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NASA CR 137,974

DEVELOPMENT AND FABRICATION OF AN  
ADVANCED LIQUID COOLING GARMENT

By J. L. Leith and C. W. Hixon

22 October 1976

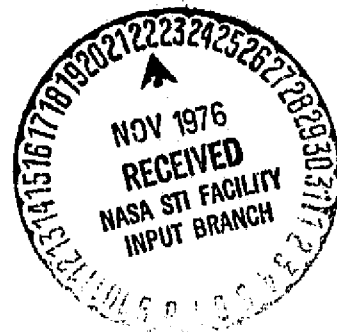
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PREPARED UNDER CONTRACT No. NAS2-9026 by  
VOUGHT CORPORATION  
SYSTEMS DIVISION  
Dallas, Texas

for

AMES RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



(NASA-CR-137974) DEVELOPMENT AND  
FABRICATION OF AN ADVANCED LIQUID COOLING  
GARMENT Final Report (Vought Corp., Dallas,  
Tex.) 87 p HC A05/NF A01 CSCL 06Q

N77-11673

Unclas  
G3/54 55049

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ADVANCED LIQUID COOLING GARMENT

Contract No. NAS2-9026  
Report No. 2-53230/6R-51388

FINAL REPORT

22 October 1976

Submitted by:

VOUGHT CORPORATION  
SYSTEMS DIVISION  
DALLAS, TEXAS

To

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
Ames Research Center  
Moffet Field, California

Prepared by:

J. R. Leith  
J. R. Leith

Reviewed by:

J. C. Utterback  
J. C. Utterback  
Supervisor  
Thermal Environmental  
Systems

Approved by:

R. L. Cox  
R. L. Cox,  
Project Engineer  
Technical R&D

C. W. Hixon  
C. W. Hixon

J. A. Oren  
J. A. Oren

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## 1.0 SUMMARY

A development program to determine the materials and fabrication techniques applicable to the fabrication of an Advanced Liquid Cooling Garment (LCG) is described herein. Based upon the program, two concepts for fabricating a flexible, elastic, thermally effective and comfortable garment which show potential for low-cost fabrication have been evolved: (1) elastomeric film/tube/expanded wire mesh composite and (2) an elastomeric tube attached to wire mesh and both overcoated with elastomer. The former was most promising and has been pursued in some detail.

The elastomeric film fin/tube concept which has been developed is a composite of polyurethane film, fine expanded silver mesh, a serpentine pattern polyurethane transport tubing and an integral comfort liner, all bonded via adhesive application and vacuum-bagged for final cure. As demonstrated by thermal analysis, the composite garment material is capable of removing a 293 watt (1000 BTU/hr) metabolic load through a head and torso cooling area of  $.46\text{m}^2$  ( $5\text{ft}^2$ ) with tube spacing of slightly under one inch.

A total of 60 test elements, each  $.15\text{m} \times .15\text{m}$  ( $6'' \times 6''$ ), have been fabricated in support of the LCG concept development. In parallel with the fabrication of these elements a continuing series of laboratory tests to support the fabrication techniques has been carried out. The elements and supporting tests are described in the appendices to this report.

Several tests on elements of the elastomeric film concept have demonstrated a high thermal effectiveness and moderate elasticity. Increased elasticity of the composite is desirable and further evaluation of materials and test element construction is recommended. It is believed that the fabrication methods developed for the elastomeric film concept will result in a simplified, relatively inexpensive production concept for manufacturing Advanced Liquid Cooling Garments.

## 2.0 INTRODUCTION

The development of Liquid Cooling Garments (LCG) for personal cooling in hot environments has been pursued since approximately 1962, although gas flow cooling through ventilated clothing dates to approximately 1950 (Ref. 1). The requirement for use of an LCG arises in the higher metabolic loads associated with strenuous activity and the impracticality of removing these loads with a vent gas system. For the Apollo program a full body LCG was constructed using 1/8" flexible Tygon transport tubing hand-stitched in several flowpaths to an elastic Spandex mesh suit. However, because of the small tubing area in contact with the skin, the Apollo LCG had a poor heat exchanger effectiveness. A water supply as cold as 40°F-45°F was necessary to satisfactorily cool astronauts with high metabolic heat loads.

The effect of chilling the skin with the 40-45°F water was an adverse reaction by the body's thermoregulatory system - the blood capillaries would constrict, lowering the effective thermal conductivity of the skin and thus blocking an efficient transfer of heat from the body's core to the surface. The result was a higher than normal core temperature plus a significant reduction in sweat production. In addition to this inhibition of normal thermal control processes, the cold tubing temperature was exceedingly uncomfortable when the astronaut allowed his temperature to rise appreciably before switching to the minimum transport water temperature.

Because of these undesirable physiological effects, and also because of design constraints the 40-45°F water temperature imposes on future heat sink designs for LCG systems, it is highly desirable to increase the thermal effectiveness of the garment. To be both effective and comfortable the LCG's must be sufficiently elastic to maintain good contact and to not significantly inhibit motion. Further, to gain application outside specialized aerospace use, production costs must be reduced drastically over current hand-crafted methods.

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The purpose of the program reported here has been to evaluate fabrication techniques and various materials that can provide high thermal fin effectiveness in a material layup that is both flexible and elastic. Accordingly, several composite configurations have been evaluated to determine their mechanical and thermal properties and their potential for low cost fabrication, comfort and conformal fit to the body. This initial effort of the advanced liquid cooling garment development was evolved from the flexible radiator concept<sup>1</sup> in which a plastic or elastomeric tubing is sandwiched between two layers of metallized film (viz., silver Teflon) in a composite layup. Alternate fin configurations consist of Teflon coated wire mesh and combined wire mesh/metallized film. The fin effectiveness of the resulting tube-fin radiator results in a system with superior heat rejection/weight ratio. Since the composite must also be elastic for the LCG application, the use of a solid layer of metal is probably precluded. The approach evaluated by Vought for advanced LCG's uses the plastic/metal composite idea already proven thermally for flexible radiators,

---

<sup>1</sup> Contract NAS9-13346 - The flexible radiator concept was conceived by Vought as a means of providing satellite heat rejection and supplemental heat rejection for on-orbit operation of payloads which require heat rejection in excess of that which the cargo bay door radiators of the Shuttle orbiter are capable of providing. The flexible radiator has a high heat rejection to weight ratio and can be deployed from a canister.



replaces the plastic tube/film materials by elastomers and uses a conducting wire mesh which is configured or woven in such a way that the overall composite retains its elasticity. Roll laminating and tooling concepts which are currently being developed for flexible radiator production are also expected to be applicable to future LCG production. Based on this, and the element fabrication and test work reported herein, it is believed that low cost production advanced LCG's will be feasible.

### 3.0 LIQUID COOLING GARMENT DEVELOPMENT

#### 3.1 Evaluation of Materials

The initial concept of an Advanced Liquid Cooling Garment (LCG), as considered in the current contractual effort, has been defined as a metal-elastomer composite with discrete flow passages. Pursuant to the development of this concept, the materials that have been evaluated include heat conducting materials, adhesives and elastomeric compounds. The heat conducting materials (metals) include foils, woven wire cloth, knitted wire mesh, expanded metal and chain link metal. Metal filled elastomers were also evaluated, but were found to not offer sufficient strength to consider further. In the LCG application, metals are totally inelastic and are therefore limited to bending or passive motion only. Metal foils, while certainly flexible, cannot be significantly stretched without mechanical failure. The remaining heat conducting fin materials all have an open area which allows deformation (i.e., bending). The requirement for high thermal effectiveness of the garment limits the choice of fin material to metals with high thermal conductivity, primarily silver, copper, gold or aluminum. An extensive survey of vendors has indicated that the wire cloth, knitted mesh and expanded metal are all available in a variety of metals, in a wide range of wire gage and grid size. The heat conducting materials evaluated by Vought are summarized in Table 1. The use of heat conducting materials in liquid cooling garment applications is discussed further in Sections 3.2 and 3.5.

The elastomers available for use in an LCG include several types of natural and synthetic rubber, and a very large variety of synthesized polymers. The thermal and mechanical properties of some of the more applicable elastomeric materials are summarized in Table 2. The characteristics of plastic and elastomeric materials have been treated in detail in Reference (2). In the liquid cooling garment application, elastomeric materials may be used as transport tubing, coating of the composite, film application and adhesive application. Polyurethane elastomers are available with ultimate elongation ranging from 200% to 600% and with a wide range of hardness (typically 50 Shore A Durometer to 90 Rockwell R). Softer materials, such as silicone rubber and latex rubber will elongate to 800%. The materials that have larger ultimate elongation are also more "stretchy" since their tensile strength is less. For the application considered here, the range of operating temperature can be accommodated by all of the elastomers listed in Table 2. Burst pressure requirements (see Section 3.3) were found to be non-restrictive for the most interesting transport tubing candidates.

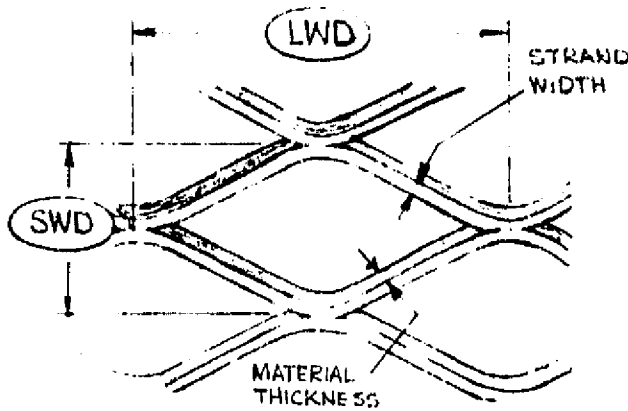
TABLE 1

HEAT CONDUCTING MATERIALS EVALUATED

|                   |   |                     |                              |   |         |
|-------------------|---|---------------------|------------------------------|---|---------|
| Woven Wire Cloth  | : | Nickel-Plated Steel | ,                            | .178mm (7-mil)                                    | 20-mesh |
|                   |   | Nickel              | ,                            | .178mm (7-mil)                                    | 20-mesh |
| Knitted Wire Mesh | : | Galvanized Steel    | ,                            | .178mm (7-mil), 6.3mm x 9.5mm (1/4"x3/8")         | mesh    |
|                   |   | Copper              | ,                            | .203mm (8-mil), 6.3mm x 9.5mm (1/4"x3/8")         | mesh    |
| Expanded Metal    | : | Brass               |                              | .127mm x .254mm                                   |         |
|                   |   |                     |                              | ( 5 Brass 10-3/0) *                               |         |
|                   |   | Silver              |                              | .076mm x .127mm, .127mm x .203mm, .127mm x .356mm |         |
|                   |   |                     |                              | (3 Ag 5-2/0) , (5 Ag 8-1/0) , (5 Ag 14-1/0)       |         |
|                   |   | Aluminum            |                              | .203mm x .203mm, .127mm x .178mm, .102mm x .178mm |         |
|                   |   |                     |                              | (8 Al 8-2/0) , (5 Al 7-1/0) , (4 Al 7-1/0)        |         |
|                   |   | Copper              |                              | .127mm x .208mm, .102mm x 1.016mm                 |         |
|                   |   |                     | (5 Cu 8-1/0) , (4 Cu 40-1/0) |   |         |
|                   |   | Nickel              |                              |   |         |
|                   |   | Inconel             |                              | .051mm x .229mm                                   |         |
|                   |   |                     |                              | (2 Inconel 9-2/0E)                                |         |
| Chain Link        | : | Steel               |                              | 24 AWG  |         |

\* Reference Table 1a

TABLE 1a



**LWD** Long way of the diamond -- measured from the center of one joint to the center of the next joint. This dimension is governed by the die used and never changes for that die. In fine expanded metal this is always parallel to the width of the coil.

**SWD** Short way of the diamond -- measured from the center of one joint to the center of the next joint. It will vary moderately with any given die as the strand width and degree of expansion are varied. The mesh count (openings per unit of length) decreases as expansion increases and conversely. Fine expanded metal is manufactured in coil form with this dimension running the length of the coil.

| 1. MESH DESIGNATION (Size) | 1. MESH DIMENSIONS (in center-to-center) |             | Number openings per sq. in. approx. | 2. THICKNESS OF ORIGINAL MATERIAL |       | 3. STRAND WIDTH |       | 4. MAX. SHEET WIDTH |
|----------------------------|--|-------------|-------------------------------------|-----------------------------------|-------|-----------------|-------|---------------------|
|                            | LWD                                      | SWD         |                                     | MIN.                              | MAX.  | MIN.            | MAX.  |                     |
| 1                          | .465"                                    | .20" .23"   | 25                                  | .003"                             | .025" | .007"           | .055" | 18"                 |
| 1/0                        | .280"                                    | .10" .125"  | 65                                  | .003"                             | .025" | .007"           | .055" | 18"                 |
| 2/0                        | .187"                                    | .077" .091" | 126                                 | .002"                             | .020" | .007"           | .035" | 18"                 |
| 2/0E                       | .187"                                    | .048" .071" | 170                                 | .002"                             | .015" | .007"           | .035" | 12"                 |
| 3/0                        | .125"                                    | .050" .065" | 300                                 | .002"                             | .015" | .003"           | .020" | 18"                 |
| FS                         | .100"                                    | .075" .065" | 250                                 | .005"                             | .020" | .007"           | .025" | 12"                 |
| 4/0                        | .077"                                    | .033" .046" | 625                                 | .002"                             | .012" | .003"           | .020" | 12"                 |
| 5/0                        | .050"                                    | .026" .030" | 1400                                | .002"                             | .010" | .002"           | .011" | 10"                 |
| 6/0                        | .031"                                    | .021" .024" | 2600                                | .002"                             | .007" | .002"           | .009" | 6"                  |

**HOW TO ORDER** Exact's customers have found the following method of specifying fine expanded metal useful and practical. Its use is recommended for positive identification of requirements.

For Example! . . .

Sheet thickness (mils) 5  
 Metal (Chem. Symbol) Ni  
 Strand width (mils) 7  
 Mesh designation 4/0

WRITTEN AS: 5 Ni 7-4/0

This is a typical commercial specification. When an application requires more specific details, they should be indicated, as for example:  
 a) .250 grams (+/- 5%) per square inch (required weight)  
 b) .010" overall thick (+/- .001") (required overall thickness)  
 c) annealed (material to be soft)  
 etc.

NOTE: Weight, overall thickness, strand width and original metal thickness must be compatible for mesh designation and total specification. See explanations above regarding chart.

TABLE 2

## ELASTOMERIC MATERIALS EVALUATED

| <u>MATERIAL</u>               | <u>AVAILABLE FORM</u>                               |
|-------------------------------|---|
| Polyurethane                  | Film, Tubing, Pellets                               |
| Fluoroelastomer               | Film, Latex or Solvent System, Tubing               |
| Silicone Rubber               | Film, Tubing, Room Temperature<br>Vulcanizing (RTV) |
| Polyvinyl Chloride<br>(Tygon) | Tubing  |
| Perfluoroelastomer            | Tubing, Film  |

Two service conditions must be considered when choosing an elastomer for use as a coating or film in a liquid cooling garment: compatibility with the skin and the hydrolytic stability of the elastomer. Some materials are subject to severe hydrolysis (reaction with water to produce weak bases or acids) and are consequently inferior contact materials adjacent to the skin, especially when perspiration is present. It is noteworthy that the materials which are less hydrolytically stable are also less capable of suppressing fungus growth. In urethanes, the polyethers exhibit a marked increase in hydrolytic stability as compared to the polyesters. Other elastomeric materials which are hydrolytically stable may not be suitable for contact with the skin, due to either chemical or mechanical irritation. The remaining considerations necessary to evaluate elastomers for film or coating application include availability, (film) thickness and processing requirements.

Adhesives are available in four general categories: (1) thermoplastic, (2) thermosetting, (3) elastomeric and (4) resin blends. The thermoplastic adhesives include hot melts, liquid dispersions (rubber cements) and various polymers and liquid monomers. Some of the more useful thermoplastics are polyvinyl acetate, polyvinyl alcohol and acrylic polymers. The thermoplastic adhesives are capable of being reformed upon heating and may thus be applied in either solid (i.e., films, pellets) or liquid form. Thermosetting adhesives include phenolics, epoxies, melamines, alkyds and the anaerobics. The thermosets are available in liquid, paste or solid forms. One-component thermosetting adhesives are usually heat cured, while two-component thermosets may be cured at room temperature. (Accelerated curing is obtained at elevated temperature.) The elastomeric adhesives include natural rubber, Neoprene and silicone rubber. RTV (Room Temperature Vulcanizing) silicones are perhaps the most well-known elastomeric adhesives. Resin blend adhesives are primarily composed of a class of phenolic/rubber compounds, such as phenolic-vinyl, phenolic-neoprene and phenolic-nylon. Proper choice of an adhesive for use in composite construction is dependent upon compatibility and bond strength of the adhesive with the elements of the composite. In the LCG application, additional requirements include elasticity of the cured adhesive, compatibility

of the cured adhesive with the skin and resistance to hydrolysis. The adhesive systems evaluated by Vought for the liquid cooling garment application are summarized in Table 3. Laboratory tests and use of adhesives in composite construction are treated in detail in Section 3.5.

The interface material used between the composite materials and the skin adds a thermal resistance and can effectively impair the thermal performance of the liquid cooling garment. In the effort described here, integration of the comfort liner with the LCG composite material should provide less bulk of the garment and minimize the thermal resistance inherent in the addition of a comfort liner. The material characteristics which must be considered in choosing a comfort liner include flexibility, elasticity and the capability to bond the comfort liner to the LCG fin-tube composite. Initial element tests have been conducted by Vought in which a double-knit cotton material ("T-shirt") has successfully been bonded to the fin-tube composite. The principal advantage in this concept is that the comfort liner may be added during construction of the fin-tube composite, thus simplifying the liquid cooling garment construction. The results of the element tests in which comfort liners have been considered are discussed in Section 3.5.

### 3.2 Liquid Cooling Garment Concepts Discussion

Two basic concepts of an advanced liquid cooling garment have been evaluated in the current effort: (1) an elastomer-coated fin-tube configuration and (2) an elastomeric film fin-tube configuration. The elastomer-coated fin-tube concept consists of an elastomer transport tubing stitched and bonded to a metal substrate (heat conducting fin) and is subsequently coated by spray application of an elastomer. The metal substrates that have been considered for this concept are woven wire cloth, knitted wire mesh and expanded metal mesh. Hand-stitching of the transport tubing to the heat conducting fin is necessary to assure sufficient contact, minimizing the contact resistance of the fin-tube interface. Spray coating with an elastomer further increases contact with the tube and allows for a smooth coated wire surface. The elastomer-coated fin-tube configuration is particularly well-suited to additional heat rejection

TABLE 3  
ADHESIVES EVALUATED

| <u>ADHESIVE</u>   | <u>TYPE</u>             |
|-------------------|-------------------------|
| GE SR585 Silicone | Thermoplastic-Elastomer |
| Nordbak Resins    | Epoxy                   |
| Urethane          | Thermoplastic           |
| RTV (Silastic)    | Elastomer               |



by latent heat removal due to the open area in the elastomer-coated fin . Construction of test elements in support of this concept is discussed later in this report.

The elastomeric film fin-tube concept is an adhesive-bonded composite consisting of transport tubing and a heat conducting fin, sandwiched between two elastomeric films. This concept does not require hand stitching of the tubing material to the heat conducting fin, but does require vacuum bagging of the constructed composite to adequately join the layers of the composite and to minimize the entrained air between the film layers. There are several advantages in fabrication of the film concept as compared to fabrication of the coated fin tube concept. In the film concept, all elements of the composite may be sprayed with adhesive and subsequently assembled and cured. Additionally, the transport tubing may be preformed into a serpentine pattern by thermoforming and positioning at assembly without hand stitching. The elastomer-coated fin-tube configuration requires multiple coats of elastomer to obtain a coating thickness which is sufficient. A minimum thickness of the elastomer coat is required to ensure that the elasticity of the fin-tube configuration is controlled by the coating; lighter coatings result in loss of resilience of the fin, whereas heavier coatings result in loss of elasticity. The coating thickness problem is avoided entirely in the film concept because the elastomer is continuous. Even for thin film elastomers (.001 inch thickness), the resilience is controlled almost completely by the elastomeric film. The elasticity of the elastomeric film fin-tube configuration is a function of the film, metal and adhesive mechanical properties. Several test elements, which have been constructed in support of the film concept, indicate that the thermal and mechanical properties of the composite must be optimized to obtain a material which yields the desired characteristics of elasticity, flexibility,

high fin effectiveness, comfort and low cost fabrication. The remaining sections of this report are a summary of the effort expended by Vought in the development of an advanced liquid cooling garment.

### 3.3 Liquid Cooling Garment Design Requirements and Groundrules

#### 3.3.1 Performance Requirements

The general requirements for developing a liquid cooling garment concept are that the garment material must be flexible and elastic, easily fabricated (low cost fabrication potential), thermally effective and comfortable. The performance requirements of the LCG are summarized here for reference (Ref. 4):

- (1) Heat load to LCG (torso and head)
  - Total: 205-293 watts (700-1000 BTU/hr)(Ref. 5)
  - Head: 31.6-58.6 watts (108-200 BTU/hr)
- (2) Skin Temperature: 24-30°C (75-85°F)
- (3) Zero heat exchange between garment and environment
- (4) Water inlet temperature of 16°C (60°F)(50°F Min [Ref 6])
- (5) Garment Area (head and torso) of .37-.46m<sup>2</sup> (4-5 ft<sup>2</sup>)
- (6) No pressure drop requirement on the feasibility articles (Ref: Apollo LCG ΔP of 22 kPa [3.2 psi] at 109  $\frac{\text{kg}}{\text{hr}}$  (240 pph) water; .0016m [.063"] ID Tubes).

#### 3.3.2 Design Assumptions

The design assumptions necessary to complete the thermal analysis and concepts development may be summarized as follows:

- (1) Cooled Head Area:  $.0929\text{m}^2$  (1 ft<sup>2</sup>)  
Cooled Torso Area:  $.3716\text{m}^2$  (4 ft<sup>2</sup>)
- (2) Contact conductance, garment-to-skin:  $329 \frac{\text{watt}}{\text{m}^2\text{C}}$  (58  $\frac{\text{BTU}}{\text{Hr-ft}^2\text{-}^\circ\text{F}}$ )  
(derived from Apollo data)
- (3) Burst pressure of 1.27MPa gage (185 psig) acceptable (corresponds to .0018m ID (.070"), 0.0046m wall (0.018") polyurethane tubing)
- (4) Design should not preclude future incorporation of ventilation for latent heat removal
- (5) Acceptable water temperature rise of 5.56°C (10°F)  
(similar to Apollo LCG)

### 3.4 Thermal Evaluation

The thermal model utilized to evaluate the thermal performance of the LCG concepts considered in the current contractual effort consists of the fin-tube model shown in Figure 1. The following assumptions are considered in modeling the fin-tube configuration:

- (1) One-dimensional fin conduction, normal to tube axis
- (2) (Constant) skin conductance boundary condition
- (3) Fluid-tube, tube wall radial  $\Delta T$  included, peripheral  $\Delta T$  neglected
- (4) Symmetric temperature distribution between tubes  
(assumes adjacent tubes at equal temperature)
- (5) Projected area of tube in contact with the body

Assumptions (1), (2) and (4) yield a closed-form mathematical solution for the (fin) temperature distribution. The fin effectiveness is the ratio of the fin heat transfer to the heat transfer from a fin whose entire length is at the fin root temperature. For the model considered here, the fin effectiveness may be expressed as

$$\eta = \frac{\text{TANH}(m\ell)}{m\ell}$$

where  $m = \sqrt{\frac{hP}{kA}}$

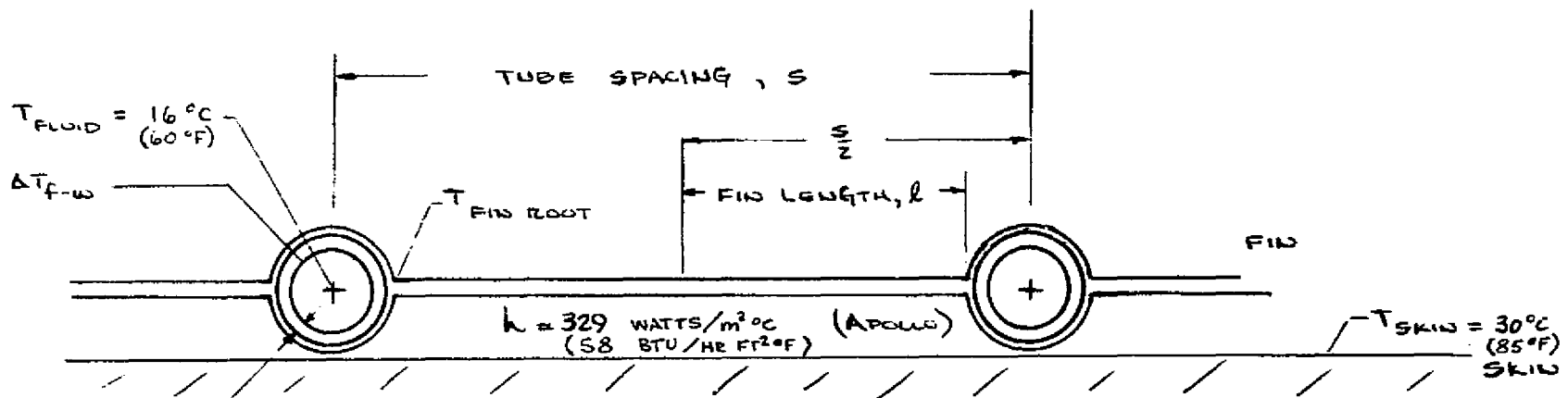
$h$  = convection (skin conduction) coefficient

$P$  = fin perimeter

$k$  = mean fin conductivity

$A$  = fin cross-section area

$\ell$  = fin length



$$\text{AT } \frac{r}{2}, \quad \frac{dT}{dx} = c$$

$$\Delta T_{f-w} = \frac{Q/L}{2\pi r_i h_f}$$

$$\Delta T_{wall} = \frac{(r_o - r_i) Q/L}{2\pi r_o k}$$

- $r_o$  = TUBE OUTER RADIUS + .001" GLUE LINE
- $r_i$  = TUBE INNER RADIUS
- L = TUBE LENGTH

FIGURE 1 THERMAL MODEL

Since the tube periphery is essentially at the fin root temperature, the tube effectiveness is 1.0. Then the total heat rejection follows as

$$Q = hA_F \eta (T_r - T_s) + hA_T (T_r - T_s) ,$$

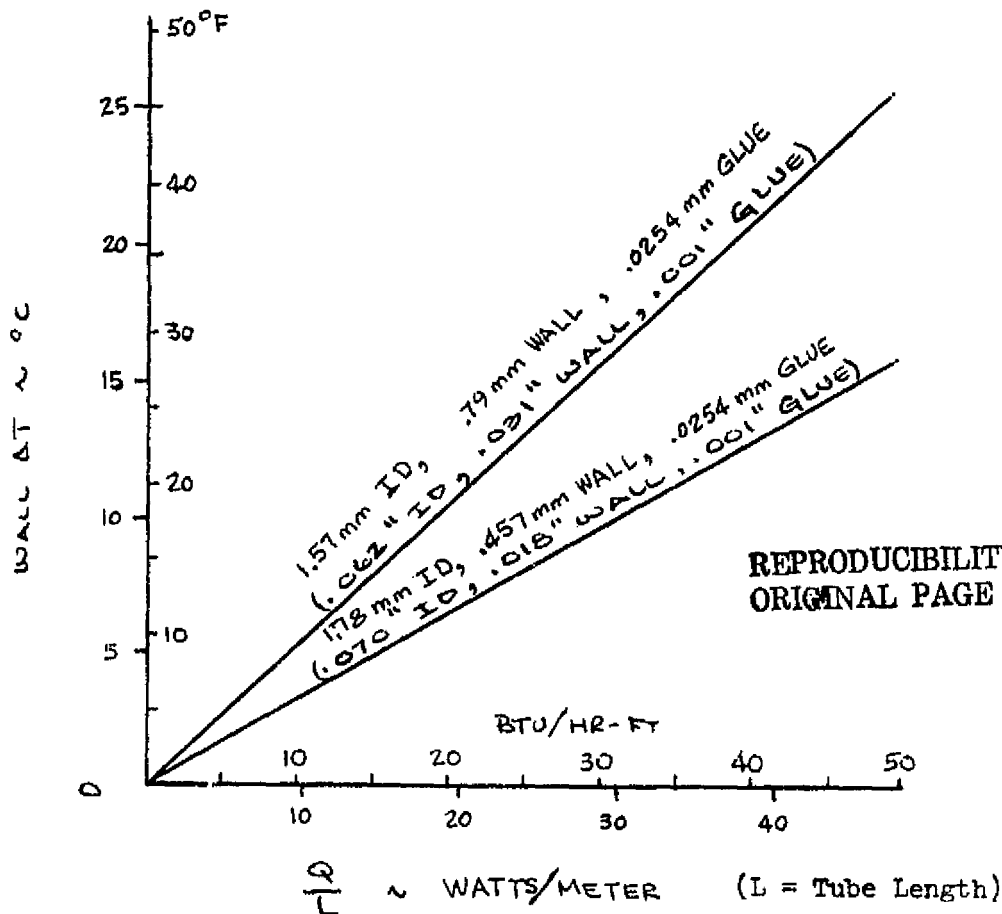
where  $A_F$  = fin area  
 $A_T$  = tube area (projected)  
 $T_r$  = fin root temperature  
 $T_s$  = skin temperature

As discussed in Section 3.5, the elastomeric film fin-tube concept evaluated in the current effort shows much more promise of use as an LCG than does the elastomer-coated fin-tube concept. Accordingly, the film concept has been developed more thoroughly and further refinement of the constituent elements of the composite has been attained. Flattened expanded metal appears to be the most useful heat conducting material due to the relative ease in which bending of the diamond pattern (mesh geometry) is effected. Consequently, in conducting the thermal analysis, expanded metal (as used in construction of all of the film elements) has been used to model the fin effectiveness and heat rejection. Specifically, expanded aluminum and flattened expanded silver have been evaluated. In modeling the fin, a solid foil of equivalent volume per unit longitudinal length of expanded metal mesh has been assumed to compute fin effectiveness (viz., two-dimensional conduction effects through the mesh geometry have been neglected). Tube wall  $\Delta T$  is shown in Figure 2 for two polyurethane tubing sizes. For equivalent heat rejection, the tube wall temperature drop increases with increasing tube spacing. The wall  $\Delta T$  penalty is much less severe for the thin-walled tubing than for the larger wall thickness tubing, especially at the larger tube spacings.

Fin effectiveness has been calculated for three fin configurations, all of which have been fabricated as test elements: (1) one layer 5A17-1/0

FIGURE 2 LCG TUBE WALL ΔT

| ITEM  | TUBE SPACING             |                         |                         |                         |
|---|--------------------------|-------------------------|-------------------------|-------------------------|
|   | .0159m<br>(5/8")         | .0286m<br>(1-1/8")      | .0413m<br>(1-5/8")      | .054m<br>(2-1/8")       |
| <b>TOTAL TUBING LENGTH:</b>                       |                          |                         |                         |                         |
| Torso (@.372m <sup>2</sup><br>4 ft <sup>2</sup> ) | 23.4m<br>(76.8')         | 13.0m<br>(42.7')        | 9.0m<br>(29.5')         | 6.9m<br>(22.6')         |
| Head (@.093m <sup>2</sup><br>1 ft <sup>2</sup> )  | 5.9m<br>(19.2')          | 3.3m<br>(10.7')         | 2.3m<br>(7.4')          | 1.7m<br>(5.7')          |
| <b>TUBING Q/L:</b>                                |                          |                         |                         |                         |
| Torso<br>(@ 234 watts;<br>800 B/H)                | 10.0 w/m<br>(10.4B/H-FT) | 18.0w/m<br>(18.7B/H-FT) | 26.0w/m<br>(27.0B/H-FT) | 33.7w/m<br>(35.1B/H-FT) |
| (@ 59 watts;<br>200 B/H)                          | 10.0w/m<br>(10.4B/H-FT)  | 18.0w/m<br>(18.7B/H-FT) | 26.0w/m<br>(27.0B/H-FT) | 33.7w/m<br>(35.1B/H-FT) |



expanded aluminum, (2) one layer 3Ag5-2/0 fine expanded silver and (3) two layers of expanded silver.<sup>1</sup> The fin effectiveness for these three fin configurations, as predicted by the one-dimensional conduction model discussed above, is shown in Figure 3 as a function of tube spacing. The single metal layer aluminum and silver fin configurations are approximately the same thermally, due to the larger metal cross-section (.005 in. x .007 in. of the aluminum mesh as compared to .003 in. x .005 in. of the silver mesh). Significant improvement to fin effectiveness is obtained for the dual layer expanded silver fin. As indicated in Figure 3, a very high fin effectiveness can be obtained for small tube spacing; however, practical limitations to the tube spacing must be considered. To obtain a serpentine tube pattern, a minimum spacing can be accommodated without closing off the tubes at the 180° turns. Furthermore, the composite elasticity is poor for the tube spacings which are of the same order as the tube outer diameter.

The heat rejection for the expanded silver mesh fin configurations is shown in Figure 4. As indicated above, the single expanded metal layer fin prediction is somewhat high, due to neglecting the tube wall peripheral conduction. According to the results depicted in Figure 4, an LCG with two layers of expanded silver mesh can accommodate a metabolic load of 293 watts (1000 BTU/hr) if the tube spacing is slightly less than one inch. Alternately, the tube spacing can be increased above one inch for a slightly greater silver wire cross-

---

<sup>1</sup> The thermal model is accurate for the dual-layer expanded silver fin because of the assumption of radial conduction only through the tube wall. For the single-layer wire configurations, the expanded metal contacts only half of the tube wall (peripherally), and subsequently only half of the tube wall is available for conduction to the fin root (significant peripheral resistance in the remaining half of the tube wall). Thus, fin effectiveness and heat rejection for the single metal layer fin configurations as predicted here are slightly high.

FIGURE 3 FIN EFFECTIVENESS

$$n = \frac{\text{Tanh}(ml)}{ml}$$

$l$  = fin length (m)  
 = 1/2 (spacing - tube dia.)

$m = \sqrt{h/kt}$  (one-sided)

$h$  = contact/convection coefficient  
 = 329 watts/m<sup>2</sup>-°C  
 (58 BTU/hr-ft<sup>2</sup>-°F)  
 $k$  = thermal conductivity  
 = 415 watts/m-°C  
 (240 BTU/hr-ft-°F)  
 (silver)  
 = 199 watts/m-°C  
 (115 BTU/hr-ft-°F)  
 (aluminum)

$t$  = effective film thickness of metal mesh (m)

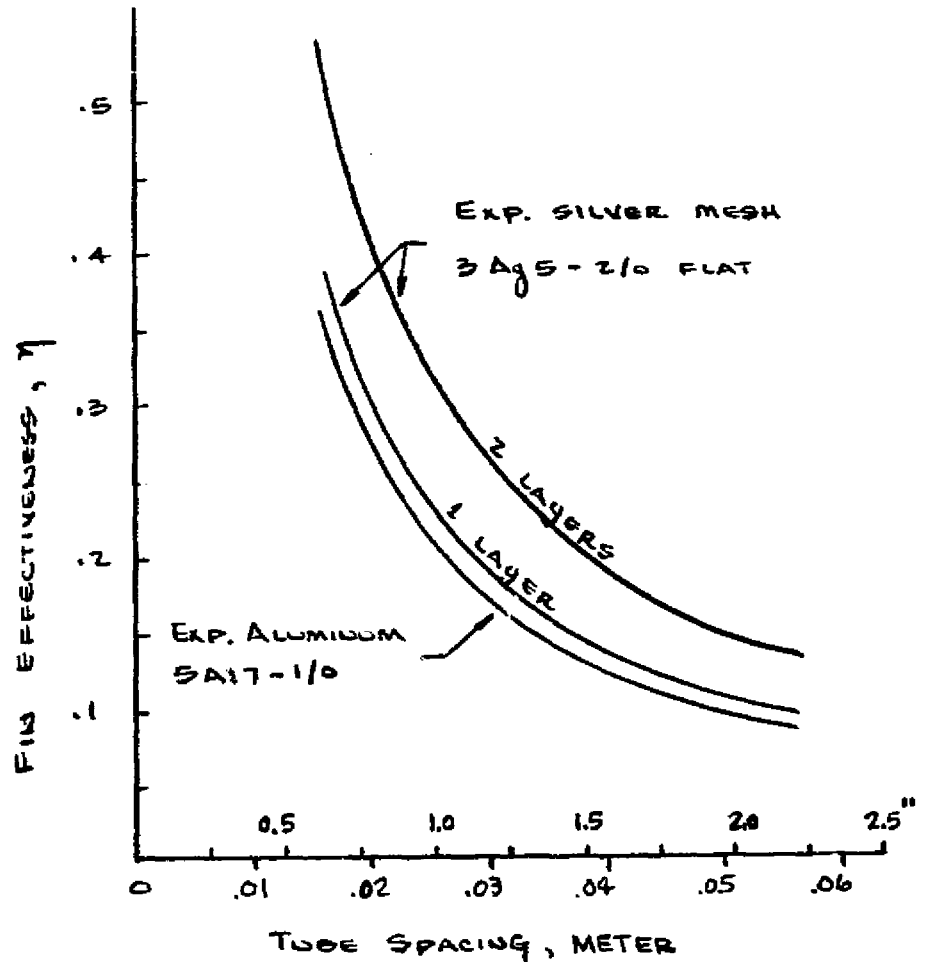
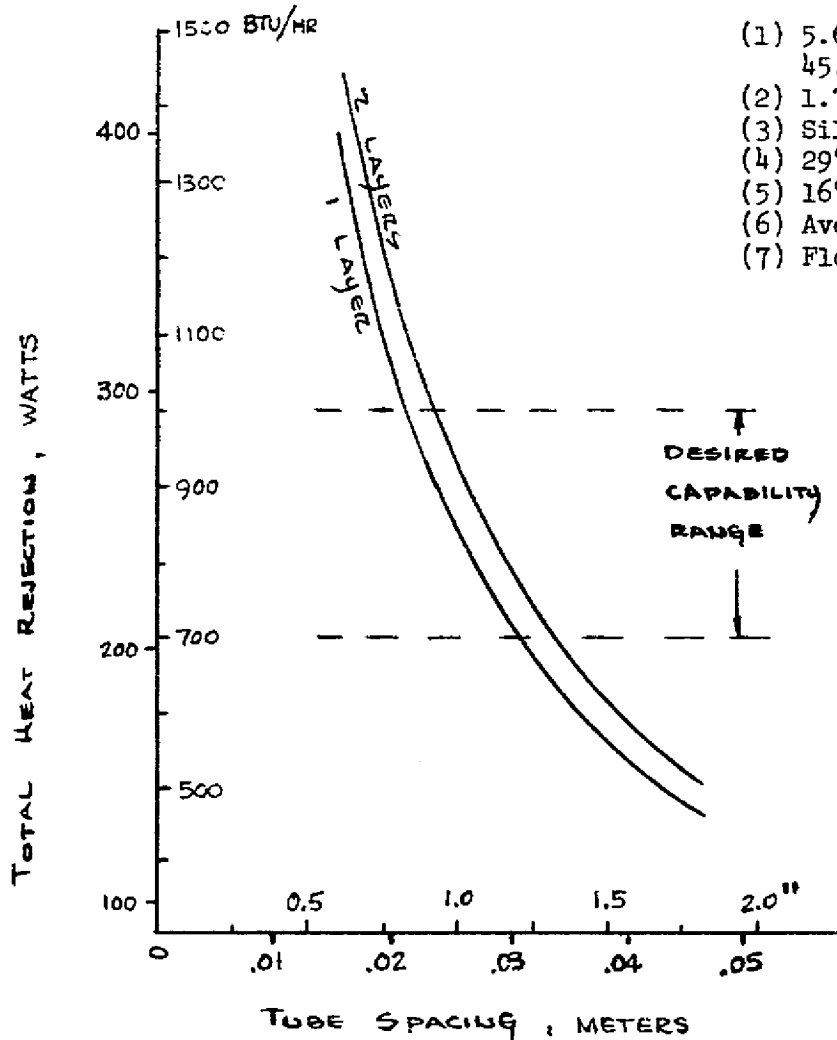




FIGURE 1 HEAT REJECTION PREDICTIONS

NOTES:

- (1) 5.6°C (10°F) water  $\Delta T$  at 293 watts (1000 BTU/hr),  
45.4 Kg/hr (100 pph water) - design point
- (2) 1.78mm (.070") ID Tubing, .457mm (.018") Wall, 10 tubes
- (3) Silver Mesh 3Ag5-2/0
- (4) 29°C (85°F) Skin Temperature
- (5) 16°C (60°F) Water Inlet
- (6) Average inlet/outlet temperature (linear) = 18°C (65°F)
- (7) Flowrate varied to maintain 5.6°C (10°F) temperature rise



LIMITATIONS:

- (1) One-layer model prediction is slightly in error (high) because tube peripheral conduction of zero is not valid if wire is only on one side of tube.
- (2) Fluid convective coefficient calculated for design point flowrate of 4.54 Kg/hr (10 pph) per tube; no correction applied for off-design flowrates

6T

section. In Figure 4, the 293 watt (1000 BTU/hr), two-layer metal fin is the design point, assuming 45.4 kg/hr (100 pph) water flow in the bank of 10 tubes (i.e., 5.6°C [10°F] water temperature rise).

Pressure drop considerations were not required for the analysis of the current contractual effort, but have been calculated and are tabulated in Table 4. As indicated in Table 4, the pressure drop for the concepts considered here are of the same order of magnitude as for the Apollo LCG. A Flexitherm<sup>®</sup> cooling patch has an LCG pressure drop of approximately 27-34 kPa (4-5 psi), but requires a 138 kPa (20 psi) preload (inflation pressure) (Ref. 3).

### 3.5 Fabrication and Element Test Results

#### 3.5.1 Elastomer-Coated Fin-Tube Concept

A total of 20 coated wire mesh test elements have been fabricated in support of the elastomer-coated fin-tube concept. Description of these test elements and qualitative elasticity data are shown in Appendix A. The coated mesh concept was evaluated for woven wire cloth, knitted wire mesh, chain link metal and expanded metal. The mesh configurations and fabricated samples are illustrated in Figure 5. A description of these elements may be summarized as follows:

(1) Woven Mesh:

4 elements of nickel-plated steel, .178mm (.007 in.) dia.  
20 mesh, including brush application of vinyl chloride or  
polyurethane and spray application of polyurethane.

(2) Knitted Mesh:

2 elements of .178mm (.007 in.) galvanized steel, 6.3mm x  
9.5mm (1/4" x 3/8") mesh. 1 element of .203mm (.008 copper,  
6.3mm x 9.5mm (1/4" x 3/8") mesh; each with basket-weave  
polyurethane tubing and spray application of polyurethane.

(3) Expanded Metal:

8 elements, incl. brass, silver, aluminum, copper, nickel  
and Inconel; polyurethane tubes stitched and bonded to 2  
copper elements, the silver element, and one aluminum element;  
polyurethane spray of 1 to 3 coats on each element.

(4) Chain Link:

1 element of 24 AWG stainless steel sprayed with polyurethane.

Only one grade of polyurethane was evaluated in the spray application, such that the following results of this series of element and fabrication tests may not be entirely general with regards to the elasticity of all possible coated meshes.

---

\* Trade name, Acurex Corporation

TABLE 4 LCG PRESSURE DROP

$$\Delta P = 4f \frac{L}{d} \frac{\dot{m}^2}{2A^2 \rho g c}$$

For 45.4 kg/hr (100 lb/hr) Total Flow to Garment

Re = 921

For laminar flow,  $4f = 64/Re$

Tube I.D. = 1.778mm (.070 in)

L - meter

d - meter

$$A = \pi d^2 / 4$$

$$\mu = 3.53 \frac{\text{kg}}{\text{hr m}} = 2.37 \frac{\text{lb m}}{\text{hr ft}}$$

$$\rho = 1000 \frac{\text{kg}}{\text{m}^3} = 62.4 \frac{\text{lb}}{\text{ft}^3}$$

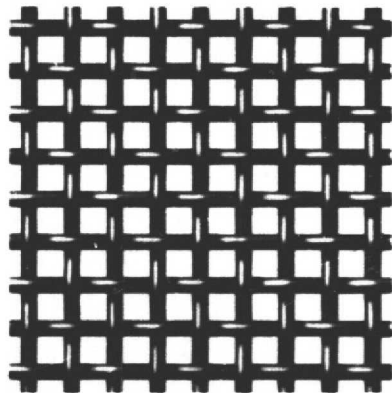
$$A^2 = 2.48 \times 10^{-6} \text{m}^2$$

$\dot{m} = 4.54 \text{ kg/hr per tube (10 tubes)}$

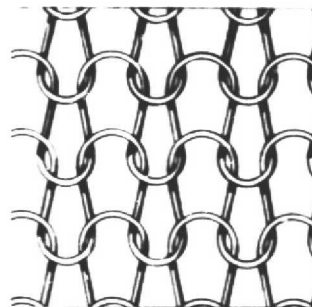
| Tube Spacing, m | Tubing Length, m | $\Delta P$ (kPa) |
|-----------------|------------------|------------------|
| 0.0159 (5/8")   | 5.9 (19.2')      | 29.6 (4.27 psi)  |
| 0.0286 (1-1/8") | 3.3 (10.7')      | 16.5 (2.38 psi)  |
| 0.0413 (1-5/8") | 2.3 (7.4')       | 11.4 (1.65 psi)  |

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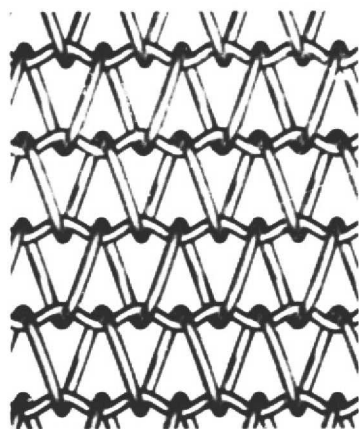
FIGURE 5 HEAT CONDUCTING MATERIAL



WOVEN WIRE CLOTH



KNITTED WIRE MESH



CHAIN LINK METAL



FLAT EXPANDED METAL

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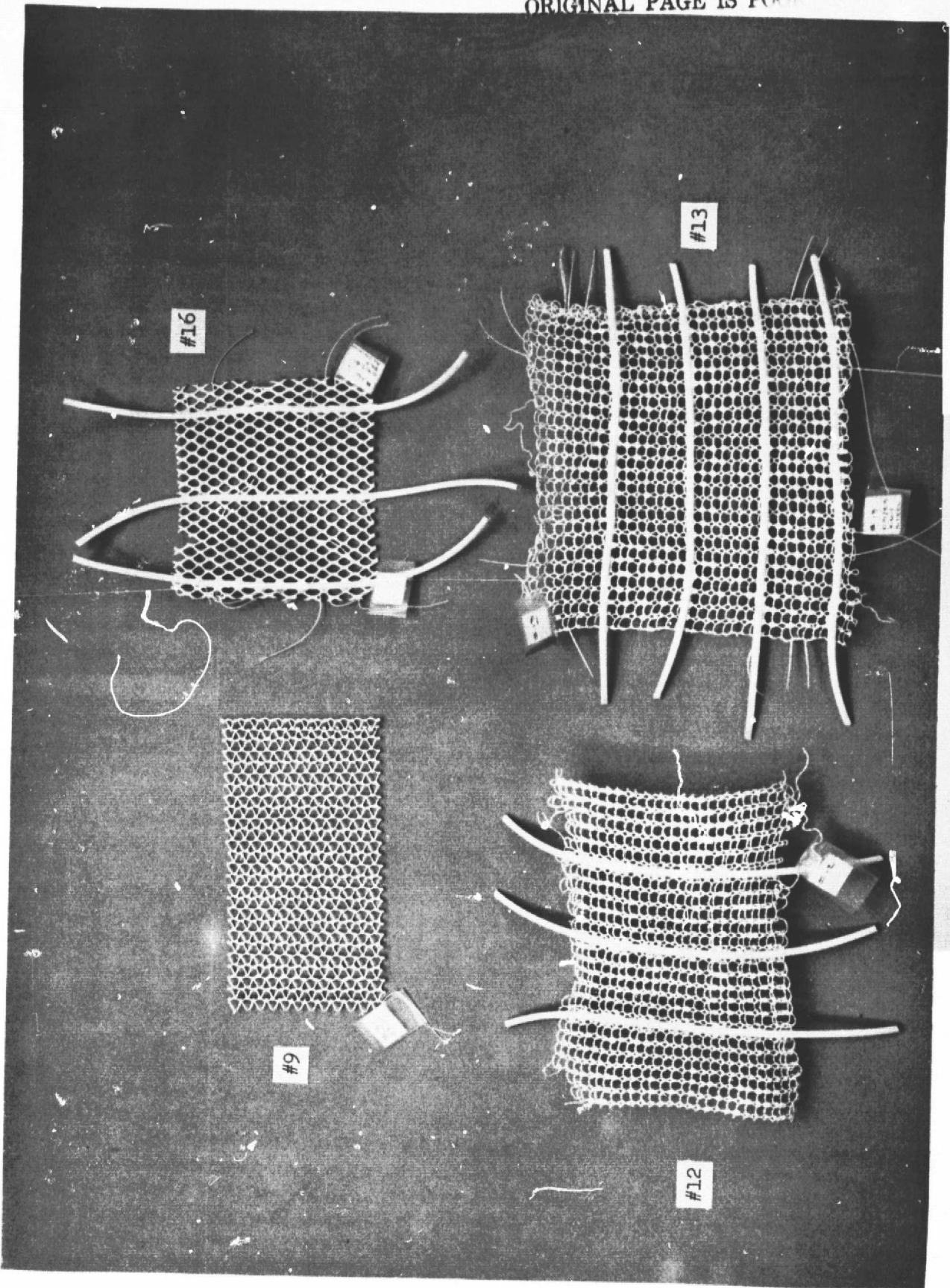


FIGURE 5a ELASTOMER-COATED FIN-TUBE ELEMENTS

The specific findings are:

- (1) The elastomer coating greatly inhibits the elasticity of the woven mesh elements (presumably) due to locking the junctions of the cross-wires. The knits are less sensitive to this coating effect, but motion (bending and relative motion of wires) is still limited. The coating has a minimum influence on the elasticity of the expanded metal elements.
- (2) The softer metals are significantly more elastic than are the harder metals.
- (3) Smaller mesh density and smaller wire gauge increase the element elasticity, especially for the expanded metal elements.
- (4) The presence of polyurethane tubing has only a small effect on the elasticity of the knitted mesh elements, but significantly diminishes the elasticity of the expanded metal elements.

The general findings of the elastomer-coated fin-tube concept element and fabrication tests may be summarized as follows:

- (1) Better control of elastomer coating uniformity is obtained by spray application, as opposed to brush-on application, although uniformity is limited.
- (2) All elements are generally poorly elastic.
- (3) Good thermal contact of the tubing with the heat conducting fin was obtained in all elements.
- (4) Hand stitching of tubing to metal required for the expanded metal elements.

### 3.5.2 Elastomeric Film Fin-Tube Concept

The elastomeric film fin-tube concept has been evaluated through the fabrication of 40 film elements. Chronologically, the film elements fabrication followed completion of the elastomer-coated fin-tube elements construction as it was concluded that the initial concept of elastomer coating offered limited elasticity. As discussed in Section 3.5.1, the heat conducting material which

offered the greatest elasticity in the elastomer-coating concept test elements was expanded metal. Accordingly, expanded metal was chosen as the baseline metal with which to initiate the film concept element tests. The elastomeric film fin-tube concept development may be divided into three general series of elements: (1) variation of the expanded metal, (2) variation of the urethane film type and thickness, and (3) comparison of urethane films with addition of a comfort liner and dual layers of expanded metal. Summaries of the three series of film concept element and fabrication tests are presented in Table 5, 6, and 7, respectively. Figure 6 illustrates representative elements photographically.

Two types of elastomeric film have been considered in the film concept development: urethane film and fluoroelastomer film. Polyether and polyester urethane films have been evaluated in a thickness range of .038 -.25mm (.0015 -.01 in). The fluoroelastomer film has been evaluated in a latex (dispersion compound) system and in a solvent system for repeated spray application to obtain a film thickness. A fluoroelastomer film has been constructed from spray application of the latex system and incorporated into a film element. A complete description of the film elements, as well as a summary of the laboratory notebook for the LCG program are given in Appendices A and B, respectively. Adhesives that have been considered in the element and fabrication tests for the film concept are a silicone adhesive and a two-component epoxy system. The silicone adhesive, General Electric SR-585, has successfully been used in film bonding applications during the Inflatable Radiator Development Program, Reference (2), and has known application, curing and bond characteristics. The two-component epoxy system, Rexnord's Nordbak 25-98 System, has cured properties of 100% elongation, can be diluted with solvent for air spray application and indicates good bonding characteristics.

Features of the elastomeric film fin-tube concept development include

- (1) Thermoformed serpentine tube pattern prior to composite construction.
- (2) Maximum metal-tubing contact area may be obtained by the use of two layers of expanded metal.
- (3) Integration of the comfort liner with the fin-tube composite may be obtained by adhesive application.

TABLE 5

ELASTOMERIC FILM IN-TUBE ELEMENTS

Variation of Expanded Metal

(1) 5-mil MP-1680 Urethane Film, SR-585 Silicone Adhesive,  
1/16 x 1/8 MP-1880 Urethane tubing.

|                                 |                   |                   |
|---------------------------------|-------------------|-------------------|
| (2) Expanded Metals Considered: | 3 Ag 5 - 2/0 Flat | Expanded Silver   |
|                                 | 5 Ag 14 - 1/0     | Expanded Silver   |
|                                 | 3 Al 4 - 1/0      | Expanded Aluminum |
|                                 | 5 Al 7 - 1/0      | Expanded Aluminum |

(3) Results: - Thermal advantage of small cross-section aluminum over elastomeric film alone is minimal (by analysis)

- Excessive stiffness and loss of elasticity for large cross-section silver.

- Small cross-section silver element slightly more elastic than large cross-section aluminum.



TABLE 6

ELASTOMERIC FILM FIN-TUBE ELEMENTS

Variation of Urethane Film Type and Thickness

- (1) Nordbak 25-98 two-part resin system, 3 Ag 5 - 2/0 flat expanded silver, 1/16 x 1/8 MP-1880 urethane tubing
- (2) Urethane Films Considered
- |                    |         |             |
|--------------------|---------|-------------|
| .25mm (10 mil)     | MP-2080 | Ester-Based |
| .089mm (3-1/2 mil) | TF312   | Ester-Based |
| .038mm (1-1/2 mil) | TF322   | Ester-Based |
- (3) Results: - Extreme loss of elasticity in .25mm (10 mil) film elements.
- Elasticity of .089mm (3-1/2 mil) films similar to that of .13mm (5 mil) films.
  - Added elasticity of .038mm (1-1/2 mil) film elements.
  - Bond of 25-98 resin system has much greater peel resistance than that of the SR-585 silicone adhesive.

TABLE 7

## ELASTOMERIC FILM FIN-TUBE ELEMENTS

Comparison of .038mm (1-1/2 mil) films to .13mm (5-mil) films, with addition of comfort liner and dual layers of small cross-section expanded silver.

- (1) Nordbak 25-98 resin system, 1/16 x 1/8 MP-1880 urethane tubing
- (2) Single and dual-layer expanded silver. Dual layer allows complete contact of transport tubing with expanded silver.
- (3) T-shirt comfort liner attached by adhesive application
  - (a) Attachment to "exterior" of two-film composite.
  - (b) Attachment in lieu of one urethane film.
    - (i) One and two-step construction processes considered.
    - (ii) Two step construction may offer greater bonding of comfort liner to composite due to second coat of adhesive (increased wicking of adhesive in comfort liner).
- (4) Results:
  - .038 (1-1/2 mil) urethane film elements offer increased elasticity over .13mm((5 mil) urethane film elements.
  - Significant thermal advantage of dual-layer expanded silver elements due to increased contact area with tubing.(by analysis)
  - Comfort liner does not appreciably affect composite elasticity.
  - Single urethane film/comfort liner elements slightly more elastic than dual urethane film elements without comfort liner.

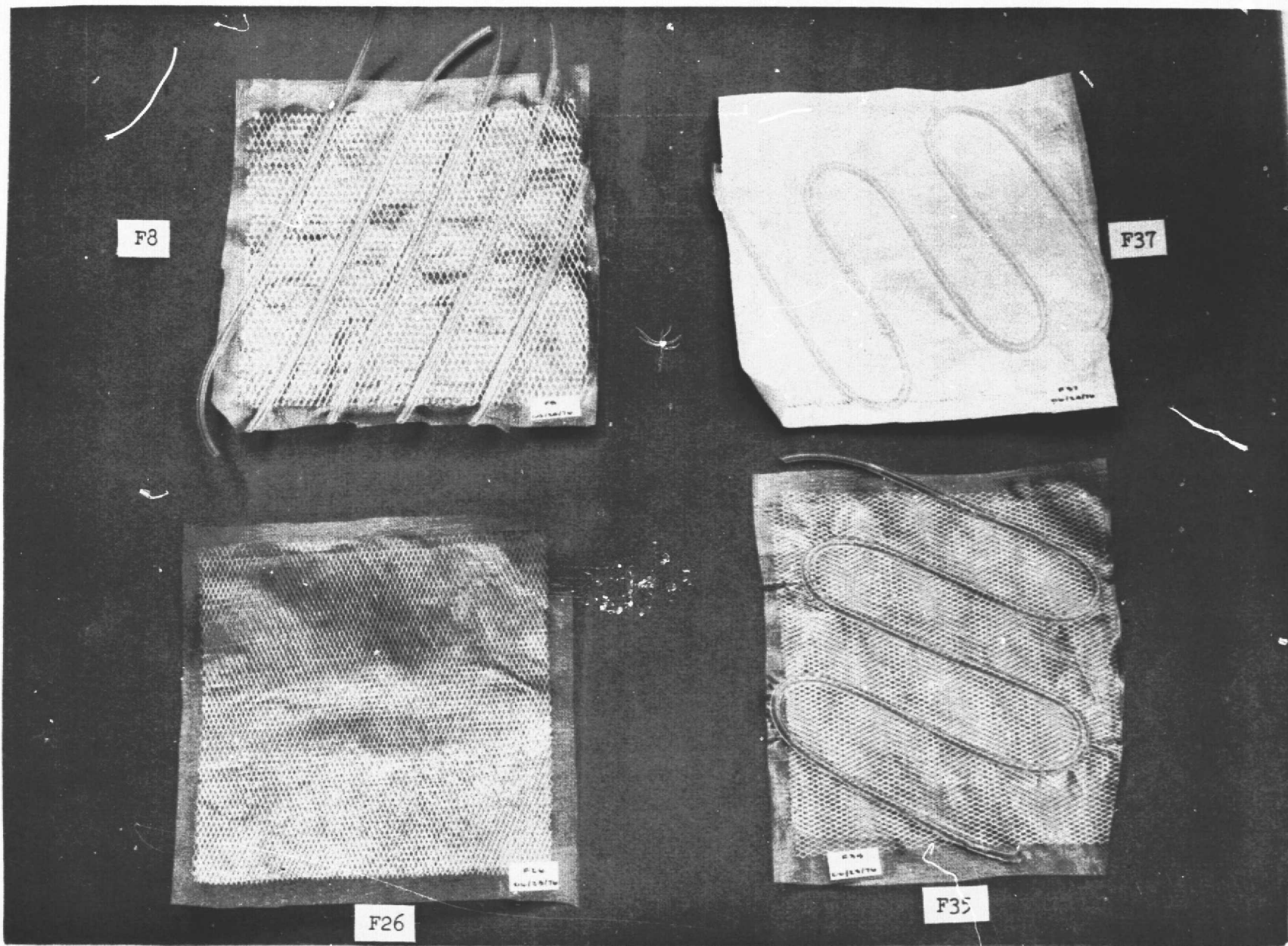


FIGURE 6 ELASTOMER FILM FIN-TUBE ELEMENTS

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- (4) A flat-sided tube-fin film configuration has been demonstrated.

Conclusions from the elastomeric film fin-tube concept development may be summarized as follows:

- (1) Multi-layer fine expanded metal offers greater thermal advantage than equivalent cross-section single-layer metal.
- (2) The .038mm (1-1/2 mil) urethane film elements are sufficiently strong and are more elastic and lighter weight than the thicker urethane film elements.
- (3) The two-part epoxy adhesive system bonds considerably better than the silicone adhesive system and indicates a uniform glue line at the film/fin-tube intersection.
- (4) Addition of a comfort liner is attainable at the initial composite layup.
- (5) Pre-processed thermoforming of the transport tubing substantially aids in construction of the composite by the capability to pre-determine the flow path.

The following assessment of Advanced Liquid Cooling Garment technology is based upon the fabrication and element tests, vendor telecons and data, and the experience directly derived from the Inflatable Radiator Program (Reference 2) reported herein.

- (1) The elastomeric film fin-tube concept appears to be superior to the elastomer-coated fin-tube concept by the measures of ease of fabrication, elasticity of the configuration and its potential for semi-automated assembly. It is expected that conformance to the body can be achieved through proper layup of the composite.
- (2) Expanded metal has been found to be superior to woven wire cloth, knitted wire mesh and chain link metal as the heat conducting agent in the fabricated composites due to the relative ease of bending of the mesh diamond when stretched. Life cycle tests must be conducted to determine expected life of the composite.
- (3) The best elements resulting from the program are given in Table 7 in detail, briefly they consist of:
  1. Nordbak 25-98 resin system
  2. MP-1880 urethane tubing
  3. Expanded silver mesh
  4. Urethane films

These elements are sufficiently better than previous LCG's to be considered the baseline by which future improvements are judged, and are believed to be suitable for fabricating full scale garment elements.

- (4) Improvements in composite elasticity should be pursued, taking into account the contribution of the elastomeric films, diamond geometry in the expanded metal and the elasticity effects of the adhesive and comfort liner. The comfort liner, adhesive and film must be more closely matched in elongation: extremely low strength (high ultimate elongation) composite components will allow greater elasticity, but if these materials are too weak, mechanical damage to the

expanded metal may become a serious drawback.

- (5) The Spandex Lycra comfort liner is apparently sufficiently elastic to include as a basic feature of the advanced LCG. Inclusion of the comfort liner at the initial time of fabrication and its integration as an element of the composite material is considered to be superior to previous concepts and appears to be the least costly method of adding the comfort liner to the garment.
- (6) Thermal improvements to the elastomeric film fin-tube concept can be effected by the following methods:
  - (a) Smaller tube wall gauge
  - (b) Closer tube spacing
  - (c) Expanded metal mesh cross-section/unit volume increase (could possibly have to be optimized with weight considerations)
  - (d) Perforation of the film to allow latent heat removal (evaporation of perspiration) if natural convection/transpiration cooling or forced suit air cooling is available. This method is available if the water loop exit temperature is too high or/and if the user is involved in activities which generate large metabolic loads.
- (7) Patterning of the LCG material appears to be the component of the development program which needs the most work. Fabrication tests are needed to determine molds, patterns, etc. that are applicable to the fabrication of a full scale Advanced Liquid Cooling Garment.

5.0 REFERENCES

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2. "Development of An Inflatable Radiator", Final Report, Report No. 2-53002/6R-51338, Vought Corporation, Systems Division, 28 May 1976 (to be released)
3. "Development of An Advanced Liquid Cooling Garment", Mid-term Briefing presented by Vought to NASA-Ames Research Center, 8 July 1976.
4. "Development of An Advanced Liquid Cooling Garment", Kick-off Meeting at Vought, 22 October 1975.
5. Telecon, B. W. Webbon of NASA-ARC to J. R. Leith, Vought Corporation, 29 January 1976 (modification to groundrules)
6. Telecon, J. R. Leith, Vought Corporation to B. W. Webbon, NASA-ARC, 10 March 1976.

APPENDIX A TEST ELEMENT SUMMARY

- I. Coated Wire Mesh Elements
- II. Elastomeric Film Elements



TABLE A-1 QUALITATIVE ELASTICITY DATA FOR COATED WIPE MESH ELEMENTS

| TEST ELEMENT | ELEMENT DESCRIPTION  | LONG-WAY DIM ELASTICITY  | SHORT-WAY DIM ELASTICITY   | CROSS-DIM ELASTICITY  | FLEXIBILITY                                       |
|--------------|--|--|--|---|---|
| 1            | .007 20 x 20 mesh nickel-plated steel wire cloth<br>Brush-application of polyurethane  | None   | None   | None  | slightly flexible                                 |
| 2            | Same as 1, but with brushed on vinyl chloride (solvent cure)   | None   | None   | None  | Slightly flexible                                 |
| 3            | Same as 1, but with spray application of polyurethane  | None   | None   | None  | Slightly flexible                                 |
| 4            | Same as 3  | None   | None   | None  | Slightly flexible                                 |
| 5            | .0045 dia nickel, fine knitted wire mesh sprayed with polyurethane   | None   | None   | Some cross-dim elasticity                                   | Slightly flexible                                 |
| 6            | 8AL8-2/0 brick Distex expanded aluminum 85% open, .074 gm/in <sup>2</sup><br>Sprayed with polyurethane   | Small elasticity; diamond formation in this pattern leaves little possible bending                             | Moderate elasticity (greater than in long-way dim)                                   | Essentially same as in long-way dimension                   | Slightly flexible                                 |
| 7            | 5 Ag 8-1/0 expanded silver; 83% open, .120 gm/in <sup>2</sup><br>Sprayed with polyurethane. 1/16 x 1/8 MP-1880 tubes @ 1-3/8" spacing in short way dim direction | Moderately elastic. Elasticity due to bending of diamond pattern. Resilience due to urethane coating and tubes | Very elastic in short-way dim. (Direction of tubes) - stretching w/resilience is 10% | Cross-dim elasticity is inferior to long way-dim elasticity | Moderate flexibility of element in all directions |

TABLE A-1 (CONTINUED)

| TEST ELEMENT | ELEMENT DESCRIPTION   | LONG-WAY DIM ELASTICITY  | SHORT-WAY DIM ELASTICITY                              | CPCSS-DIM ELASTICITY         | FLEXIBILITY              |
|--------------|---|--|---|------------------------------|--------------------------|
| 8            | 2 Inconel 9 - 2/OE flattened expanded Inconel<br><br>Sprayed with polyurethane  | Poor elasticity in long-way direction<br><br>Overspray of urethane appears to have adversely affected the elasticity of this element | Moderate elasticity in short way direction            | Cross-dim elasticity is poor | Element is very flexible |
| 9            | 24 AWG stainless steel chain link<br>C-11<br>B-48-55-24<br><br>Sprayed with polyurethane  | No Elasticity<br><br>Elastomer coating has locked relative movement of individual wire strands                                       | No Elasticity   | No Elasticity                | Slightly flexible        |
| 10           | 5 mil x 6 mil dense diamond expanded nickel<br><br>Sprayed with polyurethane  | No Elasticity<br><br>Significant overspray of polyurethane. Small diamond size yields little possible bending of the diamond         | No Elasticity   | No Elasticity                | Slightly flexible        |
| 11           | 5 mil x 8 mil large diamond expanded copper sprayed w/polyurethane.<br>1/16 x 1/8 MP-1880 tubes @ 1-1/8" spacing in long way dim direction. | Moderately elastic in long-way direction   | Very elastic in short way direction (normal to tubes) | No cross-dim elasticity      | Moderately flexible      |

TABLE A-1 (CONTINUED)

| TEST ELEMENT | ELEMENT DESCRIPTION  | LONG-WAY DIM ELASTICITY   | SHORT-WAY DIM ELASTICITY                              | CROSS-DIM ELASTICITY                   | FLEXIBILITY     |
|--------------|--|---|---|--|-----------------|
| 12(A)        | .007 galv steel medium density knitted wire<br><br>1/16 x 1/8 MP-1880 tubes @ 1-3/8" spacing in short-way direction. Sprayed w/polyurethane          | Slightly elastic in long-way direction<br><br>Elastomer coating has locked up relative motion of adjacent wire strands, thus restricting composite elasticity   | Inelastic in short way direction (direction of tubes) | Moderate elasticity in cross-dimension | Fairly flexible |
| 12(B)        | Same as (A) except w/ tubes in long-way direction  | Slightly elastic in long-way direction  | Mostly inelastic in short-way direction               | Moderate elasticity in cross dimension | Fairly flexible |
| 13(A)        | .007 galv steel medium density crimped knitted wire mesh<br>1/16 x 1/8 MP-1880 tubes @ 1-3/8" spacing in short-way direction; sprayed w/polyurethane | Slightly elastic in long-way direction<br><br>Same comments as for elements 12(A) and (B). The crimped pattern of this element aids its elasticity considerably, especially in the short-way direction. | Slightly elastic in short-way direction               | Moderate elasticity in cross dimension | Fairly flexible |
| 13(B)        | Same as 13(A) except w/tubes in the long-way direction   | Slightly elastic in long-way direction<br><br>Crimped pattern aids elasticity more for short-way direction  | Fairly elastic in short-way direction                 | Moderate elasticity in cross dimension | Fairly flexible |

TABLE A-1 (CONTINUED)

| TEST ELEMENT | ELEMENT DESCRIPTION   | LONG-WAY DIM ELASTICITY   | SHORT-WAY DIM ELASTICITY                | CROSS-DIM ELASTICITY                   | FLEXIBILITY       |
|--------------|---|---|---|--|-------------------|
| 14(A)        | Flattened copper filament coarse density knitted wire mesh<br><br>1/16 x 1/8 MP-1880 tubes @ 1-9/16" spacing in short-way direction<br>Sprayed w/polyurethane | Fairly elastic in long-way direction<br><br>Initial elasticity of the mesh is absent after elastomer coating due to inhibition of relative wire motion (as w/elements 12 and 13). | Slightly elastic in short-way direction | Moderate elasticity in cross dimension | Fairly flexible   |
| 14(B)        | Same as 14(A) except w/ tubes in the long-way direction   | Slightly elastic in long-way direction  | Fairly elastic in short-way direction   | Moderate elasticity in cross dimension | Fairly flexible   |
| (15)         | 4 Cu40 - 1/0 Distex expanded copper sprayed w/polyurethane, 1/16 x 1/8" MP-1880 tubes @ 1-1/2" spacing.<br>.305 gm/in <sup>2</sup>                            | Fair elasticity in tube direction<br><br>40-mil strand width is much too large for this pattern.  | Fair elasticity normal to tubes         | Mostly inelastic in cross-dimension    | Fairly flexible   |
| (16)         | 15 Al35-1 expanded aluminum sprayed w/polyurethane. 1/16 x 1/8 MP-1880 tubes @ 1-9/16" spacing in long-way direction  | Inelastic in long way direction<br><br>Material thickness and strand width are too large  | Slightly elastic in short-way direction | Mostly inelastic in cross-dimension    | Slightly flexible |
| 17           | 5 brass 10-3/0 expanded brass sprayed w/polyurethane no tubes,<br>66% open, .236 gm/in <sup>2</sup>   | Mostly inelastic in long-way direction<br><br>Diamond size is too small to allow any appreciable bending.   | Slightly elastic in short-way direction | Mostly inelastic in cross-dimension    | Fairly flexible   |

TABLE A-2

SUMMARY OF THE FILM ELEMENTS<sup>1</sup>

| <u>ELEMENT</u> | <u>DESCRIPTION</u>   |
|----------------|--|
| F1             | Composite of (2) 5-mil MP-1880 urethane films<br>SR-585 Adhesive<br>5Al7-1/0 Expanded Aluminum   |
| F2             | Same as F1, but with 3Al4-1/0 expanded aluminum  |
| F3             | Same as F1, but with 3Ag5-2/0 flat expanded silver   |
| F4             | Same as F1, but with 5Ag14-1/0 expanded silver   |
| F5             | Composite of (2) 5-mil MP-1891 <sup>2</sup> urethane films<br>SR-585 Adhesive<br>5Al7-1/0 expanded aluminum<br>1/16 x 1/8 MP-1880 urethane tubing in<br>serpentine flow pattern                    |
| F6             | Same as F5, but with 3Al4-1/0 expanded aluminum  |
| F7             | Same as F5, but with 3Ag5-2/0 flat expanded silver   |
| F8             | Same as F5, but with 5Ag14-1/0 expanded silver   |
| F9             | Composite of (2) 9-mil Viton L-31 films <sup>3</sup><br>Nordbak 25-98 Resin system (adhesive)<br>3Ag5-2/0 flat expanded silver<br>1/16 x 1/8 MP-1880 urethane tubing in<br>serpentine flow pattern |
| F10            | Same as F9, but with (2) MP-1880 5-mil urethane films  |
| F11            | Composite of (2) 10-mil MP-2080 urethane films<br>Nordbak 25-98 resin system (adhesive)<br>3Ag5-2/0 flat expanded silver   |

<sup>1</sup> The film elements are all nominally 6 inches x 6 inches. All have been vacuum-bagged and subjected to thermal cure. Further comments on fabrication commence on page B1.

<sup>2</sup> The difference in mechanical properties of MP-1891 and MP-1880 is shown on page B9.

<sup>3</sup> The Viton L-31 films were fabricated by Vought by repeated spray application of Viton latex system (L-31 compound dispersion system) onto a base sheet of polyethylene.

TABLE A-2 (CONT'D)

| <u>ELEMENT</u> | <u>DESCRIPTION</u>   |
|----------------|--|
| F12            | Same as F11, but with addition of 1/16 x 1/8 MP-1880 urethane tubing in a serpentine flow pattern (thermoformed prior to assembly)   |
| F13            | Same as F11, but with 5Ag14-1/0 expanded silver  |
| F14            | Same as F12, but with 5Ag14-1/0 expanded silver  |
| F15            | Same as F11, but with 5Al7-1/0 expanded aluminum   |
| F16            | Same as F12, but with 5Al7-1/0 expanded aluminum   |
| F17            | Composite of (2) 1-1/2 mil TF322 urethane films<br>Nordbak 25-98 resin system (adhesive)<br>3Ag5-2/0 flat expanded silver<br>1/16 x 1/8 MP-1880 urethane tubing in serpentine flow pattern (thermoformed prior to assembly)  |
| F18            | Same as F17, but with two layers expanded silver (one either side of tube, adjacent in fin cross-section)  |
| F19            | Composite of (2) 1-1/2 mil TF322 urethane films<br>Nordbak 25-98 resin system<br>(2) layers of 5Al7-1/0 expanded aluminum (one either side of tube, adjacent in fin cross-section)<br>1/16 x 1/8 MP-1880 urethane tubing (thermoformed) in a serpentine flow pattern<br>Vacuum bagged with aluminum plate against one side (yields element with one flat side, tube above) |
| F20            | Same as F17, but with (2) 3-1/2 mil TF312 urethane films   |
| F21            | Same as F18, but with (2) 3-1/2 mil TF312 urethane films   |
| F22            | Same as F19, but with (2) 3-1/2 mil TF312 urethane films   |
| F23            | Composite of (2) 5 mil MP-1880 urethane films<br>Nordbak 25-98 resin system (adhesive)<br>3Ag5-2/0 flat expanded silver  |
| F24            | Same as F23, but with (2) layers of expanded silver  |
| F25            | Same as F23, but with (2) 1-1/2 mil TF322 urethane films   |
| F26            | Same as F24, but with (2) 1-1/2 mil TF322 urethane films   |

TABLE A-2 (CONT'D)

| <u>ELEMENT</u> | <u>DESCRIPTION</u>   |
|----------------|--|
| F27            | Composite of (2) 5 mil MP-1880 urethane films<br>(2) layers of 3Ag5-2/0 flat expanded silver<br>2nd step addition of adhesive-applied cotton<br>"T-shirt" comfort liner  |
| F28            | Same as F27, but with (2) 1-1/2 mil TF322 urethane films   |
| F29            | Composite of (1) 1-1/2 mil TF322 urethane film<br>One layer 3Ag5-2/0 flat expanded silver<br>(1) cotton "T-shirt" comfort liner (i.e.,<br>same as F25, but with "T-shirt" in lieu<br>of one of the urethane films)   |
| F30            | Same as F29, but with (2) layers expanded silver   |
| F31            | Same as F29, but a 2-step fab process:<br>(a) Polyethylene in lieu of one urethane film<br>(b) Peel off polyethylene (after vacuum cure)<br>(c) Spray adhesive 2nd time and attach "T-shirt"<br>(d) Vacuum cure 2nd time   |
| F32            | F30 2-step fab (same as F31, but with 1-1/2 mil TF322<br>urethane film)  |
| F33            | Single-step process. Same as F29, but with 5 mil MP-1880<br>urethane film  |
| F34            | Same as F33, but with (2) layers of 3Ag5-2/0 flat expanded<br>silver   |
| F35            | Composite of (2) 5 mil MP-1880 urethane films<br>Nordbak 25-98 resin system<br>(2) layers 3Ag5-2/0 flat expanded silver<br>1/16 x 1/8 MP-1880 urethane tubing in ser-<br>pentine flow pattern (thermoformed prior<br>to assembly)                                      |
| F36            | Same as F35, but with (2) 1-1/2 mil TF322 urethane films   |
| F37            | F30 with 1/16 x 1/8 urethane tubing (serpentine)   |
| F38            | Composite of (1) 5 mil MP-1880 urethane film<br>(2) layers 3Ag5-2/0 flat expanded silver<br>1/16 x 1/8 MP-1880 urethane tubing in ser-<br>pentine flow pattern (thermoformed)<br>Cotton "T-shirt" comfort liner in lieu of<br>2nd urethane film<br>Single-step process |

TABLE A-2 (CONT'D)

| <u>ELEMENT</u> | <u>DESCRIPTION</u>   |
|----------------|--|
| F39            | F28 with serpentine urethane tubing  |
| F40            | F27 with serpentine urethane tubing  |
| F41            | F37, but with serpentine pattern aligned in long dimension of expanded silver diamond <sup>4</sup> |
| F42            | F37, with with comfort liner of 58% nylon, 42% spandex lycra                                       |
| Deletions      | Elements F27 and F34 were deleted due to depletion of materials.                                   |

---

<sup>4</sup> Elements F5 - F8 and F41 have serpentine patterns aligned with long dimension of the expanded metal diamond. All other film elements with serpentine tubing have tubing aligned along solid length of metal.



APPENDIX B LABORATORY NOTES SUMMARY



Test Elements

Urethane Spray - (Paint Shop)

- (3) .007 20 x 20 Ni-Plated Steel
- (4) Same as (3).
- (5) Wire mesh 62N .0045 in dia. (ACS Industries)
- (6) Expanded Aluminum .003" Thick  
(Exmet) 85% Open .074 GM/in<sup>2</sup>
- (7) Expanded Silver .005 in thick 1/0 mesh  
(Exmet) 83% Open  
.12 GM/in<sup>2</sup>
- (8) Expanded Inconel .002 in thick.  
(Exmet) 66% Open  
.22 GM/in<sup>2</sup>
- (9) Stainless Steel chain link - 24 gauge  
C-11  
8-48-55-24  
Ashworth Bros.
- (10) Expanded Nickel .005 Matl thickness  
(Die mesh Corp) .006 Strand
- (11) Expanded Copper .005 Matl thickness  
(Die mesh Corp) .008 Strand  
.015 Overall Thickness
- (12), (13) and (14)

Knitted mesh elements have "Basket-Weave" 1/8 x 1/16 MP-1880 polyurethane tubing. Very good mechanical contact of mesh to tube - spraying of urethane on these elements should yield a high  $\eta$ .

Comments on (3) - (9) Elements:

Most of these elements were oversprayed and thus have large chunks of urethane at wire intersections. Some are heavy enough such that gravity effects are dominant.

All of the wire intersections that were free to slide are locked up - However, rotation is possible (See element # (9)).

- (13) Crimped Knitted Mesh .007 Galv. Steel
- (14) Knitted Copper Mesh

- Elements (12), (13), and (14) have basket-weave urethane tubes.

- Primer and 1st coat urethane on (12), (13) and (14) on 03/23.
- Element (11) tied 2 urethane tubes to element (#(11) has 1 coat urethane on it at this stage) - (1 w/4 places tied) (1 w/3 places tied) to
- Bring tubes in close contact with metal. Spray one light coat urethane on tube-fin.
- Sprayed 2nd coat urethane on element #10 (expanded Ni).

Elements (12), (13) and (14) are double-weaved

Side A - tubes are in direction of weave

Side B - Tubes are normal to direction of weave

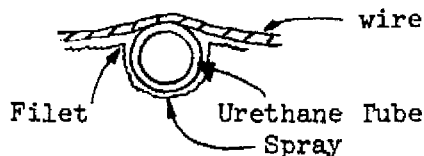


- |      |                                  |   |
|------|----------------------------------|---|
| (15) | Expanded Copper<br>(Exmet)       | 4 cu 40 - 1/0 Distex<br>Overall thickness - .070<br>- .305 GM/in <sup>2</sup> |
| (16) | Expanded Aluminum<br>(Exmet)     | 15 Al 35-1<br>- 66% Open<br>- .220 Gm/in <sup>2</sup>                         |
| (17) | Expanded Brass<br>(Exmet)        | 5 Brass 10 - 3/0<br>- 66% Open<br>- .236 Gm/in <sup>2</sup>                   |
| (18) | Knitted Mesh<br>(ACS Industries) |   |

- 2nd coat urethane on #10 is much too heavy
- Inspection of (11), (12), (13), and (14):

(11) Inconclusive - sprayed only on tube side

(12)-(14) Urethane buildup on wire adjacent to tube looks good; should need - 2 more coats to properly form filet:



- Sprayed elements (11), (12), (13), and (14)  
(1st coat on one side of (12)-(14))
- Hand-stitched 3 urethane tubes each to elements (7), (15), and (16) - to sprayed with urethane on 03/26 - sprayed at 3PM - 03/25
- Element (17). (Expanded Brass) - very stiff  
has 1 coat urethane

Cumulative

|                |  |   |             |
|----------------|--|---|-------------|
| (1), (2)       | 1 coat brush-on                                | } | with primer |
| (3), (4), (5)  | 1 coat urethane spray                          |   |             |
| (6), (8)       | 1 coat urethane spray<br>#(8) - much too thick |   |             |
| (9),(10),(11)  | 1 very heavy coat<br>#(10) - 2 coats           |   |             |
| (12),(13),(14) | 1 coat on one side<br>3 coats on other side    |   |             |
| (15), (16)     | 1 coat → Add tubes →                           |   | 2nd coat    |
| (17)           | 1 coat urethane                                |   |             |
| (7)            | 1 coat - Tubes -                               |   | 2nd coat    |

3/26/76

- Sprayed one coat on "Lean side" of (12), (13), and (14)
- Sprayed one coat on "Lean side" of (11)
- Sprayed both sides of (15), (16) and (17)

Elastomer-coated Fin-tube concept elements  
with tubing (MP-1880, 1/16 x 1/8) are:

- No. 7
- No. 11
- No. 12
- No. 13
- No. 14
- No. 15
- No. 16

## II. Elastomeric Film Fin-Tube - Concept Fabrication and Element Tests

5/12/76

Prepared test elements from 12 x 12 sheets of 5A17-1/0 and 3A14-1/0

Sprayed 3 sheets (6" x 6") of 3A14-1/0 and 4 sheets (6" x 6") of  
5A17-1/0 with light coat of urethane.

5/13/76

Cut tensile elements (3 each of the 2 aluminums) for Quan Elasticity Test.

Prepared the tensile elements for one more coat of urethane.

No. 18 - Attached tubes in cross-dimension to one of 6" 5A17-1/0 elements.  
Tube spacing 1 1/4 in.

Prepared No. 18 element for one more coat of urethane.

Cut (4) 8" x 8" pieces of MP-1880 urethane sheet (5 mil) and prepared  
these plus one each of the expanded aluminum elements above to be sprayed  
with SR-585 silicone adhesive.

Sprayed urethane sheet and exp. aluminum with 585 room temperature cure  
overnight (toluene evaporation).

Vacuum Bag Friday morning

5/14/76

Constructed two urethane/expanded aluminum laminates. Bagged elements:

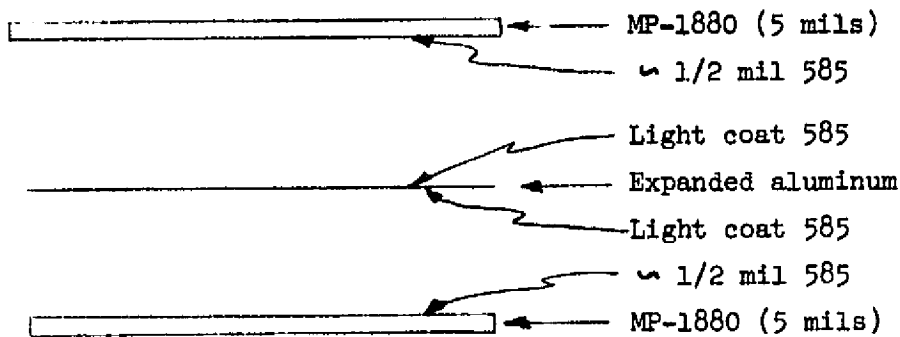
- F1: 5 A17-1/0      Each with (2) 5-mil MP-1880 urethane films.
- F2: 3A14-1/0      SR-585 silicone adhesive

SR-585 Cure

5/14/76

|              |             |           |
|--------------|-------------|-----------|
| 45 min. 150F | In: 1:00 PM | Out: 1:45 |
| 45 min. 175F | 1:45        | 2:30      |
| 1 hour 200F  | 2:30        | 3:30      |

Urethane Sheet/Expanded Aluminum/SR-585 Laminates:



Urethane to urethane edges miced at 11 mils.

Results of Cured Urethane Film/Exp. Aluminum Elements: (F1 and F2)

Both composites are extremely flexible and at least as elastic as previous expanded metal/elastomer coating elements.

5/20/76

585 Mixture

80 ml SR-585 Lot No. 53372-A (07/23/75)

8:1 with Toluene: 640 ml toluene

|        |     |          |
|--------|-----|----------|
| 80     | 585 |          |
| 720 ml |     | (320)    |
|        |     | 240 + 80 |
|        |     | 400      |

Prepared MP-1891 films (4) for exp. metal/urethane film/urethane tubes

MP-1880 films (2) for 5 Ag14-1/0  
 3 Ag 5-2/0 Flat (Tubeless)  
 Silver/Film

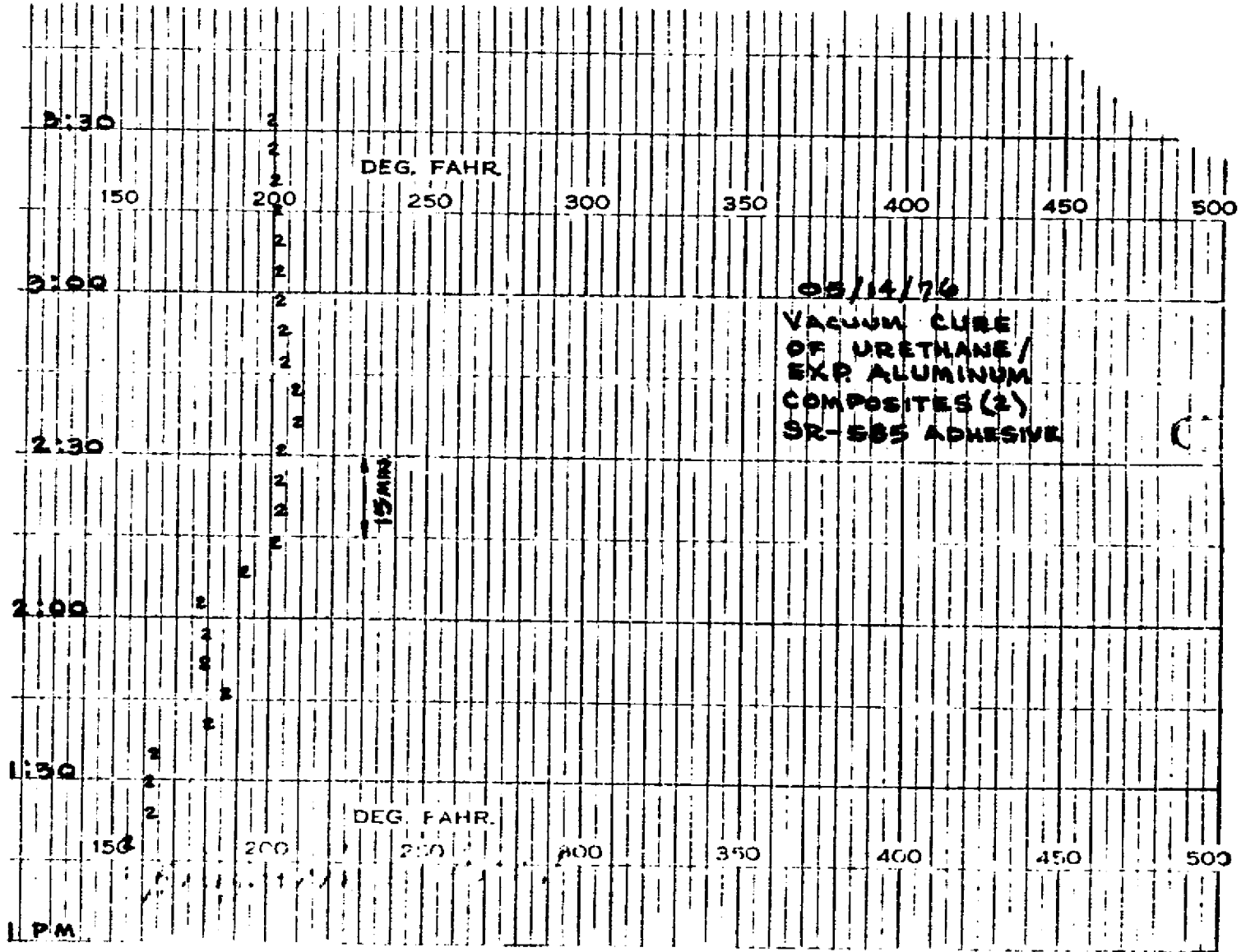
5/21/76

MP-1891 has been deleted and/or replaced by MP-1890 due to lack of material MP-1891 is ether based (as is MP-1880). Ether-based urethanes have greater resistance to hydrolysis than ester-based urethanes. Additionally, resilience and low temperature flex are greater for the ether-based urethanes.

ACTUAL CURE : SR-585

150 F 30 MIN  
175 30 MIN  
200 90 MIN

2 1/2 HR





Test Elements to Paint Shop at 8:30 a.m.:

- (4) MP-1891
- (2) MP-1880
- (1) Each 6" x 12" of
  - 5 Ag 14-1/0
  - 3 Ag 5-2/0
  - 5 Al 17-1/0
  - 3 Al 14-1/0

Spray with 585 (Added 2 drops of catalyst @ 8:25 a.m.)

1880 and 1891 Mechanical Properties

|                    | <u>MP-1880 Ether</u> | <u>MP-1891 Ether</u> |
|--------------------|----------------------|----------------------|
| Durometer (+5)     | 85A                  | 87A                  |
| Tensile (PSI)      | 5-6000               | 5-5500               |
| Elongation (%)     | 400-500              | 300                  |
| Elongation Set (%) | 8 - 12               | 20                   |
| Modulus (# @ 300%) | 2500 - 3000          | 3000                 |

Constructed 6 Composites

|    |                |  |
|----|----------------|--|
| F3 | 3 Ag5-2/0 flat | } /urethane film (MP-1880)               |
| F4 | 5 Ag14-1/0     |  |
| F5 | 5 Al7-1/0      | } /urethane film (MP-1891)<br>with tubes |
| F6 | 3 Al14-1/0     |  |
| F7 | 3 Ag5-2/0 flat |  |
| F8 | 5 Ag14-1/0     |  |

Used SR-585 adhesive 1:8 with toluene air dried for ~ 72 hours after spraying on Friday 5/21/76. Two drops catalyst added.

- F8 Tubes in cross-dimension
- F5-F7 Tubes serpentine in cross-dimension
- F5 and F6 with MP-1880 .070 x .105 tubes
- F7 and F8 with MP-1880 1/16 x 1/8 tubes

Bags prepared Monday evening. Bag on Tuesday morning.

5/25/76

Bagged the two silver/urethane elements and the four elements with tubes.

|                        |      |            |
|------------------------|------|------------|
| Start cure at 10:40 am | 150F | 30 minutes |
|                        | 175F | 30 minutes |
|                        | 200F | 90 minutes |

End cure at 1:10 pm

Elements are outstanding.

Element Test with Viton Fluoroelastomer Latex System:

(Viton L-31 fluoroelastomer dispersion system)

2" x 3" .007 Ni-plated 20 x 20 woven steel wire.

11:25 Dipped once and absorbed excess on paper towel air dry

11:32 2nd coat brushed on - shook off excess air dry

11:45 3rd coat brushed on - blew excess L-31 out of openings (open mesh) air dry

11:50 4th coat (same as No. 3)  
Air dry

2:35 5th coat (same as No. 4)  
Air dry

2:50 6th coat (Same as No. 3)  
Air dry

Coating buildup is heavy at the wire intersections. Apparent entrapment of air (bubbles visible) - 300F cure may release some of the bubbles (?)

Nordbak 25-98 Epoxy Element Test

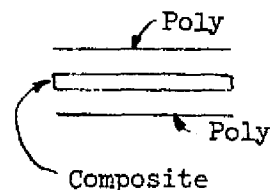
Nordbak Resin/MP-1891 Film/5A17-1/0 Composite:

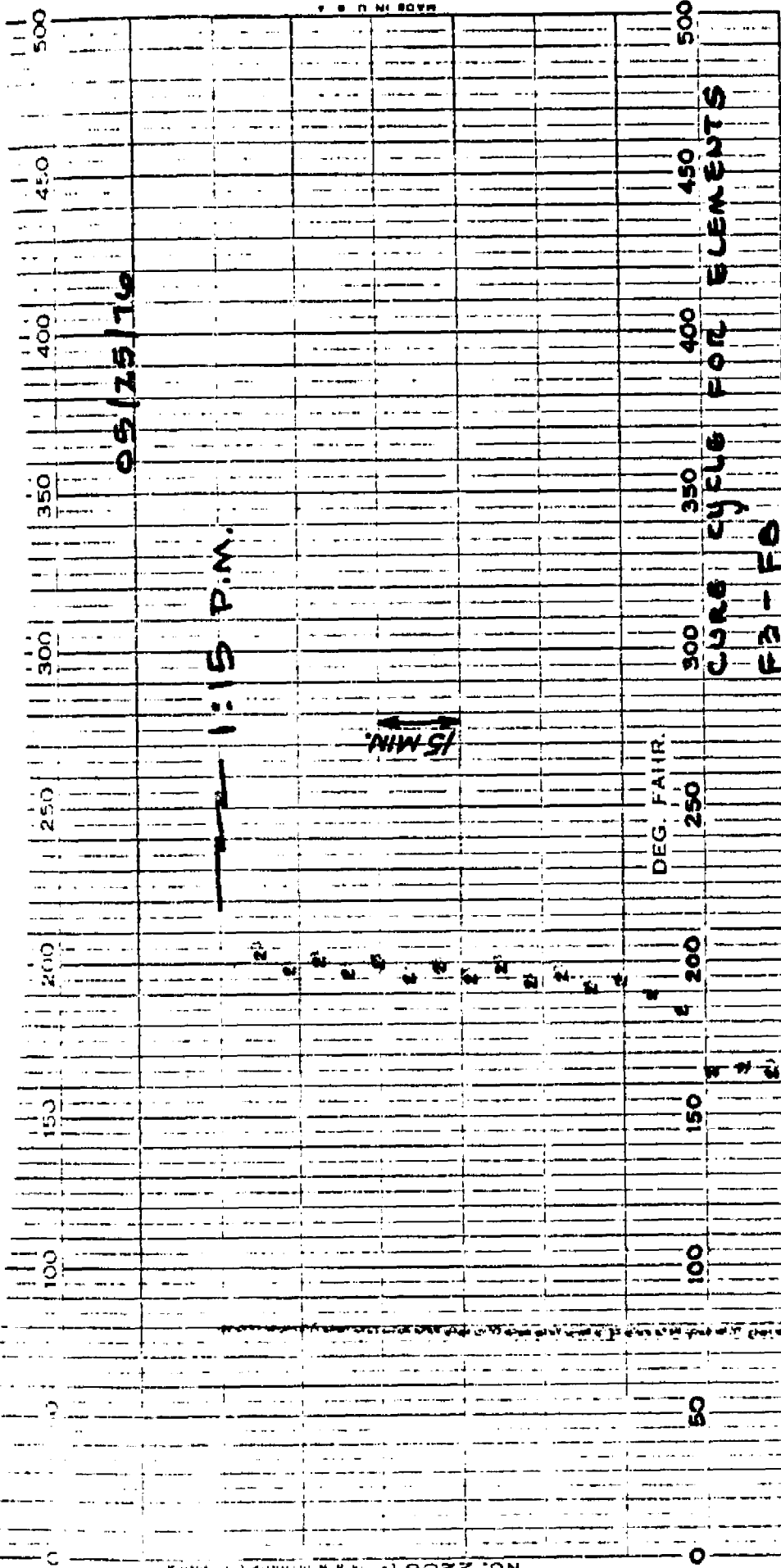
Resin: Hardener Mixture is 1:1 by weight

8.46 gm Resin (25-98) Mixture of Batch 48-91

8.46 gm Hardener

- . 5-Mil MP-1880 Urethane Film
- . Brush-on Application
- . 10 mil Poly Protective Cover
- . 5A17-1/0 Mesh inserted in composite vacuum bag to squeeze out excess resin sys. Cork hold overnight.





05/25/76

1:15 P.M.

15 MIN.

DEG. FAHR.

CURE CYCLE FOR ELEMENTS  
F3 - F6

ADHESIVE: GE SR-585  
: TOLUENE 1:1

MP-1000 FILMS  
1591

Normal cycle is "overnight at 77°F"

5/26/76 - Results: Too much epoxy in laminate. Should spray for next test.

Next Round of Elements

Viton Latex System Spray (1 element)

Rexnord Resin Epoxy System Spray - Can this system be diluted?  
(Solvent add)

Not in Lab on 5/27 or 5/28

6/10/76: Per telecon with Jim Hallstrom  
(Chemist at Rexnord):  
Toluene dilutes sys - inc. cure  
and working time. Ketones inhibit  
cure chemically. 5/31/76

Reviewed Viton Solvent System Preparation

Need dry MEK (No. 16 Bulletin does not state how dry MEK must be)

0161 Compound - composition by weight

|                      |     |             |
|----------------------|-----|-------------|
| Viton B              | 100 |             |
| Maglite γ (Magnesia) | 15  | 0161        |
| DIAC No. 3           | 3   | Dry Polymer |
| MEK                  | 450 | Solvent     |

15% Viton by weight

18% solids by weight

Element No. 18

5A17-1/0 with tubes sprayed with polyurethane - much more flexible  
than previous elements.

6/02/76

- Preparation of Viton Latex System Elements

(Tubes taped to plate via Scotch No. 810) Pre-bent serpentine tube  
pattern on SS plates - cook at 112C for 120 minutes (231.6F)  
(i.e., thermoformed)

In: 3:00 3 patterns - 1 pattern in at 4:00 out at 6:00  
Out: 5:00



Construction of Expanded Metal/MP-1880 Tubing/Viton L-31 latex sys elements.

(Did not remove remaining adhesive from tape on tubes)

Tie tubes to exp. metal with nylon string sprayed 5 coats L-31 on elements.

Must wait 5 minutes between coats

Suggest: one very light coat Viton every 30 minutes for 4 - 5 hours.

Viton agglomerated at metal intersections (too heavy).

Viton film: Sprayed 5 coats Viton L-31 on Polyethylene film.  
Dried for 1 - 1 1/2 hours. Peeled off quite easily. Film measures 9 - 9 1/2 mils thick.

Next time try 4 light coats (One every 30 minutes).

Elements:

|        |                |  |
|--------|----------------|--|
| No. 19 | 5A17-1/0       | Serpentine MP-1880 (1/16 x 1/8) Viton L-31 |
| No. 20 | 3 Ag5-2/0 flat | Serpentine MP-1880 (1/16 x 1/8) Viton L-31 |
| No. 21 | 5 Ag14-1/0     | Serpentine MP-1880 (1/16 x 1/8) Viton L-31 |

(Deleted due to overspray of Latex System at Paint Shop)

6/4/76 (Morning)

Vendor calls

Wrote notebook notes for last 1 1/2 days

Notes on Rexnord Resin-Epoxy Systems

- May be sprayed with airless as is
- May use conventional solvents to dilute, but will have to figure out a reasonable cure cycle.

Suggested Element Tests (Complete early part of week of 6/7)

- 25-98 Nordbak resin to Viton L-31 film.
- Thermal cure of Viton L-31 film:

|      |                      |
|------|----------------------|
| 300F | 30 minutes (min/nom) |
| 250F | 60 minutes (min)     |
| 225F | 2 hours (min)        |
- 25-98 Resin film (maybe)

6/7/76 - Airless spraying of 25-98 to polyethylene

Thermoform (3) lengths of MP-1880 1/16 x 1/8 tubing in serpentine patterns:

In: 1:30  
Out: 3:00

T = 121°C (249.8F)

250F - 90 minutes

Viton B Solvent System

Viton B compound 5.38 gm  
MEK @ 4.85:1 26.09 gm  

---

31.47 gm Mixture

$\rho_{\text{MEK}} \doteq .805 @ 25\text{C}$   
(Merck Index)

SP GR 25L = .804  
 $\nu_{\text{MEK}} = 32.45 \text{ ML}$

Cut Viton B compound into small pieces. Emersed in 26 gm (~ 32.4ML) MEK in polyethylene beaker. Stir. Covered beaker and let set overnight.

Nordbak 25-98 Resin System

1:1 by weight

50 gm Resin

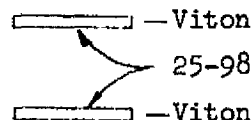
Dilute with 180 ml toluene. Mix (Mixes fairly easily)

Add Hardener (50 gm) prior to usage and toluene to obtain required viscosity to stray.

6/8/76

Elements to be constructed (Suggested)

- (1) 25-98 Resin System Film 4 coatings @ 15 minutes
- (2) 25-98 Resin System to Viton Film Bond  
Vacuum Bag - cure
- (3) 25-98 Resin System to urethane film with  
expanded metal and tubes - vacuum bag - cure
- \* (4) 25-98 Resin System to Exp. Metal/Urethane tubes  
(Spray - earlier elements) - air dry 48 hours
- ∕ (5) Viton Films (2 - 3 coats  $\doteq$  3 - 5 mils). Construct  
like F1-F8 elements.
- ∕ (6) Viton Film/Exp. metal/urethane tubes/SR-585 adhesive.  
Similar to F1-F8.



- 
- \* No. (4) will result in 3 elements: 5A17-1/0, 3 Ag5-2/0 flat and 5 Ag14-1/0
  - ∕ No. (5) will require 4 films to construct the elements using the 4 expanded metals.
  - ∕ No. (6) will result in 4 elements.

Viton B Solvent System

Mixture of 06/07 (5.38 gm Viton B compound/26.1 gm MEK) is completely dissolved - try on larger scale now. (Mixture is fairly homogeneous. No Viton B compound particles are visible).

|                  |                  |                   |
|------------------|------------------|-------------------|
| Viton B Compound | 47.83 gm         |                   |
| MEK @ 4.85:1     | <u>231.98 gm</u> | /.804 = 288.53 ml |
|                  | 279.81 gm        | 320 ml            |

Prepared 5 Polyethylene Patches for Film Mfr.  
(Spray of L-31 dispersion compound)

- 1 25-98 film Spray 2nd coat on
- 2-5 Viton B Fluoroelastomer Compound (Solvent sys)  
4 light coats @ 30 minutes

6/09/76

Need 25-98 resin system spray on 9 mil Viton film of 06/03/76 and MP-1891 polyurethane

Vacuum Bag these 2 elements complete with urethane tubing (serpentine) and expanded metal.

Viton Solvent System will need  $\leq$  1 day ambient mixing.  
Viton B compound is mostly dissolved in MEK. Total mixing time by 8:00 a.m. 06/10 will be  $\sim$  42 hours for 320 ML system.

Tomorrow (06/10/76)

- 4 Spray (4) Viton films - 4 coats ( $\sim$  light ) at 30 minutes
  - 1 Spray (1) 25-98 film - 1 coat min.  $\leq$  4 coats if possible (i.e., drying of film in 1/2 - 1 hour, etc.)
  - 1 Spray 9 Mil Viton film with 25-98 sys - 1 light coat
  - 1 Spray MP-1891 5-mil film with 25-98 system.
- Vacuum Bag the 25-98 Viton and MP-1891 composites.



Mix 50GM 25-48 hardener w/25-98 resin/toluene solution.

Cure cycle: Viton B/25-98 composite.

Requirement: Must have 30 min, 300F high end cure for the Viton Film.

|      |        |            |         |
|------|--------|------------|---------|
| 175F | 45 Min |            |         |
| 200F | 45 Min | <u>Max</u> | 338.20  |
| 250F | 30 Min | <u>Max</u> | -287.04 |
| 300F | 30 Min | <u>Max</u> | 50.26   |

Cure cycle: MP-1891/25-90 Composite.

Normal cure is 24 MRS at room ambient temp.

Per J. Hallstrom, rexnord, acceleration cure of the 25 - 98 system may be obtained for:

150F 2 Hr Cure

\*If viton/25-98 composite is - easily constructed, spray the 4 new Viton films w/the 25-98 resin system Friday a.m.

Thursday Afternoon:

Viton B solution was much too thick. Complete webbing of solution when sprayed. Try 2x MARK, i.e. Viton B compound: MEK, 1:9.7 in 1/3 steps.

(4.85) 4/3(') 5/3 ('), 2 (')

06/10/76

New Viton A Solvent 54E Mek

56.75 GM Viton B Compound

Start 300+ ML MEK

(06/11): ~ 1/3 Dissolved in MEK

Let Ambient mixing continue for balance of weekend.

25-98 Resin Sys of 100 GM (50-50: Resin-Hardener) Diluted w/80 ML TOLUENE:

- o Even spray
- o Viton L-31 element looks good
- o MP-1891 has significant swelling (Probably due to toluene content of the mixture)

Vacuum-Bagged Viton L-31/3Ag 5-2/0 Flat/MP-1880 1/16 x 1/8 tubes/25-98 sys and MP-1891 Film/3Ag 5-2/0 Flat/MP-1880 1/16 x 1/8 tubes/25-48 sys.

Ambient cure under vacuum for 16 hours

In 4:00 p.m. 06/10

Out 8:00 a.m. 06/11

Inspection of Viton L-31 and MP-1891/25-98 Resin System Elements

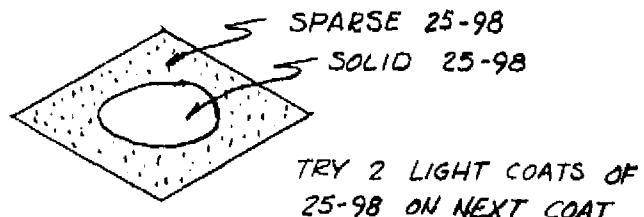
- F9: Viton L-31 latex sys, 9 mil nominal (DuPont)  
MP-1880 1/16 x 1/8 urethane tubing (J. P. Stevens)  
3Ag 5-2/0 Flat Expanded Silver (EXMET)  
Nordbak 25-98 Resin System (Rexnord)
- F10: MP-1891 .005 in (Ether-Based) Urethane Film (Stevens)  
MP-1880 tubes  
3 Ag 5-2/0 Flat  
Nordbak 25-98

Comments:

F10: Apparent good cure

Some evidence of air space between films at the tube line, center of element elasticity may be somewhat less for this element (w/ the 25-98 adhesive) than for the equivalent element with SR-585 adhesive (Ft)\*, most likely one to the 100% Elongation possible for the 25-98 (SR-585 should presumably have unlimited elongation).

Diamond openings in metal show inconsistent levels of 25-98:



\*B. Webbon, NASA-ARC, has F7 and F3

06/11/76

F9: Viton film opposite the expanded metal is separated at several locations (very low tensile modulus in uncured state) otherwise, element is very good.

Suggest curing Viton films prior to layup in the composite.

This particular film was ambient cured for 7 days at 75F.

Next Viton Films: Spray 4 light coats @ 30 min/air dry  
(cure) thermal cycle 150F 30 Min

300F 30 Min

2 coats 25-98 Resin Sys  
Layup composite  
Vacuum Bag  
Thermal Cycle 150F 2 Hr Min

#### Urethane Film Elements

10-mil MP2080 Polyether Urethane, Matte Finish-Both sides

- (1) Each with 3 Ag 5-2/0 Flat Expanded Metal  
5 Ag14-1/0 Flat Expanded Metal  
5A17 -1/0 Flat Expanded Metal

And MP-1880 Urethane tubing-Thermoformed serpentine  
25-96 Resin sys. -2 light coats - film  
7 light coats - expanded metal  
1 light coat - tubing

- (1) Each - as above, but with SR-585 in place of the 25-98 Resin system.  
[Note: Did not use SR-585 adhesive - 6 elements (F11-F16): 3 with tubes, 3 without]. Cut MP2080 urethane for 10 elements.

Viton Films: (Solvent sys. requires mixing - 2x daily)

Repeat film construction of 06/10 with the Viton B compound/MEK ratio as - 1:9.

Added 350 ml MEK - Start mixing (from scratch!\*)

Totals: 56 GM Viton B Compound  
650 ML MEK

\*Viton gelled over wknd

#### Viton B Solvent System

Added 50ML MEK to solution. Continued agglomeration of Viton. System is not accepting solvent dilution, may have to start over again!

Cumulative: 56 GM Viton B Compound  
700 ML MEK (870.6 GM MEK)

15.5:1

25-98 System of 06/10/76 (5 days = 120 hours)

System has gelled since 06/14 with Toluene at 2.24:1, 120 hours required in sealed container!

Prepared 4 serpentine tube patterns

250F  
90 Min

Prepared Six Elements (F11-F16)

MP-2080 10-Mil Urethane Film

F11-F12 MP-2080 Film  
25-98 Resin Sys\*  
3Ag5-2/0 Flat Expanded Silver  
F11-with tubes ‡ (F12 - without tubes)

F13-F14 MP-2080 Film  
25-98 Resin Sys  
5Ag 14-1/0 Expanded Silver  
F13 - with tubes (F14-without tubes)

F15-F16 MP-2080 Film  
25-98 Resin Sys.  
5Al7-1/0 Expanded Aluminum  
F15-with tubes (F16-without tubes)

\*Rexnord 25-98 Resin Sys: 58 GM Resin  
58 GM Hardener  
180 ML Toluene

‡ MP-1880 1/16 x 1/8 Urethane tubing thermoformed in serpentine pattern

06/16/76

Viton B solvent sys. is probably unusable. Compound will not dissolve (- Premature Jello!)

Constructed F11-F16 Elements.

10-MIL 2080 Film is difficult to form around tubing. Also, the 10-MIL film is too tough (and thick) for use in the LCG.

Cure Cycle: 150F-2 hours, under vacuum.

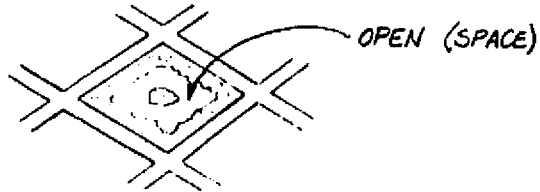
25-98 Resin Sys was mixed (with hardener) @ 1p.m. on 06/15. Sprayed elements @ noon today. Resulting sprayed films were much more sticky than films of 06/11/76 (F9 and F10): should mix hardener - 8-12 hours prior to use (For Toluene - diluted system).

06/17/76

Results:

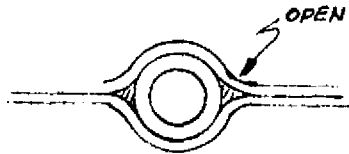
- F11 Bonding of Urethane to Urethane is good  
F13 Evidence of either (1) Trapped air inside diamond.  
or (2) Non-closure of Urethane due to film thickness  
or (3) Insufficient glue (Resin)

Matte finish of film may require much more resin than would a flat finish



- F12 } At the tube ends, film peels off very easily  
F14 } Should try to spray tubes to get enough 25-98  
F16 } Adhesive between tubing and Urethane film - 4  
Bonding much better on these  
Elements than F11, F13, F15

\* apparant air GAP entire length of and either side of tubes, where films meet



This problem is probably due to large thickness of Urethane film and/or Polyethylene cure-cover and canvas bag and/or insufficient adhesive.

Fabrication Notes:

On thin film elements, delete bleed cloth on top of elements (must have bleed cloth at periphery), but place 1-mil Polyethylene cover over element;

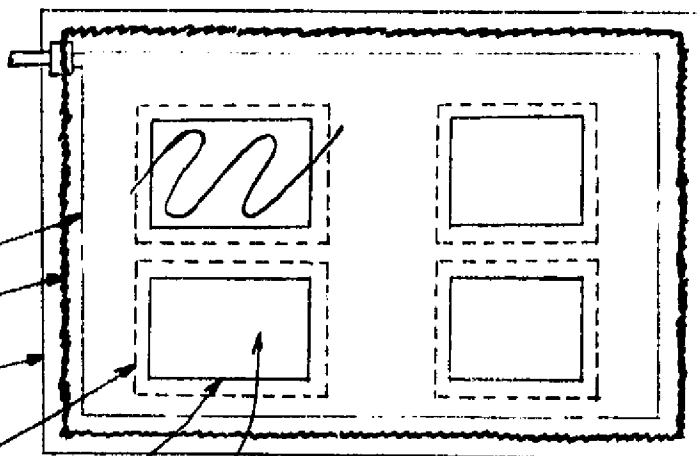
(Gives minimum material between buffer matl (Poly, bleed cloth) and Mylar Bag)

Bleed Cloth (Canvas)

"Tacky Tape"

1-Mil Mylar

Edge of Element



Canvas Opening

Polyethylene cover over elements (Precludes sticking element to Milar Bag)

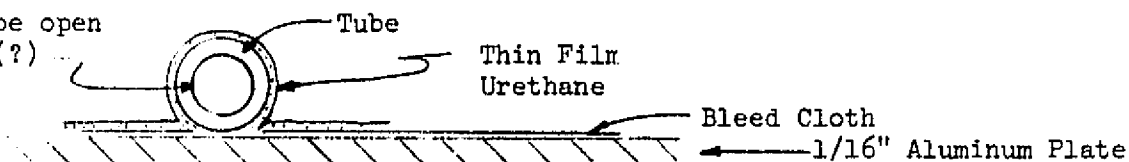
06/18: Used this approach for F18, F21 and F19, F22

06/17/76

To obtain element with a flat side, try:

Vacuum Bag

Inside tube open to ATMOS (?)



≡ F19 and F22

Received thin film Urethane today!

|       |           |             |
|-------|-----------|-------------|
| TF312 | 3 1/2 MIL | Ester-Based |
| TF322 | 1 1/2 MIL | Ester-Based |

Prepared 3 elements each:

Tomorrow (Friday, 06/18/76):

6 elements: Use 3Ag5-2/0 Flat Exp Silver

|            |   |     |                        |               |         |
|------------|---|-----|------------------------|---------------|---------|
| [F17, F20] | 1 | (4) | Laminate Configuration | TF322         | (TF312) |
|            |   |     |                        | 25-98         |         |
|            |   |     |                        | 3Ag5-2/0 Flat |         |
|            |   |     |                        | 25-98         |         |
|            |   |     |                        | MP-1880       |         |
|            |   |     |                        | 25-98         |         |
|            |   |     |                        | TF322         | (TF312) |
| [F17, F21] | 2 | (5) |                        | TF322         | (TF312) |
|            |   |     |                        | 25-98         |         |
|            |   |     |                        | 3Ag5-2/0 Flat |         |
|            |   |     |                        | 25-98         |         |
|            |   |     |                        | MP-1880       |         |

25-98  
3Ag5-2/0 Flat  
25-98  
TF322 (TF312)

[F19, F22] 3 (6)

Try: Open tubes to  
atmosphere  
(Deleted)

Flat side elements, with two pieces  
of 5A17-1/0 (As in #2 and #5), MP-1880  
tubing, 25-98 Resin sys. for TF322  
(TF312).

#### 25-98 Resin System Mixture

62GM Resin  
64GM Hardener  
130ML Toluene

Expanded Metal required for F17-F22:

(6) 6" x 6" 3Ag5-2/0 Flat  
(4) 6" x 6" 5A17-1/0

Prepared (3) serpentine tube patterns. (3) left from 06/16/76. Total = 6.

240F  
90Min

#### Prepared:

3 Films TF312  
3 Films TF322  
6 Tube Patterns, MP-1880  
6 6" x 6" 3Ag5-L/0 Flat  
4 6" x 6" 5A17-1/0

Sprayed all components of composites with 25-98 Resin System:  
Silm series F17-F22.

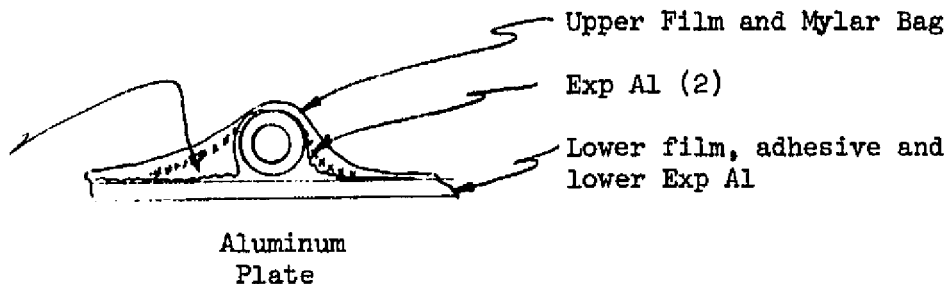
#### Composite Construction (F17-F22):

25-98 sys mixed; sprayed 5 hours after adding hardener.

Spraying MP-1880 tubing with the 25-98 did not ease tacking problem upon  
construction. Only mechanism available to locate tubing in desired position  
is lateral movement (by hand) in completed composite configuration.  
Worked well for double-layer 3Ag5; moderately well for single-layer 3Ag5;  
Not very well at all for double-layer 5A17.

For F18 and F21 (Dual-Layer Exp Silver), MF-1880 tubing located easily in place.

F19 and F22: Upon bagging, Mylar bag and top Urethane film did not appear to completely close around tube-



Air and 25-98  
or Air only  
or 25-98 only

For Monday: (06/21/76)

Evaluate F17-F22 elements

Define construction of any other elements to be made today.

Define work to be completed prior to mid-term review.

Start putting together mid-term briefing document.

Work!

2 Hour 150F cure for F17-F22:

In 5:15 p.m.  
Out 7:15 p.m.

06/21/76

Results:

F17: TF322 1 1/2 MIL Urethane Film  
25-98 Resin Sys.  
3Ag4-2/0 Flat Exp Silver  
MP-1880 1/16 x 1/8 tubing

Element has good elasticity and flexibility glue line @ tubing is extremely good peel test of films yields tearing of urethane film prior to separation of 25-98 system there may be some difficulty in comparing the B. F. Goodrich TF322 and TF312 to the J. P. Stevens Urethane films, because of the stiffer properties of the Goodrich films



F20: TF312 5/1/2 MIL Urethane Film  
25-98 Resin Sys.  
3Ag5-2/0 Flat Exp Silver  
MP-1880 1/16 x 1/8 tubing

The 3 1/2-MIL TF312 composite is much less elastic than the TF322 film composite (F17), due to greater thickness of the TF312 (the film mechanical properties are - equivalent). The tube glue line is good; but large buildup of 25-98 are visible at several locations. Preliminary test of the TF322 yields much less effort required to separate the films than with the TF312 composites (i.e., F17).

F18: TF322 1 1/2 MIL Urethane film  
25-98 resin sys.  
3Ag5-2/0 flat exp Silver - 2 layers  
MP-1880 1/16 x 1/8 tubing  
Cured without bleed cloth on central element area.

Element is somewhat less elastic than F17 good glue line at tubes, but large amounts of 25-98 Resin at tube/film/film intersections



Air bubbles in 25-98 Resin

F21: TF312 3 1/2 MIL Urethane Film  
25-98 Resin Sys.  
3Ag5-2/0 flat exp Silver - 2 layers  
MP-1880 1/16 x 1/8 tubing  
Cured without bleed cloth over central part of element

Stiffness for the element is much greater than that of F20 (1 layer exp Silver)

Too much glue; air bubbles at 180° tube bends

F19: TF322 1 1/2 MIL Urethane film  
25-98 Resin Sys.  
5A17-1/0 Exp Aluminum - 2 Layers  
MP-1880 1/16 x 1/8 tubing  
Bleed cloth/aluminum plate on flat side,  
no bleed cloth on other side

Element is elastic and flexible; less elastic than F18.

Obtained desired result of flat element on one side (to be placed adjacent to skin)

Too much glue at tube-film-film intersection; some air in 25-98 system.

F22: TF312 3 1/2 MIL Urethane film  
25-98 Resin Sys.  
5A17-1/0 Exp Aluminum - 2 layers  
MP-1880 1/16 x 1/8 tubing  
Bleed Cloth/Aluminum Plate on Flat Side,  
No Bleed Cloth on other side

Element is fairly stiff  
Obtained flat element  
Too much glue at tube/film/film intersection with entrapped air

F29: (1) 1 1/2-MIL TF322 film  
(1) 3Ag5-2/OF  
(1) Cotton T-Shirt  
(1) Polyethylene sheet on T-shirt (not necessary)

F30: (1) 1 1/2-MIL TF322 Film  
(2) 3Ag5-2/OF  
(1) Cotton T-shirt

\*\*

F31: F29 2-Step: Polyethylene in lieu of T-Shirt (first step)

\*\*

F32: F-30 2-Step: Polyethylene in lieu of T-shirt (first step)

F33: (1) 5-MIL MP-1880 film 06/24/76  
(1) 3Ag5-2/OF (Construct - F30)  
\* (1) Cotton T-shirt

F34: (1) 5-MIL MP-1880 film  
(2) 3Ag5-2/OF (Construct - F30)  
\* (1) Cotton T-shirt

NOTES:

\*Method of Construction for F27, F28, F33 and F34 TBD from F29, F30 vs. F31, F32.

\*\*Second Step: Sprays Avail., affix T-shirt

06/21/76

Morning - Evaluated elements of 06/18

Afternoon - 2 1/2 hours meeting with Roy Cox

LAST SERIES OF FILM ELEMENTS

Tomorrow (Tuesday 06/22/76)

a.m. - Prepare elements as follows:

I - without tubes

|      |     |                       |
|------|-----|-----------------------|
| F23: | (2) | 5-MIL MP-1880 films   |
|      | (1) | 3Ag5-2/OF             |
| F24: | (2) | 5-MIL MP-1880 films   |
|      | (2) | 3Ag5-2/OF             |
| F25: | (2) | 1 1/2-MIL TF322 films |
|      | (1) | 3Ag5-2/OF             |
| F26: | (2) | 1 1/2-MIL TF322 Films |
|      | (2) | 3Ag5-2/OF             |
| F27: | (2) | 5-MIL MP-1880 Films   |
|      | (2) | 3Ag5-2/OF             |
| *    | (1) | Cotton T-shirt        |
| F28: | (2) | 1 1/2-MIL TF322 Films |
|      | (2) | 3Ag5-2/OF             |
| *    | (1) | Cotton T-shirt        |

II W/MP-1880 1/16 x 1/8 tubing

F35: (2) 5-MIL MP-1880 Films  
 (2) 3 Ag5 - 2/OF  
 (Like F18, but use bleed cloth)

F36: (2) 1 1/2 MIL TF322 films  
 (2) 3 Ag5-2/OF  
 (Like F18, use Bleed Cloth)

F37: F30 w/tubes

F38: F34 w/tubes (Construct like F30)

F39: F28 w/tubes (2-Step)

F40: F27 w/tubes

Total Films Req'd (F23-F40):

(13) 5-mil MP-1880 Do not have this much 1880 (but almost)

(15) 1 1/2-Mil TF322

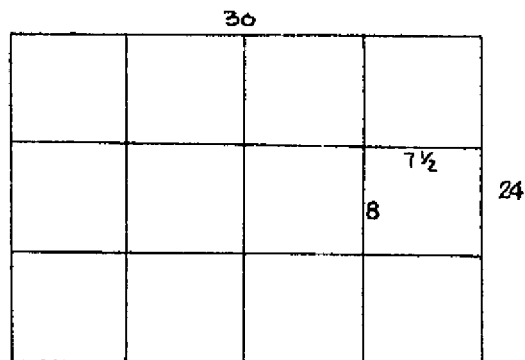
3 Ag/5 - 2/0 Flat

MP-1880 5-MIL Film 30 x 24"

(12) 7/1/2 x 8 films

or

(16) elements



Mixture of 25-98 Resin System

76 Gm Resin  
 150 ML Toluene

281 Gm Total w/ can and stickoid

Cooked (4) tubes @ 250F

80-90 min

06/23/76

Mixed 76 Gm hardener w/25-48 sys sprayed 25-48 sys on films, tubes and exp silver

Prepared mylar bags - AM

Construct elements immediately after lunch.



From Wednesday 6/23/76

Thermoformed (4) Serpentine Tubes 90 min @ 120C (248F)

Sprayed films, exp silver and tubing w/toluene -  
diluted 25 - 98 resin sys

Constructed F29, F31, F33, F37 - F40. 2nd Step completed for  
F28 and F32.

Vacuum bagged elements. Accelerated cure for adhesive: 2 hours @ 150F

|           |   |
|-----------|---|
| In: 4:15  | Deleted elements F27 and F34 due to depletion |
| Out: 6:15 | of 3 Ag5 - 2/0 F Exp silver and MP-1880       |
|           | 5-mil polyurethane.                           |

Results of Elements F23 - F40

T-shirt material appears to adhere to films ok. Adhesive bleeds through  
the T-shirt (as expected), but does not coat the T-shirt.

6/25/76

Bond of T-shirt material to composite for the 2-step process (i.e., F32)  
is far superior than for the one-step process (~ F30).

Urethane - Urethane bond on F39 is very strong. Appears to be stronger  
than previous elements F39 Requires 2nd step to attach T-shirt.

F38 T-shirt to film bond is fairly strong.

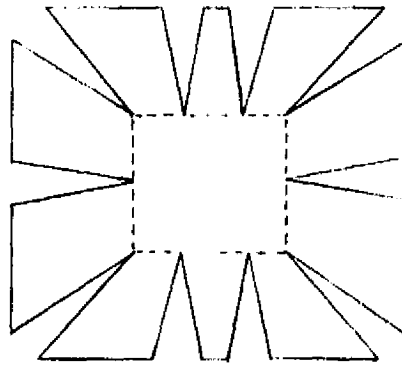
Element Completion

|     |  |
|-----|--|
| F31 | } 2nd step of construction required:<br>Spray w/25-98 system; attach T-shirt material;<br>vacuum bag and use accelerated cure for 25-98<br>system. |
| F39 |  |
| F40 |  |

Full tests for F1 - F40

Head Garment Element Test

|           |   |
|-----------|---|
| 1-Mil     | Polyethylene (or mylar) inner bag material (adjacent<br>to styrofoam head.) |
| 1 1/2-Mil | TF322 Polyurethane film to contour around head.                             |
| Trim      | 5A17-1/0 Exp. Aluminum (2 pieces):  |



Cut out ~ 1/3 of material.

Wind Tubes (Try to thermoform tubing)

6/29/76 Vendor calls

Office work

3:30 - left for dental appointment

6/30/76

Finished 2nd step element construction of films F31, F39, and F40.

2nd step of construction consisted of spraying urethane films (outside) w/25-98 resin system (F39, F40) and attaching T-shirt w/subsequent vacuum bag and accelerated cure for the Nordbak resin system.

F31: Peeled off polyethylene cover sheet (leaving cured adhesive exposed), spray 25-98 system and attached T-shirt.

Vacuum Bag: Cure 150F, 2 Hours

Results: Excellent adhesion of T-shirt to remaining composite.

(Polyethylene Film  
in Layup)

Note: In the initial layups of the single-film, dual-step construction (F31, F32), the polyethylene dummy film apparently did not alter curing process of the Nordbak 25-98 resin system. Removal of the polyethylene film was quite easy, starting with one edge and slowly peeling off the film. No Adhesion of 25-98 system to polyethylene (i.e., QED). T-shirt attachment appeared to be more permanent for the 2-step process, as opposed to the single-step process, due to:

- (1) 25-98 application to cured 25-98 surface.
- (2) More available adhesive to attach T-shirt.

7/01/76

REPRODUCIBILITY OF THE  
ORIGINAL PAGE IS POOR

- Mylar/Rubber cement/mylar - Cook @ 150F
  - Material would not stick together at all
- Urethane foam head - Cook @ 250F  $\sim 1$  in<sup>3</sup> element
  - Placed in aluminum dish.
  - 20 minute in air circulating oven melted material to  $\sim 1/8$  in depth.
- Alternate bag materials: mylar, tedlar, nylon, Kapton, Teflon and polyethylene.

Polyethylene - No known adhesive agent.

Tedlar, Kapton - similar mechanical properties as mylar.

Nylon, Teflon - Will stretch only a small amount.

Teflon has difficulty in adhesive applications.

Head Garment Construction - 1st Cut

6/30/76

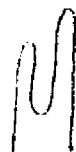
Construction steps followed those of the single-step, single-film, double wire, T-shirt elements of last week. Molded around styrofoam head.

Difficulties:

- (1) Mylar bag material would not conform to surface contour of head. Substantial gathering of mylar material at "Ear level" of head. Tried cutting sections out of the bag and sealing with Scotch No. 810 magic transparent tape (very little help).
- (2) Cut bleed cloth to  $\sim$  approximate shape. Could not get correct shape for bleed cloth.
- (3) Thermoformed MP-1880 tubing on SS hemi mixing bowl, approximately flow path pattern which was decided upon:

Plan Form

(Front)



180° Tube bends were ok, but overall shape and "straight" runs of tubing did not come out well at all.



Head Garment Construction - 1st Cut (Cont'd)

Difficulties (Cont'd)

- (4) Exp. aluminum (5A17-1/0) was difficult to position and cut to fit. Attempts at placing tubing resulted in disturbing wire position.
- (5) 1 1/2-mil TF322 film: could not control film bulk at locations where material gathered.
- (6) Bleed cloth (outer) - same probelms as No. 2 above.
- (7) Outer Bag: Difficult to get material to conform.  
Could not close bag.

Suggestions for 2nd cut at Head Garment

- (1) Construct in sections:

Front Right  
Front Left  
Rear Right  
Rear Left

Join (?) - Tubing connectors,  
Common tubing, etc.

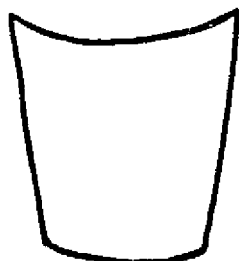
- (2) Layup with exp. metal to film and exp. metal to T-shirt as cured composites - then make 2nd composite with (T-shirt/metal) tubes - (Film/metal) i.e., simplify Number of composite elements.
- (3) Use patterns for all sections:



Side (1/2)



Top (1/2)



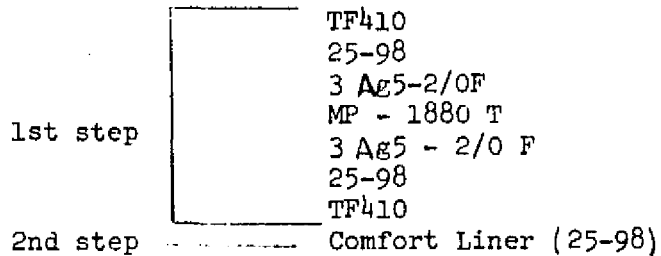
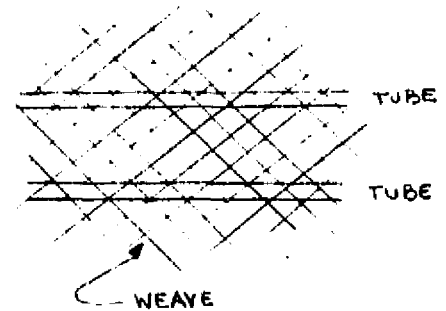
Neck (Back)

Element Construction (Per discussion at NASA-ARC, 7/08/76)

See Roy's notes from Briefing.

Suggested Elements: (K1 - K3 this contract;  $\geq$  K4: Follow-on):

- K1: Tube Alignment Variation
- K2: Comfort Liner Variation  
(Stretch fabric - Burlington)
- K3: Airless spray of 25-98
- K4: Rexnord's Nordbak 50-93 epoxy sys
- K5: K3 w/ 50-93 sys
- K6: TF410 Element - Similar to F39:



- K7: TF410 Element - Similar to F37:

TF410  
25-98  
3 Ag5-2/OF  
MP - 1880 T  
3 Ag5 2/O F  
25-98  
Comfort Liner

- K8: TF410 element - Similar to F26 (K6 w/o tubes or comfort liner)

Other: MP-1880 film, if available (PF)

Viton film, if available

Latex rubber film ( $\sim$  700 - 800% ult. elongation)

Urethane adhesive (Dissolve "Pellethane" - Mfd.  
by Upjohn - in toluene - spray appl.)

Additional Notes on Materials

Urethane Film: The thin films manufactured by Goodrich are limited to  $\leq$  350% elongation (TF410). This is the lowest modulus urethane that Goodrich has been able to manufacture (1700 PSI at 100% elongation). TF410 is a polyether urethane, is thus more hydrolytically stable than TF312 and TF322, which are polyester urethanes. For TF312 and TF322, modulus at 100% elongation is 3000 psi.

TF410 available  
in 1 1/2 - mil  
minimum thickness

The urethane films manufactured by J. P. Stevens are available in a minimum thickness of 5 mils. Telecon with Bruce Abbot: to obtain thinner films, a new die head for the extruder is needed ( $\sim$  \$5 - 10K), but their manufacturing people will probably not consider custom work at this time. The MP-1880 ultimate elongation is 500% and the modulus at 300% elongation is 3000 ( $\sim$  1000 psi at 100%). Stevens was quite willing to do a custom extrusion prototype run of .070 x .106 MP-1880 tubing. Perhaps at some future date they could give us an estimate for the thin film.

Tubing: Thermoforming temperature needs to be 325-350°F for short time period. We should try di-electric heat sealing to thermoform tubing (information from a Mr. Blank of Di-electric for production runs, may try injection molding of dry polymer pellets (available from Upjohn of Connecticut, which is J. F. Stevens' supplier of dry polymer).

Nordbak Resin System: Telecon with Dave Foltz of Rexnord: Airless spraying of adhesive should decrease wicking of adhesive into comfort liner, upon vacuum bagging, and provide a stronger bond due to higher viscosity of the non-diluted adhesive.

7/17/76  
Other elements: N-5 .005 nickel wire, 20 mesh/film element

Elements F41 and F42 (and Deletion of F43) 8/11/76

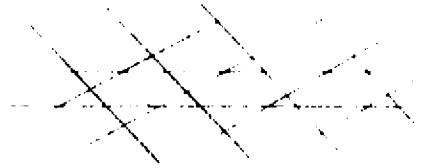
25-98 Resin System

51 gm Resin  
51 gm Hardener  
80 ml Toluene

Comfort Liner - 58% Nylon, 42% Lycra Spandex (RN 16396)

F41 Alternate Tube Routing

Run tubing in LWD (Long Dimension of Diamond)

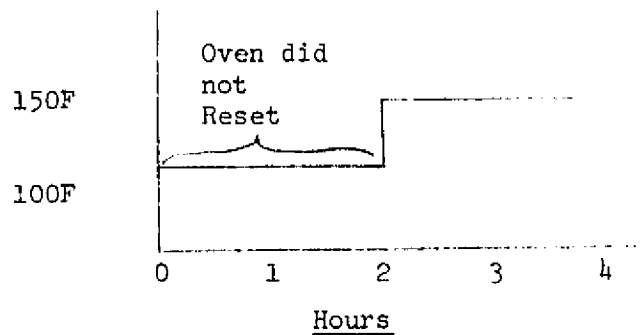


Composite

- (1) 1 1/2-mil TF322
- (1) "T-Shirt" (compare F41 directly to F37) 25-98 sys.

Results

(Elasticity F37 - Cure cycle went ~



F42 "Girdle" Material (Lycra) comfort liner

58% Nylon                      Very elastic in all directions  
42% Lycra Spandex            (Planer)

Element not elastic. Suspect cure cycle for 25-98 Sys affected cured epoxy (check with Jim Hallstrom, Chemist at Rexnord)

F43 Smallest Airless Spray Requires  $\geq$  1/2 gal. charge of material

(Remaining 25-98 Resin on Hand  $\sim$  100gm  $\ll$  1/2 gal)

APPENDIX C

# Hi-TUFF extruded polyurethane tubing

Hi-TUFF tubing offers superior performance to all other flexible rubber and plastic tubing when a product has need for greatly improved abrasion resistance, flex-life, low temperature flexibility, tear-strength, higher working pressure, ozone resistance, solvent and fuel resistance, and longer aging properties. Hi-TUFF Polyurethane contains no plasticizers to leech out or migrate and cause contamination and ultimate hardening.

Hi-TUFF Polyurethane Tubing has proven superior in the following applications.

|                               |                  |   |
|-------------------------------|------------------|---|
| Oil lines                     | Degreasing lines | Bumpers                                     |
| Gasoline lines                | Solvent lines    | Rollers (cut to length and pressed on core) |
| Granular material flow lines  | Air lines        | Gaskets (lathe cut to specific thickness)   |
| Metering or peristaltic pumps | Vacuum tubing    | Cryogenic applications                      |
| Cable jacketing               | Slurry transfer  | Fluidics and metering devices               |

## Additional Design Features of Hi-TUFF Tubing:

1. MP Polyurethane Tubing retains flex and softness from  $-80^{\circ}\text{F.}$  to  $+225^{\circ}\text{F.}$
2. Provides more functional life with thinner walls.
3. Outstanding resistance to weather, ozone, oxygen, and radiation.
4. Contains no plasticizers.
5. High impact, cut and abrasion resistance.
6. May be fabricated, formed, sealed, and bonded using conventional thermoplastic methods.
7. Smooth bore to fit standard fittings.
8. Outstanding flex-life.
9. Excellent resistance to oil, grease, fuels, and most chemicals.
10. Offers longer life in clamp or pinch applications.
11. Hi-TUFF Tubing is considered tasteless and odorless, and some grades meet FDA dry and wet food standards.

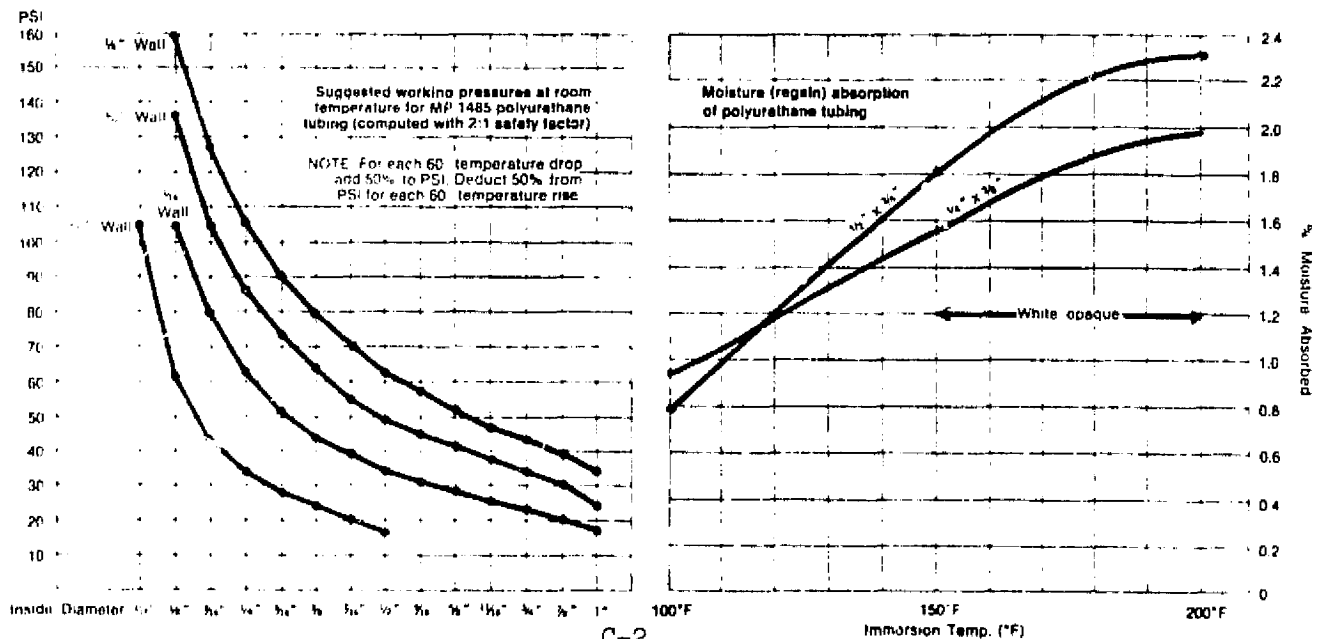
## Hi-TUFF Polyurethane Tubing

Available from stock in Clear MP-1485 and MP-1880. Colors, other formulations, and special diameters are available on special order.

Size ranges: From 1/16" to 1 1/4" I.D. with various wall thicknesses.

Tolerances:  $\pm 3\%$  on diameters, but not less than  $\pm .005"$ .

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# Hi-TUFF polyurethane thin gauge sheeting and film

Hi-TUFF Polyurethane sheeting out-performs all other plastic film and thin-gauge rubber sheeting where product applications require superior toughness, abrasion resistance, tear-strength, flex-life, low temperature flexibility, oil and gasoline resistance, and longer aging properties. Hi-TUFF Sheetting can be vacuum formed, dielectrically sealed, blow-molded and solvent or heat-bonded to substrates.

## Typical Applications:

Fluid Containers  
Dust Boots and Bellows  
Protective Covers  
Packaging  
Conveyor Belting  
Overlays  
Cable Jacketing  
(slit and spiral wrapped)

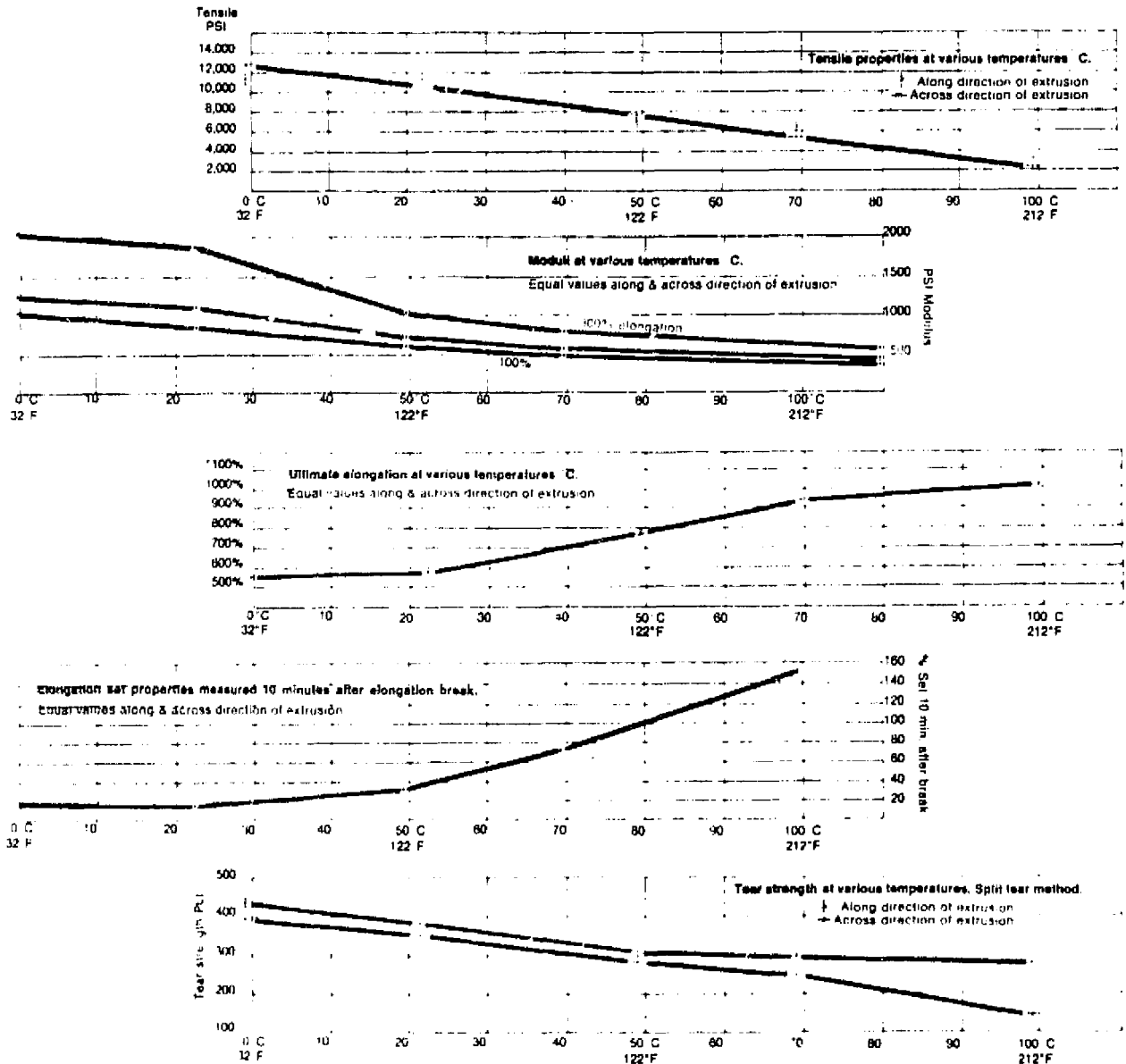
Diaphragms  
Life Support Systems  
Skin Covering for Foams  
and Sponge  
Bag-in-Box Packaging  
Oil and Grease Pouches  
Bearing and Tool Packaging

Lamination to Fabrics  
Gaskets  
Seals  
Noise/Vibration Damper  
Moisture/Vapor Barrier  
Flexible Fuel Tanks  
Dry Chemical Packaging

Available: MP-1880, MP-1885, MP-1890, MP-1891, Natural or Black — colors on special order. Thickness from .005" to .035" in 36" wide rolls. Up to .090" in 18" wide rolls available on special order. Tolerances .005" to .010 ± .001"; .015" to .035" ± .002"; .040" and over ± .003".

Length: Continuous rolls of approximately 50 lbs, bulk pack for 36" widths and 25 lb. rolls for 18" widths.

# Hi-TUFF polyurethane extruded sheeting and film



TUFTANE 410

Product Data Sheet

# tuftane®

FILM AND SHEET

**TUFTANE TF-410**

A polyether based thermoplastic polyurethane film or sheet product which is very flexible, even at extremely low temperatures. Because of its polyether linkage, TF-410 has improved resistance to hydrolysis and fungus attack. Suggested applications include cable fairing, gaskets, tape and fabric laminations where light stability is not critical.

| 1.0 mil Film  | ASTM Test Method    |            |
|---|---------------------|------------|
| Specific gravity  | D 792-66            | 1.11       |
| Durometer   |                     | 85A        |
| Yield, sq in/lb   |                     | 24,900     |
| Tensile strength, psi   | D 882-61T MD        | 6,000      |
| Modulus at 100% elongation, psi   | D 882-61T MD        | 1,700      |
| Elongation at break, %  | D 882-61T MD        | 350        |
| Tear strength (Graves), lbs/in  | D 1004 MD<br>TD     | 250<br>380 |
| Tear propagation, lbs/in  | D 1938-62T MD<br>TD | 250<br>250 |
| Abrasion resistance, grams lost<br>Taber CS-17 wheels 1,000 cycles<br>1,000 gm load (75 mil sample) |                     | 0.010      |
| Moisture vapor transmission,<br>gms/24 hr · 100 sq in   | E-96-E              | 70         |
| Gas transmission rate<br>cc/24 hr · 100 sq in · ATM   | D 1434              |            |
| Oxygen  |                     | 1,000      |
| Nitrogen  |                     | 450        |
| Carbon dioxide  |                     | 4,300      |
| Brittle temperature, °F   | D 1790-62           | -100       |
| Heat-seal range, °F   |                     | 350-400    |
| Appearance  | Frosty or colors    |            |
| Slip  | Medium Slip         |            |

B.F. Goodrich General Products Company / 500 South Main Street, Akron, Ohio 44318



TF410-7581

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# tuftane®

FILM AND SHEET

**TUFTANE TF-322** - A product designed for fabric lamination.

A polyester based thermoplastic polyurethane film product especially designed to be receptive to adhesives, inks and top-coats without heat curing. TF-322 provides the same level of light stability as TF-312, making it equally suitable for many fabric lamination applications covered by American National Standard Performance Requirements for Textile Fabrics, including certain upholsteries, shower curtains and most garments. Because of its good reception of lacquers, TF-322 is also suggested for extrusion coating or laminating to non-wovens for shoe upper materials.

| 1.0 mil Film   | ASTM Test Method        |            |
|--|-------------------------|------------|
| Specific gravity   | D 792-66                | 1.21       |
| Durometer  |                         | 50D        |
| Yield, sq in/lb  |                         | 23,000     |
| Tensile strength, psi  | D 882-61T MD            | 9,000      |
| Modulus at 100% elongation, psi  | D 882-61T MD            | 3,000      |
| Elongation at break, %   | D 882-61T MD            | 200        |
| Tear strength (Graves, lbs/in)   | D 1004 MD<br>TD         | 250<br>500 |
| Tear propagation, lbs/in   | D 1938-62T MD<br>TD     | 260<br>400 |
| Abrasion resistance, grams lost<br>Taber CS-17 wheels 5,000 cycles,<br>1,000 gm load (75 mil sample) |                         | 0.003      |
| Moisture vapor transmission,<br>gms/24 hr • 100 sq in  | E-96-E                  | 40         |
| Gas transmission rate<br>cc/24 hr • 100 sq in • ATM  | D 1434                  |            |
| Oxygen   |                         | 75         |
| Nitrogen   |                         | 45         |
| Carbon dioxide   |                         | 450        |
| Brittle temperature, °F  | D 1790-62               | -100       |
| Heat-seal range, °F  |                         | 350-400    |
| Appearance   | Amber - clear or colors |            |
| Slip   | Low Slip                |            |

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TUFTANE 312

Product Data Sheet

# tuftane®

FILM AND SHEET

## TUFTANE TF-312

A polyester-based thermoplastic polyurethane film or sheet product containing a UV stabilization and antioxidant system which provides light stability adequate for many fabric lamination applications such as certain upholstery, shower curtains and most garments specified by the American National Standards Performance Requirements for Textile Fabrics. Physical properties of TF-312 are similar to those of TF-310.

| 1.0 mil Film   | ASTM Test Method        |         |
|--|-------------------------|---------|
| Specific gravity   | D 792-66                | 1.21    |
| Durometer  |                         | 50D     |
| Yield, sq in/lb  |                         | 23,000  |
| Tensile strength, psi  | D 882-61T MD            | 9,000   |
| Modulus at 100% elongation, psi  | D 882-61T MD            | 3,000   |
| Elongation at break, %   | D 882-61T MD            | 200     |
| Tear strength (Graves), lbs/in   | D 1004 MD               | 250     |
|  | TD                      | 500     |
| Tear propagation, lbs/in   | D 1938-62T MD           | 260     |
|  | TD                      | 400     |
| Abrasion resistance, grams lost<br>Taber CS-17 wheels 5,000 cycles,<br>1,000 gm load (75 mil sample) |                         | 0.003   |
| Moisture vapor transmission,<br>gms/24 hr • 100 sq in  | E-96-E                  | 40      |
| Gas transmission rate<br>cc/24 hr • 100 sq in • ATM  | D 1434                  |         |
| Oxygen   |                         | 75      |
| Nitrogen   |                         | 45      |
| Carbon dioxide   |                         | 450     |
| Brittle temperature, °F  | D 1790-62               | -100    |
| Heat-seal range, °F  |                         | 350-400 |
| Appearance   | Amber - clear or colors |         |
| Slip   | Non-slip                |         |

B.F. Goodrich General Products Company / 500 South Main Street, Akron, Ohio 44318

**B.F. Goodrich**

TF312-7581

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## TRANSPORT TUBING MATERIALS

| MATERIAL           | MANUFACTURER  | DENSITY<br>gm/cm <sup>3</sup> | MODULUS*<br>LB/IN <sup>2</sup> | UTS<br>LB/IN <sup>2</sup> | % ELONGATION | AVAILABILITY<br>AND SIZES                             |
|--------------------|---------------|-------------------------------|--------------------------------|---------------------------|--------------|---|
| Tygon              | Norton        | 1.35                          | -                              | 1650                      | 450          | 1/16 x 1/8, ...<br>Other - Custom                     |
| Fluran             | Norton        | 2.0                           | 205                            | 1300                      | 350          | 1/16 x 1/8, ...<br>Other - Custom                     |
| Polyurethane       | J. P. Stevens | 1.15                          | 3000*                          | 6000                      | 500          | 1/16 x 1/8, ...<br>Other - Custom                     |
| Silicone<br>Rubber | Moxness       | 1.35                          | 1200*                          | 1200                      | 300          | 16 - Mil Wall for<br>.032 - .102 I. D.<br>is standard |

Note: Typical Thermal Conductivity of all tubing materials: 0.12 BTU/Hr-Ft<sup>0</sup>F

\* Modulus @ 100% elongation

\* Modulus @ 300% elongation

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resin systems  
 Technical Bulletin

Nordbak® 25-98 epoxy  
 (Preliminary)

Description: Nordbak 25-98 epoxy in an unfilled, room temperature cure system designed for potting applications where a Shore A hardness is required. It's low viscosity and reasonable gel time allow excellent coil penetration with minimum air entrapment.

Advantages: Low viscosity, Shore A hardness, room temperature cure.

Application Characteristics

Viscosity, cps (Pa · S)  
 (ASTM D-2393)

|          |             |       |       |
|----------|-------------|-------|-------|
| Resin    | 77°F (25°C) | 9,700 | (9.7) |
| Hardener | 77°F (25°C) | 100   | (0.1) |
| Mixed    | 77°F (25°C) | 500   | (0.5) |

Gel Time @ 77°F (25°C)  
 (ASTM D-2471)

1-1/2 Hours

Cure Cycle

06/10/76:

Overnight at room temperature  
 Accelerated cure: 2 Hours @ 150°F  
 per Jim Hallstrom, Nordbak Chemist.

Mixing Ratio  
 by Weight

1 part resin to 1 part hardener

Color

|          |              |
|----------|--------------|
| Resin    | Amber        |
| Hardener | Clear, White |
| Mixed    | Clear, White |

Typical Cured Properties

Hardness, Shore A  
 (ASTM D-2240)

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Specialty Chemicals  
 Division

4300 N. 127th Street  
 Brookfield, WI 53005  
 414 781-5204

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