AN IMPROVED METACARPAL JOINT FOR AN EVA GLOVE

by

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Approved by:

____
Major Professor

Dedicated in loving remembrance to my sister

Patricia Jo Bolden.

August 15, 1958 -- May 28, 1984

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One of the author's responsibilities in the team design project was to write the final report. Other team members were involved in the writing. Thus the final report, and by extension, this master's report is not the author's sole contribution, but incorporates work of all the design team.

SUMMARY

The ASEE/NASA EVA glove design competition had two main objectives. These were the organization and management of a multi-disciplinary design team in the university environment and the design of the EVA glove.

The Kansas State University team consisted of four faculty advisors and six student members. One graduate and one undergraduate student were selected from each of the three disciplines of mechanical engineering, industrial engineering, and clothing and textiles. The project was conducted primarily by the students with the faculty serving as advisors. The complete team met once a week to discuss administrative tasks and to set project priorities. In addition, a student meeting was held each week, at which time work assignments were made for individual duties. Accountability was maintained by periodic student reports on activities, by three progress reports, and a final report.

The project resulted in two master's papers and numerous exposures in the news media. A project display was viewed by approximately 9,000 people at the Kansas State University Open House. Presentations concerning the project were made to several technical organizations, as well as papers writtern for professional journals.

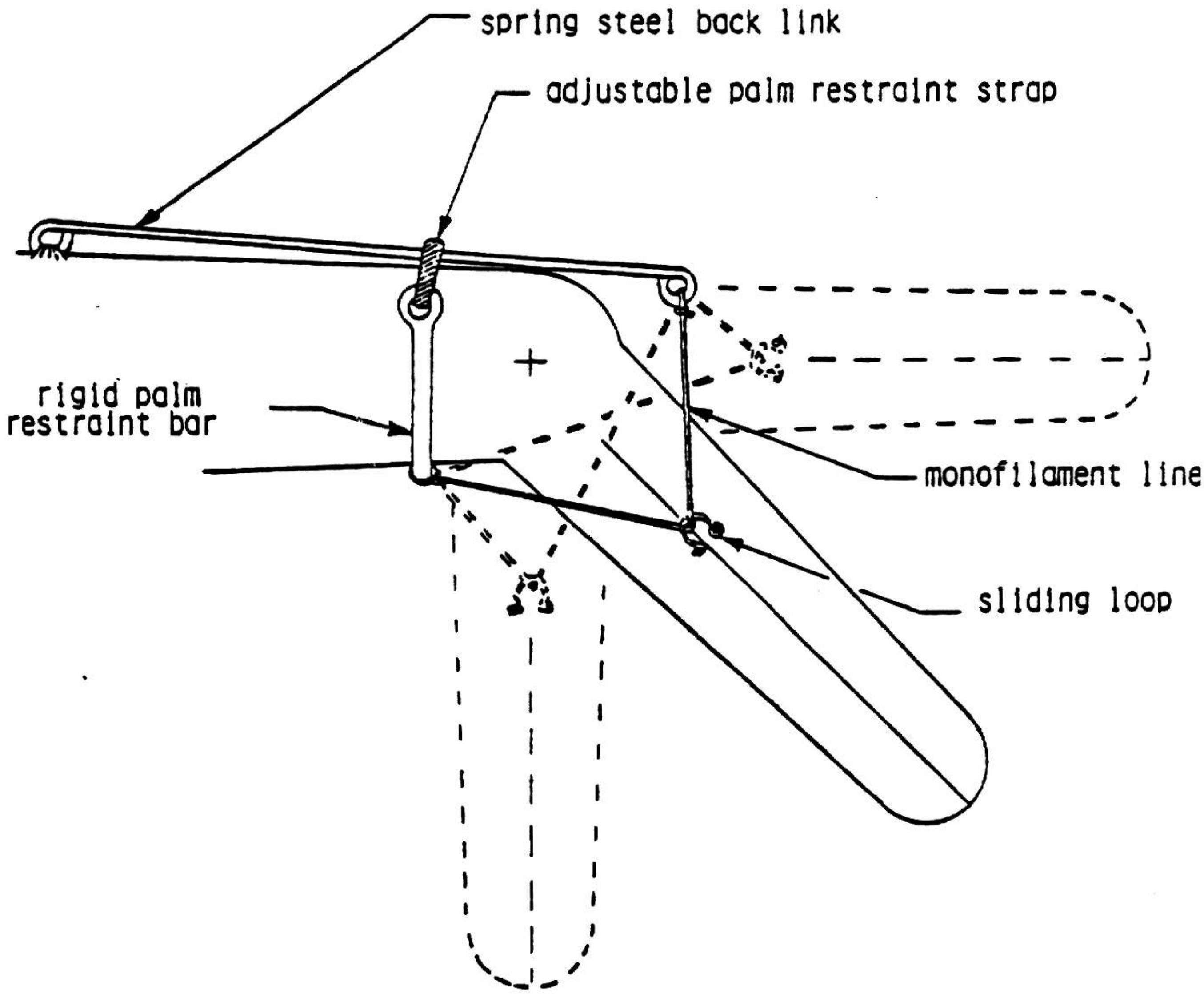
The glove design project evolved through several typical design steps. These included the initial idea sessions, an organized literature search, and the creation of a problem statement. Early in the project, the problem was more clearly

understood when the team tested a work glove with a bladder and a palm restraint bar in a vacuum chamber. The specific design problem was further defined by communications with and trips to NASA. After defining the problem, an experimental and theoretical method for design was selected, with over 30 models being constructed and tested. This method produced immediate, concrete results. In the final step, communication skills were required for organizing and preparing a final report and presentation.

The final glove design allows the individual movement of the joint between the metacarpal and the first phalangeal bones of the fingers. The individual movement was considered an obtainable goal over the less complicated problem of these joints moving as a unit. Additional features of the final design is the minimal force necessary to flex the joint and the absence of a restoring force to return the joint to the original position once it has been flexed.

The design concept is shown in Figure 38 (see next page). The glove contains a palm restraint bar which is needed to decrease ballooning and to provide fastener locations. Excess material at the joint is provided for movement. Each finger is restrained with a line and loop system which carries the axial pressure loads. The restraint consists of nylon lines running from the palm restraint through metal loops located on the sides of the fingers to tie points on links extending from the back of the glove. This allows the fingers to move in an approximately circular motion about the metacarpophalangeal joint. The metal loops provide less friction than polyolefin tubing (which was tested first). The restraint layer is made from ripstop and plain weave polyester fabrics provided by ILC Corporation. A polyester triaxial weave material was tested but found only to be an advantage in pattern layout.

The design is simple in pattern development and is adaptable to the present manufacturing techniques used by ILC. The use of tie beads provides precision adjustment of the loop lines which allows the glove to be customized for different size hands. These features can be easily incorporated into the present EVA glove design.



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INTRODUCTION

Proposal

The American Society for Engineering Education (ASEE) in conjuction with the National Aeronautics and Science Administration (NASA) issued a program request during the summer of 1984, offering to make one-year awards of up to $30,000 each to four different educational institutions for the design of an extravehicular activity (EVA) glove for the NASA space suit. The project had two main thrusts. The first, which was of interest to ASEE, was the method of establishing and managing design teams in an educational environment. The second, which was of concern to NASA, was the development of new ideas on how to gain more dexterity in the EVA glove under a higher internal pressure.

The format for the program was a design team competition. Eligibility for the competition was open to any group of undergraduate or graduate students, supervised by a recognized faculty member of a university.

Kansas State University submitted a proposal before the August 1, 1984 deadline, along with nine other proposals from eight other institutions. The KSU proposal described an interdiscplinary design team consisting of four faculty members with expertise in mechanics, textiles, ergonomics, and heat transfer, and a six member student team, consisting of one graduate and one undergraduate student from the departments of Mechanical Engineering, Industrial Engineering, and Clothing and Textiles. An application review panel, organized by ASEE, reviewed all submitted proposals. The following four teams were selected to receive funding: Kansas State University, The Massachusetts

Institute of Technology, The University of Oklahoma, and Worchester Polytechnic Institute. An award letter of confirmation from ASEE stated that John Lisack was the ASEE representative and Dr. Vic Vykukol (NASA - Ames) was the NASA represenatative coordinating the program. (Later in the project the NASA representative was changed to Mike Rouen at the Johnson Space Center in Houston.)

The four design teams were to work independently from September 1984 to May 1985 to design the best possible glove. In May 1985, a panel of engineers and scientists judged the submitted designs and determined Kansas State University to be the winner. Their design team, as well as all other design teams, was invited to view a space shuttle launch.

The design team competition was intended to provide engineering students with an opportunity to work as a design team to help solve a real design problem. Both ASEE and NASA view the glove design competition as a model for possible future projects. The program not only benefits the universities, but serves ASEE's function in engineering education, while introducing new innovative design ideas to the scientists and engineers at NASA. It also allows interaction between the universities and government in areas of mutual interests.

Background of the Problem

With the advent of the space shuttle and plans for a permanent space station, NASA anticipates a significant increase in extravehicular activities (EVA) as a major element of space operations. NASA generally is satisfied with the advances made in space suit technology. The space suit has progressed to the point where astronauts can efficiently perform complex tasks in space. However, the gloves are performing below par from both a dexterity and effort viewpoint.

The problem is the lack of nitrogen in the space suit atmosphere due to the lower suit pressure, which causes unacceptable delays in EVA missions. The space shuttle cabin pressure is maintained at 14.7 psi while the EVA suit pressure is maintained at 4.3 psi. This pressure differential requires astronauts to follow a complicated routine of a "pre-breathing protocol", which can take up to three hours, before donning their suits for going EVA. The purpose of this prebreathing is to purge nitrogen from the body. If the astronauts did not complete this procedure, the pressure change from cabin pressure to suit pressure would cause the bends. (This is a painful condition brought on by gaseous nitrogen coming out of solution in the blood.) The consequence is that an astronaut can not put on a suit and immediately go EVA; this makes repeated EVA missions a problem.

To avoid the time-consuming nitrogen purge procedure, NASA wishes to build an EVA suit that will operate at a higher pressure of 8 psi. This increased pressure will allow nitrogen to be included in the suit atmosphere, and therefore decrease the likelihood of contracting the bends. Some experts predict that a more acceptable suit pressure may be as high as 9 or 9.5 psi (Dr. Lt. Col. Bill Harvey, telephone conversation, November 7, 1984).

Increasing suit pressure causes major problems in glove design. Mobility design characteristics that are acceptable at

4.3 psi do not work efficiently at the higher 8 psi pressure. In addition, the increased pressure makes it more difficult to incorporate glove design features that counter the mobility restraints caused by the higher pressure difference.

The efficiency of the suited astronaut is heavily dependent on the use of the hands to perform tasks. Astronaut William Fisher says, "The hands are everything; it's no use going to an improved suit if the hands can't be improved." (Astronaut William Fisher, telephone conversation, October 17, 1984). Therefore, NASA has identified space suit glove technology as an area needing innovative design concepts for future development. The new 8 psi design requires a fresh approach and innovative ideas that consider the human hand's extreme complexity. This is one reason NASA has invited universities to study the problem.

NASA believes the present glove can be improved through new ideas, materials, and manufacturing. Thus the KSU student design team worked on the development of innovative design concepts for the glove. The design approaches considered were determined by the students. The student design team used materials currently used in the EVA glove and evaluated other materials as well. The goal was to deliver to NASA prototype gloves which incorporated the team's designs.

Team Organization at KSU

For the project, a variety of technical disciplines were needed: thermal design, mechanical design, ergonomics, textiles, and functional clothing design. Each area had to be considered and integrated into the glove design. To accomplish this, the project consisted of an interdisciplinary student design team. The students represented the fields of industrial engineering, mechanical engineering, and clothing and textiles, with one graduate student and one undergraduate student from each area. Each team member provided a specific technical background and interacted directly with all other group members.

The project was a student project with the students responsible for the planning, making decisions, carrying out the work, and reporting the results. The student involvement included attending formal weekly meetings, preparing progress reports and demonstrations, actively participating in project development, and maintaining accountability for individual contibutions to the design effort. In depth involvement was expected from each team member.

The students selected for the design team were: Nesby Bolden, graduate student in industrial engineering; Kim Ellis, undergraduate student in textile science; Jon Held, graduate student in mechanical engineering; Janice Huck, graduate student in clothing and textiles; Carlyn Solomon, undergraduate student in industrial engineering; and Paul Stephens, undergraduate student in mechanical engineering.

All team members served on the design team during the 1984 fall semester and the 1985 spring semester. For their participation, each graduate student received three semester hours credit for a graduate level problems course from his/her department. The undergraduate students received a total of four semester hours credit in honors research and/or senior design project courses.

The faculty advisory group had experience in interdisciplinary research design projects and provided the diverse technical expertise needed. They were: Dr. George Eggeman, Assistant Professor of Mechanical Engineering; Dr. Byron Jones, Associate Professor of Mechanical Engineering; Dr. Stephan Konz, Professor of Industrial Engineering (project coordinator); and Dr. Elizabeth McCullough, Associate Professor of Clothing and Textiles. Their respective areas of technical expertise are mechanics, heat transfer, ergonomics, and textiles.

The faculty served primarily as resource people. They indicated possible sources of information, served as consultants on technical matters, provided outside contacts, and arranged for the use of specific facilities and equipment. During the beginning weeks of the project, the faculty presented background reviews on various topics of engineering and textile science. Dr. Konz made presentations on "The Design Process" and "Hand Tools", Dr. Jones on "Heat Transfer and Thermal Protection of the Hand", Dr. Eggeman on "Engineering Mechanics", and Dr. McCullough on "Concepts in Textiles and Apparel Manufacturing".

Periodically the faculty also reviewed and critiqued the team's progress reports and graded each student's contribution to the project. The student grades were determined by the entire advisory group. To aid in the evaluation, students made five minute presentations describing their specific contributions to the project. These presentations were conducted in front of the entire team at the end of each semester, and covered that semester's activities.

The six students and four advisors met formally for one hour each week throughout the project (except during student vacations). This time was used for project planning, intra-team communications, administrative matters, and the delivery of oral technical presentations by students or advisory committee members. Specific short-term and long-term task assignments for individual members of the team were delegated at the meetings also. A typed agenda was circulated at least one day before each weekly meeting; minutes for each meeting were recorded by a specified student. This student recorded and distributed the minutes for one month and was succeeded by the next student according to alphabetical order.

The students chose Jon Held to be the student project leader. He presided over the project meetings, as well as the student meetings. During the last two months, Janice Huck assumed administrative duties as Held concentrated on glove designs.

Outside of the regularly scheduled meetings, the students worked individually or in small groups to develop various aspects of the project. During this time the students interacted with individual faculty on a one-to-one basis or in small groups. All members of the design team provided significant technical contributions and became familiar with the work of the other team members.

Information Development

The money allocated to the project allowed the team to maintain contact with NASA and various other organizations and industries. With NASA, this interaction occurred through reports and printed material, KSU progress reports (which we encouraged them to critique and return to us), telephone communications, and through travel to these facilities for consultation. The travel included one visit to NASA at Ames and three to NASA at Houston. This travel allowed the team to obtain information during various stages of the project. Interaction with other organizations was through telephone calls, letters, printed materials, as well as personal visits by members of the design team. Locations visited included the Kansas Cosmosphere and Discovery Center in Hutchinson, Kansas and ILC Corporation in Fredrica, Delaware. Consulting with personnel at all four locations proved to be quite helpful. Details of these visits are described later.

Additional information and criteria for the project, including detailed design parameters (i.e. glove size, safety factors, structural loads, etc.) were supplied by NASA during our October 19, 1984 visit to Houston by five team members. In January, two team members visited ILC Corporation, the present manufacturer of the glove, to gain additional information on the glove construction. Five team members made an additional trip to NASA Houston in March to have NASA critique our prototype glove and determine what additional design factors should be considered. Two team members visited NASA Houston in May 1985 for a final review of KSU glove prototypes and the final written report.

Literature Review. During the early stages of the project, an extensive literature search was conducted to gain information about the design topic. Some of the sources used were a computer search, investigation of the NASA - Houston library, as well as reviewing NASA films. With the exception of one report from the Illinois Institute of Technology (Exploratory Development of Pressure Suit Mobility Joints, Gloves, and Helmet), the literature review did not give the team much useful information regarding the EVA glove design.

Progress Reports. As stated in the original proposal, three progress reports were prepared by the design team and submitted to ASEE and NASA on the dates specified in the proposal. (See Table 1.) This was an important part of the design project since each report was used as a tool to determine what had been accomplished and set priorities for future work.

Table 1. The Project Schedule for Written Reports

Date	Report	Appendix
November 1	Progress Report #1	A
December 20	Progress Report #2	B
February 15	Progress Report #3	C
May 15	Final Report	

The progress reports also allowed ASEE and NASA officials to monitor the progress of the design team. The progress reports were prepared by the student design team; they were distributed to the individuals listed in Table 2.

Table 2. Progress Report Distribution Roster

Representative	Organization
Dr. Hubert Vykukol	NASA - Ames
Mr. Mike Rouen	NASA - Houston
Dr. George Nelson	NASA - Astronaut
Mr. John Lisack	ASEE
Mr. Max Ary	Kansas Cosmosphere
Ms. Ruthan Lewis	Lockheed - Houston
Faculty Advisory Members	KSU
Design Team Students	KSU

Trip to NASA - Ames. The project began on September 1, 1984. The first visit to NASA was made on September 12, 1984. Dr. George Eggeman met with Dr. Vic Vykulol at NASA - Ames to discuss project design criteria. This was an important first step in defining the problem.

In preparation for the trip, the team compiled a list of questions for Eggeman to ask Vykukol. The questions were the result of a brainstorming meeting where many different ideas were discussed. When Eggeman returned, he presented to the group a verbal and written report on these questions. This narrowed the scope of the project and focused the team on developing a problem statement. See Appendix D for the NASA - Ames trip report.

NASA - Houston was unable to schedule a visit with the design team until October 19, 1984.

Trip to Cosmosphere. As a source of possible information, the team contacted Mr. Max Ary, Executive Director of the Kansas Cosmosphere and Discovery Center, in Hutchinson, Kansas. Mr. Ary sent material containing information about the EVA space suits and gloves used in Mercury, Gemini, and Apollo space programs.

Eight group members (Bolden, Ellis, Held, Huck, Jones, McCullough, Solomon, and Stephens) visited the Cosmosphere on October 16, 1984 to examine the exibits on display and interview the staff personnel.

The technician who worked in suit restoration and his assistant spoke to the group. The design group members examined the collection of gloves and exhibits which were on display. The team members also examined a larger collection of gloves, suits, boots, helmets and tools that were not available for viewing by the general public.

Max Ary allowed the design team to borrow certain items: an Apollo EVA glove, a glove prototype with fingernails, a pair of unused Apollo glove bladders, and a boot with Kapton layers interspaced with marquisette net. Items that the Cosmosphere donated to the design team included two Chromel finger gloves used on EVA and a fabric swatch of Beta fiberglass cloth.

During the visit to the Cosmosphere, Dr. Elizabeth McCullough tape recorded our discussion and later distributed a typed to all team members. A summary report on the visit is contained in Appendix E.

First Trip to NASA - Houston. The design team sent five team members (Bolden, Held, Huck, Konz, and Solomon) to the NASA facilities at Houston on October 19, 1984, to further define the problem, the expectations, the objectives, and to obtain answers to questions.

Before the trip, the team contacted NASA to obtain information about the visit and to present to NASA officials a compiled list of topics for discussion. The team also requested a meeting with astronauts and permission to visit the NASA library. The idea of making several trips to Houston to receive information throughout the duration of the project was accepted by NASA.

This trip to NASA gave more of the members a chance to interact directly with NASA personnel at a detailed technical level. The formal presentation at Houston was approximately two hours long. In the remaining time, the design members spent an hour interviewing Astronaut Dr. George Nelson (NASA glove expert) and visited other potential information sources at the NASA Houston campus.

Each student who attended the trip to Houston recorded notes which were compiled into a trip report. (See Appendix F.) Jon Held gave an informal report of the trip to the entire team at the next team meeting and presented pictures he took during the visit. The group brought back a short film on EVA (NASA Movie HQ 309 "Space Shuttle: EVA" from Johnson Space Center Public Relations Branch) which was shown at the end of the meeting. The team also received "Teacher's Packets" which were available for the team members to review.

The NASA trip enabled the group to refocus goals for the project. At this time the metacarpal and thumb were designated as primary design areas.

Trip to ILC Corporation. By the start of January, the problem had been better defined and several models had been designed, built, and tested. With this background, a trip to ILC (the current manufacturer of the EVA glove) was considered as a worthwhile venture. The intent of the trip was to learn more about the design, manufacture, and construction of the EVA glove. Two students (Ellis and Held) visited the facilities at ILC on January 7, 1985. The students took a list of compiled questions and the latest KSU prototype glove for possible testing and comments by ILC engineers.

Information obtained from ILC greatly helped the students with material selection, glove assembly, and manufacturing criteria. During the visit, ILC supplied the team with enough materials to construct a glove prototype using the present 'state of the art' fabrics. Pictures also were taken to illustrate some of the manufacturing and test procedures. Upon their return, Ellis and Held discussed their visit with the design team. A summary report on the visit is included in Appendix G.

Second Trip to NASA - Houston. On March 8, 1985 five members (Eggeman, Ellis, Held, Jones, and Stephens) of the team visited the Johnson Space Center. The KSU design progress was discussed and several glove prototypes were tested.

A design meeting was held with Mike Rouen and his supporting staff. The most significant finding was that Rouen was expecting the fingers to move as one unit at the metacarpal joint (i.e. only a power grip). He believed that the bending of individual fingers should be addressed at a later stage of the program.

Several gloves designed by KSU, along with several NASA gloves, were tested in the NASA vacuum chamber. In the tests, flexibility of the metacarpal joint was studied. The trip report is included in Appendix H.

Third Trip to NASA - Houston. On May 15, 1985, Held and McCullough visited NASA - Houston to show NASA officials the final KSU designs and the final written report.

Interaction with ASEE and NASA Officials. Several telephone calls were made with John Lisick and F.X. Bradley at ASEE headquarters. Most of these contacts concerned arrangements for budget and final project meeting. Bradley visited KSU on January 24, 1985, and met with the KSU administration, faculty advisors, and the student team. He later prepared a report for ASEE concerning the design team's progress.

Throughout the duration of the project, correspondence was maintained with Mike Rouen through telephone conversations and by mail. Documentation of the phone calls and literature received from Rouen is included in Appendix I.

Interaction with Lockheed - Houston. On October 23, 1984, Dr. Stephan Konz attended a session, organized by NASA and Lockheed, at the Human Factors Society meeting in San Antonio. This led to a number of telephone converations between Konz and Ruthan Lewis of Lockheed in Houston. She sent to the design team material listed in Appendix J; this gave us a much better understanding of how the glove will be used.

Interaction with David Clark Company. The design group telephoned the David Clark Company, a firm doing research on EVA glove design. The company informed the group that they were under orders not to talk to any of the EVA glove design teams.

GLOVE DESIGN

Definition of Glove Design Problem

The definition of the design problem was to design a space suit glove to enhance singular flexibility of the individual fingers at the metacarpal (metacarpophalangeal) joint while pressurized at 8 psi.

As in most design projects, the original goals were modified and evolved from ideal expectations to an acceptable condition. In the original project announcement, NASA stated that the scope of the design task would be limited to the fingers, thumb, and palm areas of the glove, with the wrist joint excluded. Manufacturing repeatability also was to be considered in the design.

After contact with NASA - Ames, the nature of the glove design problem was better defined. NASA was satisfied with a wrist joint which was in the developmental stage. The major areas of concern were the metacarpal and thumb flexibility. Finger flexibility was not a problem in the present design. Eventually the thumb flexibility was removed from the design problem.

The constraint of individual movement of fingers versus all fingers moving as a unit was not discussed until near the end of the project. In March 1985, it was discovered that NASA only expected to be able to move the fingers as a unit (i.e., the power grip). In the meantime, the KSU team has solved the more difficult problem of individual finger flexibility (i.e., pinch and precision grips as well as power grip). Therefore, the problem statement included the individual movement of each finger at the metacarpal joint and was considered by the KSU team to be an acceptable goal.

The biggest design problem of EVA space suit gloves is rigidity resulting from the pressure difference between the inside of the glove and the surrounding vacuum of space. Work must be applied to flex the joints; this results in fatigue and abrasion on the astronauts' fingers. The problem is compounded with the human hand, which has a multi-axis capability of movement. An additional problem is the glove's bulk, which is needed for thermal protection, micrometeroid protection, and abrasion resistance.

The most important design challenge was to maintain constant volume in the joint area throughout the bending motion. Work is done when the volume of the metacarpal bladder is decreased:

$$W = -\int P \, dv$$

where

W = work

P = pressure

v = volume

When considered on the whole, pressure remains essentially constant in the glove; therefore, the pressure term can be moved from under the integration:

$$W = -P\int dv$$

To reduce the work necessary to bend the metacarpal joint (or any joint), volume change must be minimized. This will be especially important with the pressure increase from 4.3 psi to 8 psi.

In addition to the work due to volume changes, it also was necessary to address the static forces caused by the pressurization. When pressurized, the glove will expand to maximize the volume within the constraints provided by the glove fabric, restraint devices added to the glove, and the hand in the glove. The desired goal was to have the glove exert minimal moments about the hand joints regardless of how the hand is bent.

In order to understand these forces, the concept of a neutral axis must be understood. This axis passes through the centroid of a glove cross-section. There is no net moment about the neutral axis due to pressure. If the glove is constrained along this axis, there is no net moment about the restraint and hence, no bending forces. Moving the restraint axis away from the neutral axis will cause the glove to bend in that direction until: (1) an additional constraint is encountered on the other side of the neutral axis, or (2) the cross-section distorts so that the neutral axis shifts until it is realigned with the restraint axis, or (3) an offsetting moment is applied (i.e., the astronaut's hand restrains the glove).

"Manloads" were another major design consideration. The space suit must have arms shorter then an astronaut's arm length. When the hands are directly in front of the chest with elbows bent sharply, the finger tips will be at the glove finger ends only if the arms of the suit are shortened. Thus, the astronauts cannot fully extend their arms. The loads on the suit created by an astronaut trying to straighten their arms are called "manloads." These loads are much larger than the pressure loads, and do not affect flexibility. The loads are carried in the fingers by the seams located between each finger. (See Figure 1.)

Loose fabric in some manner must be available at the metacarpal area to allow for flexibility. Any design enhancing metacarpal flexibility will have to prevent the fabric around the joint from carrying axial loads.

Basic principles of kinematics and mechanics were used in the metacarpal joint design. Detailed analysis of small sections of the metacarpal joint was not considered because of the complexity of joint movement when the fingers bend independently. Instead, an experimental approach was taken. Glove design ideas and concepts were developed. Then glove models incorporating the ideas or concepts were constructed, tested, and evaluated. These models were pressurized from 1 - 10 psi to subjectively determine their behavior and ease of flexibility.

The first models, constructed early in the project, were used primarily as study aids to evaluate joint behavior under pressurized conditions. These large scale models were constructed from inexpensive cloth. Later in the project, a series of gloves incorporating design ideas were constructed and evaluated while pressurized.

NASA expectations for final presentation varied. Mike Rouen (NASA - Houston), suit engineer at the Johnson Space Center, felt the challenge to the design teams was to balance the requirement for handling the pressure load with the need for manual dexterity, while reducing the bulkiness of the glove as much as possible. Rouen's expectation for the project was an innovative metacarpal joint for an EVA glove. He wanted at least a final

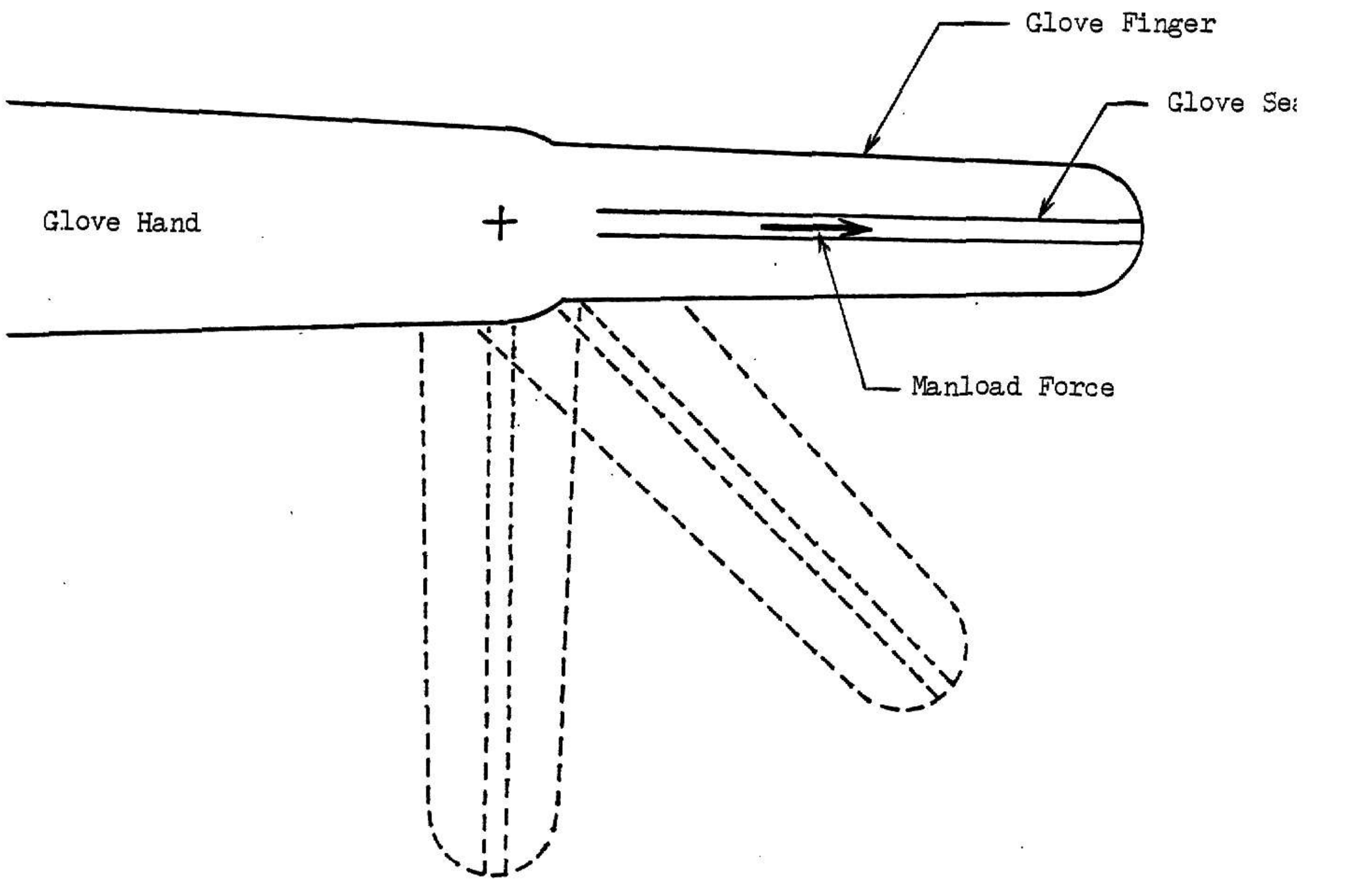


Figure 1. The Seams on the Finger of the Glove Carrying the Manload Forces

idea on paper. If a prototype was constructed, the appearance was not a major concern as long as the glove was designed for an 8 psi pressure differential.

Dr. Vykukol (NASA - Ames) was concerned with the development of ideas, material types, and manufacturing processes. He wanted to have a prototype if possible, but realized the cost or work required may prevent it.

Model Evaluation Test Equipment

Models were pressurized in one of two ways in order to evaluate their performance. The most common method was the modified bell jar. Two bell jars were used, one was glass and the other tinted plastic. Because of the safety advantages of using the plastic bell jar, it was used for most model evaluations even though it was more difficult to make observations with it. The glass bell jar was predominantly used when visibility was very important during testing and for public demonstrations.

When models were pressurized in the bell jars, the models were attached with a hose clamp to a 4" diameter PVC tube. The PVC tube was connected to an inner tube sealing device. This sealed a 6" diameter opening in the bell jar. This design allowed the user to insert a hand into the pressurized model to test flexibility. Figures 2 and 3 show the bell jars with associated equipment.

The partial vacuum was created in the jar with a vacuum pump while the model protruded into the jar. Thus the interior of the model was at atmospheric pressure and the exterior (the jar interior) was 1 to 10 psi lower. A vacuum gauge, regulator, and

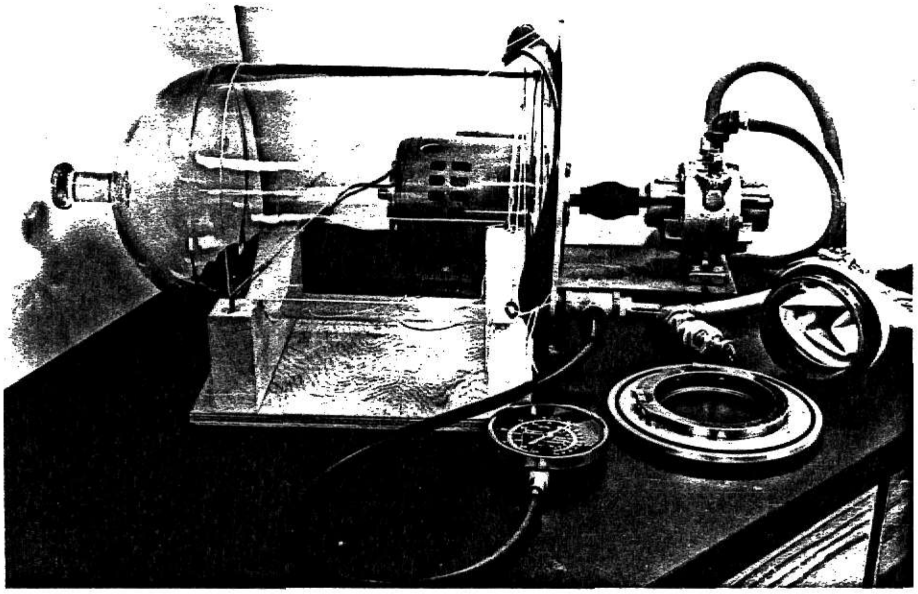


Figure 2. Glass Bell Jar

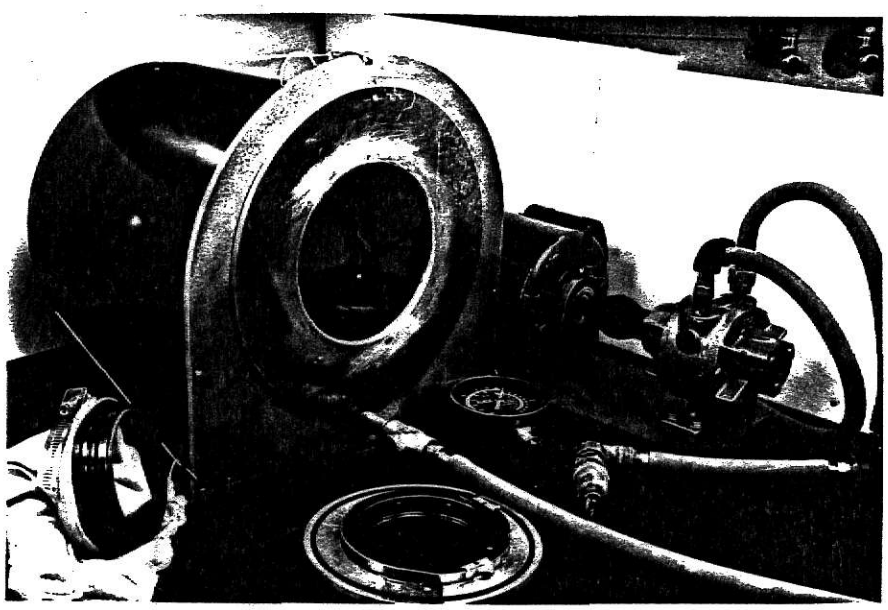


Figure 3. Plastic Bell Jar

safety release valve were included in the equipment.

The second method of pressurizing involved inflating the model with compressed air. This method increased the glove interior pressure from 1 to 10 psi over atmospheric pressure. After mounting the model onto a stand which closed the open glove end, an air hose, connected to a compressed air line, delivered air into the model. A pressure gauge and regulator were used to measure and control the pressure. (See Figure 4.)

As requested by Bradley of ASEE in March 1985, the KSU design team supplied this equipment for the other design teams to evaluate their glove prototypes in Washington, D.C..

Development of Design Principles

The first series of models were constructed to simply study the problems associated when bending a pressurized joint. They were intended to provided a basic understanding of the principles upon which the later glove designs would be based.

Pressurizing Joint Test. Model 1 was used to study the concept of bending a pressurized cylinder and to determine the effect that additional joint material had on flexibility. This extra material was provided by using pleats. The pleats were located on an 8" long, 6" diameter cloth cylinder. A plastic bag, inserted inside the model, served as the pressure bladder. (See Figure 5.)

When the model was pressurized, an unanticipated problem was discovered. The extra material provided by the pleats ballooned outward causing the model to tend to become spherical in shape. This effect took up any extra material provided by the pleats.

With the testing of Model 1, another important design

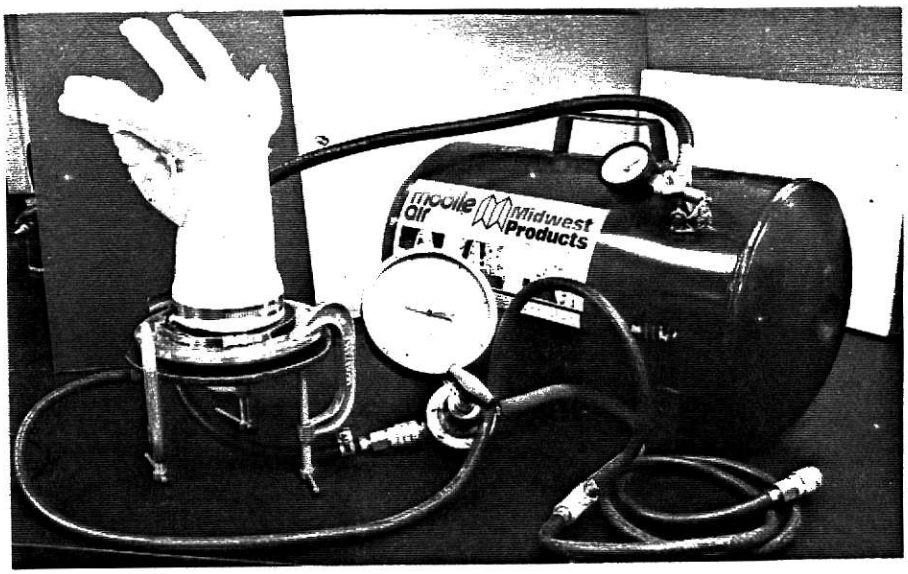


Figure 4. Model Mounted on Pressurizing Stand

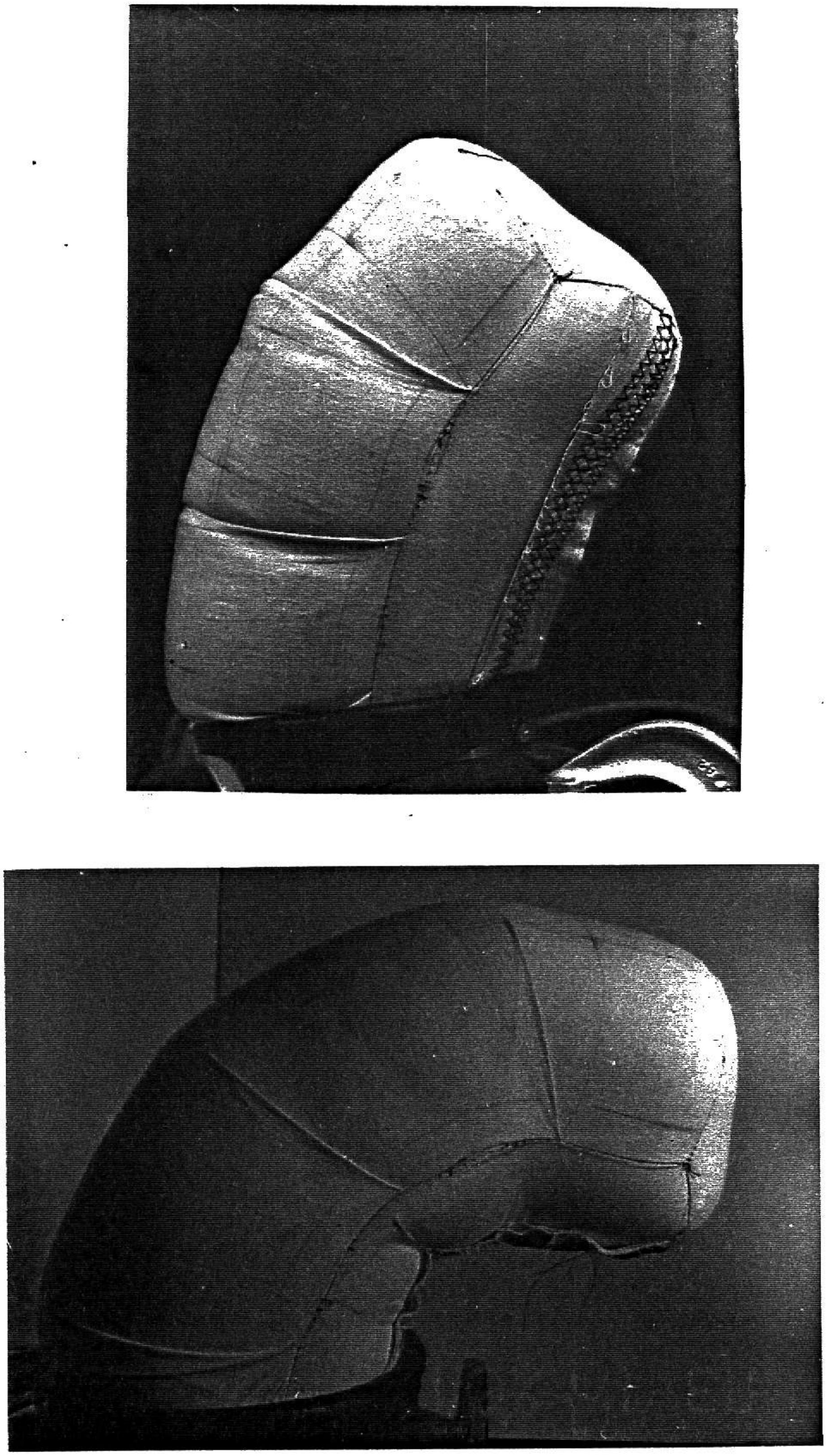


Figure 5. Model 1. Concept of Bending a Pressurized Cylinder

constraint was demonstrated. When the restraint axis was lowered, the cylinder assumed a curved shape when pressurized.

Testing of Different Types of Fabric Fullness. Fabric fullness may be controlled by the use of pleats, tucks, darts, or gathers. In the large scale models, several of these construction techniques were tested as a method to control ballooning and provide flexibility. The type of pleats investigated were box pleats, knife pleats, and gores.

1. Box Pleats. The box pleat model, Model 2, was constructed to determine the behavior of this type of pleat when pressurized. (See Figure 6.) The pleats were constructed in a fabric tube that was 4" in diameter and 8" long. A plastic bag was used for the pressure bladder inside the cylinderical cloth tube. The tube was closed at one end and open at the other. A wood end plate, 1/4" thick with a 4" diameter, was used to seal the cylinder's end. To secure the plate, a drawstring was used.

It was inflated to 5 psi in the bell jar and then flexed. Once inflated, the model expanded to maximize the extra volume provided by the pleats. This prevented the pleats from unfolding and refolding as the model was flexed. However, this model still possessed a high degree of flexibility because the pleats acted in essentially the same manner as gores (explained below).

2. Knife Pleats. Model 3 was constructed to investigate the behavior of pressurized knife pleats. (See Figure 7.) The model was constructed similar to Model 2, except it was constructed with knife pleats. When pressurized and tested for flexibility, the model behaved essentially the same as the box

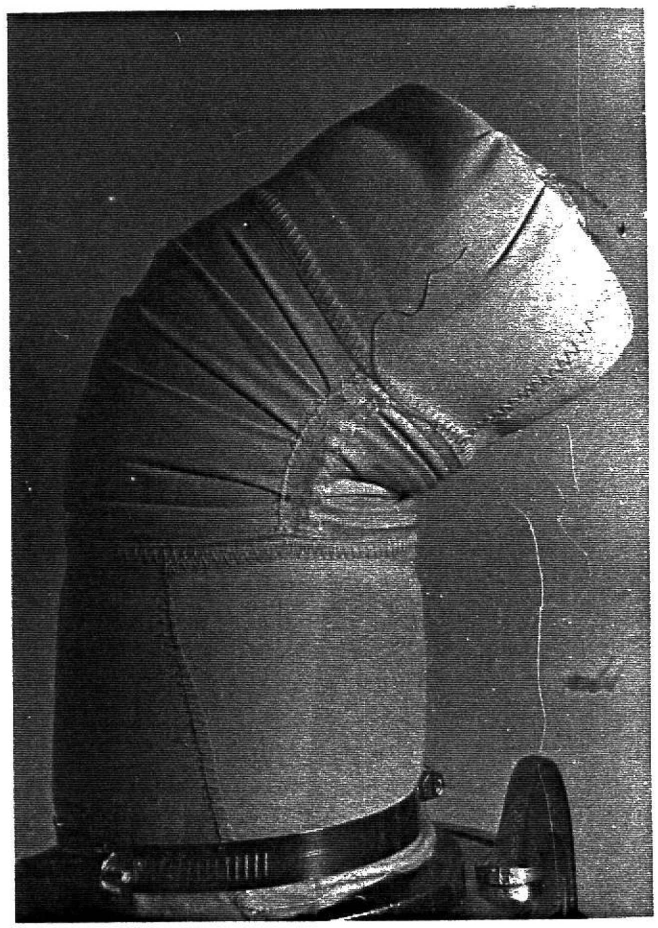


Figure 6. Model 2. Box Pleat Model

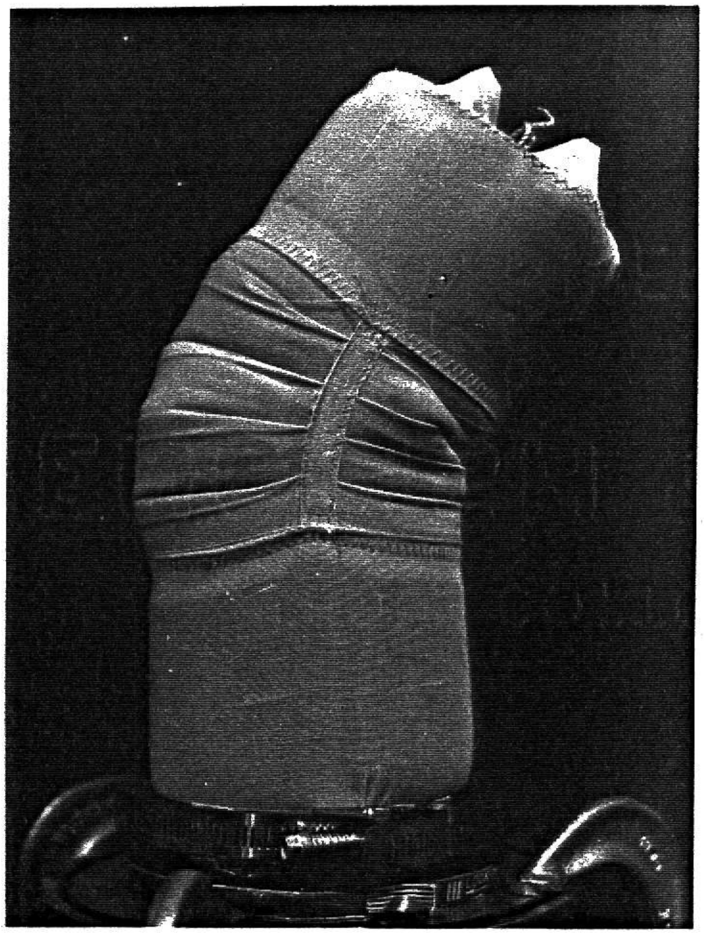


Figure 7. Model 3. Knife Pleat Model

pleat model.

3. Gores. The gore model, Model 4, was constructed similar to Model 3, except it was constructed with gores. (See Figure 8.) When pressurized and tested for flexibility, the model again behaved as the others.

At this point in the project, it appeared that the pleat construction technique used at the uniaxial joint was unimportant. What is necessary for flexibility is extra material located at the joint to allow for bending and centered side seam axes. It was now clear that a design must have loose fabric of some type, include a restraint axis that always concides with the neutral axis, and maintain constant volume. These three features are difficult to include in a metacarpal joint design due to the complexity of this region of the hand.

The next series of models were constructed to study methods of removing the restraint from the fabric sideseams. This was attempted by the use of simple linkages.

Testing of Linkages. Based on the theory that a parallel linkage can be used to maintain constant length during rotation, a parallel linkage idea was used to design a metacarpal joint that would maintain relatively constant volume. The linkage system, when attached to a finger, was designed to transfer the axial load on the fabric from the finger region to the fabric behind the metacarpal joint. (See Figure 9.) Thus, the fabric around the metacarpal joint was decoupled from the axial load. Several large scale models were constructed to evaluate this concept.

To test this idea, Model 5 was constructed. It attempted to

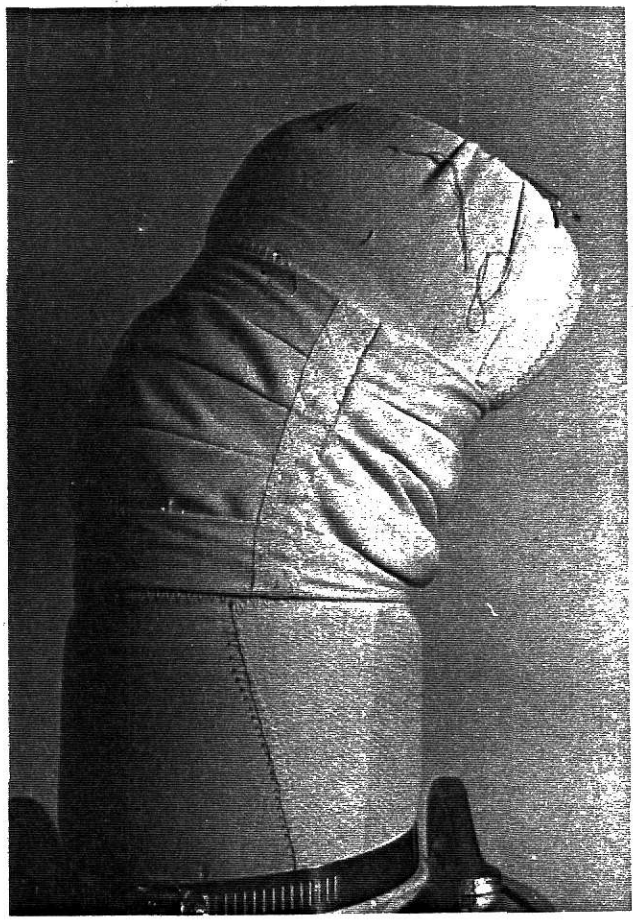


Figure 8. Model 4. Gore Model

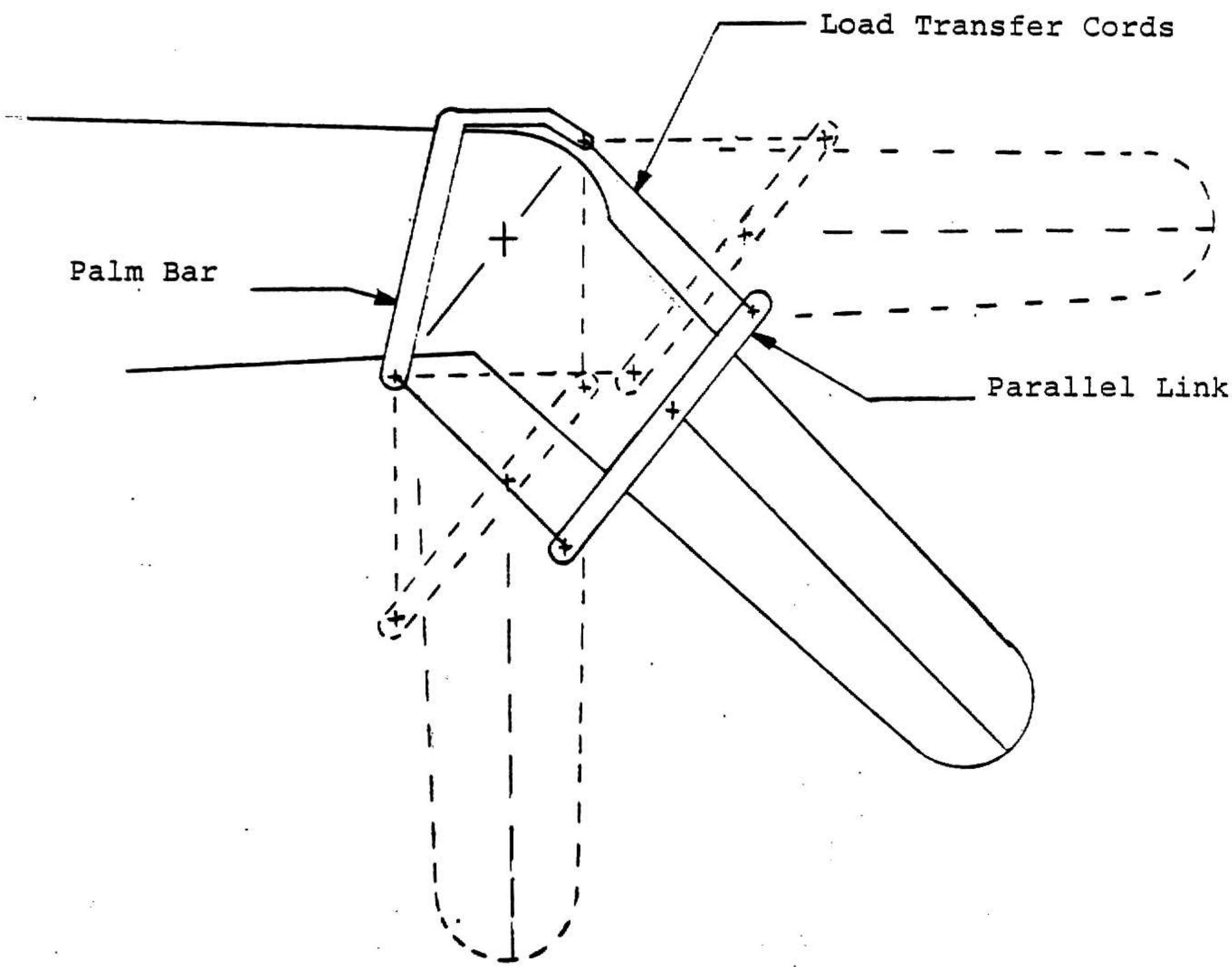


Figure 9. Theory of Parallel Links Applied to a Finger

maintain a constant circular arc throughout the motion path using linkages. (See Figure 10.) It was desired that the principles of the parallel linkage could be transfered to a working model and demonstrate high flexibility when pressurized. The model consisted of a cylindrical fabric tube with knife pleats on both sides.

The cylindrical tube used in Model 5 was sealed by applying a circular wood disk on the end of the cylinder. A small rod was attached across the back of the wood disk to secure the disk in place. Attached to the ends of the rod were two aluminum links. Four strings were secured around the opening of the tube; the other ends were tied to the links. A plastic bag was used for the bladder.

When the Model 5 was pressurized in the bell jar, ease of flexibility was determined. It was difficult to adjust the strings so that they were all the same length. When pressurized, a toggle action resulted, due to the straight section within the string lengths. The model assumed a bent position in one direction or the other as shown in Figure 11.

It was the intent of Model 6 to correct some of the problems discovered with Model 5. Due to the relative success of the knife pleats, they were used again in this model. The link was attached by bolts at the end of the pleated section of the tube. Figure 12 shows the completed model. When Model 6 was inflated in the bell jar, there was still a slight toggle associated with it.

Included on Model 6 was a bolt assembly to secure the link.

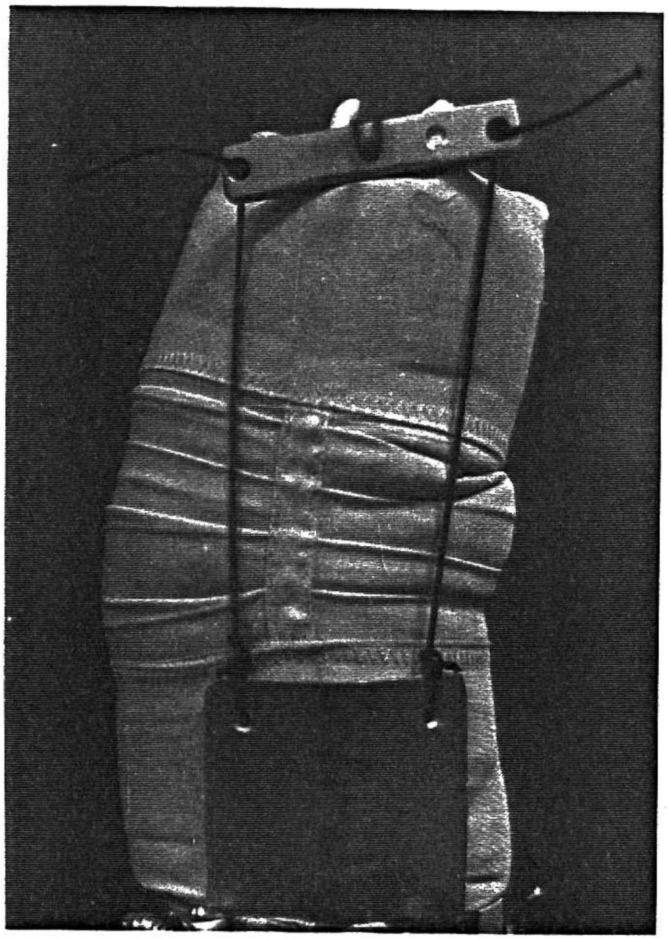


Figure 10. Model 5. First Large Scale Model Using Linkages

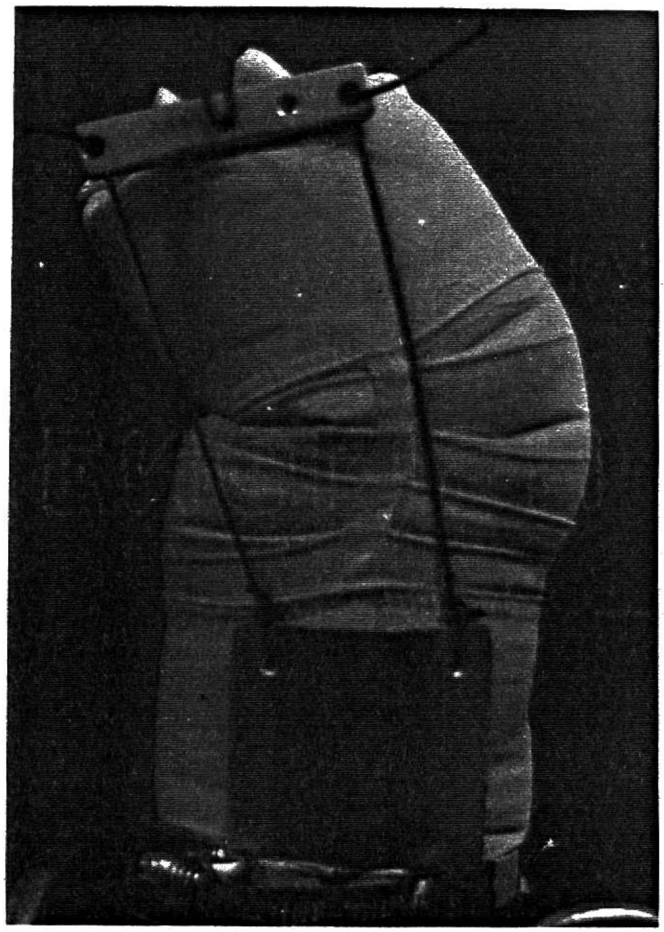


Figure 11. Model 5 Pressurized in Bent Position

Figure 12. Model 6. Large Scale Model with Knife Pleats and Shortened Linkages

Figure 13 shows the bolt assembly with flat washers and lock washers. Two layers of cloth with a flap were used to protect the bladder from the bolt assembly.

Since any type of pleats seemed to be satisfactory in the previous studies, Model 7 was constructed with no pleats. The model consisted of a simple straight tube, shortened by strings. Model 7 had the same bolt assembly used in Model 6. When the model was pressurized, a bad toggle resulted.

In Model 8, the link was formed in the shape of a triangle. (See Figure 14.) This geometry moved the center of rotation from the base of the linkage system to a location behind this base. The model, pressurized in the bell jar at 4 psi, was tested for ease of flexibility. When the model was flexed, the links splayed (twisted) outward. There also was a toggle associated with this model.

In Model 9, the triangular link was redesigned to position the lower attachment directly below the metacarpal axis. (See Figure 15.) Model 9 was pressuized in the bell jar at 3 psi. It splayed out, but not as much as in model 8. Model 9 still had a bad toggle associated with it.

Model 10 modified Model 9 by tying the top holes on the plates together and tying the bottom holes of the plates together. This was done in an attempt to reduce splaying. (See Figure 16.) Model 10 was pressurized at 3 psi in the bell jar. The modification reduced the splaying significantly and the tube assumed a natural bent position. Also, the bottom string formed a crease in the tube that made bending easier. It also was apparent that the cloth tube was too large in diameter and bulged

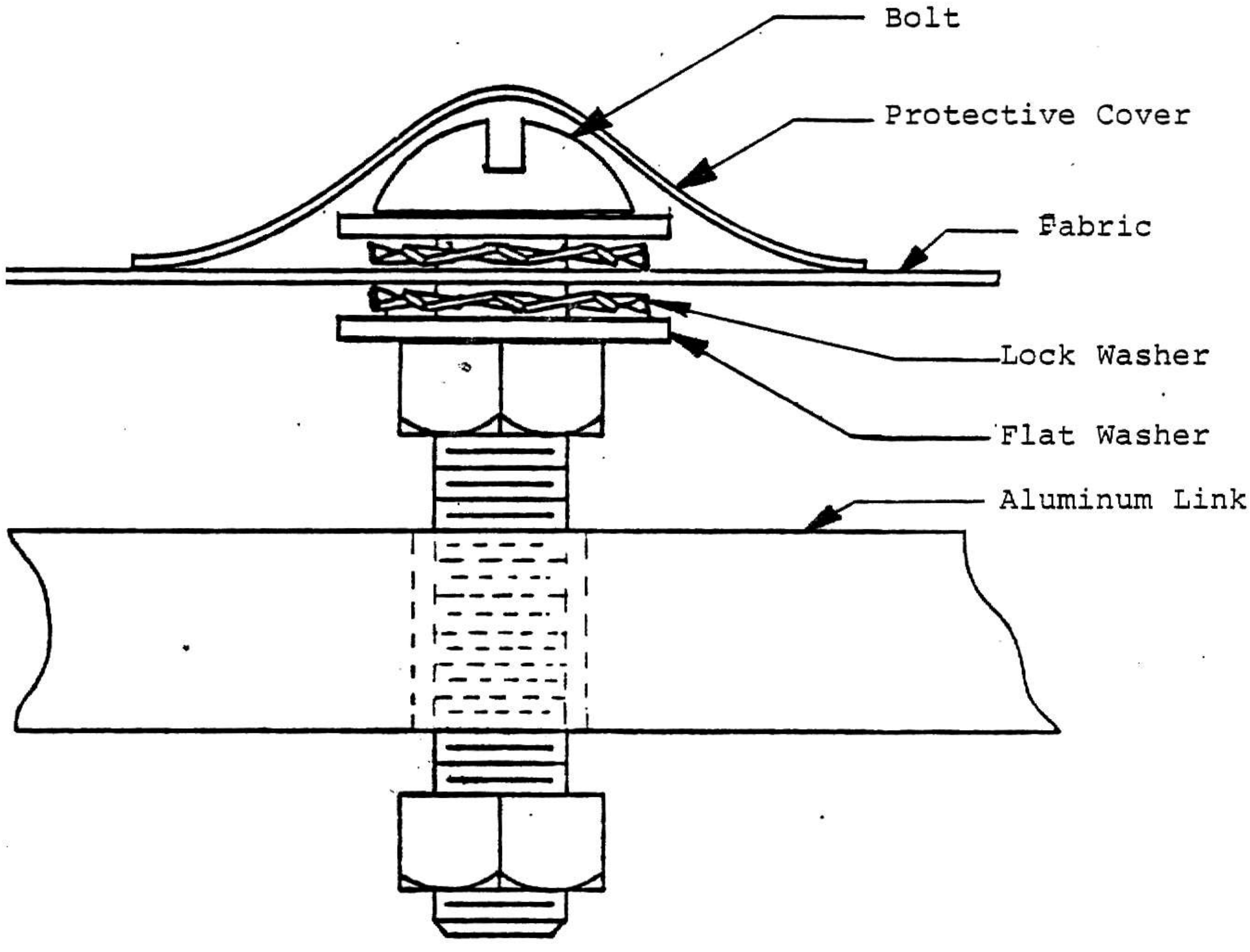


Figure 13. Bolt Assembly Used to Secure Linkages

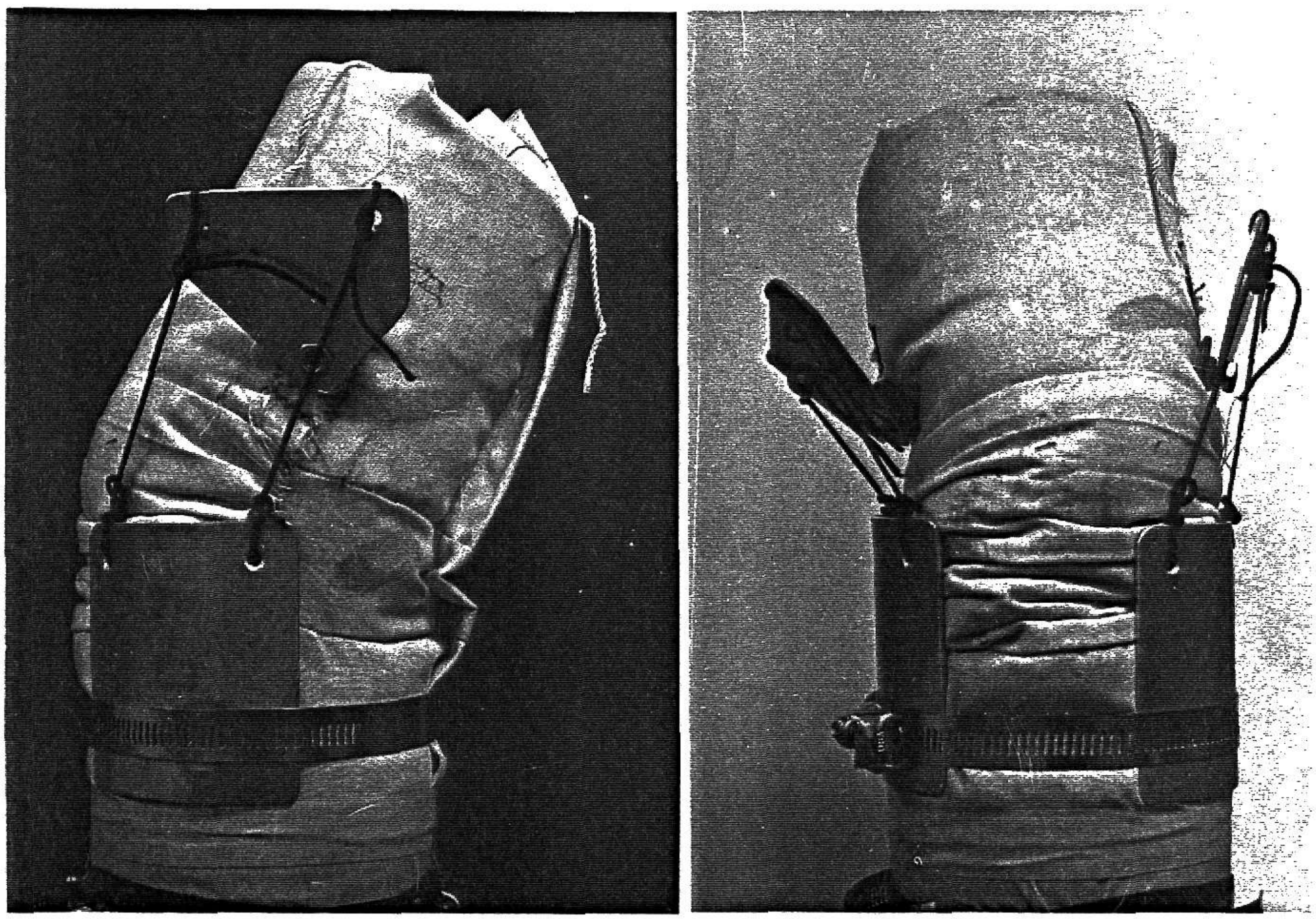


Figure 14. Model 8. Large Scale Model Constructed with Triangular Shaped Links

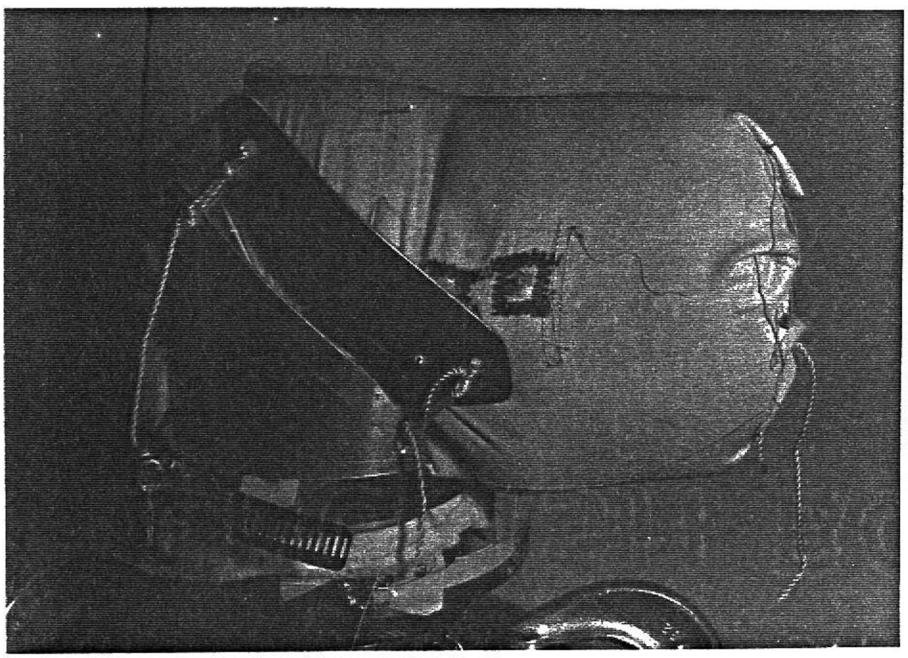


Figure 15. Model 9. Large Scale Model with Improved Triangular Links

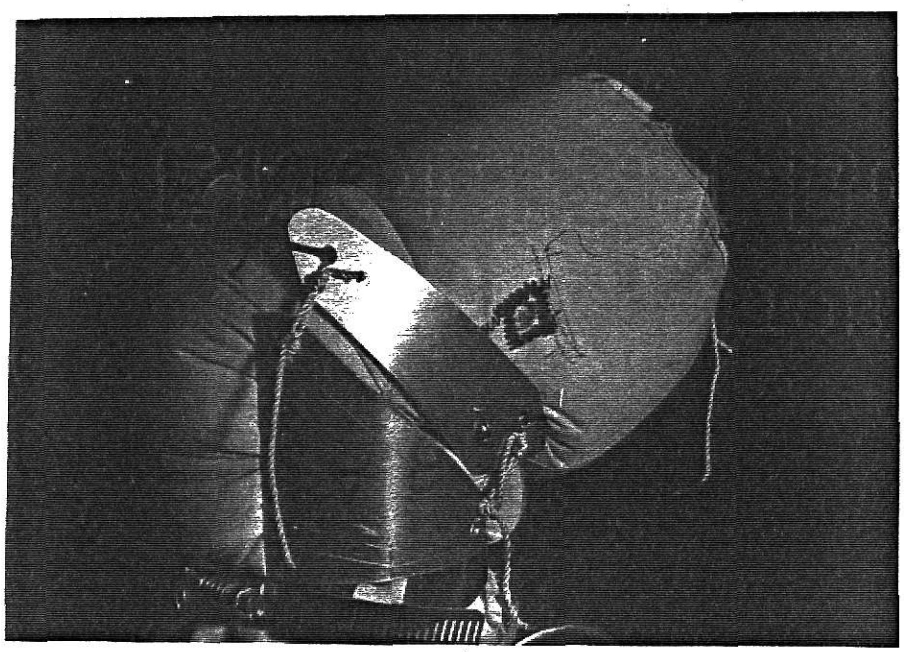


Figure 16. Model 10. Linkage Plates Used in Model 9 Secured Together

out at the top in the area between the aluminum sides. (See Figure 17.)

In an attempt to construct a model that would bend easily, Model 11 was designed and constructed. This design provided extra material at the joint. The pattern for Model 11 is shown in Figure 18. New wrap-around aluminum links were used in this model to eliminate the splaying experienced in previous tests. Wires were used to restrain the links instead of the strings used previously. Wires were used because of the difficulty encountered with tying the strings to equal lengths. (See Figure 19.) When pressurized, the model assumed a bent position and was difficult to move because the top part of the tube had a larger diameter than the bottom.

Model 12 was produced by modifying Model 11. The modification consisted of reducing the diameter of the top of the tube by constructing tucks. (See Figure 20.) This modification reduced the difference in diameters, but the model still acquired a bent position when pressurized.

Model 13 was constructed using the wrap-around alumimum links with the fabric cylinder used in Model 6. (See Figure 21.) Model 13 was modified further by reducing the tube diameter by sewing a seam along its length. This modification also lowered the restraint axis so that it was below the neutral axis. Model 14 went into a bent position when pressurized. However, the flexibility was better then previous designs.

Model 14 was made by reducing the top diameter of Model 13 by employing tucks on the top of the tube. When Model 14 was in

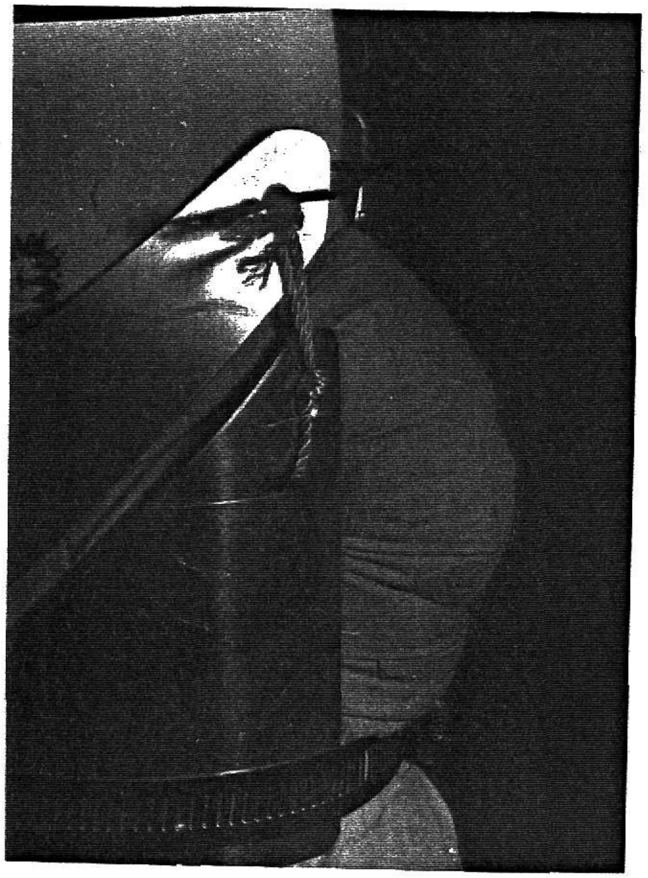


Figure 17. Model 10 With Fabric Bulging Out

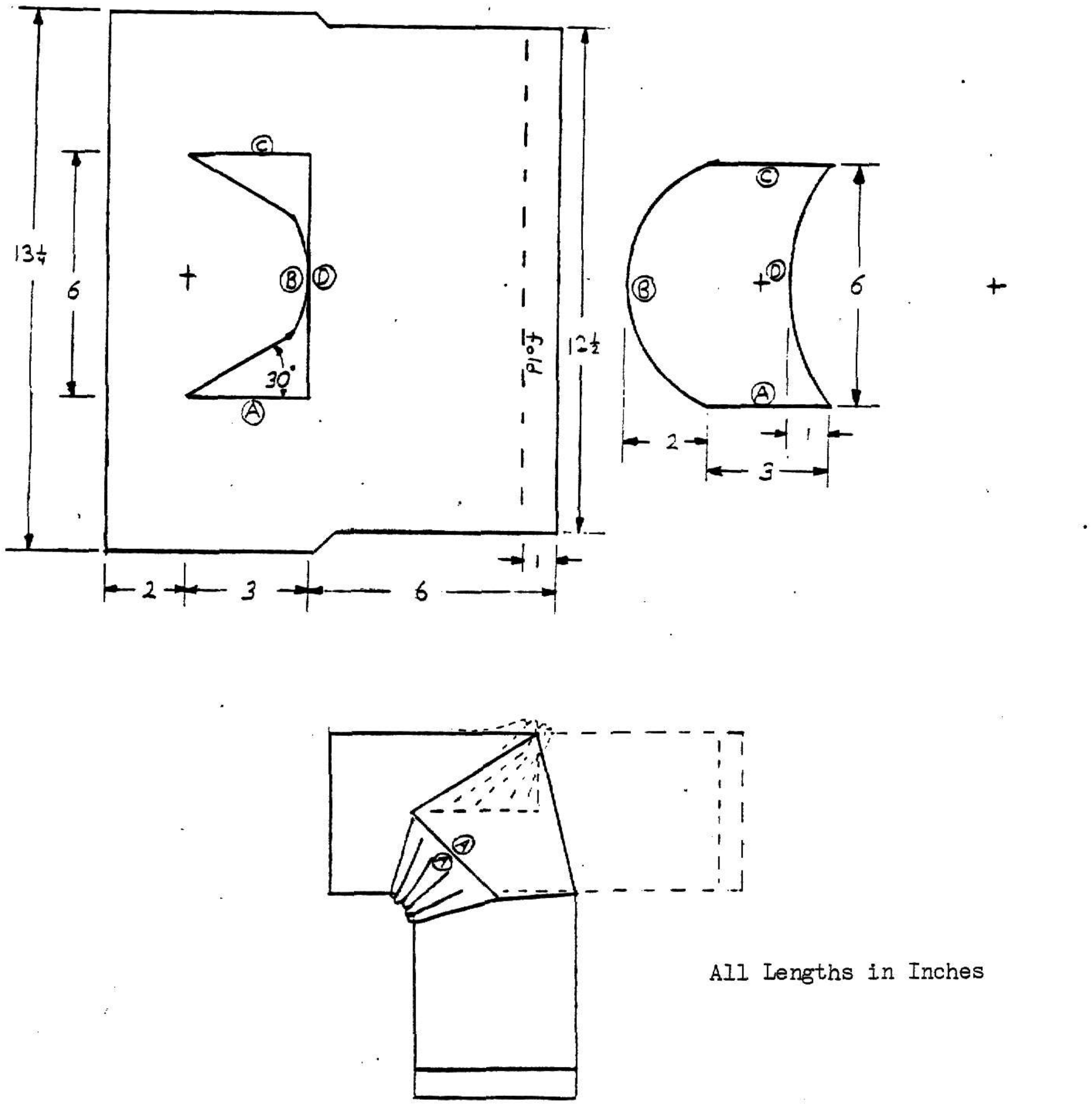


Figure 18. Drawing of Pattern Used to Construct Model 11

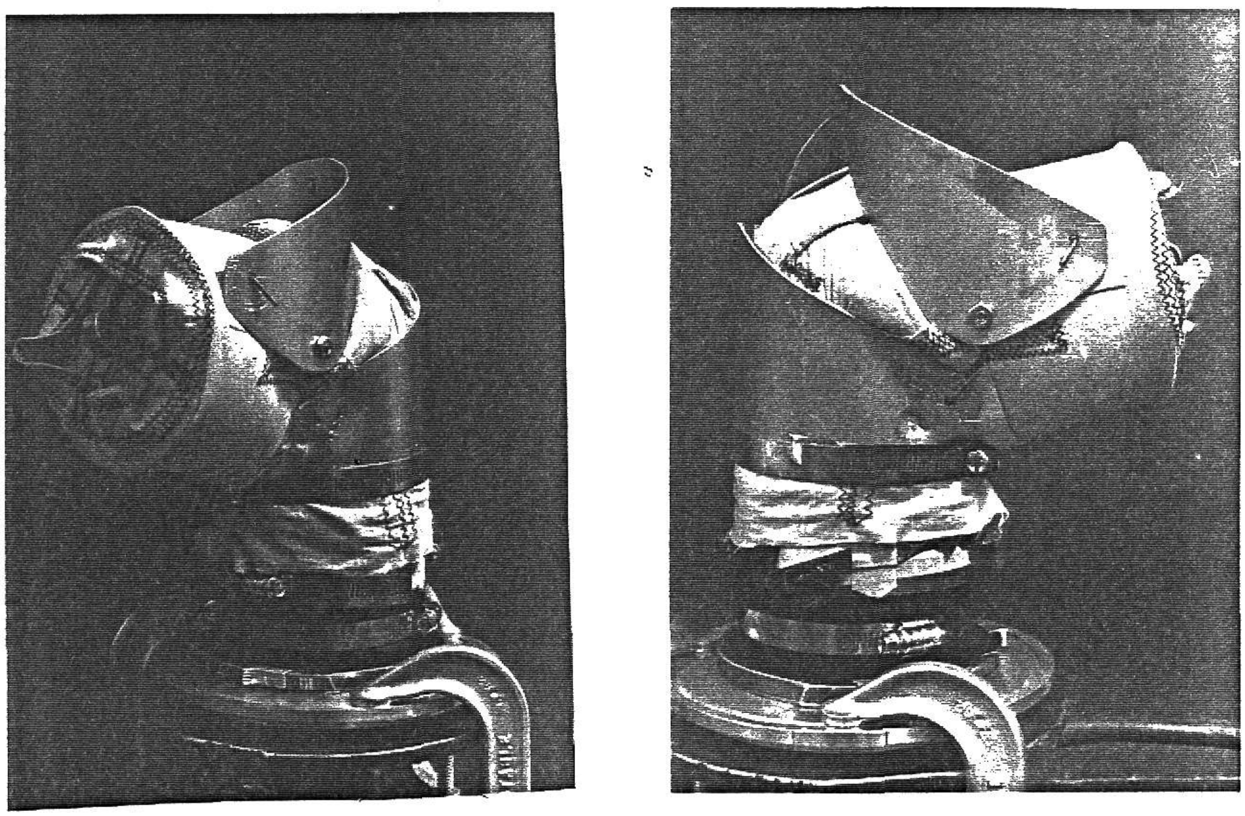


Figure 19. Model 11 Constructed With Wrap-Around Links

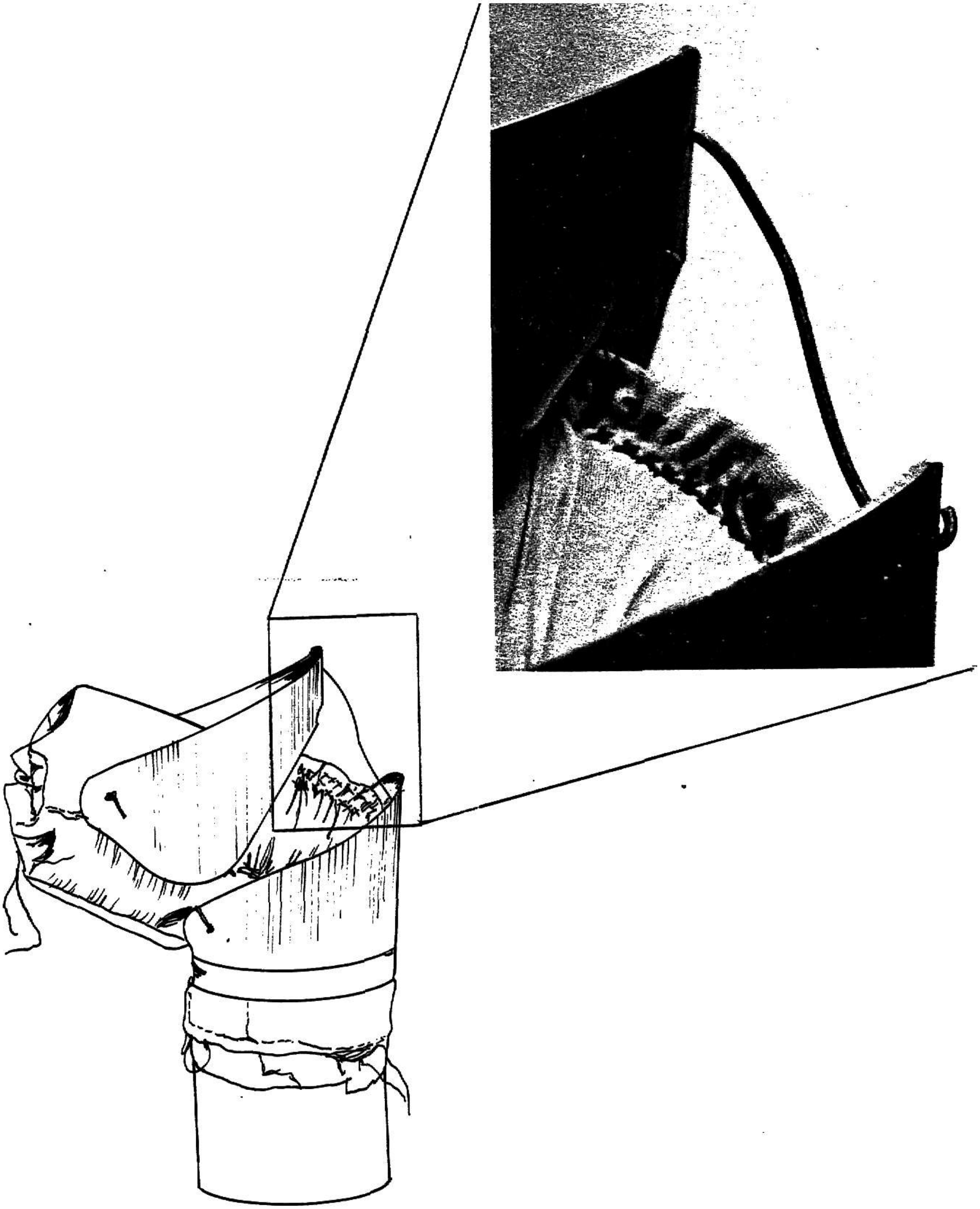


Figure 20. Model 12. Modification of Model 11 by Reducing Tube Diameter

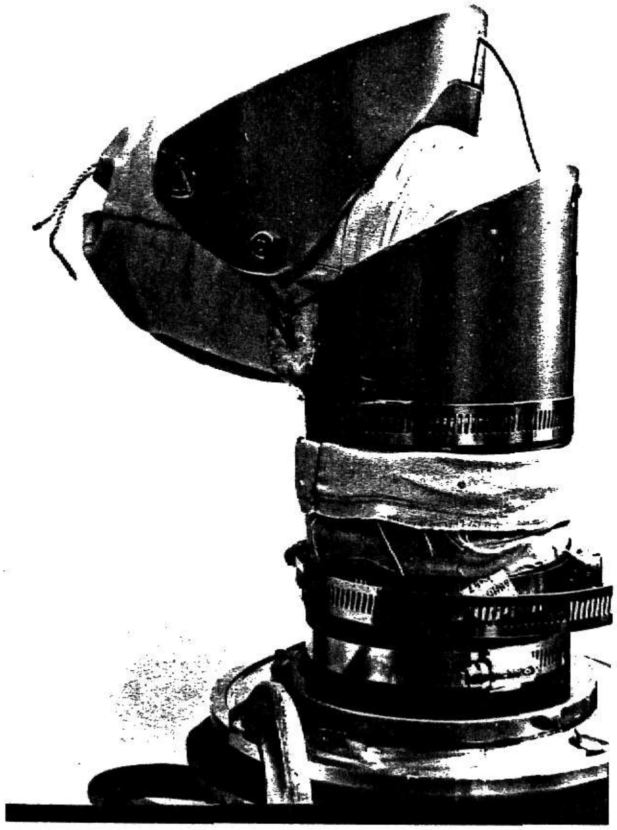


Figure 21. Model 13 With Wrap-Around Links

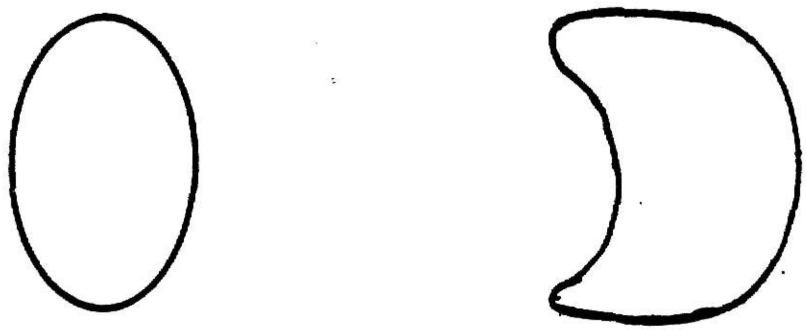
the bell jar at 3 psi, the modifications further improved the flexibility.

The previous tests proved that linkages could be used to decouple the axial load from the fabric in the simulated metacarpal joint. The linkages allowed constant length in the joint, but did not provide true constant volume. However, they did demonstrate that with proper design, a reasonably flexible joint could be achieved.

Incorporation of Metacarpal Flexibility Into Glove

One possible cause for some of the problems encountered with the previous large scale models was the oversize of the metacarpal tube joint models. Also the restraint of the cloth tubes is different than that experienced on an actual glove. (See Figure 22.) It was expected that some of the problems would diminish when full scale glove models with their smaller tube (finger) diameters were used. However, the large scale models were helpful in understanding the flexibility problem and in refining design concepts. The next phase involved working with full scale gloves. These two phases overlapped considerably.

Studies With Conventional Gloves. Pressurization of conventional gloves was undertaken to better understand how a glove will react under pressure. The three different types of gloves pressurized were a chemical protective glove, a leather glove, and a meat cutter's glove. These gloves, and those produced later by the team, were lined with a latex bladder to make them air tight. The latex bladders were used because they are flexible and readily available. The final design used a rucathane bladder.



Cross Section of PVC Tube

Cross Section of Finger

Figure 22. Cross Section of PVC Tube vs. Finger Restraint

1. Chemical Protective Glove. Model 15 was a simple chemical protective glove made from rubberized fabric. (See Figure 23.) It was tested in the bell jar with and without a palm restraint in order to observe the effect of a palm restraint on ballooning. A remarkable improvement of metacarpal flexibility was noticed when a crude palm restraint was added.

2. Leather Glove. Model 16 was a leather work glove. (See Figure 24.) A wraparound aluminum link was tested on the first finger. When the glove was pressurized in the bell jar it completely immobilized the link because the link was too small. Next, the link was pulled back to allow free fabric for flexibility. The modification was still not successful when pressurized because there was no link motion.

3. Meat Cutter's Glove. During the time of the tests using the oversized models other ideas were tried. One such idea was a meat cutter's glove, constructed of steel chain mail. A preliminary test was done using a small version of the glove. It seemed to offer good finger flexibility and was thought to have good metacarpal flexibility, but was too small for adequate testing. Because of this preliminary test, a larger glove, (Model 17) was ordered for further testing. (See Figure 25.) When this glove was tested, it was discovered that the metacarpal flexibility was poor.

Design Concepts. The first gloves that were designed, built, and tested were used to obtain a better understanding of how certain sections of the glove must perform. The preliminary design areas tested were the use of finger links, palm bar re-

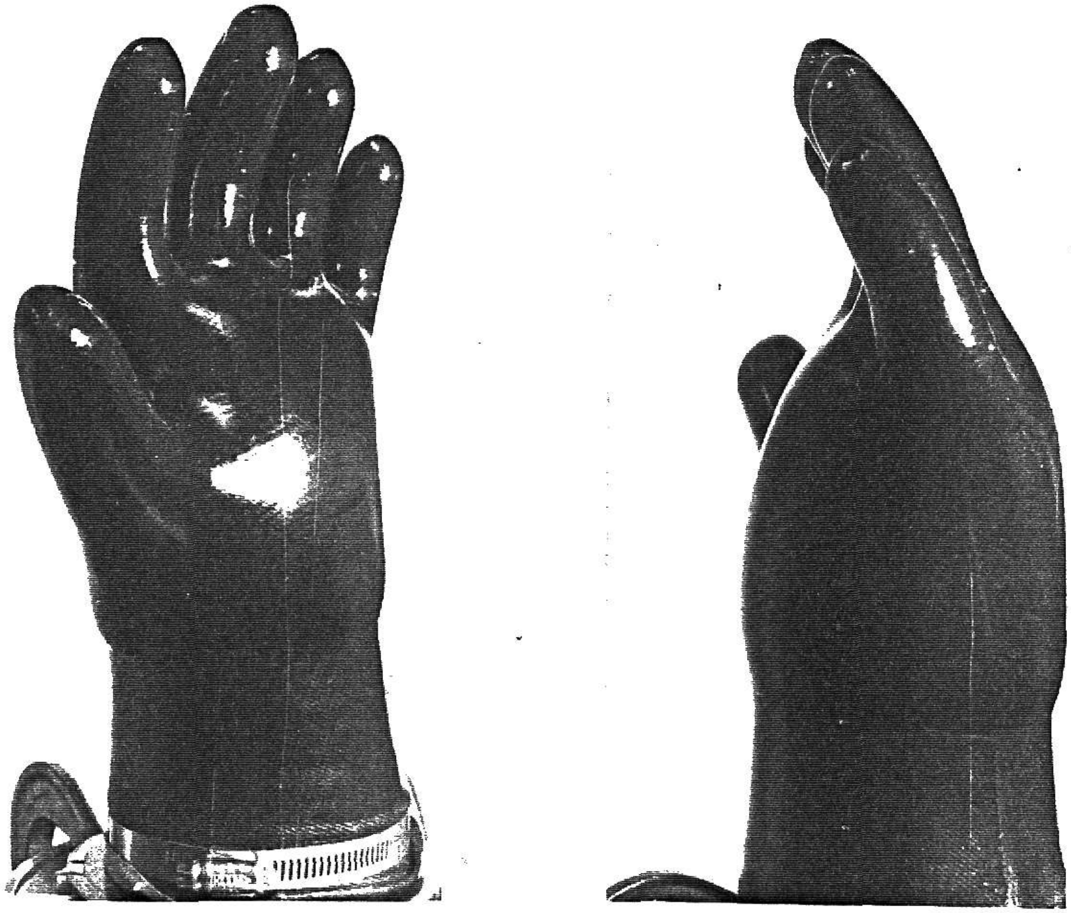


Figure 23. Pressurized Chemical Protective Glove

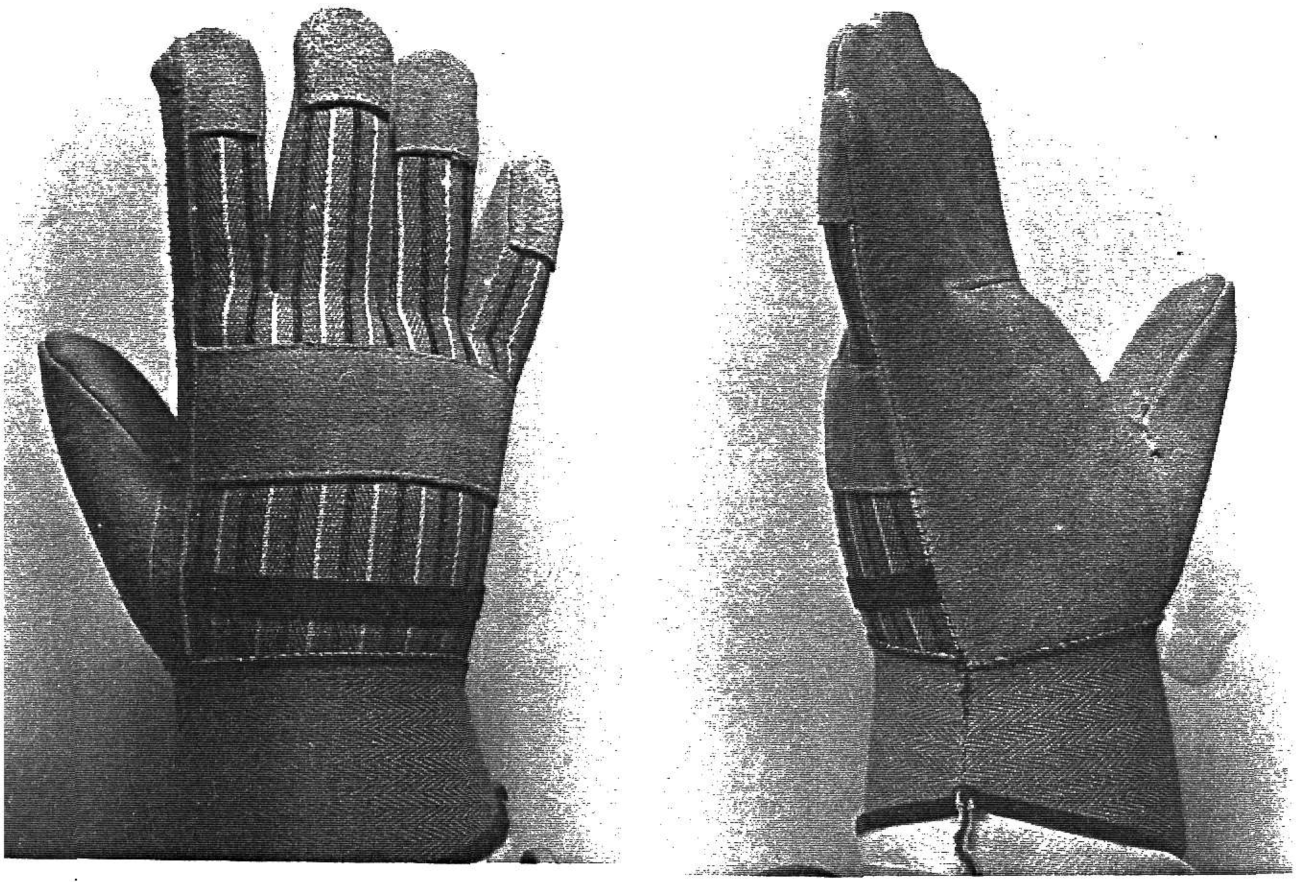
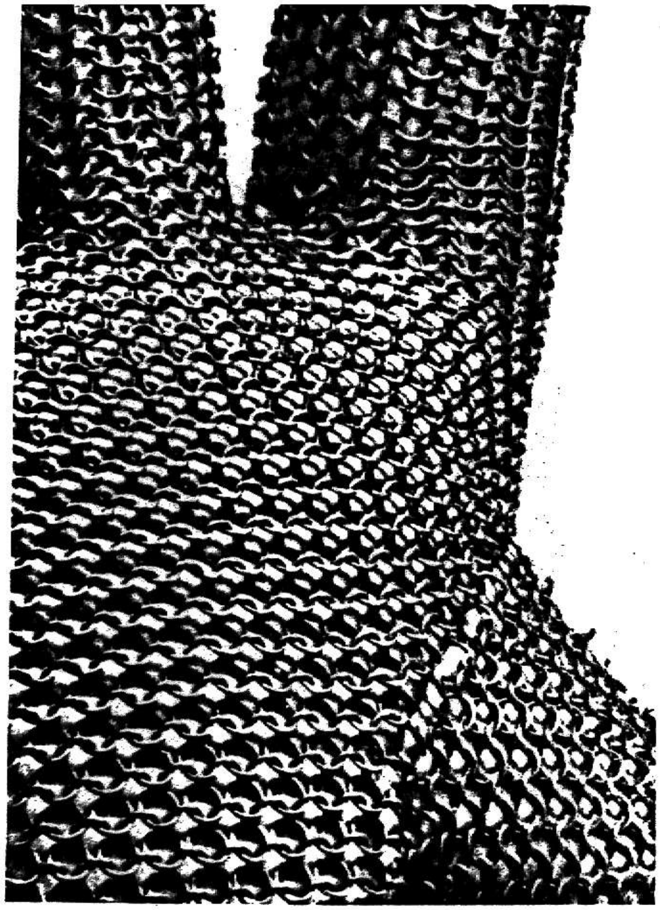


Figure 24. Pressurized Leather Glove



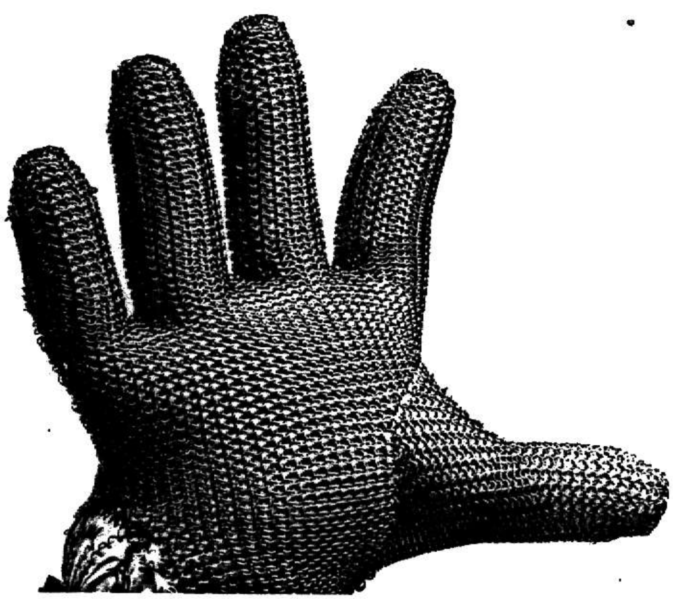


Figure 25. Pressurized Meat Cutter's Glove

straints, finger rings, and finger cables.

1. Finger Links. Three different glove design ideas were built and tested using the finger links as a means to try and maintain constant volume in the metacarpal region during bending. The principle behind the linkages is the same as detailed in <u>Testing of Linkages.</u>

First, attached to the middle finger was a U-shaped link. (See Figure 26.) When pressurized, the glove expanded to immobilize the link. The link used was the same link used for the leather glove tested previously. Next, a longer link was constructed for the third finger of that same model and tested. (See Figure 27.) This was successful and provided good flexibility for up to 30^{o} of motion.

Second, the model was constructed with small flat aluminum links on the sides of the fingers similiar to Model 6. The side links splayed outward when pressurized until no force was carried by the cord, rendering them useless. The links were also restricted by cloth friction.

Third, again U-shaped linkages were attached by nylon cord to the rigid palm and backplates as shown in Figure 28. A cord on each side of the finger was attached to the palm restraint; another cord was attached from the back of the link to the rigid back. The linkage was attached to the second finger. The link was restricted from rotating due to ballooning of the glove finger, resulting in friction between the fabric of the finger and the side of the link. When pressurized, the link bottom strings were loose at angles greater than 30^{o} of metacarpal flex. Fabric friction seemed to be the only factor causing this since

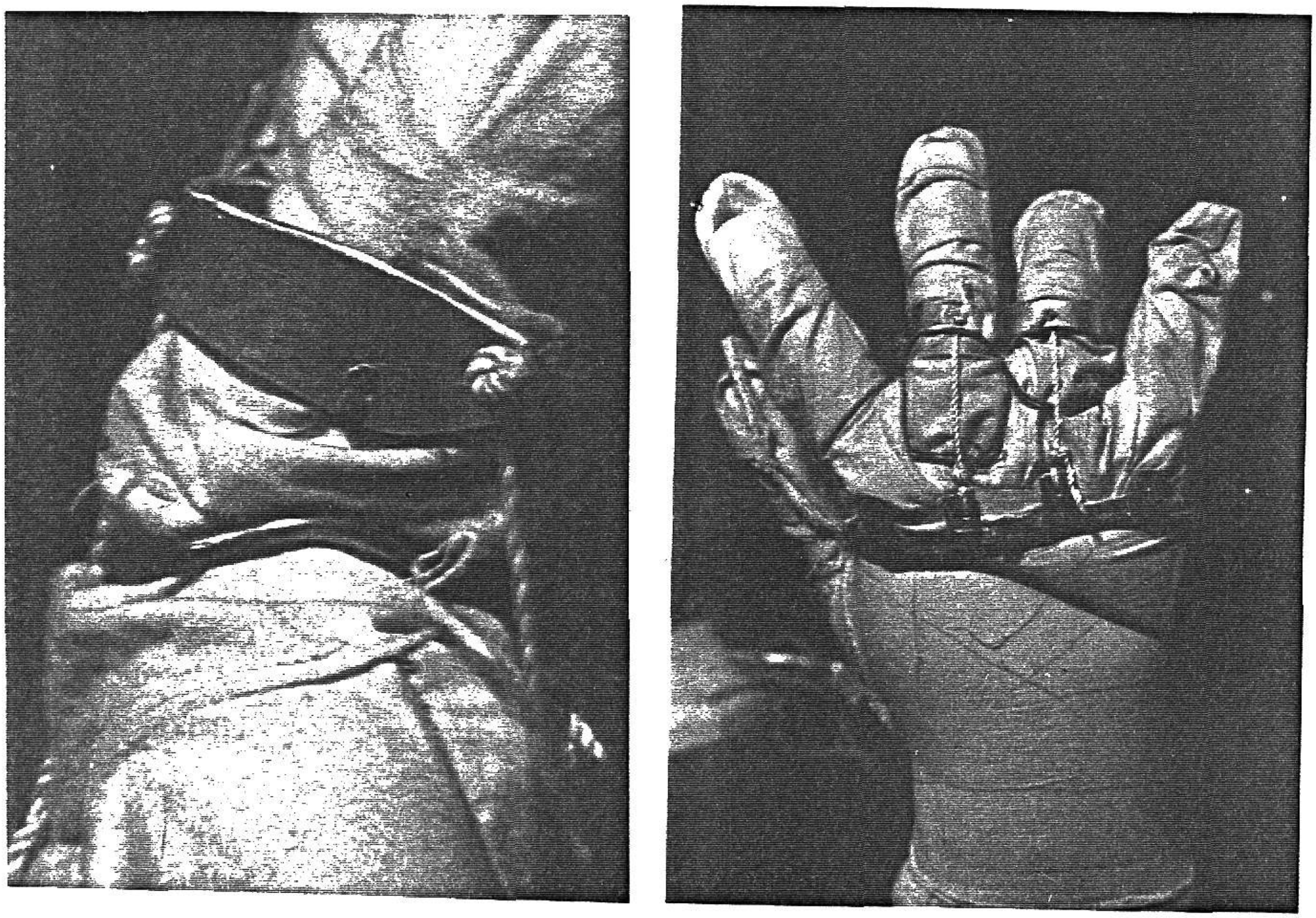


Figure 26. U-Shaped Finger Link

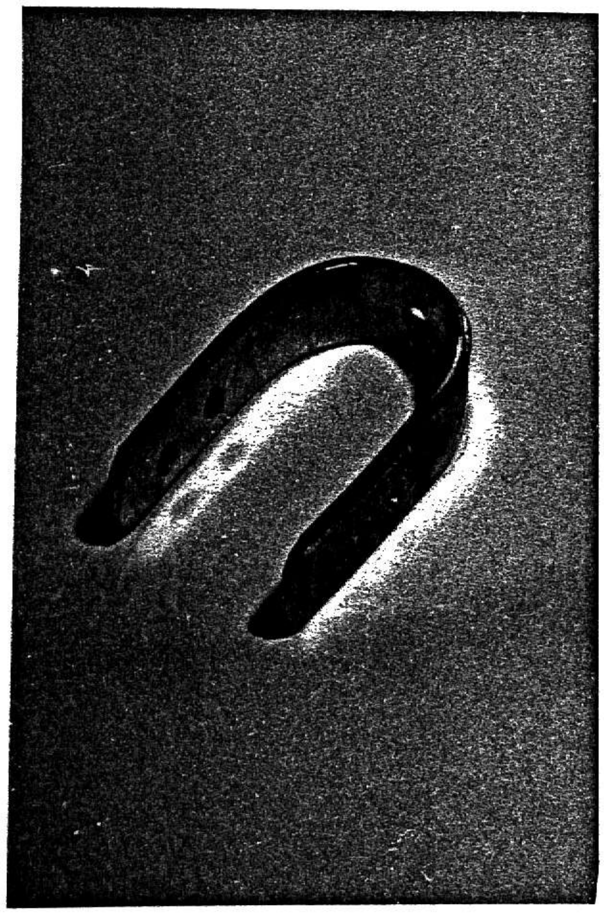


Figure 27. Longer U-Shaped Finger Link

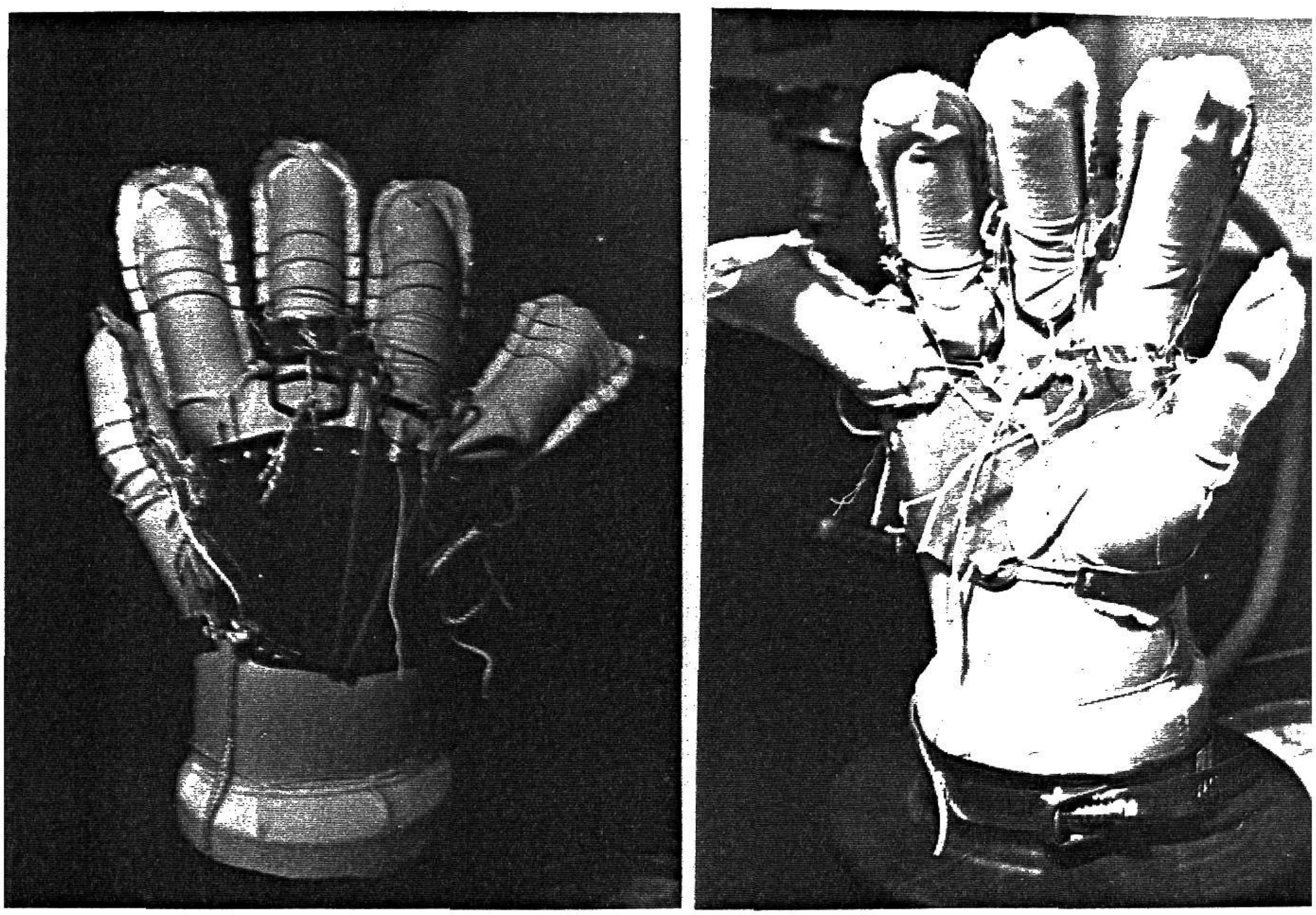


Figure 28. U-Shaped Finger Link Attached to Rigid Palm and Backplates

the link did not appear to be reaching an end of travel.

It was first thought that the reason the link was unable to rotate was due to ballooning of the glove finger. To correct for this ballooning, a ring was designed for the base of the finger. The purpose of the ring was to restrict the cloth from ballooning around the base of the finger. The model now seemed to work. However, when the link was detached, there was no change in model performance. The link was not contributing to glove flexibility. Therefore, the concept of using finger links was abandoned. It did not seem possible to obtain the amount of flexibility required while using this idea. (The finger rings are discussed further in a separate section.)

2. Palm Bar Restraint. After the very first glove was tested, the importance of a palm bar restraint was realized. The palm bar restraint was used to restrict ballooning in the palm of the hand. In several of the models tested, it was also used as a means to secure hardware. Four different types of palm bar restraints were developed and tested. The first palm bar was made from a single steel rod and went all the way around the hand. (See Figure 29.)

The second palm bar incorporated aluminum sheeting which was formed to fit around the front and back of the hand and functioned as rigid palm and back restraints. (See Figure 30.) When pressurized, they seemed to work fine with respect to restricting ballooning. However, it was thought that palm bars constructed from large wires would be better for palm flexibility. Also, the back of the glove should be made from two pieces instead of

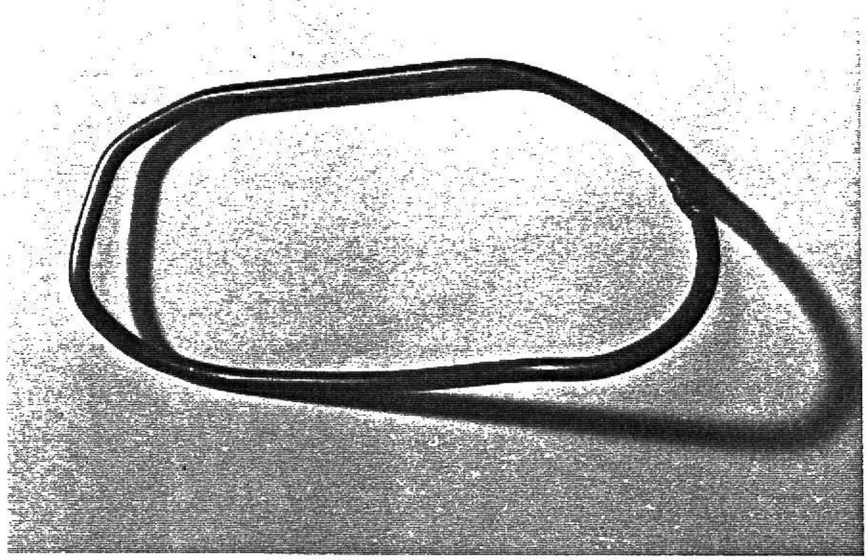


Figure 29. First Palm Bar

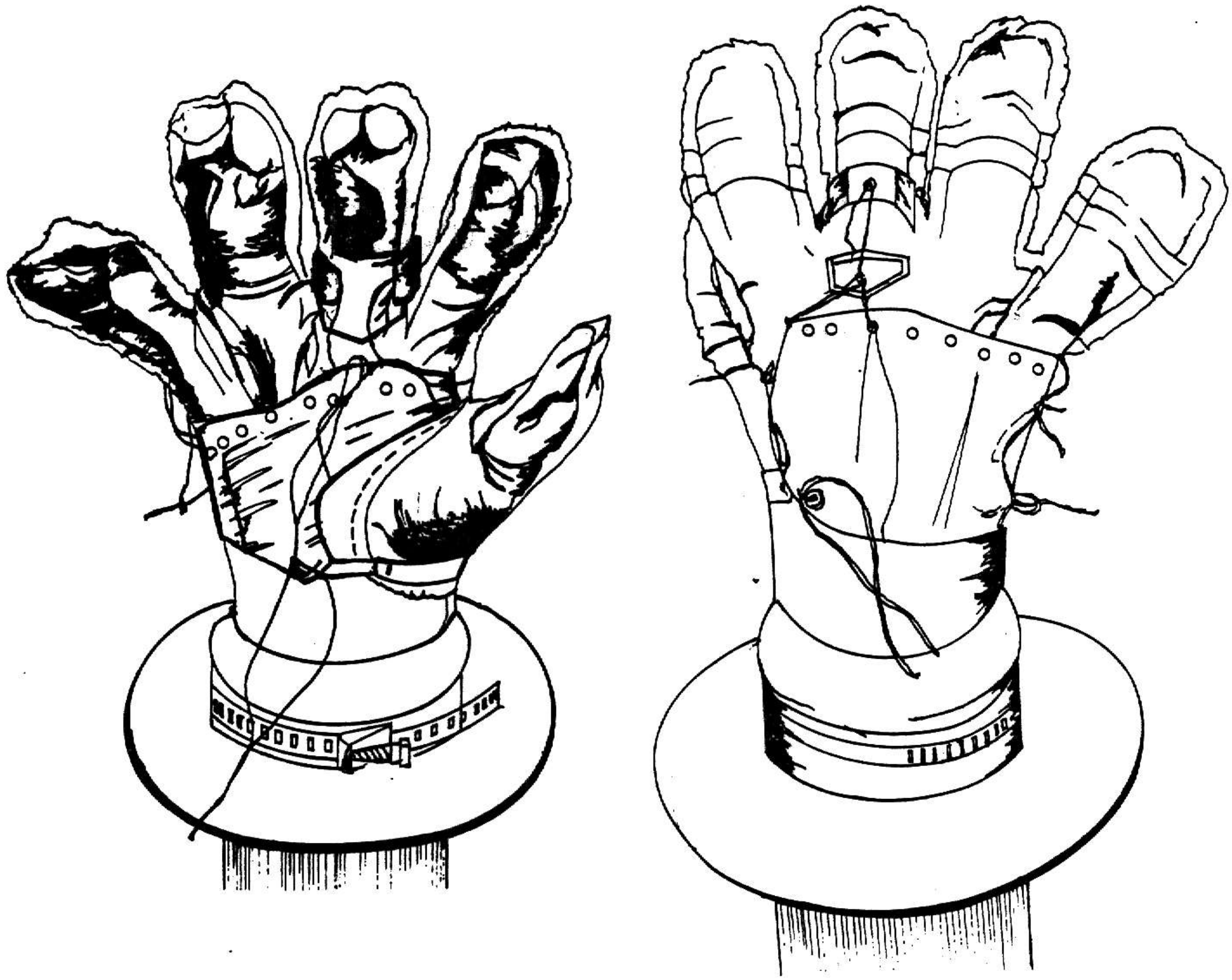


Figure 30. Solid Palm Restraint

just one as this might give added flexibility to the palm.

The third palm restraint went all the way around the hand, as it did in the first palm bar. Attached to this palm bar were large hooks that were on the side of each finger. (See Figure 31.) This rigid palm restraint with the hooks was too big and uncomfortable.

The forth palm restraint was modified by constructing it in two pieces. There was a metal palm bar in the palm of the hand and an adjustable cord across the back of the hand. (See Figure 32.) This idea was later refined by constructing the sides of the bar longer to make them more comfortable.

3. Finger Rings. To correct the problem of ballooning which was occurring between the finger crotch and the palm restraint bar, a ring was made for the base of the finger to restrict ballooning at this critical point. Three different ideas using finger rings were developed and tested.

To restrict the ballooning at the base of the finger, the first finger ring was built. (See Figure 33.) When pressurized, the ring also formed creases in the material to help in the bending. The addition of the finger ring helped with metacarpal flexibility and the idea of using them looked promising.

The second ring was designed to not rotate when the finger was flexed as well restrain the cloth from ballooning around the base of the finger. (See Figure 34.)

The third type of finger rings was made from two pieces of material to reduce the amount of material between the fingers and to reduce the bulk in this critical area. Fishing line (50 pound test) ran through the finger crotch and connected the two pieces

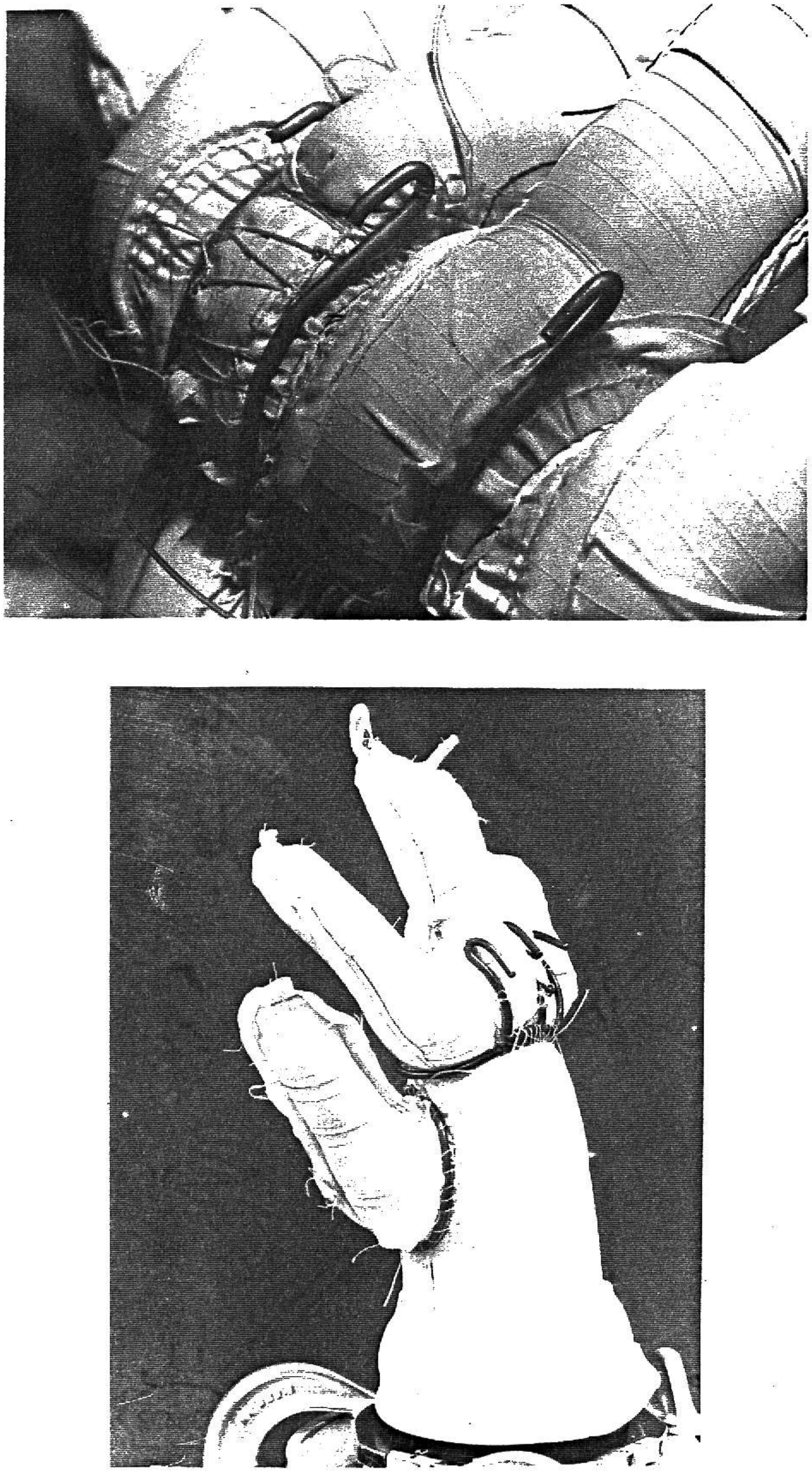


Figure 31. Palm Bar Restraint With Large Hooks

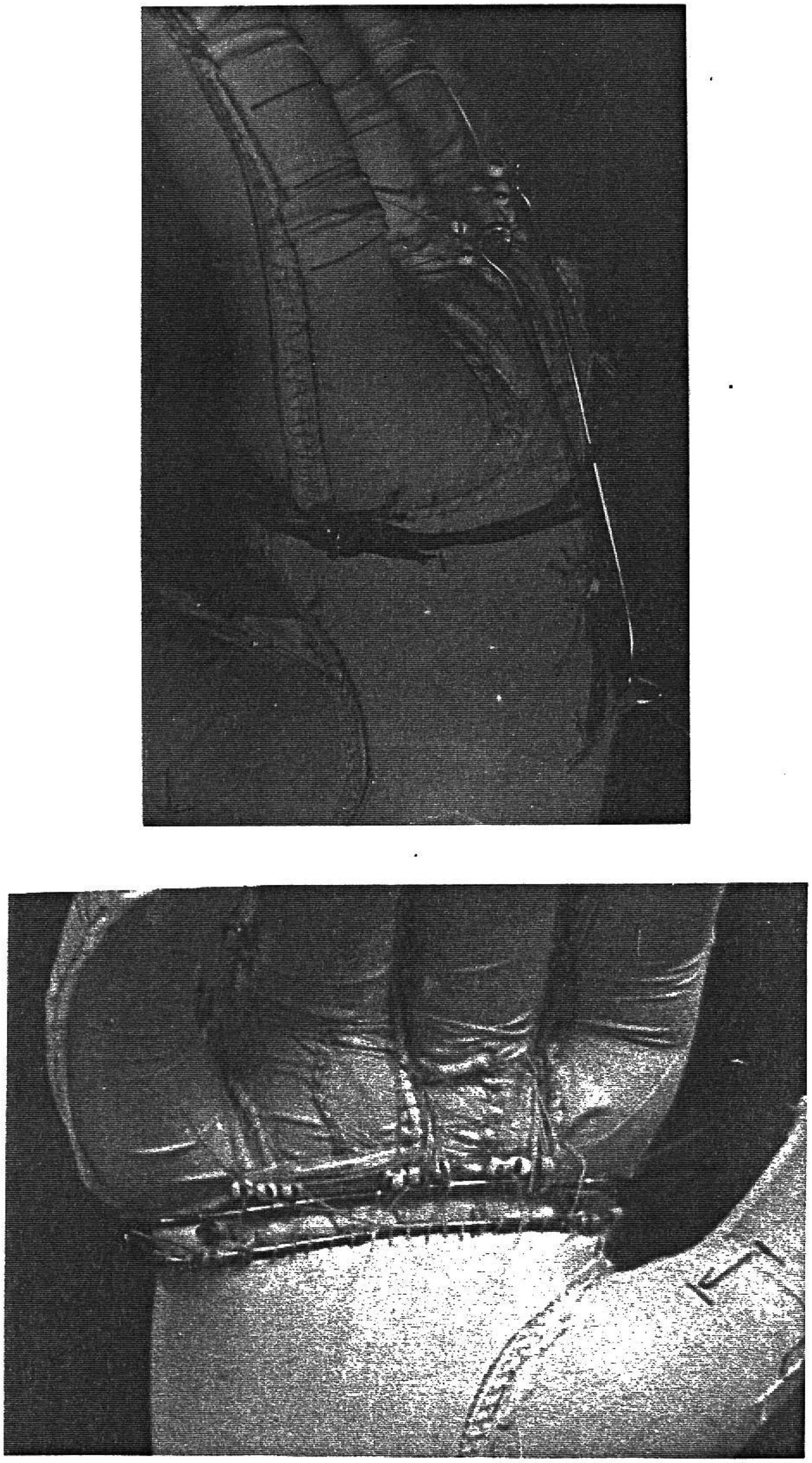


Figure 32. Adjustable Palm Bar Restraint

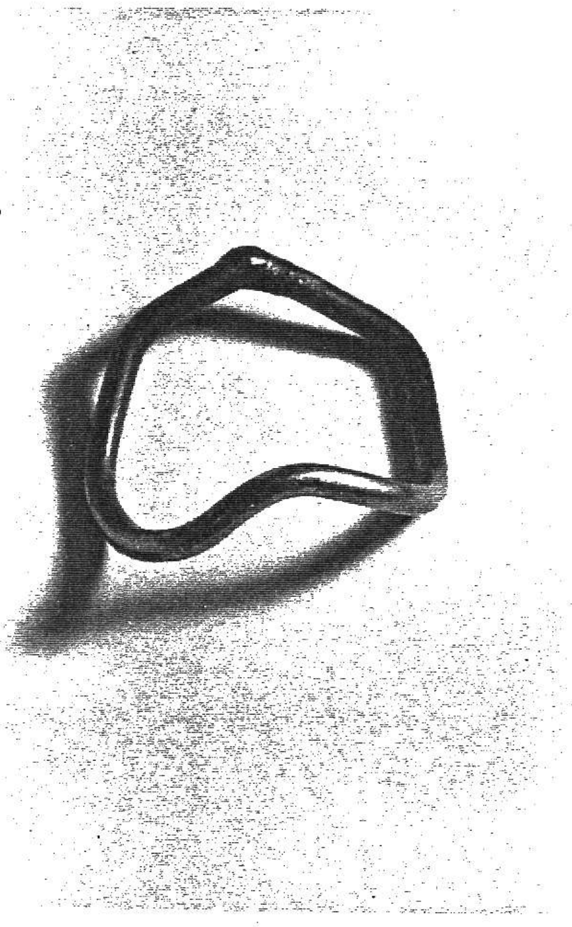


Figure 33. First Finger Ring

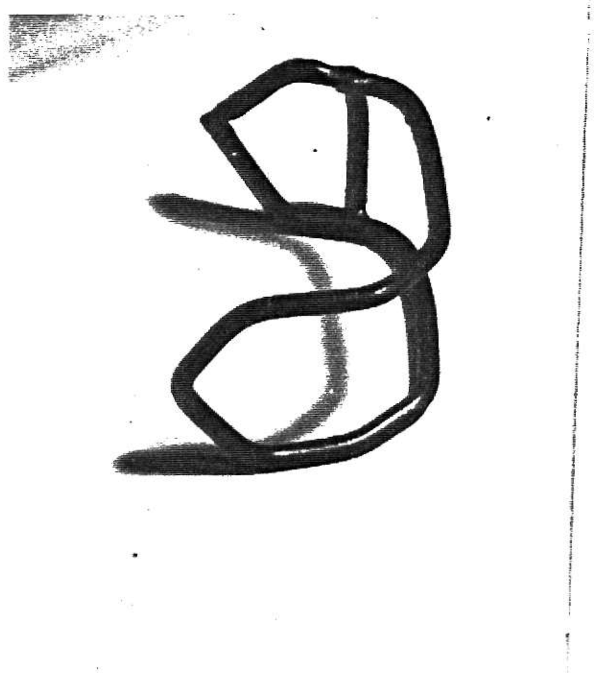


Figure 34. Second Finger Ring

together. (See Figure 35.) Even though these rings provided good metacarpal flexibility, they were not included in the final design. Overall, finger rings resulted in too much bulk making the glove uncomfortable.

4. Finger Cables. Because of the deficiencies of the linkage design, it was replaced by a sliding cord design. Rather then using linkages to transfer the loads away from the knuckle joints, a line and tube arrangement was used. With proper placement of the line, the tube rotates about the axis congruent to the knuckle axis in a circular arc. This helps minimize the change the volume during bending.

Figure 36 shows the first line and tube model. Plastic tubing was attached to each side of each finger. The line was attached to the palm bar, ran through the tube located between the fingers, and was attached to the back of the palm bar. The metacarpal joint could bend at a pressure of 8 psi and remain bent. The model performed much better than previous models, however the friction force resulting from the line sliding in the plastic tubing was a problem that was addressed in the next model.

To reduce friction between cable and pulley, plastic shrink tubing was replaced by metal sewing hooks. Figure 37 shows the glove model and the accompanying hardware. The palm bar had large hooks that were on the side of each finger. The hooks on the palm bar restraint were positioned so that tie points could be placed in the proper location. This model worked well and had a good range of motion. When the finger was bent, it stayed

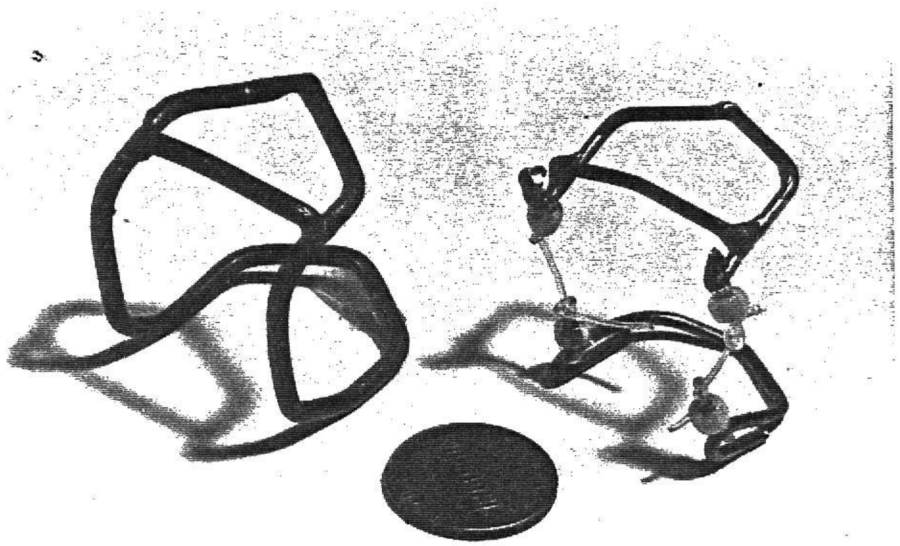


Figure 35. Comparison of Second and Third Finger Rings

Figure 36. First Line and Tube Model

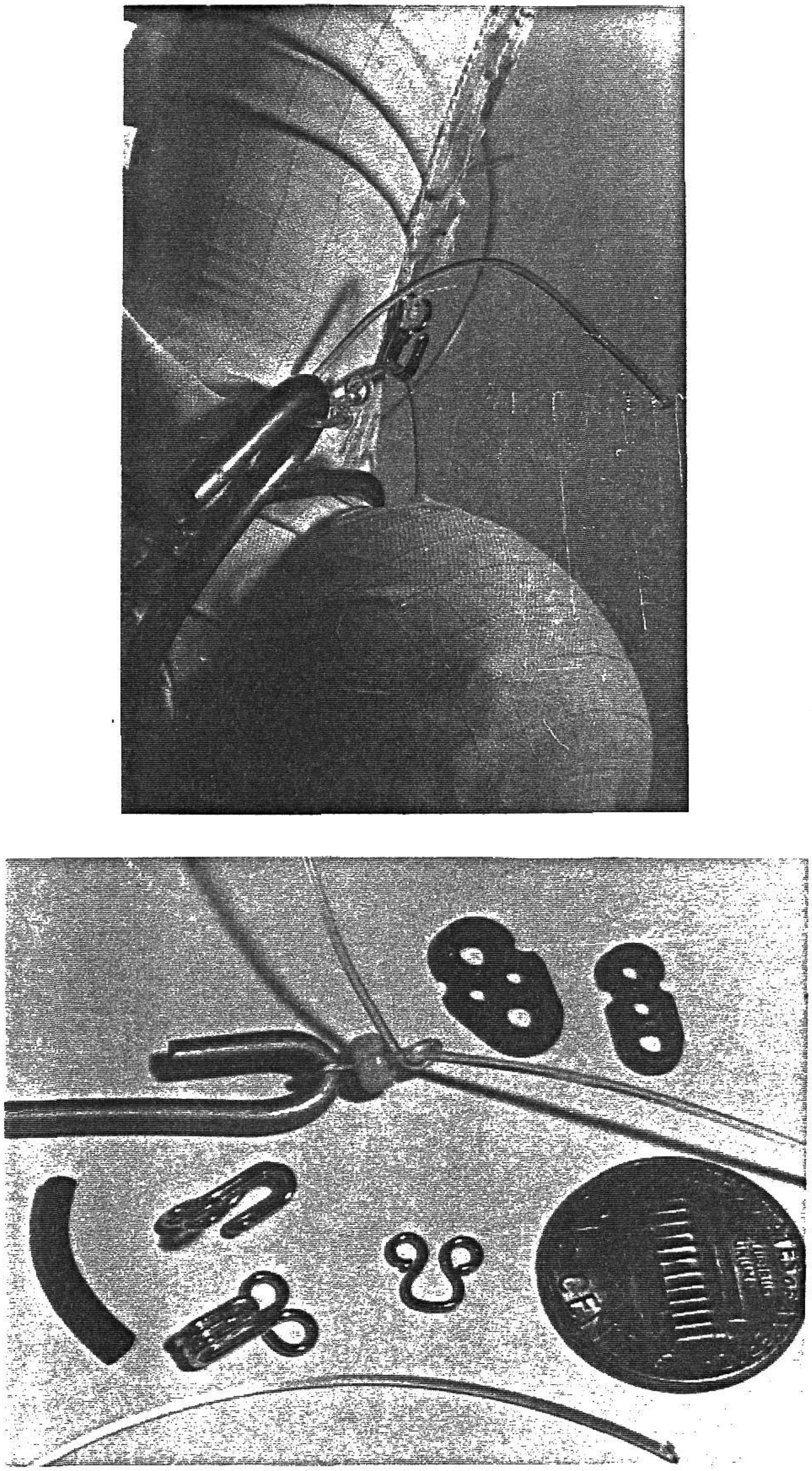


Figure 37. Glove Model With Large Metal Hooks and View of Accompanying Hardware

bent at 8 psi.

In the next design, the sewing hooks located on each finger were replaced by metal sewing loops to eliminate any possibility of the line disengaging. The line was secured to one of three cantilever rods which were secured to the back of the glove. These rods replaced the hooks on the back of the palm restraint bar. The design concept is shown in Figure 38. This model worked very well.

Whole Metacarpal Design. Most of the effort in the project was directed at designs which improved metacarpal flexibility by providing flexibility for individual fingers. Late in the project, after discussion with NASA engineers, it was felt that a second approach to improving metacarpal flexibility should be pursued at the same time the work on the single finger approach continued. This second approach treated all four metacarpal joints as a single unit.

The concept of whole metacarpal flexibility is essentially the same as the successful design currently used for the fingers. The fabric is restrained axially along the sides of the joint and excess glove fabric is provided on the back of the joint to allow for the expansion needed during bending. However, the design is much more difficult at the metacarpals because of the high aspect ratio of the cross-section of the hand through the metacarpals as compared to the nearly circular cross-section of the finger. A simple pleating approach like that used on the finger would balloon into an unmanagable circular cross-section. To maintain an appropriate shape, rigid restraint pieces were incorporated into the design. Figure 39 shows how the rigid

KSU EVA DESIGN

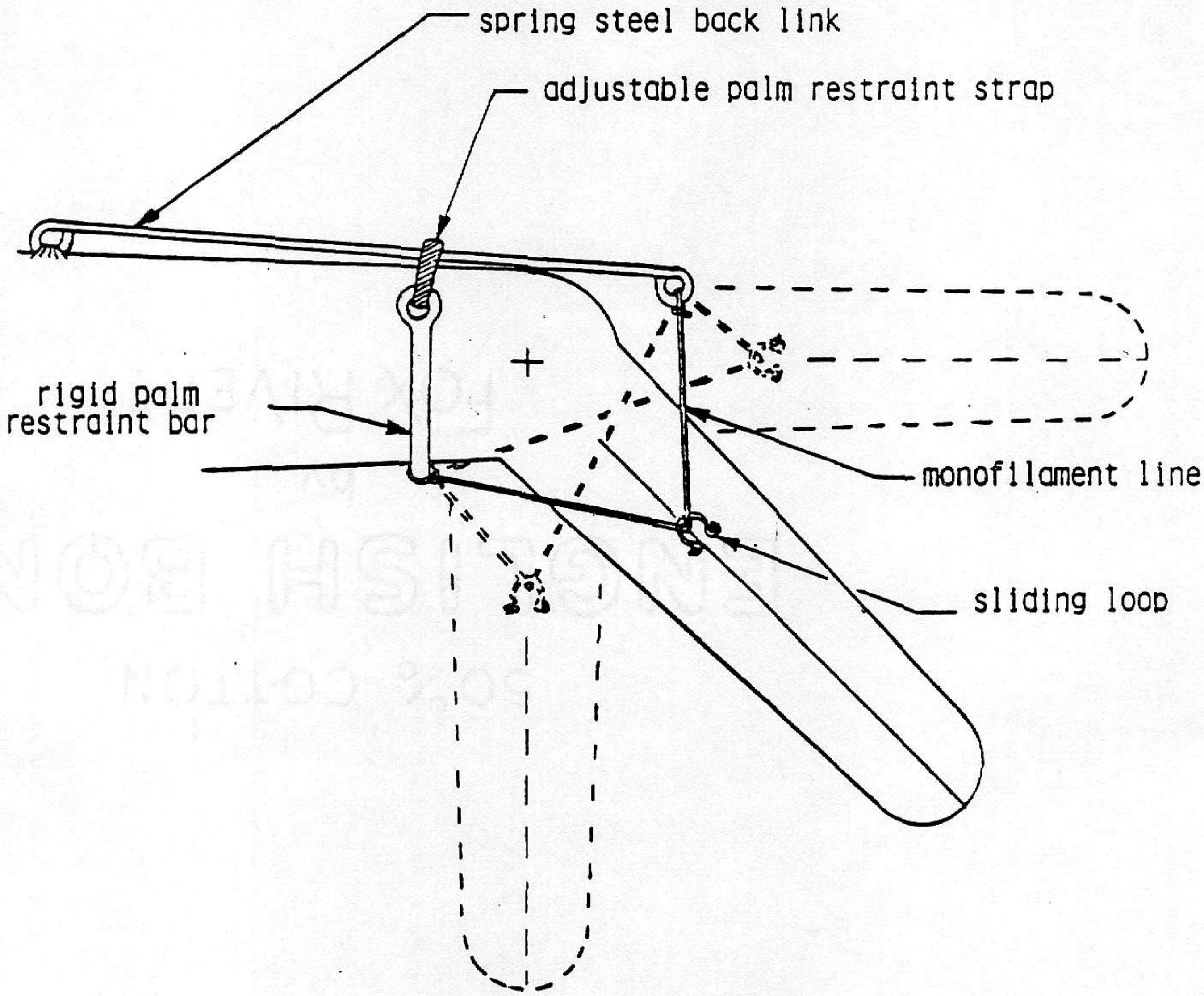


Figure 38. Drawing of Glove Design With Sliding Loops

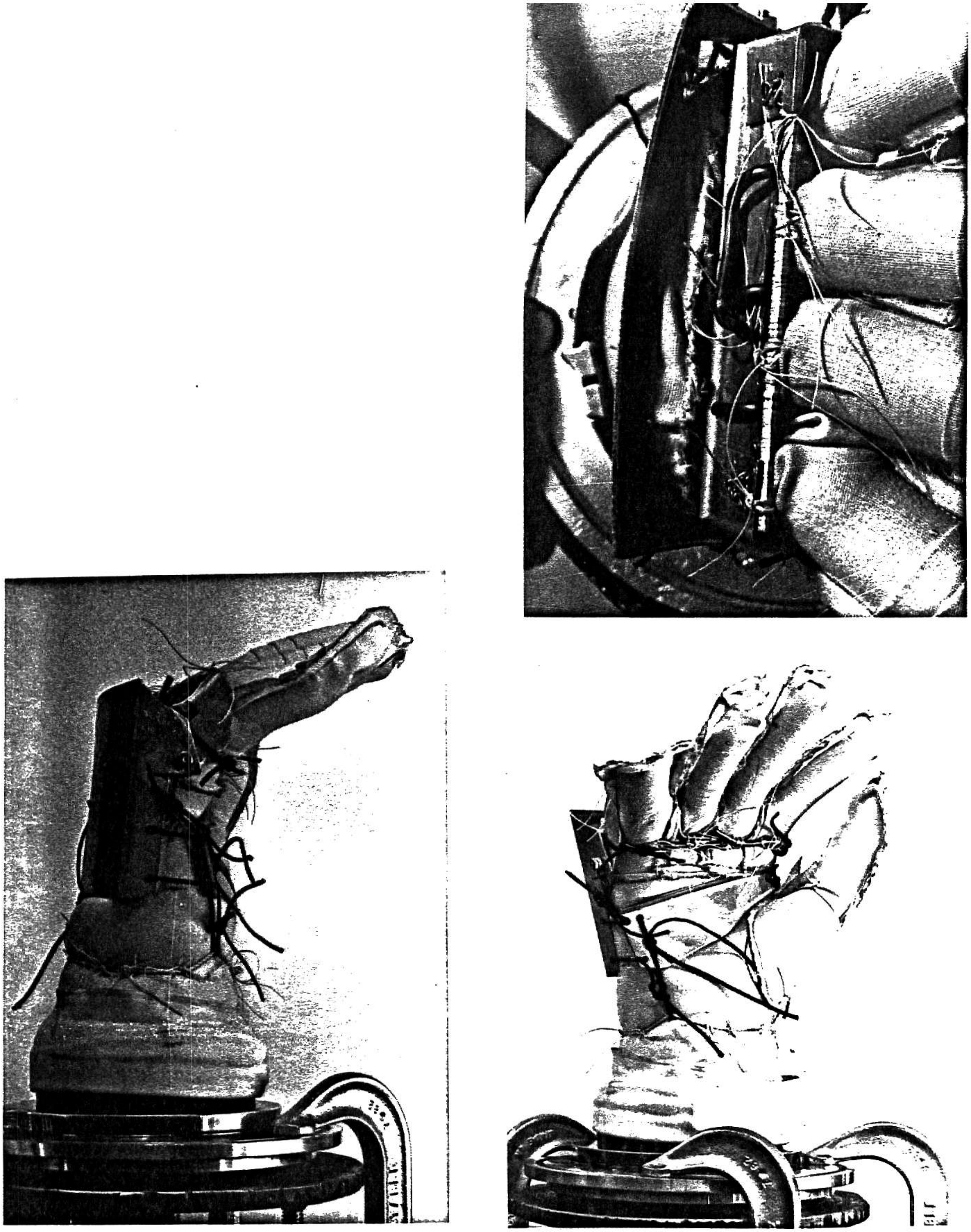


Figure 39. First Glove Model With Whole Metacarpal Flexibility

pieces were used. A plate (back piece), covering the back of the hand and extending out over the metacarpal joints, was attached to the back of the glove. A smaller plate (palm piece) was attached to the palm of the glove. The palm and back pieces were then held together with adjustable cords. An additional rigid restraint (outer piece) was attached to the glove just past the metacarpal joints. The outer piece consisted of a flat plate on the back side and a round bar on the palm side. Wire restraints passed through finger crotches and attached to palm bar. A pin joint, aligned with the metacarpal joints, was made on either side of the glove connecting the outer piece to the palm piece. This configuration allowed the rigid restraints, rather than the fabric to carry the axial load. Approximately 3/4" of excess fabric, was placed over the back of the matacarpal joints to prevent the fabric from limiting joint bending. The back piece restrained this fabric from ballooning.

This design produced good metacarpal flexibility. The glove had a neutral position of about 45° bend in the metacarpal; the joint could move relatively unhindered about 20° in either direction from this location with 8 psi of pressurization. Additionally, the hand could be fully straightened or fully closed. A 3/4" diameter cylinder could be readily grasped but a significant amount of effort was required to maintain the grasp. It was learned from this design that the metacarpal joints do not all bend uniformly as an object is grasped. The little finger must bend approximately 30° more than the index finger. The rigid outer piece prevented this action and most of the grasping action was between the thumb and index finger and, to a lesser extent, the middle finger. However, there was still good individual finger mobility with any finger capable of touching the thumb and the first two fingers capable of touching the base of the palm. It was also discovered that the location of the pin joint was critical and this design did not work as well with team members hands that did not match the sizing used. However, it was also found that fabric sizing was less critical since the geometry was constrained by the rigid pieces rather than the fabric dimensions.

A second version of this design was constructed. (See Figure 40.) It provided for adjustment of the pin joint location. The outer piece was given 30^{o} of twist to allow for the difference in metacarpal bending when grasping. The wire restraints through the metacarpal crotches were eliminated as they appeared to serve no purpose. The excess fabric over the back of the metacarpal joint was increased to approximately 1.5" since it appeared that there was some restriction here in the first design.

The overall flexibility with this design was about the same as with the first version. The 30^{o} of twist in the outer piece allowed all of the fingers to work well when grasping and appeared to considerably improve the ability to grip. The adjustment in the pin joint allowed the glove to be used by people with large or small hands. Additionally, adjustments in the joint allowed the neutral position of the joint to be varied from about 45^{o} to 90^{o} (based on the index finger joint). The 45^{o} bend appeared to be the best. The excess material tended to balloon

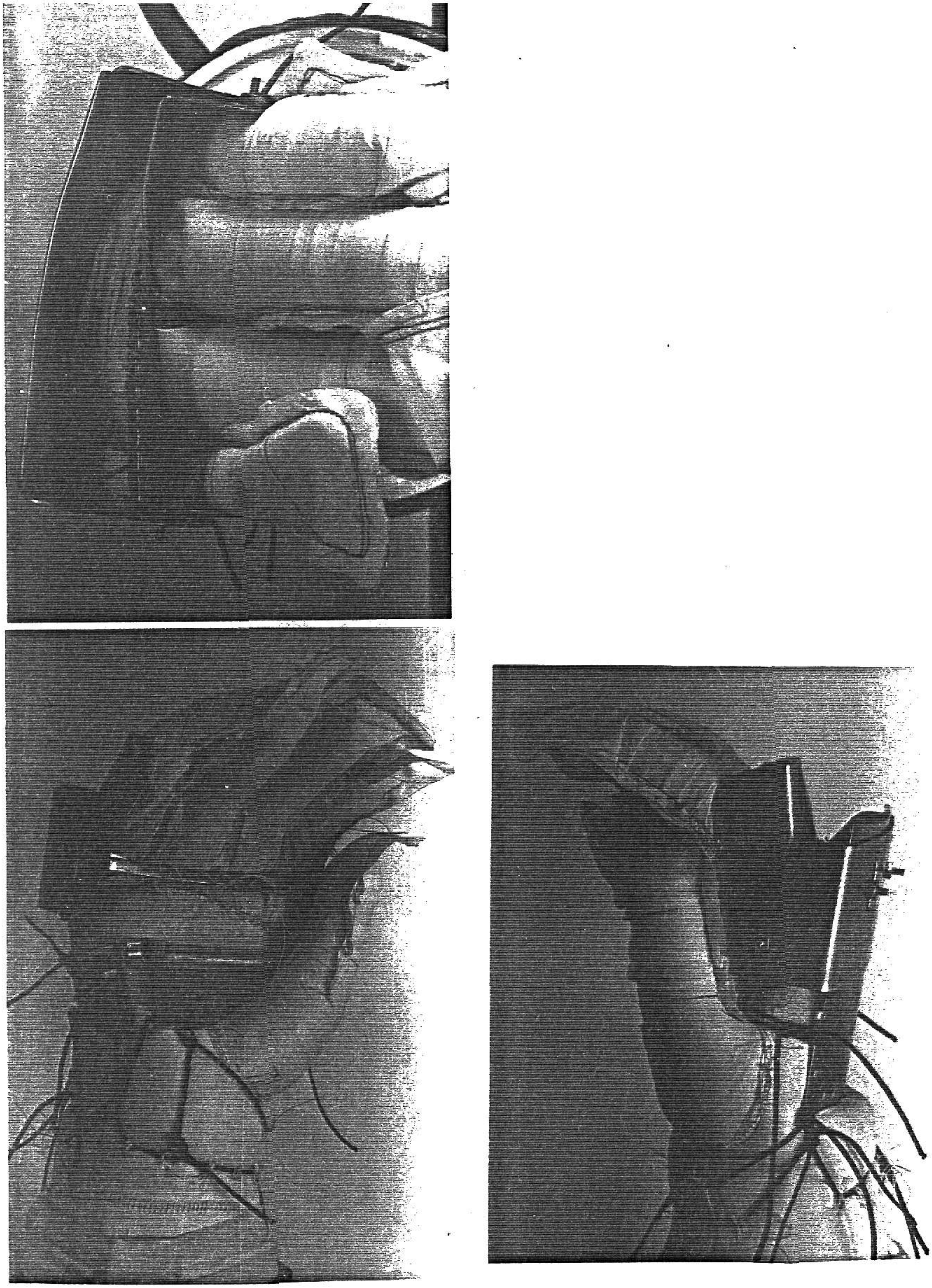


Figure 40. Second Model With Whole Metacarpal Flexibility

up excessively against the back piece. It did not return well after bending the metacarpal to achieve a closed hand and made it difficult to fully open the hand. Thus, it appears that this much excess fabric is not desirable.

The primary intent of these two gloves was to demonstrate that this design could achieve good flexibility in the metacarpal joint. However, they are not intended for direct incorporation into gloves. As tested, the rigid restraints are too bulky and cumbersome. However, it should be possible to eliminate much of the bulk and make it suitable for use with EVA gloves.

Materials

In choosing materials for a specific end product, properties desired in the end product must be identified. Specific properties desired for the restraint glove include high tenacity (strength/weight), abrasion resistance, and low moisture regain. These properties are attained by choosing an appropriate fiber type for the restraint.

Properties of two fiber types which might be considered for the restraint glove are listed in Table 3.

Both nylon and polyester have high tenacity and excellent abrasion resistance, but differ in moisture regain. The high moisture regain of nylon not only decreases the tenacity but degrades the fiber. Natural fibers are eliminated for this same reason.

Table 3. Selected Fiber Properties

	Tenacity, (g/denier) Dry	Wet	Abrasion Resistance	Moisture Regain, (%)
Nylon HT	6.0 - 9.5	5.0 - 8.0	excellent	4.0 - 4.5
Polyester HT	6.3 - 9.5	6.3 - 9.5	excellent	0.4 - 0.8

Moisture regain becomes an important parameter since the suit is a closed system in which sweat cannot evaporate. Another consideration is that EVA training is done underwater, so materials must not lose tensile strength when wet. Based on the criterion of strength, abrasion resistance, and moisture regain, polyester is a fiber type which will maximize important restraint properties.

Teflon fibers exhibit low friction; therefore, if used as cording in the KSU design, friction between the cording and the loop could be minimized.

Triaxial Weave fabric was also considered for the KSU restraint design. The fabric has the inherent advantage of dimensional stability and looser restrictions on glove pattern layout since the fabric has three grains instead of two.

Samples of triaxial weave fabric were obtained and used to construct a glove. (See Figure 41.) The pattern used to make the glove was very similar to that used with the plain weave fabric with the exception of the removal of pleats from the fingers. This was done to test for stretch of the fabric on the

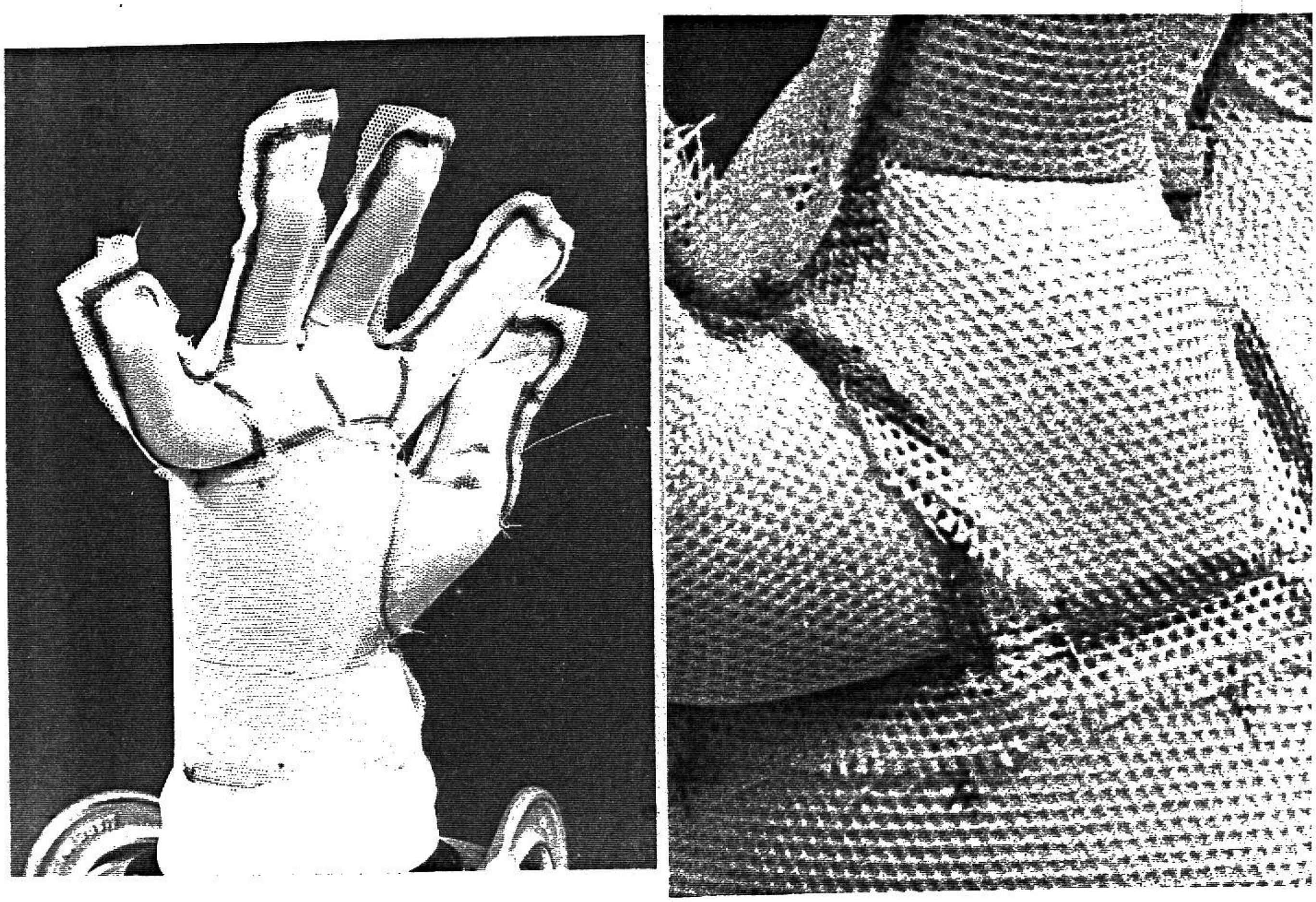


Figure 41. Glove Made From Triaxial Weave Fabric

bias, which would hopefully eliminate the need for pleats. When the triaxial weave glove was inflated in the bell jar no stretch was present. It performed similar to traditional biaxial weave fabric.

Design Finalization

The final KSU design incorporated the favorable features of the previously tested design ideas and materials. The final glove contains an adjustable palm restraint bar which is included to decrease ballooning and provide fastener locations. Excess material at the metacarpal joint is provided for individual movement of the fingers. Each finger is restrained with a line and loop system as shown in Figure 38. This system carries the axial pressure loads. The restraint consists of nylon lines running from the palm restraint bar, through metal loops located on the sides of the fingers to tie points on cantilever rods extending from the back of the glove. This allows the individual finger to move in an approximately circular motion about the metacarpophalangeal joint. The restraint layer was made from ripstop and plain weave polyester fabrics provided by ILC Corporation. (See Figure 42, 43, 44.)

When pressurized up to 10 psi, minimal force was required to flex the metacarpal joint and there was no restoring force to return the joint to the original position once it had been flexed.

Figure 42. Model of Final KSU Glove Design

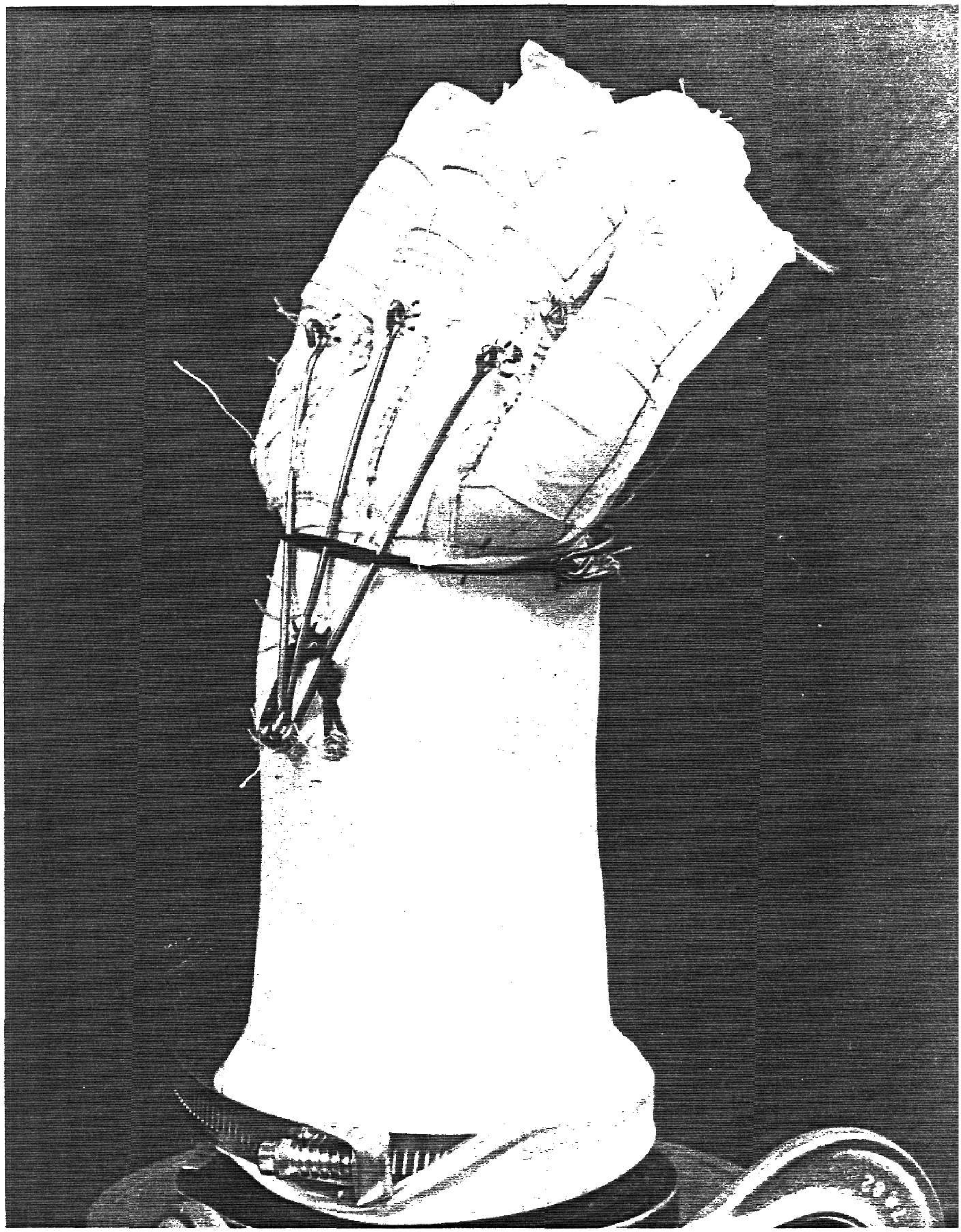


Figure 43. Model of Final KSU Glove Showing the Cantilever Rods

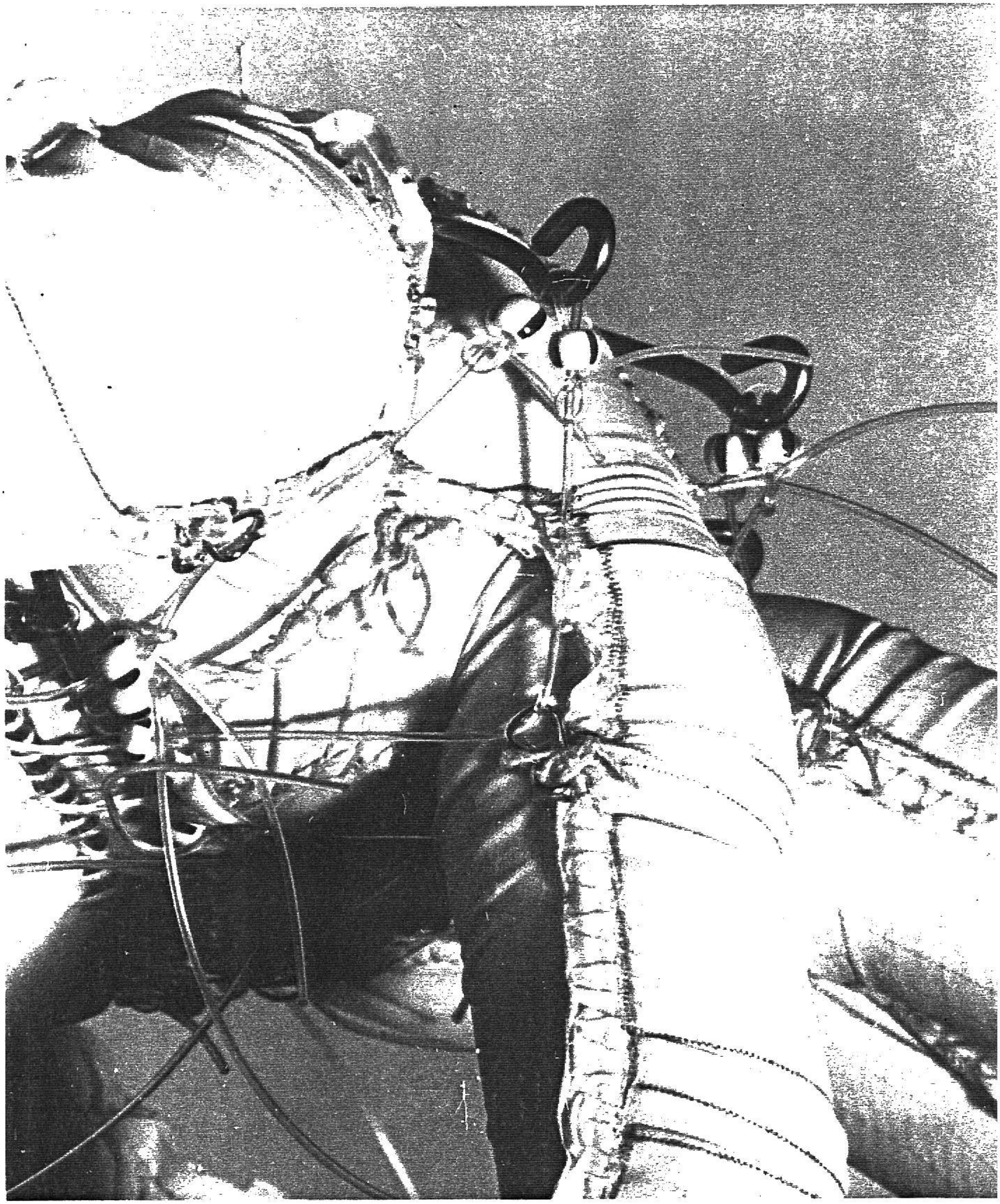


Figure 44. View of Final KSU Glove Design Showing Hardware Attachments

MANUFACTURABILITY OF KSU RESTRAINT LAYER DESIGN

MANUFACTURING CRITERIA

ILC Corporation is the present manufacturer of the restraint glove. The manufacturing process is a non-automated, custom process. One seamstress constructs an entire glove through layout, cutting, sewing, and quality control. Hardware is added in the Hardware Assembly Area.

Laying the pattern on the fabric is a critical step. The pattern must follow the fabric grain for proper load distribution and to eliminate deformation when the glove is pressurized. Pattern markings for stitching and component placing also depend on proper layout. Following quality control checks for proper layout, the fabric is cut out with a hot knife within a specified tolerence.

The sewing process is divided into two seperate procedures. First the finger section is constructed, followed by construction of the palm section. The two components are then joined. Quality control includes checks of the number of stitches per inch, seam allowance, finger length, and placement of load patches. These checks occur when joining any two points on the glove pattern.

Hardware such as cording is incorporated in the sewing process, while hardware such as the palm restraint is installed in the final assembly. Hardware is checked in the final glove inspection.

The entire process of restraint manufacturing takes 90 hours per pair.

Glove manufacture may neccessarily be more mechanized at a future point when the demand for restraints increases with more EVA projects.

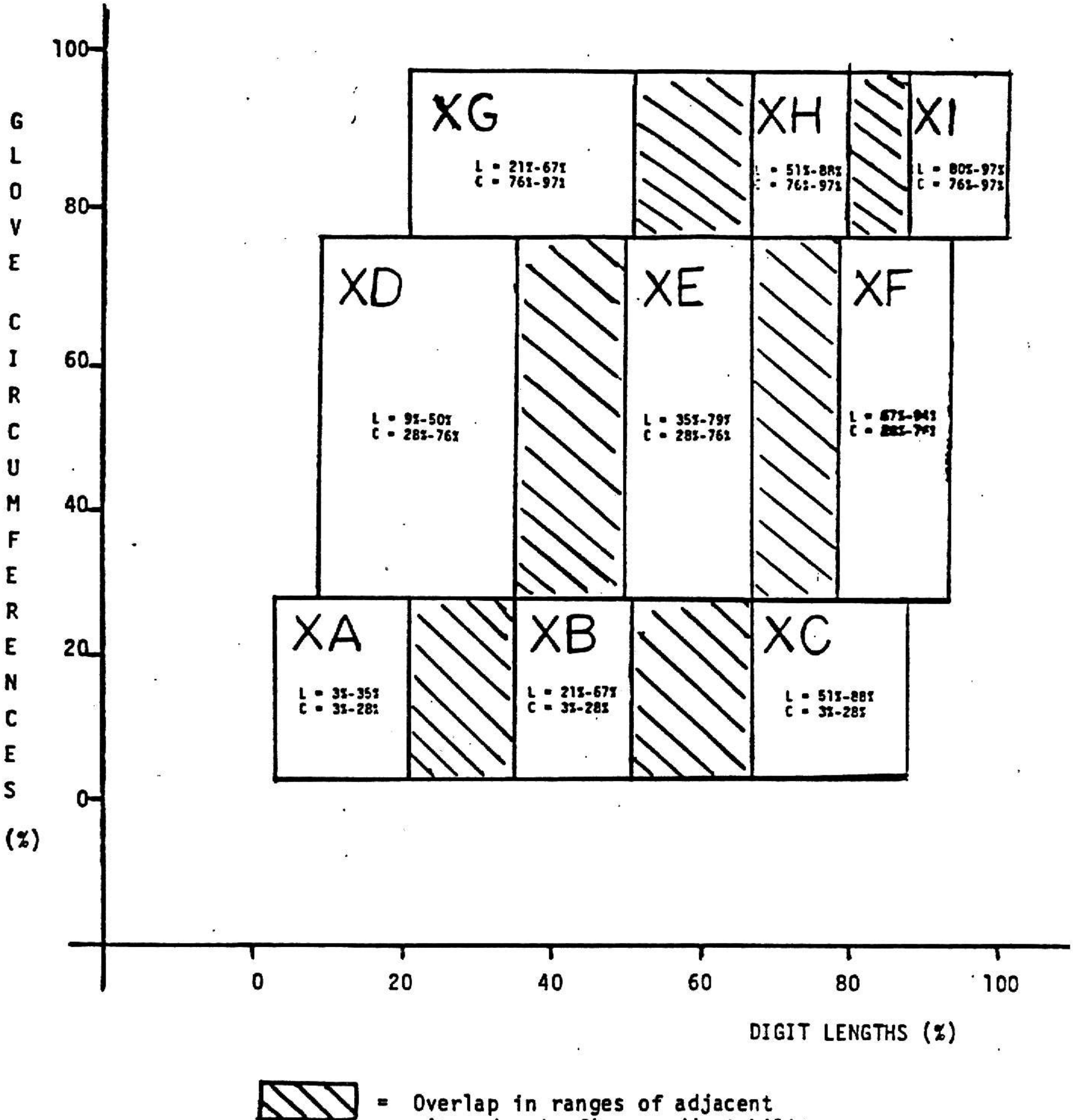
The restraint layer currently used by astronauts on EVA could be easily modified to incorporate the KSU design. The only software design change needed from the current ILC restraint layer is the addition of excess fabric across the metacarpal area to allow bending flexibility. All of the proposed hardware changes are added after the current restraint is manufactured. The materials added would not significantly increase weight or cost of the glove.

Glove Sizing

ILC has nine glove sizes to fit 95% of all male astronauts trained for EVA. Should an astronaut, male or female, fall outside the size parameters a custom size glove is made. The glove sizing system is based on dimensions of glove circumference and finger length.

The critical dimension is the glove circumference; this is divided into "small", "medimum", and "large". Within each of the nine sizes there are also three finger sizes "short", "medium," and "long". Figure 45 shows the resulting NASA size chart detailing the male astronaut population percentiles covered by each of the nine gloves.

Size adjustments are easily achieved in the KSU restraint by an adjustable knot which is used to attain the desired monofilament restraint line length. (See Figure 37.) Restraint line length can be permenantly fixed at the optimal size, while retaining the option of cutting and replacing cord if size adjust



XA-XI designation allows distinction of Modified and Baseline glove sizes.

Figure 45. Percentile Ranges Covered by Modified Glove Sizes

ments need to be changed.

Because of high flexibility in adjustability, tolerences on hardware placement are not critical. The astronaut can adjust the hardware to achieve optimal sizing. Also, the adjustability of the design enables one size of hardware to fit most sizes of gloves.

DESIGN CRITERIA

Because addition of the KSU design only requires minor production changes in the current restraint layer, restraint layer integrity should not be greatly affected. Sliding loop attachment areas, the cantilever link attachment area, restraint line attachment areas, and the palm restraint bar attachment areas will have additional force loads imposed by the design. Load patches sewn on the restraint, if necessary, will cure the problem caused by the additional loads. Also, failure of any part of the KSU design additions will not directly critically affect the potential survival of an astronaut in EVA. Any such failure would only diminish the flexibility of the metacarpal joint.

INFORMATION DISSEMINATION

Information regarding the progress and results of the project was disseminated through a variety of media. Radio and television interviews of students were conducted which provided the general public with information regarding the project. In addition, several presentations were made by various team members. Groups to whom the presentations were made included the Society of Experimental Stress Analysis, thè American Society of Mechanical Engineers, Omicron Nu (National Home Economics honorary), the Industrial Engineering Advisory Council, and the Kansas Cooperative State Research Service. The final project presentation was made to the American Society of Engineering Education in Washington. D.C. on May 31, 1985.

After being informed of KSU's involvement in the design project, Lee Willis, a KSU graduate and engineer at the Johnson Space Center arranged for NASA to furnish an exhibit at the All University Open House on March 29 - 30, 1985. The exhibit included a space suit, a Extravehicular Manuvering Unit (EMU), a Stinger (a device the astronaut uses to capture a satellite) and various space hand tools.

Due to NASA budgetary problems the visit was partially subsidized by the Kansas State design team. The design team donated $600 to help reduce NASA travel expenses.

The visit was a big success. The design team obtained a much better understanding of the EVA mission tasks from talking with Willis and other NASA personnel as well as examining the displays. The NASA exhibits were very popular as the crowds usually were four deep around the exhibit. The college had approximately 9,000 visitors.

The KSU student design team provided a display and slide presentation next to the NASA exhibit and demonstrated their various glove prototypes. Another display describing the project was provided in the Department of Clothing and Textiles.

Several publications were forthcoming from this project. An abstract was included in the USDA-sponsored North Central Region research group, an announcement was included in the American College Professors of Textiles and Clothing newsletter, and an article has been submitted to the Journal of Engineering Education. In addition, the project provided the basis for two student team members' master's papers.

REFERENCES

Slowik, J., Marcum, A., and Burns, M. *Exploratory development of pressure suit mobility joints, gloves, and helmet*, (Report Number J6028 - Final), Illinois Institute of Technology, Chicago: Illinois, ITT Research Institute, April 1970.

APPENDICES

APPENDIX A

KANSAS STATE UNIVERSITY
PROGRESS REPORT 1

1 November 1984

Kansas State University received oral notice of selection for the project by the American Society for Engineering Education in August, 1984. The team held its first meeting on September 7, 1984. The team is comprised of six students and four faculty members. Student members are: Jon Held, Mechanical Engineering; Paul Stephens, Mechanical Engineering; Kimberly Ellis, Textiles and Clothing; Janice Huck, Textiles and Clothing; Carlyn Solomon, Industrial Engineering; and Nesby Bolden, Industrial Engineering. Faculty persons are: Stephan Konz, Industrial Engineering; Byron Jones, Mechanical Engineering; George Eggeman, Industrial Engineering; and Elizabeth McCullough, Textiles and Clothing. The student team meets twice weekly, with faculty attending one of the regularly scheduled bi-weekly meetings.

Initial contact with NASA was made by Dr. Eggeman on a September 12, 1984 visit to Ames, California. Mr. Vykukol of NASA answered some questions regarding the project. Through this contact, it was determined that NASA is satisfied with the present wrist joint, and the EVA glove was the primary concern.

Members of the team visited the Cosmosphere in Hutchinson, Kansas on October 16, 1984. In addition, four student team members and one faculty person have visited NASA Houston (October 19, 1984). Steve Bursen of the Cosmosphere showed the team many older suits and gloves from projects Mercury to Apollo. Various IVA and EVA gloves were loaned to the team for future reference and testing. During the NASA Houston visit, Mike Rouen and astronaut George Nelson were able to provide additional information about present gloves and design criteria for future gloves. It was conveyed that the primary design parameter to be considered should be the metacarpals under 8 psi conditions. A full report of the NASA Houston visit is presently being compiled.

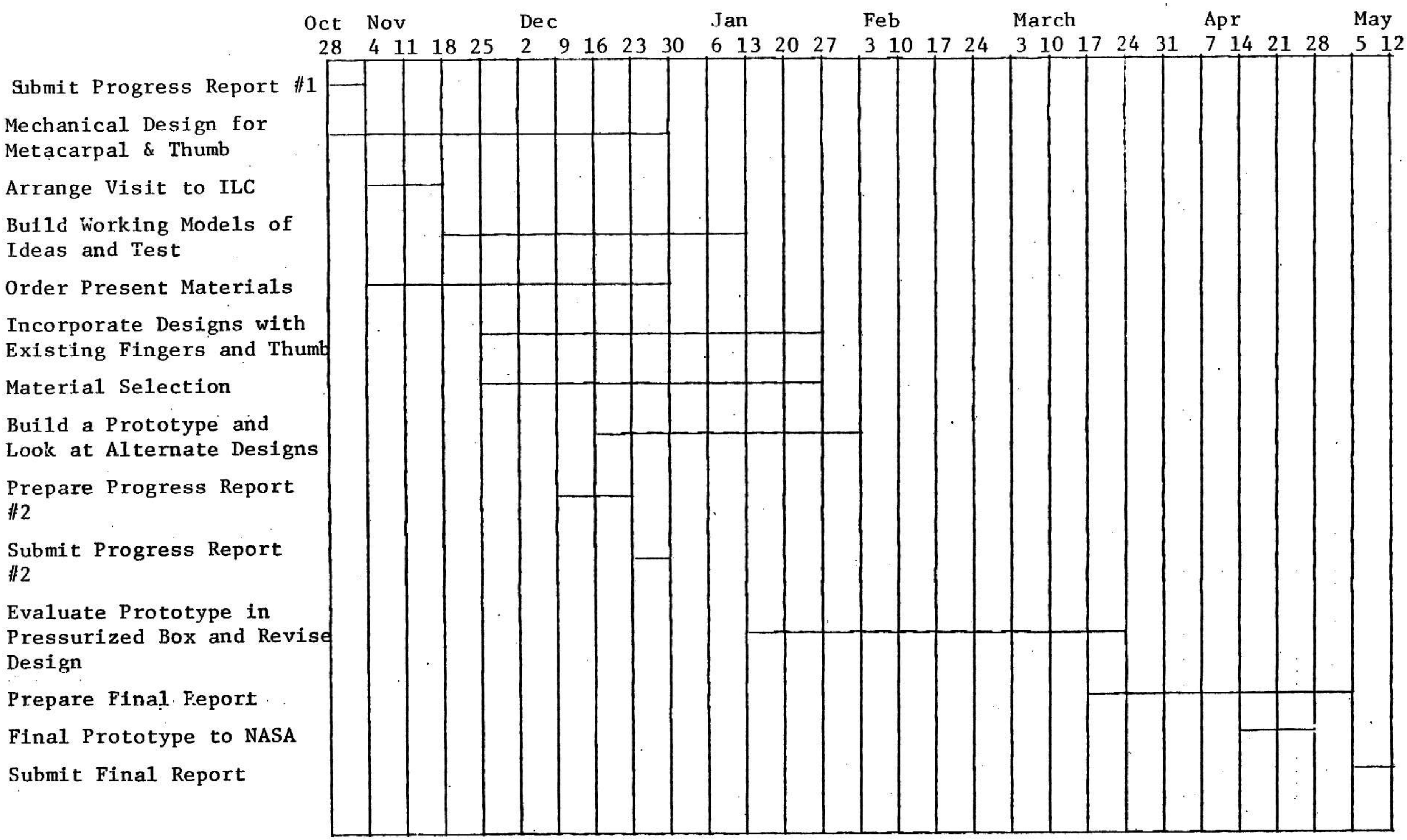
In addition to these visits, the team has conducted an extensive literature search. Library accounts, a central location for storing information, and computer search accounts have been established. During weekly meetings, faculty members have presented information on basic engineering design criteria, design of hand tools, heat transfer and thermal aspects of glove design. Future presentations by faculty are scheduled.

A number of designs have been considered by the team to solve the problem of glove flexibility under pressure. The most important aspect of any design is maintenance of constant volume. In addition, problems of thermal and micrometeroid protection must be addressed. Some tentative design decisions have been made by the team. The major area of concern, metacarpal and thumb flexibility, have yet to be solved. This is an area of continuing area of focus for the team. The team will be constructing pressurized oversized working models to test concepts that are developed. Attempts to obtain materials used in the manufacture of present gloves will be made.

It is planned that a prototype glove will be constructed and tested by January 20, 1985. A series of re-designs will follow to improve the design. The final prototype is scheduled for completion by March 20, 1985.

NASA Glove Design Team

Extended Time Plan



APPENDIX B

KANSAS STATE UNIVERSITY
PROGRESS REPORT 2

20 December 1984

The faculty members have completed presenting their initial reviews of their areas of expertise related to EVA glove design to the team.

A number of designs have been considered by the team. A vacuum box has been constructed using a plastic bell jar. Pressure tests have been made on a number of uniaxial cloth joints to achieve a working knowledge of different construction techniques. Types of joints that have been tested include box pleats, gores, and gathers. Biaxial joints will be tested in early January, 1985.

The major area of concern, metacarpal and thumb flexibility, has yet to be solved. Tests on large scale (wrist sized) models of these joints presently are being performed. Some models show promise, but still have problems that need to be addressed.

Our present best design for the metacarpal joint consists of a pair of cables on either side of the proximal that link the upper and lower surfaces of the gloves to a triangular coupler connected to the neutral axis of the finger (see Fig. 1). This arrangement transmits the force from the neutral axis to the upper and lower surfaces; it also moves the finger portion in a circular path centered at the metacarpal joint so constant volume can be achieved.

An interesting test consisted of a steel mesh safety glove constructed of small steel rings with a latex glove bladder. Although it was tested for finger flexibility, a surprisingly flexible metacarpal joint also resulted. This mesh glove will continue to be studied and tested to determine the reasons for its flexibility.

We will attempt to obtain materials used in the manufacture of present gloves. Two members of the student team will be visiting Internatonal Latex Corporation in Dover, Delaware in early January. Two members will visit Sager Glove in Illinois in January.

A glove incorporating our ideas will be constructed and tested by January 30, 1985. A series of re-designs will follow to improve on this prototype. The final prototype should be completed by March 20, 1985.

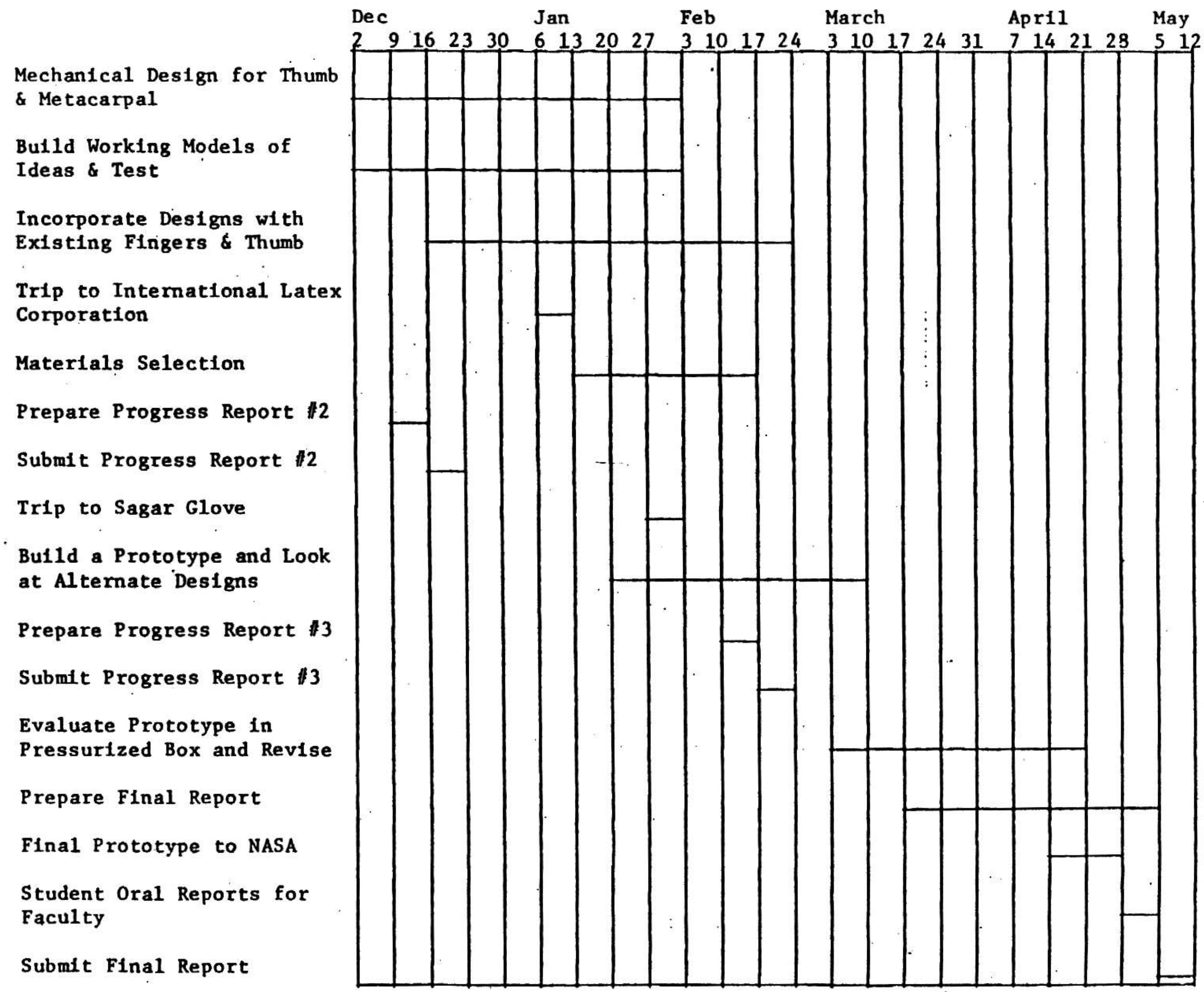
Some of the ideas that we would like to get your feedback on are:

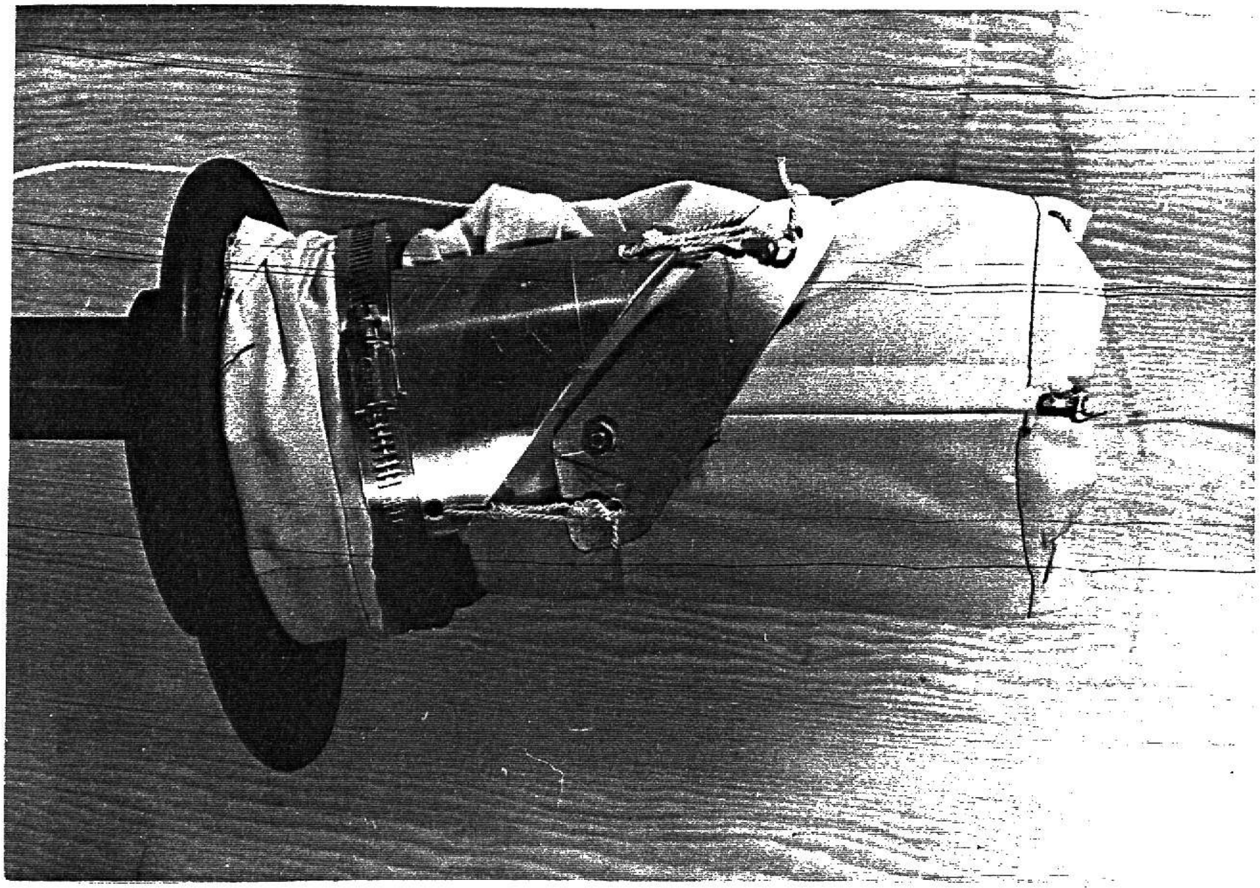
1. An extension section above the wrist to reduce the man loads on the suit. It would be designed so that, when the suit was pressurized, there would be no change in length but extension could occur when the force was increased above the pressure force (such as when an arm is extended).
2. The main body and backside of the fingers might be made of a series of rigid shells giving good protection and still allowing flexibility.
3. Metal fingernails might be included on the glove to help grip and maneuver small objects.
4. Comments on our metacarpal joint.

An extended time plan is included with this report.

NASA GLOVE DESIGN TEAM

EXTENDED TIME PLAN





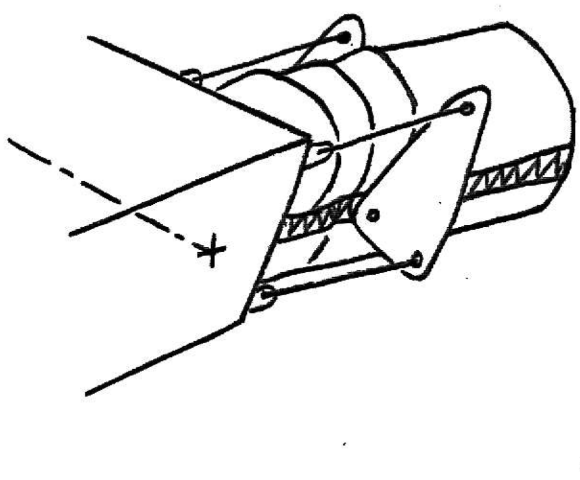


Fig. 1

APPENDIX C

Progress Report 3

February 15, 1985

Prototype Development. During December, work continued on large joints, which represented the metacarpal. A large scale model with a wrap-around link was constructed (see Figure 1). Many different designs of cloth tubes were tested using this link, with limited success. Since the restraints placed on the fabric are different in a glove than on a large scale model, it was determined that a glove should be tested.

The first prototype glove was constructed in late December, 1984 (see Figure 2). Links were made for the fingers of aluminum and this linkage was tested. There were problems with the cloth ballooning around the base of the fingers. This was solved with a restraint ring (see Figure 3). The restraint ring helped the flexibility and, at 6 psi, the metacarpal joint was extremely easy to flex for the first 30 degrees of motion (the 30 degree limit due to the link reaching a limit of travel). This glove was taken to ILC and they seemed favorably impressed.

The second prototype had simpler construction in the finger area. The fingers consisted of two fabric pieces where eleven had been required for the first prototype. This simplified construction but did not seem to affect operation of the fingers when tested. A new design of link, restraint ring, and palm restraint were tested on this glove (see Figure 4). The link did not work, seeming to have too much friction with the cloth, and did not rotate with respect to the finger. The glove was still fairly flexible at 7 psi. It was then discovered that the restraint ring alone was 80 percent as flexible as the combination of link and restraint. The link by itself was about 30 percent as flexible.

Construction has begun on a fatigue tester that will flex fingers and thumb of inflated glove models approximately once every second. A third glove was constructed of nylon and will be tested on the fatigue tester to look for weak points in the design of the restraint layer. Bladders (current and possible alternatives) will be tested with this tester to determine the effect of fatigue on bladders. The tester will include apparatus that will mark the time the bladder fails (i.e., leakage begins). The tester should be operational by February 17, 1985.

The latest idea was to replace the links with strings and tubes (see Figure 5). This was tested this week. It worked very well, and we expect this will be part of our final design. The strings reduced the bulk of the hardware and yet are compatible with ideas proven in the past. It is also thought that many parts of the restraint rings could be replaced with string, and this should improve the comfort in this area.

Three palm restraint designs have been tested. It is believed that a two piece hard back, with separate palm bars, might be best. This will be tested on future prototypes.

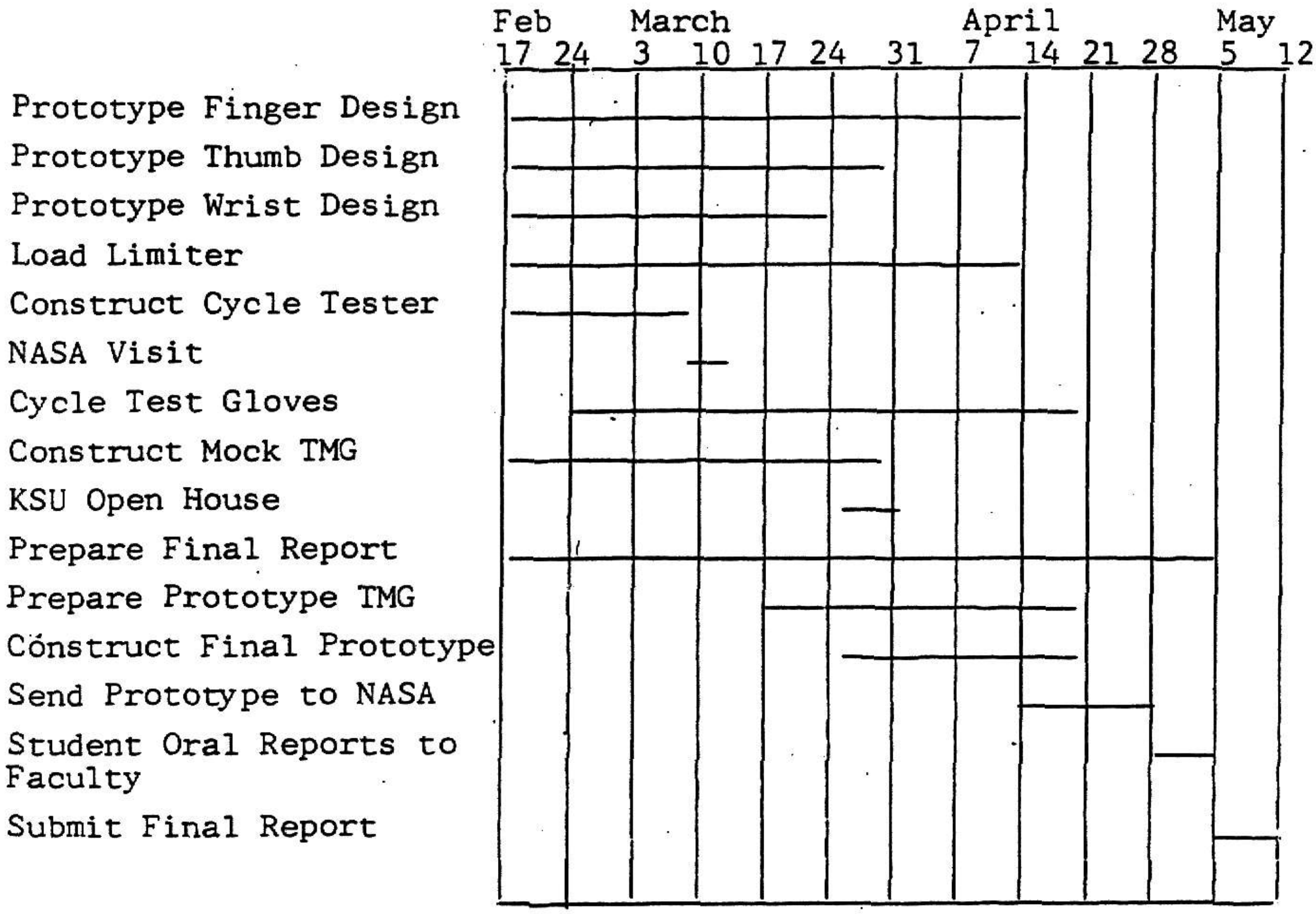
Travel. Two student team members visited ILC in Dover, Delaware on January 7, 1985. The students were able to speak with design engineers Mel Case, Dave Slack, and Hal Wright, as well as Bill Dougherty and Jim Clougherty. The trip was beneficial in three specific areas pertaining to the project: mechanical design, critique of KSU's prototype, and evaluation of presently used textile materials.

ILC personnel explained design characteristics of the present gloves and why ideas in past prototypes did not work. These gloves were demonstrated in a pressurized box along with KSU's prototype. The design engineers pointed out good points of the students' prototype.

ILC provided specification sheets for the present textile materials being used, pointed out important parameters to consider in material selection, and demonstrated several testing procedures. In addition, ILC provided materials for construction of a final prototype.

EXTENDED TIME PLAN

January 15, 1985



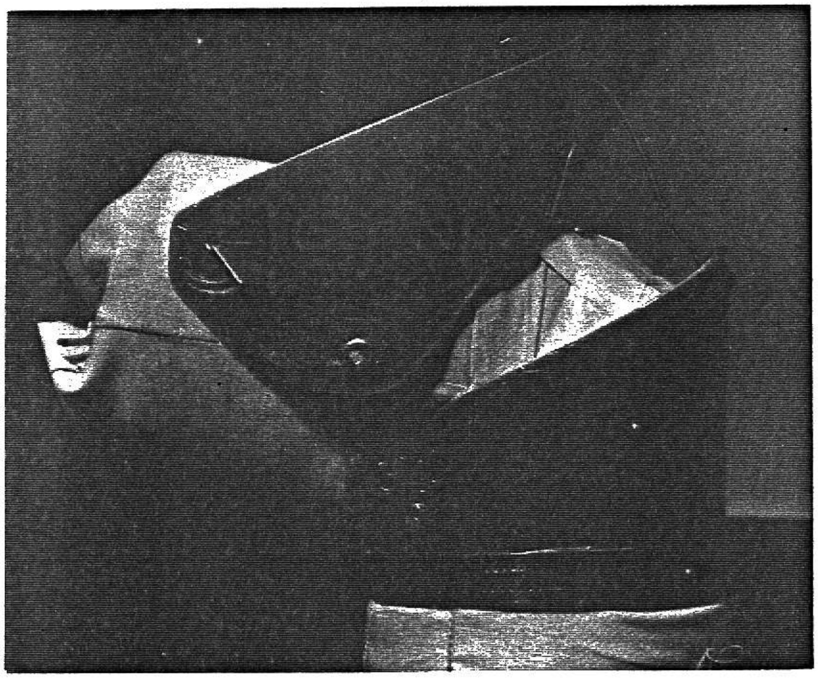


Fig. 1

Fig. 2a

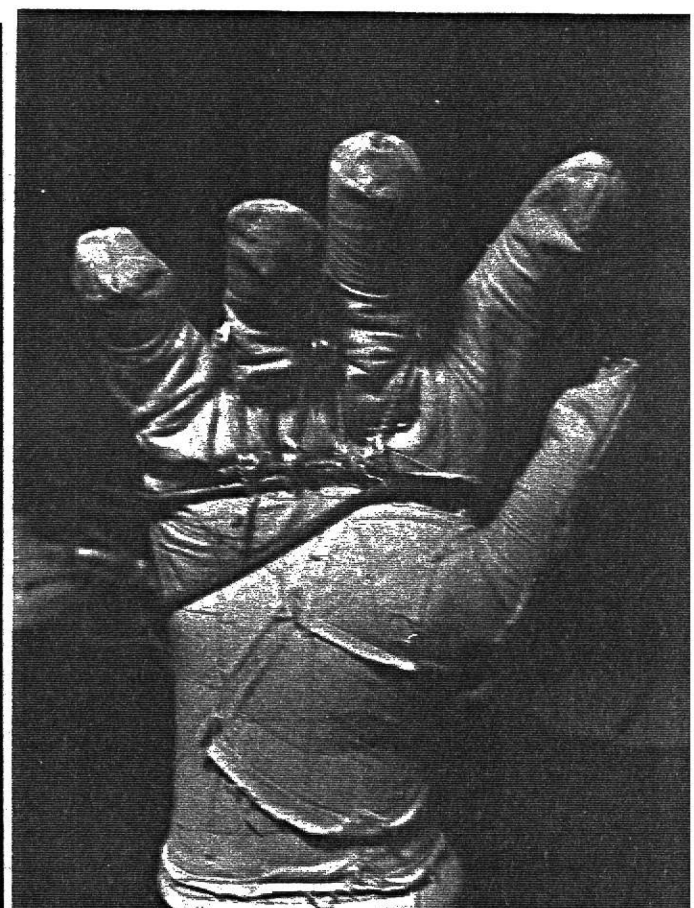


Fig. 2b

Fig. 2c

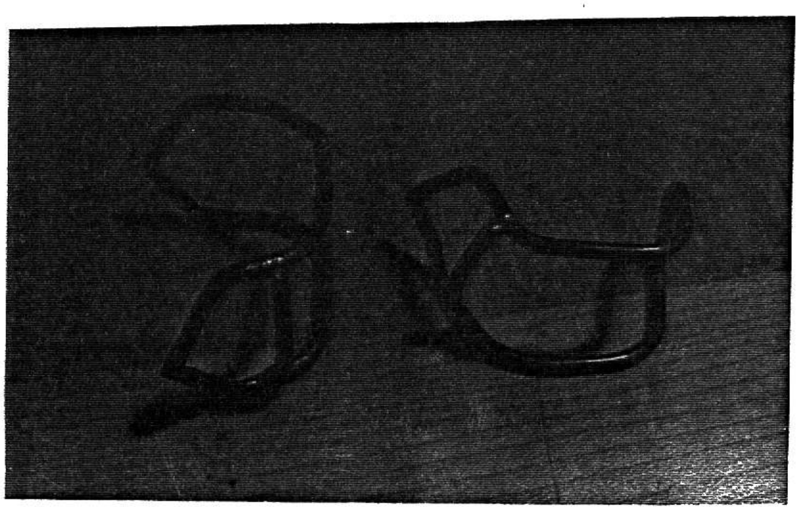


Fig. 3

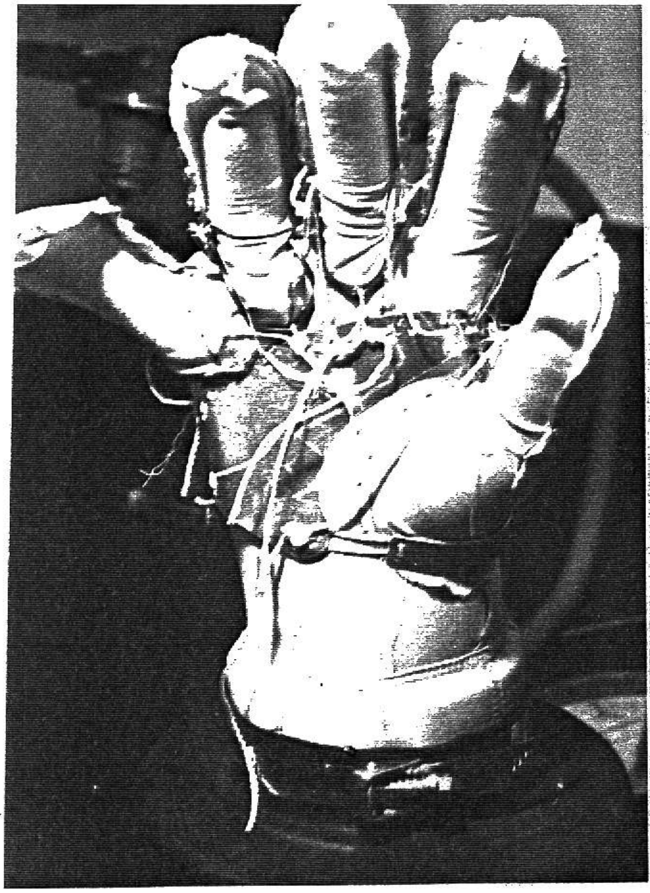


Fig. 4a

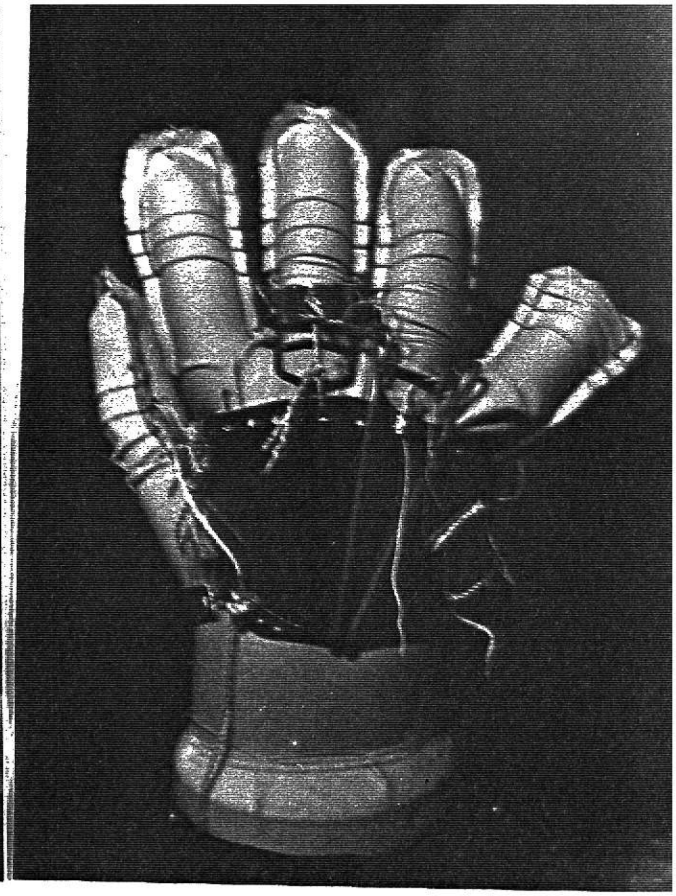


Fig. 4b

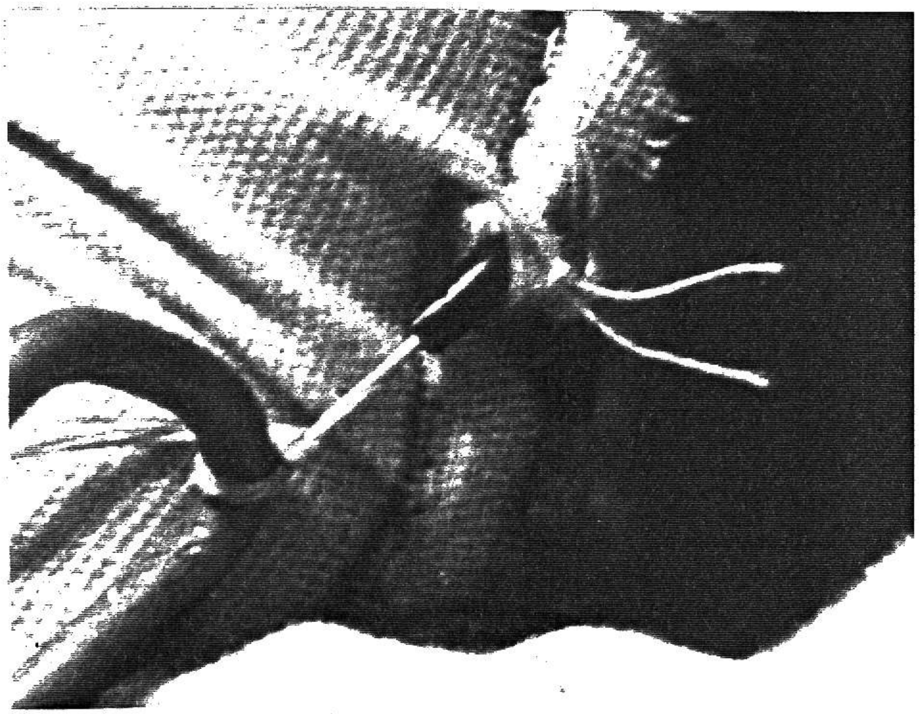


Fig. 5

APPENDIX D

Notes on G.W.E. visit to Ames, September 12, 1984

Ames is a research center, Houston is operations.

Dr. Vykukol's office is in a laboratory area and he is a project leader. The amount of project management at this time has not been defined. He is concerned with the development of ideas, material types and manufacturing processes. He would like to have a prototype if possible but realizes cost/work may prevent this.

The laboratory contains many different versions of gloves. A vacuum chamber is present and is a rectangular box shape. Cost efficiency and stress analysis would lead to a clear glass cylindrical tube with metal ends. Glove is custom fitted.

Molded neoprene rubber gloves were the first models and have shelf life problems along with being pressure sensitive. Multilayer fabric (latest with teflon outside) are presently used. Lots of pleats and accordian joints.

Wrist joint is not a problem. NASA is progressing toward hard materials in the space suit.

Water emersion tests and use of adhesives should be considered.

What is the date for the first visit to NASA? Is it appropriate for the whole team to come or should we wait until a later date to have the whole team visit?

Second week of October, a letter from ASEE will be sent to confirm date. Number of attendees depends on what team determines.

Can we expect any visitors from NASA? When? How many?

No.

Will NASA be able to supply us with a sample of the current version of the astronaut's EVA glove?

Maybe, policy decision must be made, but not likely. Glove costs $25,000 to $30,000.

Can we get a detailed description of the astronaut's tasks and functions so we can get a better idea of what the glove must allow the astronaut to do?

Houston meeting.

Can we get a list of related NASA publications or bibliography that will help us with our literature review?

No, but NASA has many publications. There are two volumes on materials.

Just what nature of interaction with NASA should we expect? Will they be providing extensive documents? Can we call them frequently? Will we be given a list of contacts for different topics? Will NASA do any testing or evaluation for us? Will they make detailed reviews of the progress reports, etc?

No procedures established. There will most likely not be close supervision.

What is the nature of the protection from micrometeoroids required? Must it always be present? Is it a major consideration in the outer glove fabric selection?

Not a concern, but there is a lot of space debris present.

What level of puncture or tear can be tolerated, if any? Is a loss of pressure integrity of the glove fatal?

None (see later note) and yes.

Can a present glove be obtained? If not, can a print or picture be sent?

See above.

Do you have information on past designs and why they didn't work?

Yes, in deficiency reports and in personal knowledge.

Is there a difference in gloves (units) for moon versus space versus inside emergency equipment?

Glove will be used in a space station environment. Possibly in six hour shifts.

Can the hand go unprotected for any length of time?

No, blood vessels rupture per USAF studies.

Is it possible to separate hand pressure from suit pressure?

No comment.

What is the design philosophy on grasping mechanisms such as muscle controlled devices used on amputees?

Gloves are gloves. Astronauts like gloves versus mittens or last three fingers encased with thumb and index finger free.

Are any materials unacceptable?

Only in their use. Titanium has been banned. Sharkskin was used in soles of the moon shoes.

What are the safety requirements for possible leaks, fire retardation, and radiation protection?

Houston meeting.

What temperatures are present?

Internal comfort conditions.

What types of tasks--twisting, push, pull? What tools are used?

Houston meeting.

What are the material's abrasion resistance and strength requirements?

Houston meeting.

Is leakage from seams an important design parameter?

None allowed. Later there is a 250 cc/min. total suit leakage which would relate back to about 50 cc/min or so for the gloves.

What numbers and sizes of gloves are to be made?

No definite answer.

What is the maximum cost possible?

Don't worry at this time.

Are there any differences between left and right hands other than the mirror image?

None.

Are astronauts required to be right-handed?

No.

Are gloves and suits individually fitted?

Yes, but long range goal is to have a more universal fit.

Is there a time analysis available on use of the glove?

Houston meeting.

What are the long range plans for use of the glove?

No answer.

What is the life of the glove expected to be?

Cycle tests are made, not specific.

How much is the glove used in a non-EVA environment?

Taken off almost immediately inside space station.

How is the glove put on and removed?

By the wearer. Glove snaps on but requires four identifiable push twist motions to remove.

What is the rate of heat transfer in EVA environments?

There is a specification for holding a 1/4 inch diameter rod of a given temperature and for a given time.

Will the glove be used with the present suit (e.g. what utilities are available to cool)?

Suit pressure.

What happens if the glove leaks (inconvenience or major problem)?

above

Will there be corrosive chemicals where the glove is used (e.g. batteries or fuels)?

No definite answer.

Should there be conductive shielding? Should electric shielding not be the top layer? Are there any uninsulated electric terminals in the work environment?

Presently, they have an electro-static charge protection on outer layer.

Could a two-glove system be used?

Presently, they have a fold back flap arrangement.

How long can a hand survive in unpressurized space environment?

above

APPENDIX E

COSMOSPHERE NOTES

Spun Beta glass was used after Apollo 1 flight
fire proof (got away from nylon)

The glove rings - red for left and blue for right hands

They are made so that the whole glove can swivel and maintain an airtight seal

Current gloves have larger rings on cuff (Apollo 15)

Inside of glove is called a bladder; it's airtight

The inside of the glove is ventilated; it has air ducts that run into it; they ventilate the hands so the hands don't get sweaty

Chromel - spun stainless steel often goes over the glass fiber Beta cloth to increase durability; it's also fire resistant

For the whole space suit, they lace a cover layer to the pressurized bladder

The woven Beta glass is coated with Teflon

The bladder is made to fit each person (astronaut) on an individual basis; the natural configuration has curved fingers and thumb - allowing room for joints.

You want the space between the bladder and the hand to be as small as possible to reduce the resistance to bending

The only difference between the IV gloves and the EVA gloves is that the EVA gloves have a protective shield (glove layer) over them

Latex bubbles (O) are put on the ends of the EVA glove for improving the dexterity (traction); used for walks on lunar surface

Beta glass is puncture-resistant and difficult to sew; could have poor abrasion resistance, particularly to bending

Kapton (comes in silver and gold) - metallic layers inside EVA glove

Gloves are made by ILC - International Latex Corporation (Playtex)

Description of boot (similar to glove)
Multilayer thermal cross section consisting of an inner liner of Teflon-coated Beta cloth followed by 13 layers of aluminized Kapton film which are separated by 12 spacers of Beta marquisette (net type construction)

Layering system is designed to stop radiant heat transfer

Steve Bursen (?) was the name of the man who showed us the gloves

The Mercury space suit was constructed in 2 layers, a cover layer of aluminized nylon and a pressure bladder of neoprene - impregnated nylon twill. B. F. Goodrich Co. made it

Litton Company and AiResearch also made suits

The Litton Hard Suit - unlike the more common soft suit that became increasingly stiff as it was inflated, the hard suit maintained its excellent mobility regardless of the pressure inside. Since the Litton design required no zippers the leakage was minimized, a great technological break through. The suit was made movable through the use of stove pipe joints and rotary ball bearing seals. Made primarily of aluminum, stainless steel and plastic, the suit provided excellent micrometeoroid protection for the space walking astronaut. The suit was bulky to store and heavy (80 lbs). More are in space shuttle so future is promising for this concept.

List of items from Cosmosphere

Boot with Kapton layers/marquisette net
Blue glove with fingernails
Pair of unused bladder gloves
EVA glove - long white cover

Keep 2 Chromel beat-up finger gloves - EVA
1 piece white Beta cloth

APPENDIX F

REPORT FROM NASA HOUSTON VISIT
October 19, 1984
by KSU Design Team

Visited: Mike Rouen
George Nelson

For this project Rouen is looking for an innovative metarcarpal joint for an EVA glove. He expects at least an idea on paper. If a prototype is constructed, the appearance is not a major concern. The glove also needs to be designed for an 8 psi pressure differential. Appendix A includes a list of glove specifications which was presented to the group at Houston.

Rouen

1. Rouen is not satisfied with the present gloves.
2. For this project, only be concerned about space shuttle EVA.
3. Rouen informed the group to only worry about the knuckle joint (metarcarpal region).
4. Hytox and crytox fluro-carbon lubricant is put on the wrist ball bearings because it does not off gas. Rouen will try to send us a glove wrist ring.
5. The gas retainer is bigger than the load retainer (polyester).
6. The axial load on the suit = pressure load (P*A) + manload. The suit normally is smaller than the person so that the gloves fit snug over the hands when working directly in front of the body. Since the suit is small and leaves very little room for stretching, bruised finger nails can occur when any stretching is done. Up to 1 ton can be applied on the suit by the astronaut's legs. This force is carried by reinforced straps and cables which are located on the seams. The hoop load is carried by the fabric.
7. External temperatures in space may range from +250 to -180 degrees F.

8. The outer fabric (beta cloth) can handle minor meteorites. Major meteorites (velocity = 20 km/s) are equivalent to a 45 cal. bullet. Do not worry about protecting the astronaut from major meteorites. They have yet to discover any holes in a suit that has gone EVA. All such suits are pressure tested.

9. Micrometeoroid protection is not needed on palm of hand, but it is needed on the back of the glove.

10. Sizing straps are laced with nylon or polyester (preferred) cord to adjust for different suit sizes.

11. The astronaut must be able to put on the entire suit by himself/herself.

12. A soft suit is preferred for ease and compactness of storage.

13. The hard suit requires too much space for storage. A soft suit with a hard torso could be stowed in the torso. Soft parts are able to fit inside the torso. Rouen said "Can space station afford volume of hard suit?"

14. At the fingers, the layers from inside out are: a pressure layer, then knitted polyurethane coated pressure restraining layer, then blue tips.

15. Commercial polyester is strength tested before being used.

16. There is a 1/32 inch tolerance on seam positioning.

17. The optional comfort glove is made of nylon tricot.

18. Kevlar is being replaced with Nomex.

19. Blue finger tips are RTV.

20. Radio heat sealing is used on the pressure bladder.

21. The polyester (of polyester pressure bladder) - - old one is sensitive to water, thins out, then leaks in water tank tests. Worry about sweat on EVA, therefore one mission per bladder.

22. The suits used in the water tank are exactly the same as the EVA suits.

23. At the very least, the hand will be uncomfortable when it is at 3 psi and the head is at 8 psi.

24. It takes 30 psi to explode the suit. It is exhausting to move at 8 psi. When you double the pressure you double the force on the suit.

25. With the old glove at 4.3 psi it was hard to bend the fingers. Jon Held estimated that a fist could not be made at 8 psi.

26. With the new glove at 8 psi it was easy to bend fingers. But the glove did not have the thermal micrometeoroid protection. Nelson said the thermal micrometeoroid protection layer greatly limits glove flexibility.

27. International Latex Company makes design decisions and builds the suit. International Latex Company is located in Dover, Delaware. They are actually in Fredrick, just outside of Dover.

28. David Clark Compay made a prototype glove with cables and tubes for the metarcarpal joint. This glove produced too much friction when pressurized.

29. A David Clark glove prototype consists of a link net fabric, similar to a chainlink fence. This material is used as a restraint layer.

30. Hamilton Standard Company no longer makes gloves.

31. A heat pad is provided for the glove. Rouen wants minimum insulation in the palm of the hand. Old glove had felt in the palm, which Rouen removed.

32. The new NASA glove fingers have a lighter fabric, more pleats, and adjustable length with side springs (1/4 inch). 9 sizes of gloves fit 50% of the astronauts. Third and second fingers are very important. Palm bar is present to resist ballooning. Nelson said he likes the palm bar very tight. Other astronauts complain about the sides of the palm bar.

33. The solar wind drains the charge so there is no need to worry about

capacitor effect of radiation insulation layers.

34. Gripping the tools during an EVA is no problem. If you let go of the tool, it does not drop. Also, tools are on a tether.

Nelson

35. The astronaut in charge of the gloves, George "Pinky" Nelson, said if he can adapt to the glove, then the glove is O.K. Nelson also said that you learn new motions during an EVA. For example, to turn something requires you to turn your entire arm. He was surprised to hear that Rowen said that the wrist joint is satisfactory. It seems to take a lot of effort to flex the wrist.

36. Nelson commented that the air tube located on the wrist hurt the back of his hand.

37. Nelson said that custom gloves are worth the price. He also said that adjustable gloves fit great.

38. 8 hours of work means about 10-12 hours of total time. Nelson would not want to do an EVA every day. It is mentally and physically taxing.

39. Nelson said that a glove which would allow you to spread your finger would be a good idea.

40. Nelson definitely prefers a soft glove over a hard glove. He also felt that improving thumb mobility was of great importance.

BACKGROUND INFORMATION

1. Heat transfer of insulated suit is 300 BTU/h which is equal to a sleeping adult. Therefore, cooling is always necessary. The cooling garment contains 300 ft of 1/8 inch tube with spandex to hold the tubes and a thin comfort lining. 32° F water is mixed with warm recirculated water as temperature control is adjusted by a rotary valve on the chest pack.

2. Helmet pad behind the head distributes air around face and into the suit. The air then exits at the extremities. Dew point is at 55° F. 4.3 psi; 1 pound of oxygen lasts for 7-8 hours. The CO_2 is removed by combination with something, charcoal filtered for smell, and extra oxygen added.

3. Drinking water bag and food bar are contained in the helmet area.

4. The gold coating on helmet visor is worth $1.76 (gold at $500/ounce).

5. The back-up purge valve on side of helmet is hard to operate according to Rouen. Astronaut Nelson says it is not difficult to operate.

6. Directional snap fasteners are used on the communicator connector. If the communicator falls off, the astronaut must immediately return inside the ship. The liner on the earphones is made of deer skin.

7. The portable life support system is bolted to the back of the hard fiberglass torso.

8. The major expense of an EVA suit is the portable life support system.

9. The suit has a rolling convolute soulder joint coupled with a wrist type joint.

10. Two sizes of the hard torso will fit 85% of the astronauts.

11. Nelson said that, with assistance, the suit can be donned in 30-45 minutes. Most of that time is spent doing checkout procedures (leak test and communications check).

12. Different color of strips on suits and badges serves to identify the astronaut.

13. A wrist mirror is used to read instrument settings on chest controls.

14. Two sizes of boots are used with 5 or 6 inserts to fit the individual astronauts.

15. Nelson says one pressure point can hurt real bad. You begin to focus on

the spot that hurts.

16. Nelson said that he only got hot (not cold) in the bay of the shuttle, which acts like a big collector.

17. Nelson mentioned a NASA document (10-67??). It has information on requirements on hand tool design for EVA.

18. Power into the suit is 1 amp at 16 volts. 16 watts will not ignite dry cotton in pure oxygen.

19. Female diaper holds 100 times its own weight, and has a liner that wicks fluid away from the body. Contains flaky powder.

GLOVE SPECIFICATION

ANTHROPOMORPHIC

FOCUS ON UPPER HAND (ADEQUATE WRIST DESIGNS ARE AVAILABLE)

WITHIN UPPERHAND-FOCUS ON METARCARPAL

SAFETY FACTORS

METALLIC PARTS	1.5 AT YIELD
	2.0 AT ULTIMATE
NONMETALLIC PARTS	2.0 AT ULTIMATE

DESIGN CAPABLE OF BEING SIZED FROM 5TH PERCENTILE FEMALE TO 95TH PERCENTILE MALE

SUIT OPERATING PRESSURE 8.0 PSID

GLOVE LEAKAGE ALLOWABLE 10 SCC/MIN O_2

WEIGHT 3.0 LBM MAX.

ALLOW GRASP OF OBJECTS AT $-180^{\circ}F$ to $+235^{\circ}F$

GLOVE SHALL BE CAPABLE OF BEING DONNED AND DOFFED BY AN UNASSISTED CREWMAN AT ZERO GRAVITY IN A PRESSURIZED CABIN

GRIP AND FEEL AS COMFORTABLE AND NATURAL AS POSSIBLE

APPENDIX G

NOTES FROM ILC VISIT, JANUARY 7, 1985

Bill Dougherty - Shuttle Manager
Jim Clougherty
Mel Case - Sr. Design Engineer
Dave Slack - Design Engineer
Hal Wright - Design Engineer

ILC is not International Latex Corporation any longer. They have 110 products in their line including pressure suits, inflatables and protective clothing. ILC employs around 400 people.

In the past the bladder was made of a polyester but is now made of polyether. The polyester is water sensitive, but the polyether is not.

Kevlar is treated with a silicone coating for abrasion resistance, and aid in gripping.

Three sources contribute to design: Vykukol, NASA crew systems division, and the contractor.

We shouldn't worry about loads influencing our design.

Load limiters have been thought of in the past. The cloth suit had inherent stretch but the rigid torso eliminated this.

Load limiters must be less than 1" long and have at least 1/2 travel with 50 pound preload.

Micrometeorite protection is a fairly unknown quantity as the actual impact is not known. The neoprene bladder on the body of the suit is effective micrometeorite protection.

There is a minimal fire propogation on the outside of the suit. The static hazard inside the suit is minimal because of sweat from the astronaut's body. Synthetics burn easily but it is a hazard which they live with.

Major problem making bladders.

Bladder shouldn't have to be stretched. It fatigues it.

Bladder/Restraint development:

1) Apollo. Bladder bonded to restraint. Custom sized.
2) Baseline. Separate bladder and restraint. Primary drawback was the difficulty in bending fingers, the bladder was stretched in bending. Polyester.
3) Modified. Longer fingers to eliminate stretching. Lighter. More flexibility. Polyether.

Chromelar (steel fabric) dropped due to possibility of frayed fabric puncturing bladder.

Convolute wrist works very well.

Sizing must be possible in design. Nine men sizes are made. No women's sizes are made as it is not cost effective.

The bladder is bonded to the restraint at various points on the fingers, palm and hand back.

Knit kevlar fingertips are dipped in polyester to hold their shape and then sewn on the restraint.

Total rotation of the thumb cannot be obtained by pleating.

Straight-stitched seams are used in construction. Seams are on the outside. Some topstitching is used.

Gloves are tested in parts:

1) Structural component tests.
2) Man cycle tests.
3) Strong man tests (try to destroy it by using it or misusing it).

A thin restraint fabric is used for mobility with patches in high load and wear areas. A triangular load patch is sewn on the back of the hand to form a path for force to travel, making the glove stronger. There is a patch between the thumb and index finger and another on the edge of the index finger at the base - a wear area.

The seam along the neutral axis of the fingers goes to the top surface to eliminate the high stress areas between fingers by giving load paths to the upper surface (back of hand).

Ripstop polyester on fingers evolved from a 2.4 oz nylon formerly used in fingers which tore and was weak. A 3 oz nylon was still a problem. NASA suggested using 3 oz ripstop, which worked well. The ripstop extends back past the knuckles. Poor abrasion resistance eliminates use in wrist.

The wrist area has excess fabric to allow for bending. Bellowing is still a problem.

Wrist rings aren't circular. Friction of the ring on fabric is still a problem.

When the present glove was designed, ILC had a 100 member staff which was responsible for the entire suit design, construction, and testing in approximately 6 months. Therefore, the glove didn't get the attention it deserved. Since then - it "worked" and hasn't been changed.

The palm restraint bar is adjustable in 8 ways on the palm and back of hand. No custom - want adjustability in sizing.

Length is so tight that they are still trying to shorten arm length 5/8" for one astronaut and can't figure out how.

Maximum load yields a 3/8" stretch. A 288 pound load is carried across the three finger crotches. The primary links on either side of the wrist connection carry 360 pounds (180 per side link).

Don't worry about loads. Do worry about abrasion.

Folds in bladder only comfort problem.

The bent finger bladder is a good idea. The relaxed position should be mid-range of movement.

One-half inch diameter is the minimum tool size.

The problem with mechanical joints is they can't be overpowered through the extended range of motion.

The ultimate pressure of a bladder used in a 4 psi glove is 10.6 psi; for an 8 psi glove, 27 psi.

Room temperature vulconizing (RTV) is still used for tips on EVA glove.

Bladder life is 6 years. They are checked every 75 pressurized hours.

Tolerance in sewing is ± 1/32 inch. Inaccuracies tend to build up influencing sizing. Stitch take up could be as great as 1/8 inch in the finger.

Pleats are placed on both the front (4) and back (7) of the finger to allow for opening the hand out. They don't want to "max out" the fabric.

In construction of the fingers the pleats are made and excess fabric is trimmed from the end prior to sewing on the Kevlar tip.

Bladder size corresponds to restraint layer size for correct fit and avoids stretching the bladder. Bladder design should be a concern.

The bladder is bonded to the restraint at 3 points on the finger.

The adhesive for bladder material for "cut and paste" bladders is AF 770 polyurethane 15" solid also known as UBS 1087 (we have sheets on this).

The torque test is performed on fingers from the outside of the inflated glove. This is a comparative test only.

Problems to be addressed:

- finger tip tactility
- ease of construction (it takes over a week for a pair of gloves)
- finger cap seam in the way

Each seamstress makes an entire glove - it's not a production line set-up.

The Nomex felt was removed for awhile due to the hot pad. It has since been put back. The hot pad is held to the glove on the hand front and back with velcro.

A pattern piece is placed on the entire ply up, cut out and basted together to hold the layers together in construction.

Mittens - one week construction time.
Comfort glove - three days construction time.
TMG - one week construction time.
Restraint - two weeks construction time.

Bladders can be removed from restraints without harming them.

It takes about one day to bond a bladder to a restraint.

The baseline bladder mold was made of porcelain. The presently used mold is made of polyester resin. The bladder stuck too badly to the porcelain. The porcelain wore badly also.

The mold is dipped into a tank, dried on a rotisserie for about 4 hours and redipped, about five dips total. After dipping they are reinforced, removed from the mold, inspected and repaired. It takes about ten days to make a bladder.

ILC makes the blue caps for the TMG.

Green dye is added to the rucothane to spot defects (air bubbles, foreign material, etc.) in the bladder.

After the glove is constructed the hardware is added.

Testing of the glove includes use of tools in and out of water.

Basic physical property tests are performed such as tensile strength, elongation, tear, etc. Fabrics are tested for # cycles or to failure.

Size E-8 lb thread is used in construction.

Don't cut on fabric bias due to ballooning and twisting. Align loads with the grain.

Adjustment of 1/4" can be obtained on finger length with strings.

Astronauts don't tie knots.

Use cylinders for fingers, not cones.

A buttonhole on the gauntlet (for a tether) is reinforced with Nomex between each ply. Teflon is the innermost and outermost layer.

Nomex is actually favored over Kevlar and Teflon, at least by the ILC engineers.

A surgical knot is used to tie the cords - not a backtack tie. A drop of adhesive on the knot holds it. The cording is 50# test braided Dacron IGFA (International Game Fish Association) trot line (Shakespear).

A hot knife is used to cut the pattern and cord, 500 degrees F tip (available in hobby shop) reostat controlled.

All knife pleats are used - actually rolling convolutes.

Bladders could be heat seal constructed for prototype construction (not production - due to many failure points).

Tight construction tolerances allows easy failure re-creation and follow up.

Five psi on the hand is harmless for a couple of minutes. Don't worry about for Open House.

Kevlar and Nomex felt on bottom of fingers, TMG on top to center seam.

Felt bonded to Kevlar. There is a problem with flexibility here.

A 301 type machine is used for sewing, 8 to 10 stitches per inch. Blunt needles, no bigger than size 16, should be used.

The Nomex thread used in the TMG can't be hot knifed. Polyester thread is used in the restraint. Nomex edges must be edge locked.

Pounds per inch (PPI) in the tongue tear test is tear force/ thickness.

Finger crotch patches not necessary in new bladder - just a hold over from old design.

Flocking has been tried on the inside of the bladder for ease in donning and removing.

Ideal bladder:

1) less tensile strength present bladder
2) high elongation
3) reasonable tear strength - around 5-6 lb.
4) good cycle life
5) as light/thin as possible

APPENDIX H

Report from NASA Houston - 2nd Visit

1. We met with many space suit designers in the morning, including Mike Rouen, Joe Cosmo, Charlie Althan, Carl Ondracek, Lee Willis, Mr. West, and Ruthan Lewis (from Lockheed). We explained our gloves and progress on flexibility or various parts of the glove. They seemed happy to see some gloves as if they did not expect any. These were pressure tested in their glove box and they commented on the flexibility. It was learned that they only expected a power grip with all fingers flexing at once. They said first solve the power grip, then worry about individual fingers.

2. We mentioned the two bladder idea to reduce the bulk of the bladder and thus make bending easier. It seemed difficult to convey the idea and it was not received very well.

3. NASA representatives will judge the prototypes, ASEE will judge the educational aspects (i.e. written report).

4. NASA had tried a steel mesh glove years ago but the friction between rings was too great, they "locked up".

5. A mesh material was used in the fingers.

6. Teflon cording and tubing is used to reduce friction.

7. The polyester fabric used in the restraint is a higher denier than what we want.

8. They suggest work on total metacarpal joint, do not worry about TMG or thumb at this point.

9. In the afternoon, a tour was provided of the NASA grounds and the shuttle mock-up.

10. The best metacarpal they had was not very flexible.

11. A tape on EVA work was watched and hand motions described by Rouen.

APPENDIX I

18 Sept.
Talked to Mike Rouen (713) 483-6193

They are not organized yet. The Ames man is coming to Houston in Oct. They have tenatively scheduled Oct. 10 - 12 for us. Need to talk for 1/2 day. Willing to give us a general tour on remaining 1/2 day if we want.

Are concerned with telling us the present solution. They want innovation. Thus are going to try to write specifications so we don't focus on present solution.

Knew that we had visited Ames because he knew of our list of questions. Said he would try to answer our questions if we sent him a list but would only answer orally. Would not do it in writing.

I mentioned that I had to go to Texas the following week and it may be that I will go on Oct. 19th instead of 12th.

Suggested we study the anatomy of the hand.

Need to have George send him our list of questions; then call him for answers. Have someone else on the line to take notes so we have two note takers.

16 Oct. 1984

Phone call from Mike Rouen

He read off a number of glove design criteria over the phone. He will give us a printed copy when we get there.

* Wants 5 finger glove in a hand shape (not 3 finger, etc)

* They have a good wrist design

* Focus on the metacarpal

* Safety factor on metallic parts = 1.5 at yield; 2 at ultimate

* Safety factor on non-metallic (including fabrics) = 2 at ultimate

* Design should be able to be sized from 5th percentile female to 95% male (small size generally most difficult)

* Design glove so it can be put on unassisted in a pressurized cabin

* Grip should be as natural/comfortable as possible; consider comfort of someone wearing glove for 7 hours

* All the factors are fuzzy and can be traded off except safety and 8 psi

* Suit pressure = 8 psi. Shuttle suit 4.3 psi (need to breathe oxygen for a day to purge nitrogen.) Want to move to 8 psi so don't need prebreathing. 8 psi is 1/2 of 14.7 psi

* Allowable glove leakage = 10 std cc/min

* Oxygen use = 1 lb in 6-7 hour; fits in two cylinders

* Weight of glove disconnect = ? Keep low as it increases intertia

* Temperature of objects in space range from -180 to 235 F.

Don't greatly insulate hand. If feel pain, remove hand and use "hot pads". We don't need to design "hot pads".

* All the astronauts with EVA experience are busy. Rouen says he will answer questions.

* Present glove mfg. is ILC Dover Industries. Rouen has contacted them and they will write us. Rouen will let us try out some gloves at Houston. Not sure if he will lend us one.

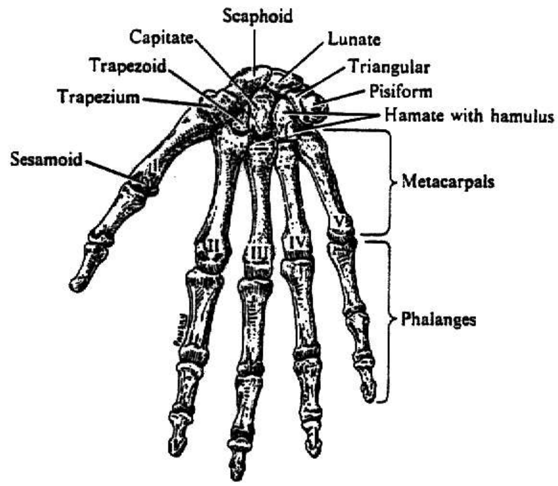
* Use of NASA library probably OK. He will check out before we get there.

* What are tasks/tools used in EVA? Look over previous mission reports and look at films of EVA. Our contact of films is Jim Poindexter (Extension 4241).

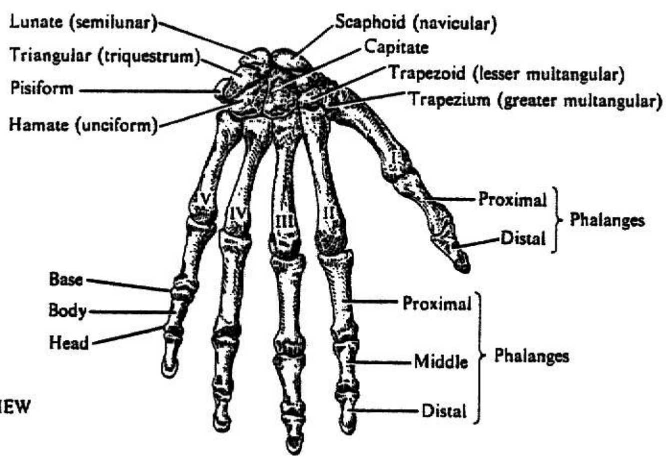
* No one at Orlando worth seeing.

SK

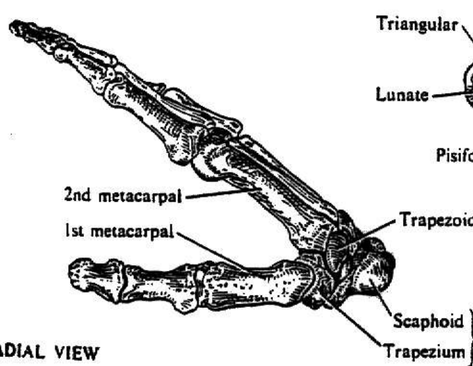
WRIST AND HAND BONES



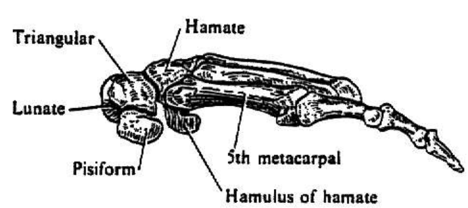
PALMAR VIEW



DORSAL VIEW



RADIAL VIEW



ULNAR VIEW

I made a phone call to Mike Rouen on Wed. Oct. 17 telling him we would like to speak to a human factors person concerning the astronaut glove. I read him the names of two who were in the Human Factors Society Directory. He discouraged it but said if we wanted to talk to them it was OK. We should just call them directly.

One person is Jerry Goodman whose interests are HF and Crew Station Project Engineering. I called (713) 483-5431. He was not in. I left a message at 483-5523 about what we wanted and would like to see him on Friday afternoon. He is to call Rouen and tell when he is available.

I then called John Lounge at (713) 483-2421. This is the "Astronauts Office" number. Lounge is not the person to contact they said; talk to Astronaut William Fisher (same number). Fisher came on the line and talked (see below) but said their glove expert was Astronaut Dr. George Nelson (713) 483-2221. Fisher found out that Nelson is available on Friday and will try to get an appointment for us; I am to call on Thursday and talk to Nelson confirming our visit.

Fisher's comments on glove Present glove is pressurized to 4.3 psi. This pressure is what causes the problems. Astronauts can use the glove for 6 - 8 hours but they are very fatigued by it. Presently they follow a complicated system to purge nitrogen from the body before going EVA. One consequence is that you just can't put on a suit and go outside; this makes repeated EVA from a space station a problem.

They are strongly considering an 8 psi suit (and thus glove); this would eliminate the nitrogen purge problem. The atmosphere of the space station is not yet decided but Fisher thinks they will probably decide on sea level.

Fisher says, "The hands are everything; its no use going to an improved suit if the hands can't be improved". There has been lots of work on the gloves by ILC, David Clark, and Hamilton Std.

Says the glove is complicated; we will need a palm restraint bar or the fist will balloon.

Also said Jim McBarron and Joe Kosmo should be contacted. They work with Rouen.

I did not mention to Fisher that other schools also had grant. He did not know anyone at universities was working on this project (thought $30,000 very low price) so it seems that other schools have not yet contacted astronauts.

Steve Konz
Oct. 17, 1984

Talked with Nelson on Thursday. Said he would be glad to talk with us. We will set up time when we get to Houston and talk to Rouen.

Summary of phone conversation by Steve Konz with Mike Rouen on Wednesday, January 23, 1985, in reply to our previous inquiries.

The summary is organized into three sections: glove design, glove manufacturing and glove use.

Glove design

*Gloves have two types of insulation:

- ** Super-insulation. On back of hand and fingers to midway around.
- ** Conductive insulation (felt). On palm of hand and fingers to midway around. Goal is to retard passage of heat or cold to hand so that hand has enough warning to let go (without the material suffering thermal damage). Then the astronaut is to use the "hot pad".

*Metal fingernails are not needed. If a fine pickup is needed, tend to use a handtool instead.

*KSU idea concerning extension section on arm-wrist OK, but don't worry about it.

*Rigid backs on fingers and hand OK. But they should not interfere with grip.

*Metacarpal join design proposed by KSU looks OK. Be sure to keep linkages between the fingers so they don't interfere with grasp envelope.

*Don't design for handedness (i.e. left or right hand being preferred). Astronauts tend to practice most tasks on earth in water tank.

*Weight of glove disconnect = 1.35 lb. Specification given us originally includes disconnect weight and glove weight. Rouen will ship an Apollo disconnect to Konz as well as a writeup giving the procedure for attaching the glove to the disconnect.

*Rouen will send a copy of the hand dimensions for an "H size" glove to Konz. (We understand there are 9 glove sizes.)

Glove manufacturing

*There are 100-125 astronauts. However, only 20-25 of these are being trained and equipped for EVA. Up to January 1985, only about 100 pairs of gloves have been manufactured. Rouen thinks they may make 80 more pairs.

*Rouen would like to have 40 "active pairs".

- **20 flight
- **20 training

*Preliminary discussion of space station operation (not construction) is that there would be 1000 h/yr of EVA. Rouen thinks this is very high. (Konz calculates that for 4 h/mission EVA and 2 people/EVA, this would require 125 missions/yr or 10/month!).

*Bladders presently are used only once/EVA. Rouen planning to start using bladders twice. Glove life is 6 yr.

Glove use

*Glove is used when controlling Man Maneuvering Unit (MMU):

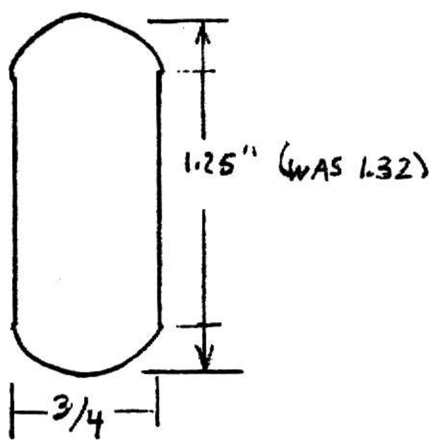
**Right hand: T bar shape held with power grip. Move arm and wrist but not fingers. May be trigger operated by pulling first (index) finger.

**Left hand: 3 axis rotational motion. No finger movement.

*On shuttle, there are two types of task. The astronauts practice both types of task in the water tank. The astronaut is made "weightless" but the tool isn't.

**Orbiter contingency.
**Planned EVA.

*There are a variety of handtools used. They almost all require use of a power grip. Rouen did not mention any which used a pinch or precision grip. There is no real manipulation of tool (or any task) as fingers don't permit it even if it was desired. They tend to "beef up" the handle grip with tape so that all the handles have the same diameter. This "standard" diameter is the same as the rail that they use to pull themselves from place to place.



*Tools in space tend to be tethered. Even if not, they don't float away. That is, maintaining the power grip (once achieved) is not fatiguing. Note that the tool grip diameter is such that little motion is requuired by the fingers. (Might be good idea to have glove grip "rest" diameter slightly less than tool grip dia so glove exerts pressure on grip automatically, rather than glove dia greater so pressure needs to come from finger muscles).

*9 sizes of gloves. (Konz thought: May be possible to "personalize" tool handles for each astronaut so they just match their glove/hand size. Modify tools with tape on handles, replaceable handles, etc.)

*Power tools in space.

**No explosive tools (concerned about accidents).
**Electricity powered tools are battery operated (no outlets and lines as of yet). There are problems with getting rid of motor heat.

Tests for gloves. (It was not clear if these are required for each glove pair or are general design goal.) The numbers seem unusual.

Motion	Frequency/h
*Hammer motion (flex/extend)	247
*Open/close hand (tinsnips?)	247
*Wrist ([redacted]) (hammer motion)	48
*Wrist (wave goodby)	89
*Wrist rotation (90° max)	112

Actual use of hand in space without tools. These motions and numbers were determined from studying videotapes of shuttle missions and Skylab missions.

Number of Motions/h of EVA	Motion	Comment
31.1	Door knob motion (open door)	Rouen worried no. is not representative (i.e., too high).
6.2	Pawing. One fist on each side of knob. Rotate knob by moving arms.	Done with fingers on earth. Pawing causes wear on TMG (micro-meteroid) fabric.
2.8	Index finger spin	e.g., Spin wrench holding nut on thread with stiff finger.
1.2	Rotational abrasion. Knurled knob rotation.	
.8	Linear abrasion. Thumb vs. 4 fingers.	
.5	Pound with side of hand (little finger side).	
.4	Fist (punch).	
.4	Push with back of hand.	

*One task observed in space is to cut lockwire on nut. (Nut is held on screw by a wire attached through nut.)

KSU
KANSAS STATE UNIVERSITY

Department of Industrial Engineering

Durland Hall
Manhattan, Kansas 66506
913-532-5606

January 29, 1985

Mr. Mike Rouen
Code EC5, Building 7
Johnson Space Center
Houston, TX 77058

Dear Mr. Rouen:

Enclosed is my summary of our phone conversation. Any modifications, corrections, or amplifications, either handwritten or by phone, would be appreciated.

Some new questions:

500-1000 / 100 hr. of EVA time

1. On the table you gave me concerning frequency of various hand motions without tools, how big a data base is that for? 10 h, 100 h, 500 h? —— + water tank training time

2. Are any triggers operated by a finger other than the (only →) index finger? Other possibilities would be thumb, four fingers, or base of hand (below little finger).

3. Are triggers continuous control (yes) or intermittent? (power tool) That is, if you release trigger, does tool turn off or is it push on or push again for off?

4. Are the tool handle grip cross sections (yes) rectangular (as with rail) or circular or do they vary?

5. Is the left hand used (NO) for any tool? If so, which one and how?

Thanks.

Steve Konz

Copy to: Dr. George Nelson
Dr. Jubert Vykukol
Mr. John Lisack

Enclosure

KANSAS STATE UNIVERSITY

Department of Industrial Engineering

Durland Hall
Manhattan, Kansas 66506
913-532-5606

February 6, 1985

Summary of a phone call from Mike Rouen to Steve Konz answering questions from letter of January 29.

*The table giving frequency of use of various hand motions is based on 90-100 h of EVA time plus about 500 h of water tank time.
*They presently have only one tool operated by a trigger--an electic drill. The trigger is operated by the index finger. It is continuous control; that is, when the trigger is released the drill shuts off.
*They attempt to keep all tool handle cross sections the same as the rail cross section.
*In the sketch of the rail (and thus grips), the 1.25 is overall length (top of curve to top of curve).
*The left hand is not used for any tool except by astronauts who are left-handed (eg. Nelson).
*Rouen will send us a description of the sizing system used for the gloves. There are about 15 sizes (although they only use 9). H is the second largest size. The sizing information is fairly cryptic and he would be glad to explain it. (He seems quite proud of it.) Even then they need to custom fit about half of the people.
*When asked about the glove bladder, it presently is used for 1 mission's EVA (21 h) and then discarded. This is quite expensive because the urethane is water sensitive (tank on ground, sweat in space). They will switch to a non-water sensitive urethane on mission 51G in the summer of 1985. Then they hope glove life will be much longer (perhaps even 6 years design life). If we want to use latex for our prototype, that's OK.
*Friday, March 1st is not a good day for a visit as Univ. of Oklahoma will visit on that day. Any other day is open.
*The distance from the front of the wrist ring to the top of the middle finger is 10 3/8 inches for a H size glove. It will be different for different glove sizes.

Call to Mike Rouen, 2/11/85

Ph # 713-483-6193, time monday 3:55

I asked Rouen about using latex bladders and why he thought urethane was better. He didn't have any definite reasons and then asked his "bladder man" if he knew of any problems with latex. None were known at that time. Rouen said that strenght was important if the restraint layer failed and when donning adn doffing. They can get stretched pretty bad when taking a glove off with sweaty hands.

He said that self life of latex could be a problem. He would like to have a self life of 15 years but settles for 6. He said latex might "revert"? He suggested that Neopreme with the thought "age white" added would have a longer shelf life and probably be fine. Latex bladders were used in Apollo.

He didn't expect this project to be concerned with bladders.

His work times are from 7:30 to 4:00 and said he would gladly return a call, if he couldn't be found when you called. He welcomed calls. Suggest a good time for him to return your call.

Jon Held

APPENDIX J

Literature Supplied from Lockheed - Houston

Adams, R.T., Contingency Operations Training Workbook, (CONT OPS 2102, National Aeronautics and Space Administration, Houston, Texas, March 27, 1981.

Beiriger, J., EVA Payload bay doors contingency tools description document, National Aeronautics and Space Administration, Houston, Texas, January 1981.

Gardner, M.F., Shuttle flight operations manual, Volume 15, National Aeronautics and Space Administration, Houston, Texas, January 6, 1984.

Lockheed Engineering and Management Services Company, Inc., Satellite services catalog tools and equipment, National Aeronautics and Space Administration, Houston, Texas, September 1983.

APPENDIX K

ASEE/NASA Project at KSU
May 10, 1985

Budget Category	Original Budget, $	Actual Expense, $	Actual as a Percent of Total Direct Costs	Difference Between Actual & Budget, $
Salaries*	16,259	15,797	69.1	462
Travel	3,100	4,203	18.4	-1103
Other Costs	600	1,786	7.8	-1186
Supplies	2,450	1,050	4.6	1400
Equipment	0	23	0.1	- 23
Subjects	450	0	—	450
Computer	0	0	—	
Total Direct Costs	22,859	22,859	100.0	0
Overhead	7,086	7,086		
Total Project Costs	$29,945	$29,945		

*Four faculty were charged to the project: Konz for 1.0 month and Eggeman, Jones, and McCullough for 0.8 month each. In addition, each of the four contributed 0.4 month which was paid by Kansas State University. Thus total faculty time for the project was 1.0 + 3(0.8) + 4(0.4) = 5.0 months. All the student time was volunteered.

APPENDIX L

KSU
KANSAS STATE UNIVERSITY

Department of Industrial Engineering

Durland Hall
Manhattan, Kansas 66506
913-532-5606

February 20, 1985

Mr. Tim Bradley
ASEE
11 DuPont Circle
Washington, D. C. 20036

Dear Mr. Bradley:

After your visit with us, the design group had a discussion on how the design project could be structured in the future. The following are some ideas which could be used to spend money this year or in the future years.

1. Grant $25 - $30,000 to the school winning this years competition for a 12-month extension of research.

   One of the serious problems of a short-term project (such as this 9 month project) is that by the time the team is "up and going", the project is over. Although a renewal project would not retain all the student members, the faculty would be able to continue. Depending on the school and how they organized the original project, some percent of the students would be able to return. In addition, the winning school would have the final reports from the three other schools.

   NASA would get the best results from university research projects like this if they set the original rules up as four schools to get $30,000 for the first year and the winner to get $30,000 for the second year. This would reduce the tendency of some schools to take the money for the first year and do nothing. It should ensure a much better final report from each team, since the final report also would be a proposal for $30,000.

2. Grant scholarships to each school.

   This concept would be beneficial to both NASA and each university. If $5,000 were donated to KSU (for example), this could be called the "NASA-ASEE Scholarship" with approximately $300-$500 from interest being given each year to "a student studying in a field of interest to NASA". NASA would get continuing benefit from the publicity as well as helping a student studying in its area. There always are students needing money.

If $20,000 is not available, there could be four smaller scholarship grants. If competition is to be maintained, larger awards could be made for the best project.

3. Have a meeting of representatives of the four teams.

   Sharing knowledge is important and beneficial to both the project teams and to NASA. The method of accomplishing this goal can range from reports to personal contact. In our discussions, opinions on having a group meeting at the end of the project ranged from negative to highly desirable. If a meeting is to be held, it should include working sessions with NASA decision makers so that positive results could be accomplished in regards to the project objectives. With the number of people involved, scheduling would be a major problem for such a meeting.

As we pointed out during your visit, we do not feel that we are in a competition. The project is challenging enough to be the driving force. If the competition format is eliminated in the future, a meeting between groups at NASA would be desirable. Brainstorming sessions, reports on literature searches and personal contacts for later use in establishing test standards such as the wrist disconnect would be of value. This would accelerate the early stages of the project and leave more test time at the end.

In closing, we appreciate the efforts of ASEE and NASA in sponsoring an inter-discipline design project. We believe that the effort is worthwhile and provides a valuable experience in the educational environment.

Sincerely,

Steve Konz

Stephan Konz George Eggeman

APPENDIX M

Directory of Project Aides

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AN IMPROVED METACARPAL JOINT FOR AN EVA GLOVE

by

Nesby E. Bolden

B.S., Kansas State University, 1983

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1985

The team from Kansas State University which participated in the ASEE/NASA EVA glove design competition consisted of four faculty advisors and six student members. One graduate and one undergraduate student were selected from each of the three disciplines of mechanical engineering, industrial engineering, and clothing and textiles. The project was conducted primarily by the students with the faculty serving as advisors. Accountability was maintained by periodic student reports on activities, by three progress reports, and a final report.

The glove design project evolved through several typical design steps. These included the initial idea sessions, an organized literature search, and the creation of a problem statement. The specific design problem was initially understood when the team pressurized a leather work glove with a bladder and a palm restraint bar. The specific design problem was further defined by communications with and trips to NASA. After defining the problem, an experimental and theoretical method for design was selected, with over 30 models being constructed and tested. This method produced immediate, concrete results. In the final step, communication skills were required for organizing and preparing a final report and presentation.

The final glove design allows the individual movement of the joint between the metacarpal and the first phalangeal bones of the fingers. The individual movement was considered an obtainable goal over the less complicated problem of these joints moving as a unit. Additional features of the final design is the minimal force necessary to flex the joint and the absence of a restoring force to return the joint to the original position once it has been flexed.

The design is simple in pattern development and is adaptable to the present manufacturing techniques used by ILC Corporation. Features of the glove design allow it to be customized for different size hands and these design features can be easily incorporated into the present EVA glove design.