AIR FORCE FIBROUS MATERIALS REQUIREMENTS

J. H. Ross
Fibrous Materials Branch
Nonmetallic Materials Laboratory

A discussion of the requirements for Fibers and Fibrous Materials is of necessity quite broad. We must talk of fibers and materials that must be quite flexible, which can be readily and efficiently compressed into small containers. Yet at the same time consideration must be given to inflexible or stiff fibers which have a high modulus for forming into composites as a reinforcement for a resinous system. This means of course that the fibers that are required do not fall into one specific class but must cover the entire area of fibers, ranging from those fibers that are considered textile like such as the present day synthetics to the short whisker type fibers grown, or formed by forcing a molten material into a high velocity heated air stream.

Over the last few years drastic changes have taken place in the uses and requirements for fibers and woven fibrous forms in Air Force systems. Prior to evaluation of aerospace systems and their needs, synthetic fibers such as nylon and Dacron* were highly satisfactory in parachutes and related items for aeronautical systems. Some problems did exist with nylon drag chutes, the major one being effect of excessive heating in the storage compartment (Figure 1). This, however, was overcome by application of additional insulation to the storage compartment. When a problem of Ultra-violet radiation damaged became important, it was quickly resolved by development of dyes which absorbed or reflected the radiation. Other problem areas such as abrasion, flexibility at low temperatures, were overcome primarily through modification to or applications of finishes to the ever present synthetic fibers. This, with a minimum of background, brings us to the present and the advance into aerospace involving environments heretofore considered beyond the capabilities of present fibrous materials.

The first effect of our ventures into outer space was the degradation that occurred as a result of excessive heating. As shown in Figure 2 one attempt to recover an instrument packaged created catastrophic damage to a nylon decelerator. Further studies resulted in similar damage to nylon systems and in addition it was found that supersonic speeds and high altitude caused flutter or buffeting which completely shredded nylon ribbons. These indications of just two simple space environment effects created a need for better understanding of the overall conditions that will effect fibrous materials, so that requirements that are established can be adequately fulfilled. Over the past two or so years many potential uses have been found for fibrous materials. The variability of these uses becomes apparent as we review Figure 3. Graphically some of the concepts of these uses might

---

* Trademark E. I. du Pont de Nemours, Inc.

be as shown in Figures, 4, 5, 6 and 7.

Basically in considering these potential uses, they should be broken down into two major categories, specifically fibers for flexible structures and fibers for reinforcement purposes. Fibrous materials for flexible structures can be subdivided into general areas namely flat woven materials and three dimensional woven materials, i.e. such as uncut double fabrics, Air-Mat. The former would in most cases be used in decelerator type uses (Figure 8) and the latter would be used in expandable structures (Figure 9). In establishing requirements for the fibrous materials to be used in specific systems it is necessary to be aware of the actual environments that are anticipated for the system. Preliminary information of this sort must be obtained from the end item engineer and although in many instances the information is based on calculations, it is sufficient to establish a starting point for materials research. Let us take as one example, deceleration systems and review two flight regimes. Figure 10 and 11 show the supersonic and hypersonic flight regimes as conceived for research studies. We can readily see the difference in temperature and strength for each regime. This reveals that in the supersonic region fibers of organic polymers having high strength and good temperature resistance could be used. However in the hypersonic region, temperature resistance becomes a real problem while strength is not as important. Thus through review of proposed flight regimes it is possible to determine the status of fiber research as related to potential environments and establish initial goals.

The use of fibers for reinforcement in composite structures creates a complete turn about in environments and needs. Here we must have a material that is strong, but primarily, in addition, must have a high modulus to create extremely stiff dimensionally stable structures. These composites as noted in Figure 3 will be used as nose cones, both ablating and nonablating, rocket nozzles and filament wound rocket cases to name a few.

From this foregoing discussion, the large number of dissimilar potential uses indicates immediately that one fiber type or composition will not be applicable over the board. It might be to the advantage of the Air Force that such a situation exists. It is conceivable that a series of fiber types can be achieved; each type covering a specific temperature range (where temperature is a problem) or a specific radiation band, or specific modulus (whether to be used in flexible or rigid structures) depending on the environment. This concept is already in fact being proven as a result of research. In the lower temperature regimes organic fibers such as HT-1 and soon PBI will be used. In the next high temperature range (1000-1500°F), glassy type fibers with temperature resistance finishes bear interest. From 1500-2000°F, fibers formed from superalloys are being studied. Considering the range of 2000-2500°F, fibers of refractory metal alloys and oxidation resistant coated refractory metals are of interest. Above 2500°F, such compositions as ceramic oxides, graphite, borides and so on will have to be considered in forming fibers.

Even though fibers of one sort or another have been formed of each of the compositions alluded to, in most cases we are no where near optimum high strength fibers. Especially in the glassy type and oxidation resistant coated refractory metal type only the surface has been scratched in reaching for suitable fibers.

In considering what is required in the area of fibers we can list those properties of most importance.

High Strength
Temperature Resistance
High Modulus
Flexibility
Abrasion Resistance
Chemical Stability

In reviewing these basic properties as related to use in flexible structures, one property is a contradiction, namely High Modulus. At the same time the ability of a fiber to have a high modulus and good flexibility poses a problem for the fiber producer, and to make matters even more difficult, the majority of data available today indicates that if a fiber has good temperature resistance then it can be expected that it will have high modulus. This is all being noted so that one specific point can be made. This is that most of the high temperature fibers that have been produced pose problems in forming into woven structures. Therefore the problems of forming these fibers into woven forms are of as much importance as the problems involved in forming the fibers. Of course in many instances involving the use of fibers as reinforcement we can overcome this problem of converting to woven form by using random fiber arrays or nonwovens, by filament winding, or lastly and the newest approach by weaving a fiber that is organic and then converting the fabric to a carbonized or graphitized structure. The first and last approach described generally results in a low strength, although high thermally resistant reinforcement, while the second approach cannot be used in all instances where a reinforcement fiber is required. Some of this above is strictly my own assumptions but have been made to aid in leading to the major point. Specifically that the key to utilizing high temperature fibers is dependent on our ability to convert these fibers whether they be organic, ceramic or metallic into highly flexible and resilient woven forms.

Many techniques for achieving this goal will be involved. Some of these include forming of ultra fine diameter fibers, stranding these fibers into yarn bundles, use of flexible high temperature coatings to prevent abrasion and enhance strength retention, use of coating systems on the woven form to aid heat resistance and flexibility. Especially difficult with these high temperature fibers is their forming into three dimensional flexible structures. Here we have a class of materials which can be covered with high temperature coatings to allow use in high temperature re-entry environments and through use of inflation gas form a light wing loaded structure capable of use as a glide or lifting body type re-entry device. These same three dimensional structures when formed of the proper organic fiber could well be used after conversion to a carbonaceous structure as a resin tank and be used as an ablating structure. Thus we can see that fibrous materials will play an ever important role in our aerospace program.

As we see it now, a number of objectives can be stated which give a pretty basic beginning for future fibrous materials. Some of these are:

1. To provide fibrous base materials which are initially flexible and packageable, and which can be deployed into predetermined dimensionally stable shapes and rigidized if required. Resistance to repeated temperature cycles within a range of - 200°F to 500°F and impermeable to inflating gases will be necessary.

2. To provide expandable materials and fibrous reinforced composites for applications in aerospace environments. Service temperatures would range from

1000°F to 2000°F for short periods and from - 100°F to 1000°F for several days.

3. To develop flexible packageable fibrous base materials which can be inflated into predetermined shapes and rigidized upon command. These materials will require high strength and resistance to temperatures from 2000°F to 3000°F for ultimate application in aerospace vehicles and systems. Oxidation resistance and gas impermeability must be attainable.

4. To provide fibers for the construction of high strength to weight ratio cases for solid rocket useage and containers for liquid propellant applications. High temperature fibrous base materials which will have a high bond strength with the case material as well as with the propellant will be required.

These cover just a few of the areas where fibrous materials would have a tremendous advantage over solid materials even of the same composition. We can see from just these four that a number of different fiber types and compositions will be required. This then is the reasoning behind our broad fiber research program. This fiber research program as you will hear range from forming organic polymers to studies of glass compositions and forming to new techniques of forming metal fibers. This range of fibers and their temperature capabilities are shown in Figure 12.

This brings us to what is necessary to achieve the optimum woven structures. There are many environments to which these woven fibrous materials in their many end uses will be exposed to. Some of the more important considerations that are of interest are shown in Figure 13. These properties of interest can be further translated into a range of numbers that although not exact can be used as the foundation for obtaining both coated and uncoated fibrous materials for first and second generation systems. Figure 14 presents some of the specific numbers which define our requirements for flexible materials capable of withstanding aerospace environments. As with flexible fibrous materials it is possible to theorize the requirements to be fulfilled to obtain the highest strength to weight ratio fiber reinforcement for rigid structures, Figure 15.

Here then are the ultimate goals of our research programs. The papers to be presented during this symposium represent the initial stage of research in the field of fibers and flexible structures. To achieve all of the requirements elaborated on here as well as those that will be evolved as new aerospace systems are designed will obviously require considerable additional research. The complexity of fulfilling the widely varying requirements which, for example calls for flexibility from a fiber that due to its composition will have a high modulus or stiffness will set the stage for very extensive and, if I might be so bold, taxing research in the fields of fiber formation and translation of fiber to woven form.

Thus our main purpose is to continually advance the State-of-the-Art in Fibrous Materials. These requirements and the papers to be presented are a step in this direction. Our ability to adequately obtain fibrous materials which will withstand these initial environments will establish the pace for future research. And in conclusion, it must be realized that the adequacy of our research results will be dependent on the continuing high degree of success being achieved by our contractors.

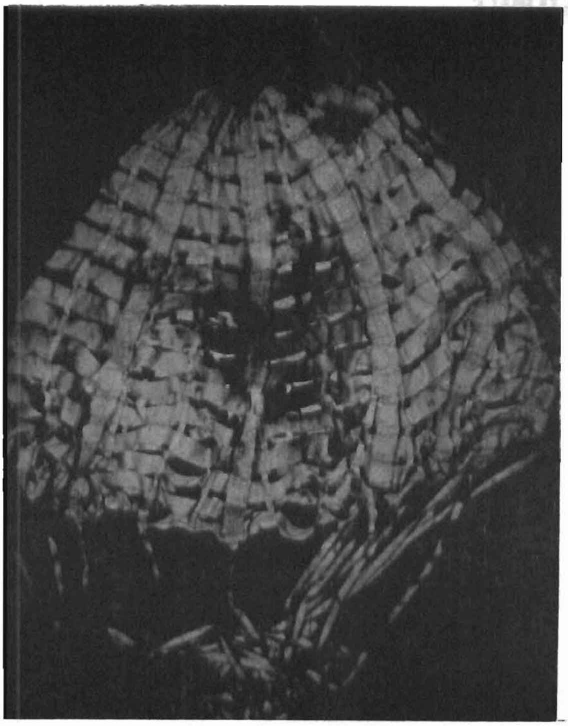


Figure 1 - Example of Nylon Parachute Degraded by Elevated Storage Compartment Temperature

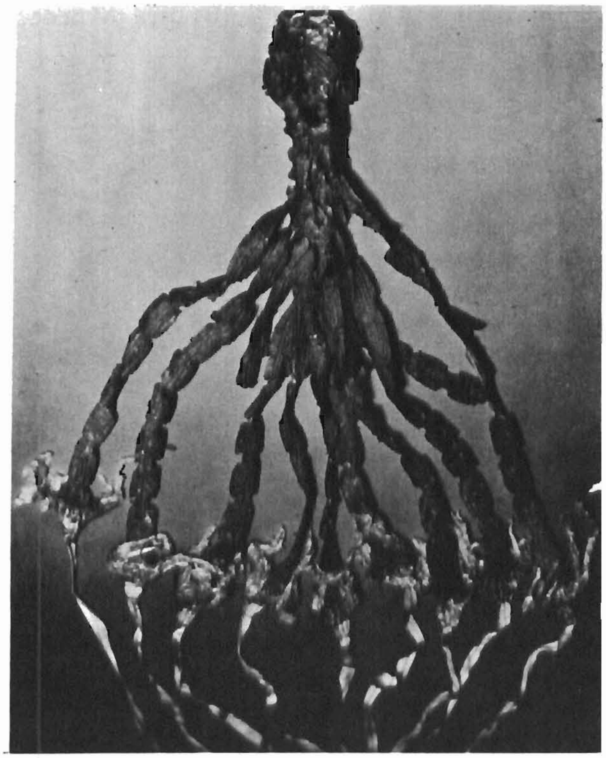
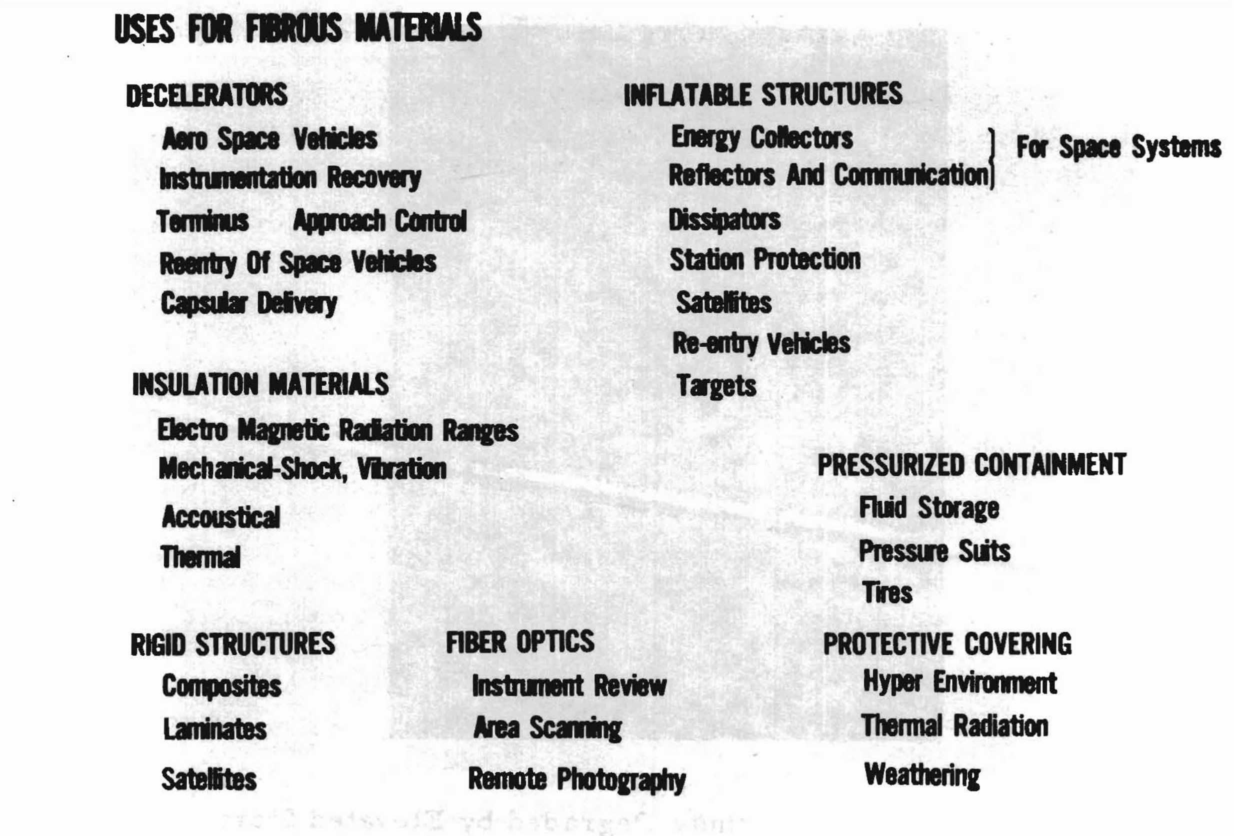


Figure 2 - Aerodynamically Melted Nylon Parachute



USES FOR FIBROUS MATERIALS

DECELERATORS
- Aero Space Vehicles
- Instrumentation Recovery
- Terminus Approach Control
- Reentry Of Space Vehicles
- Capsular Delivery

INSULATION MATERIALS
- Electro Magnetic Radiation Ranges
- Mechanical-Shock, Vibration
- Accoustical
- Thermal

RIGID STRUCTURES
- Composites
- Laminates
- Satellites

FIBER OPTICS
- Instrument Review
- Area Scanning
- Remote Photography

INFLATABLE STRUCTURES
- Energy Collectors } For Space Systems
- Reflectors And Communication } For Space Systems
- Dissipators
- Station Protection
- Satellites
- Re-entry Vehicles
- Targets

PRESSURIZED CONTAINMENT
- Fluid Storage
- Pressure Suits
- Tires

PROTECTIVE COVERING
- Hyper Environment
- Thermal Radiation
- Weathering

Figure 3 - Uses for Fibrous Materials

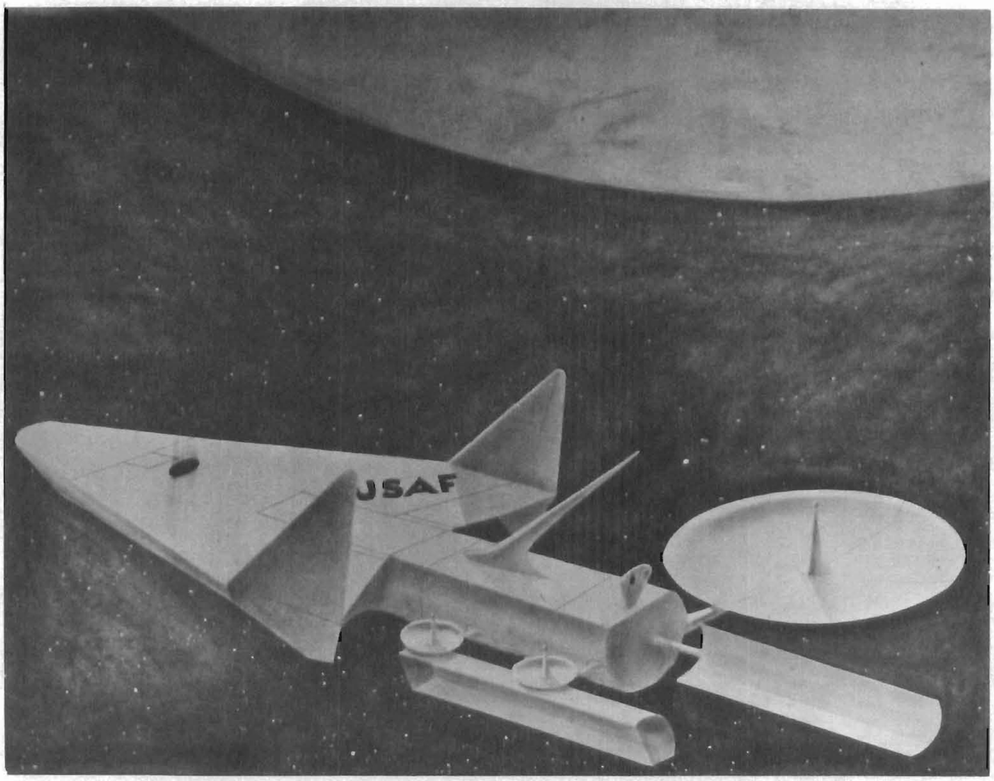
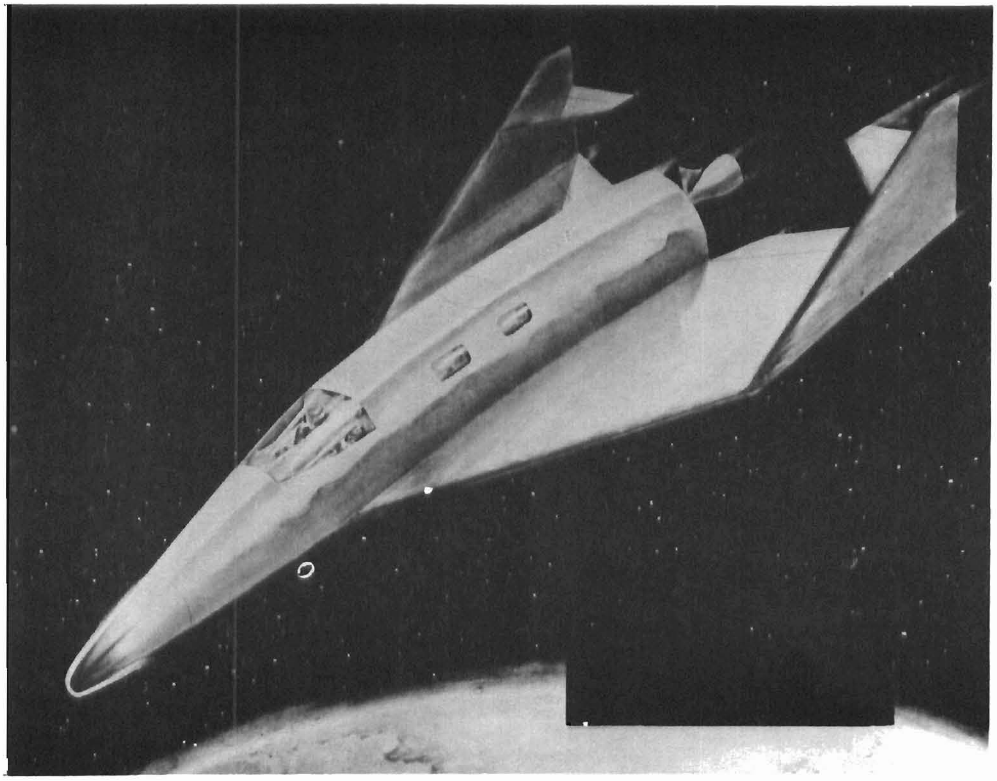


Figure 4 - Concept of an Expandable Winged Vehicle



[redacted]

Figure 5 - Applied Research in Space

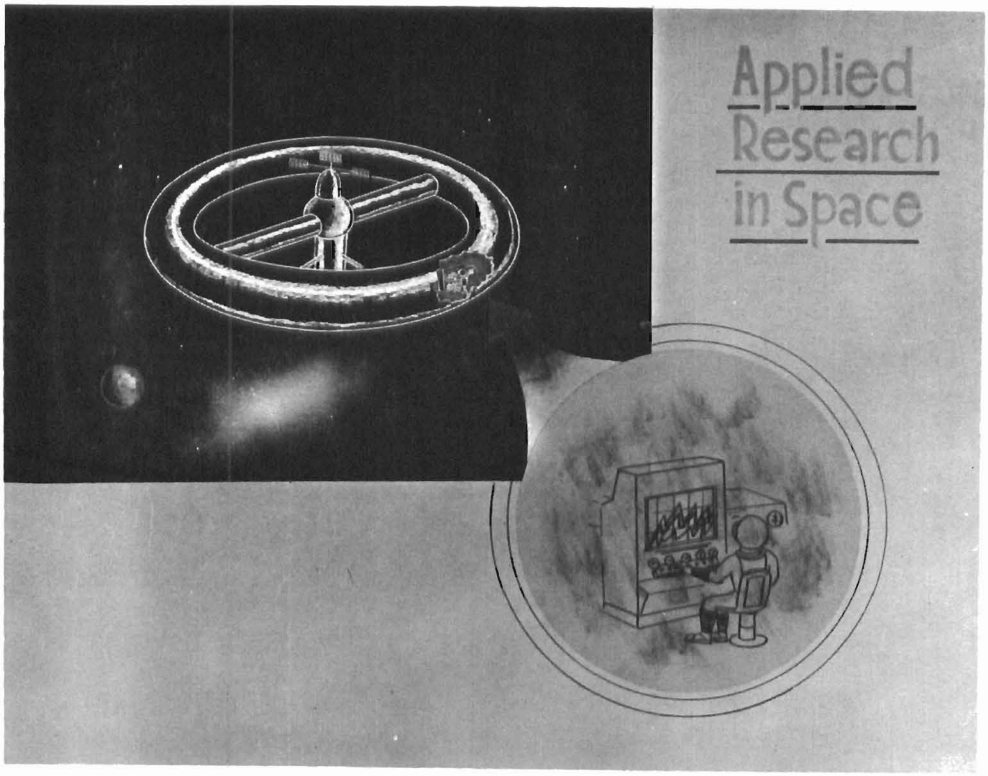


Figure 6 - An Example of Expandable Materials

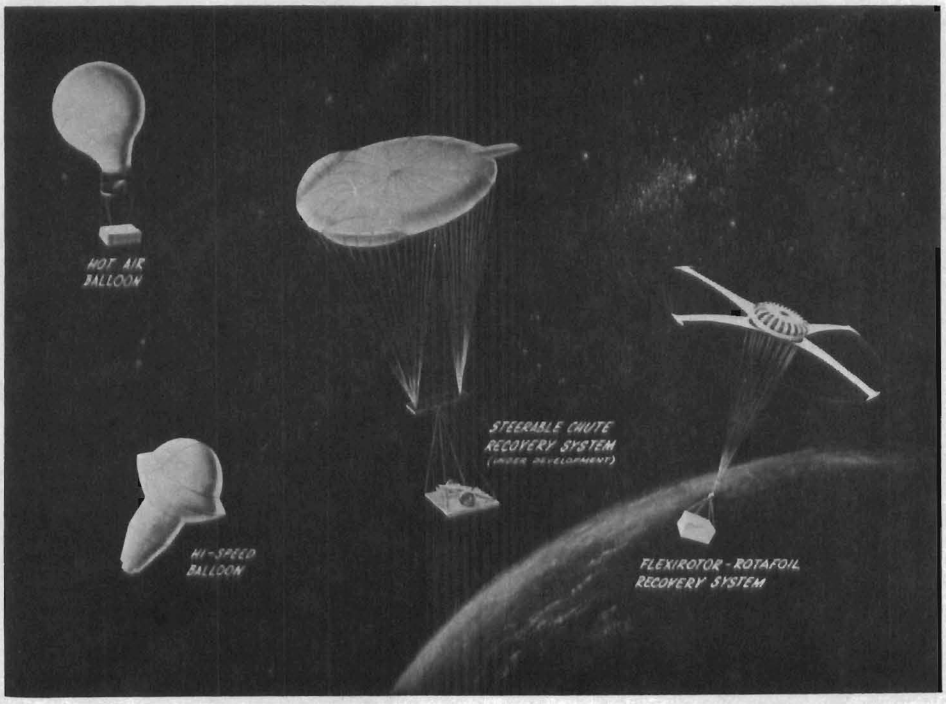


Figure 7 - Deployable Aerodynamic Decelerators

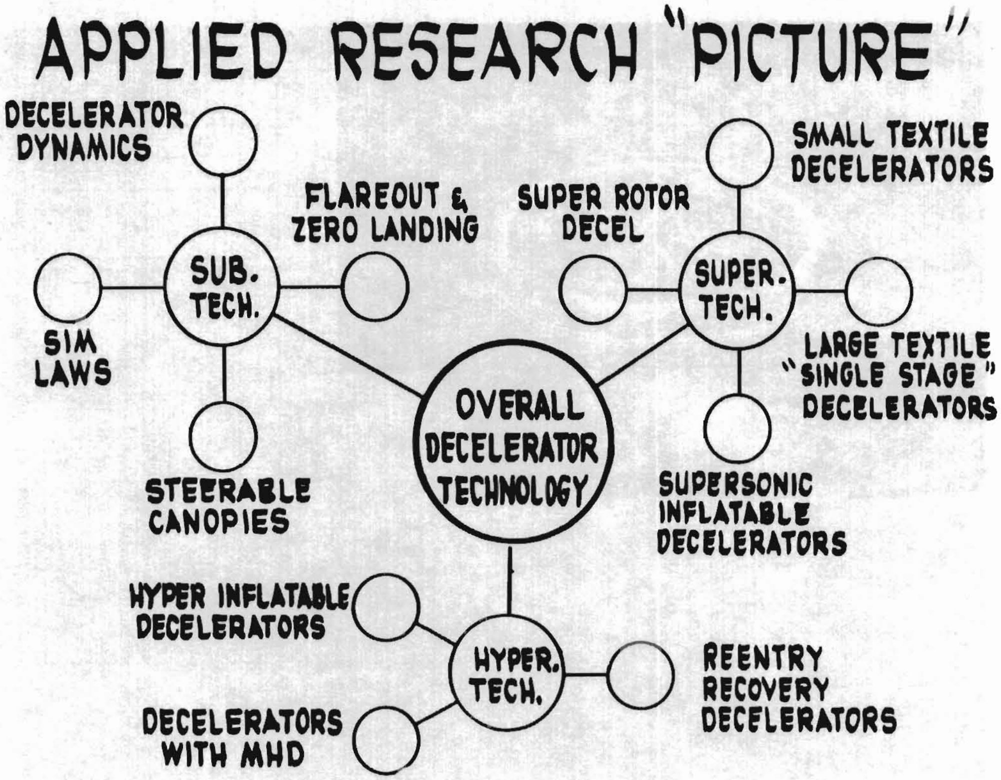


Figure 8 - Applied Research "Picture"

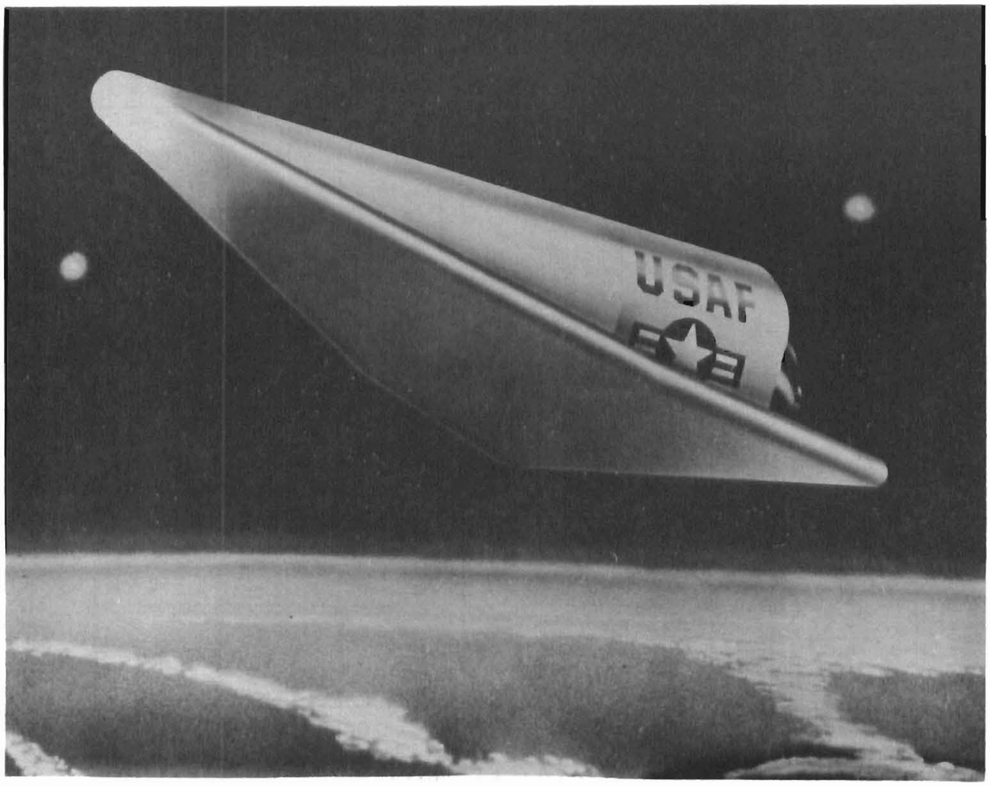


Figure 9 - An Example of Expandable Materials

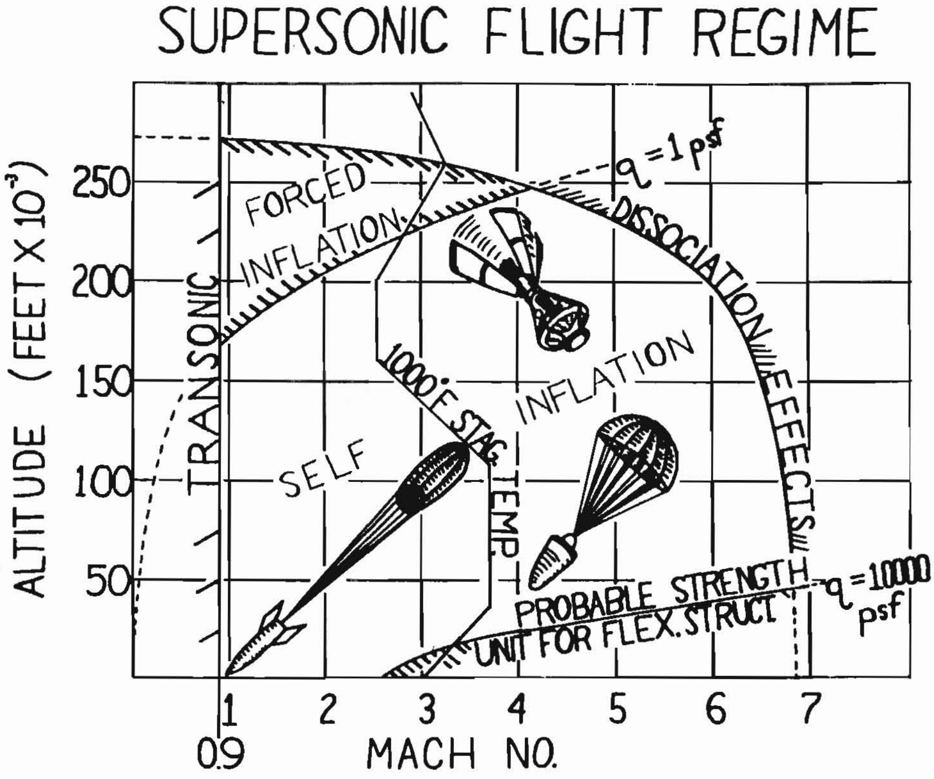


Figure 10 - Supersonic Flight Regime

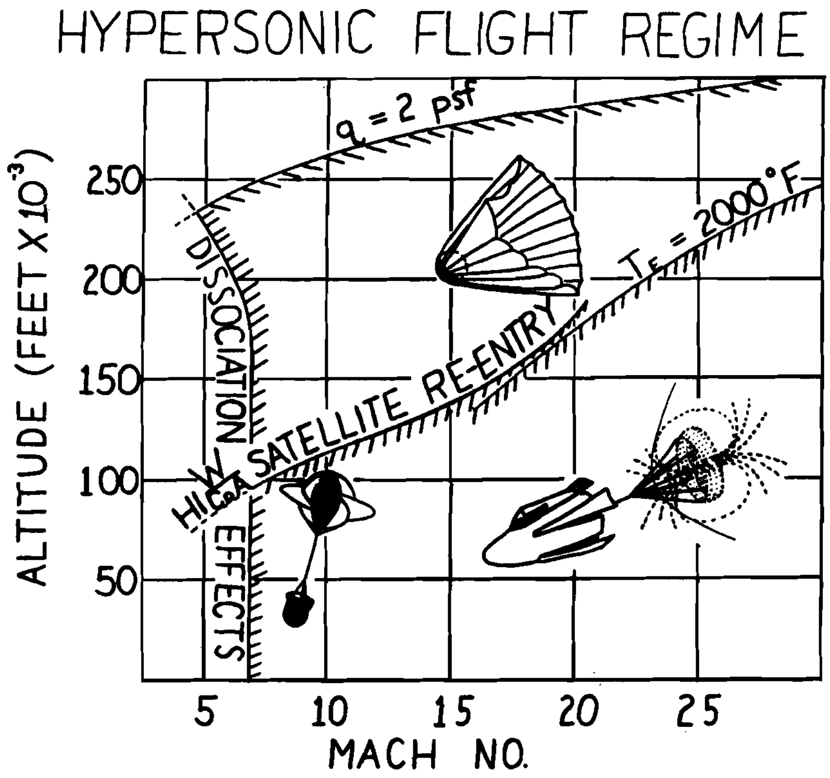


Figure 11 - Hypersonic Flight Regime

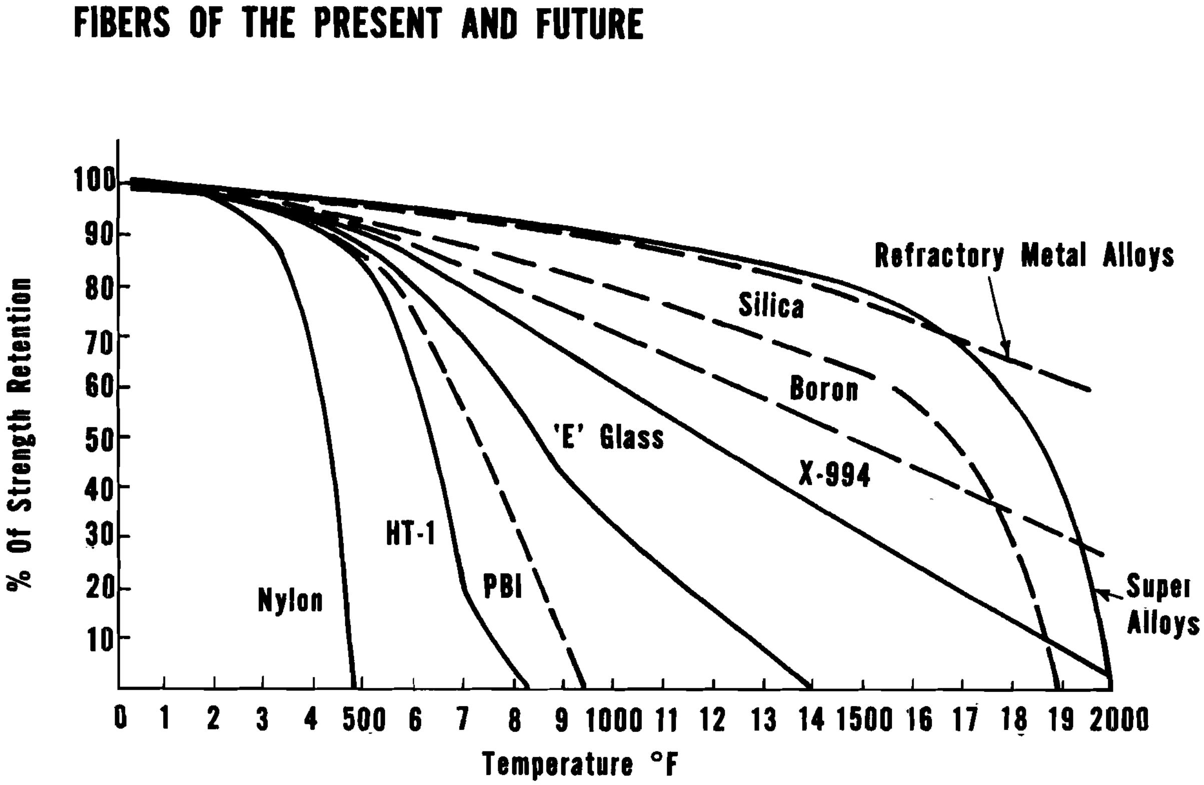


Figure 12 - Fibers of the Present and Future

PROPERTIES OF INTEREST

- High Strength
- Thermal Resistance
- Flexibility Or Rigidity
- Permeability
- Coating Adhesian
- Radiation Stability
- Fatigue Resistance
- Abrasion Resistance
- Compactability
- Chemical Stability
- Energy Absorption
- Bulk

Figure 13 - Properties of Interest

TARGET REQUIREMENTS

Temperature	75%	2,400°F For Max. Of 20 Secs. 2,000°F For Max. Of 5-10 Min. 1,500°F For 10-20 Min.
Vacuum And Solar Radiation	80% Strength Retention	Continous Or Intermittent Exposure Totaling 4×10^7 Langleys At Orbital Altitude
Flexibility	No Failure	Crease Flexing And Compressive Creasing In Cycles For 24 Hours
Compaction	90% Strength Retention	Packing Pressure Up To 150-250 lbs/sq. in.
Vapor Permeability	Impermeabile	Inflated With Air Or Helium In An Atmosphere Of Complete Vacuum At 1,200°F -1800°F
Chemical Resistance	Inert Or Non-Corrosive	Ozone (11 P/M 100 M FT) Ionized Gases
Meteorites	No Penetration	Micro Meteorite Bombardment

Figure 14 - Target Requirements

FIBERS FOR REINFORCEMENT

PROPERTY	TODAY	REQUIRED
TENSILE STRENGTH		
SINGLE FIBER	500-530	
PSI x 10^3	650-700	700-1000
YOUNG'S MODULUS		
SINGLE FIBER	10.5-11.0	
PSI x 10^6	12.0-12.5	50-60
TEMPERATURE		
RESISTANCE, °F	1100-1400	3000

Figure 15 - Fibers for Reinforcement