two sewn near the tip of each restraint finger and thumb, that integrate to two short cords that are sewn to the respective positions on the TMG tips. This integration allows easy installation and removal, yet provides effective integration of the fingertips for good tactile feedback. The second component of the ORU system is the hook and pile located on the palm of the restraint and TMG. This provides a simple ORU attachment and prevents the TMG palm from folding out, away from the restraint.

PHASE VI CUSTOMIZATION PROCESS

When a crewmember is selected for a customization, he/she is scheduled for handcasting. This process captures, as a plaster representation, all of the characteristics of a subject's hand for use in the glove development.

Handcast of Crewmember Coleman
Figure 4

From this handcast, landmarks are identified that are key to the proper fit and function of the Phase VI glove.

The next step is the laserscanning of the handcast. This process creates a database that represents the subject's hand and is formatted for use in the Phase VI design programs. Through extensive use of CAD and C programming, this database is processed through automated algorithms to create a surface model. This model becomes the foundation of all of the production tooling for that custom glove.

Following the developed Phase VI design guidelines, design engineers incorporate the necessary easements to generate the 3D model from which the bladder tooling is made. Advances in CAD NURBS surface design has allowed a completely modeled surface of the glove to be created. This 3D model is then processed to SLA equipment for tooling creation. As a cost savings and process improvement, ILC Dover has acquired in-house SLA equipment; this has significantly reduced tooling turn-around time and, due to the recent advancements in SLA technology, yielded extremely accurate parts. As a result of these advances in CAD and SLA, model making has virtually been reduced to SLA part clean up and processing for production.

SLA Tooling for Crewmember Grunsfeld

Figure 5

Following bladder tooling development is the design of the restraint layer of the glove. This layer is modeled with the appropriate easements to create a bladder and restraint system that is a very conformal fit for the subject. From this model, all fabric patterns, palmbar tooling and palm plate parts are derived.

As the next phase of the custom glove development, TMG mold tooling is developed from the 3D model. In addition, flat patterns are automatically generated using sizing information and information pulled directly from the 3D TMG model. With this design process, a conformal TMG garment fit is achieved. As with the bladder, TMG tooling is processed to SLA equipment.

When all design effort is complete, the fabrication of a training glove begins. All patterns for the custom glove are processed to laser cutting equipment. As a result of this new piece part making process, highly accurate parts are created, resulting in a more manufacturable and repeatable glove size. The few exceptions to this process are special materials that require hand processing.

When all manufacturing processes are complete, the bladder, restraint and TMG are integrated and delivered for crewmember fitcheck. These gloves represent the training gear that the crewmember will use to prepare for his/her EVA mission. It is at this point that the building of their flight glove begins.

CERTIFICATION EFFORT

For the Phase VI flights on STS82 (Harbaugh) and STS-88 (Ross), the Phase VI glove was certified to the equivalent of a single mission. This certification allowed the gloves to be flown on one shuttle mission for all EVA's, including contingencies. To certify the glove, the traditional cycle model was used. It was these same cycle requirements that had certified the 4000 series glove program. After returning from their maiden flight and three EVA's of use, Ross' Phase VI gloves were inspected and found to be in excellent condition.

Subsequent to that first mission, the Phase VI glove has been re-tested to meet the current ISS spacesuit requirements. This includes cycle life in comparison to previous designs and increased structural requirements to address satellite man-loading and ISS specific use.

Since Phase VI gloves have been designated primarily for ISS construction, it was decided that the traditional certification cycle model should be revised to include glove cycling that was representative of ISS assembly. Previous glove certification sought to isolate specific glove motions and generate cycle numbers based upon the observed motion and cycle count as documented on Shuttle EVA video. With only one ISS assembly mission to set precedence, the NASA community developed requirements based upon expected mission duration and a maximum EVA contingency plan. However, it was realized that ISS assembly presented new challenges to the glove; it is expected that this assembly will be far more hand-intensive than all previous space flights. With this, the traditional cycle motions were achieved using specific ISS tools and certification equipment developed to represent crew translation to and from the work-site. Throughout the test, task parameters were rigidly maintained through real-time cycle count and the use of metronomes to control the cycle rate. The following table indicates the cycle requirements, including a factor of safety of 2, for each isolated motion of the glove design.

MOTION	CYCLES
Finger Flexion/Extension	**90284**
Wrist Flexion/Extension	**25292**
Wrist Adduction/Abduction	**34208**
Wrist Rotations	**40224**

Glove Cycle Requirements
Table 1

Certification tasks included the use of a handrail resistance tool; this was used to simulate the EVA crewmember translating on orbit while assembling or maintaining ISS. The tool was constructed of the specified ISS handrail cross-section and was configured as a wheel assembly to allow repetitive cycling without the use of upper or lower torso effort. This specific task provided wrist adduction and abduction as the test subject rotated the handrail tool through its rotation. In addition, finger flexions were included as the subject grasped and released the rail during the task.

Handrail Resistance Tool with Phase VI Glove
Figure 6

To achieve the high requirement of finger flexions, a modified handrail task was developed. This task simply required the subject to grab and release the handrail at a specified number of cycles per minute. Not only did this task verify the robustness of the glove design, but provided excellent qualitative information on TMG cycle wear. Coordinated with this task was the use of a flight-like safety tether hook. This tether was actuated to simulate crewmember transferring the safety tether as they translate around the EVA worksite.

Another task defined for certification was the ISS connector task board. Using hydraulic and electrical connectors of identical ISS configuration, the test subject was required to correctly throw the connector levers, disengage the connector and reengage and re-throw the lever to complete the connection. Through this task, finger flexion and wrist adduction/abduction cycles were achieved.

ISS Hydraulic and Electrical Connectors
Figure 7

To achieve remaining motions such as wrist rotations, flexion/extension and adduction/abduction, traditional certification tooling was utilized. These included a tool representing the ease / access handle on the Shuttle as well as a simple handle and bearing assembly.

In August 1999, the Phase VI certification cycling was complete. In January 2000, all required paperwork was completed and certification of Phase VI gloves was closed. For all future shuttle missions, this glove now has NASA acceptance for on-orbit and space station use.

PHASE VI PROGRAM STATUS

Under the Phase VI Implementation Program, Phase VI flight gloves are currently being fabricated or have been delivered for 57 EVA crewmembers. Training gloves for nearly half of these customizations have been delivered and are currently being used in Neutral Bouancy Lab (NBL) training. As part of an ongoing effort, named EVA crewmembers are fitchecked 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 some crewmembers. To maintain the high level of performance of this design, strict criteria are evaluated to determine the acceptability of a “non-custom” fit; if all parameters are not met, a custom glove is recommended.

CONCLUSION

The Phase VI glove 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. Phase VI glove certification has set a new precedence by including space station specific hardware as well as new fixtures simulating specific EVA operations such as handrail translations. The Phase VI glove is the product of many years of advanced glove research and development. It combines the lessons learned from the flight program glove designs as well as incorporating novel concepts from advanced glove designs. The Phase VI glove provides a revolution in EVA glove design and performance. The Phase VI glove provides better fit for improved crewmember comfort and improved mobility. These performance improvements allow crewmembers to work more effectively on increasingly more complex missions.

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