Appendix C
NASP Materials and the X-30 Materials Consortium

Materials Consortium

The five prime National Aerospace Plane (NASP) engine and airframe contractors have joined into a uniquely funded contract arrangement to demonstrate the production readiness of advanced materials critical to the success of the X-30. The Materials Consortium (officially designated as the NASP Materials and Structures Augmentation Program) places contractors, in competition for Phase III of the NASP program itself, in a cooperative arrangement. Each of the five contractors has lead responsibility for the development of one material type, including the fabrication processes to produce structures, but each also participates in the efforts of the others. All data developed by the contractors are shared equally on a nonproprietary basis, including industrial research and development (IRAD) that was completed or ongoing prior to the contract awards. In addition, a large portion of the funding is being transferred to subcontractors, universities, and research institutes directly supporting the prime contractors in advanced development work.

The Consortium members and their area of principal investigation are: General Dynamics-refractory composites (including carbon-carbon and ceramic matrix composites), Rockwell-titanium aluminide alloy development (Ti_3l and TiAl) and scale-up effort, McDonnell Douglas-titanium metal matrix composites (including SiC fiber reinforced Ti_3Al), Rocketdyne-high conductivity materials (including copper matrix composites), and Pratt & Whitney-high creep strength materials (including monolithic and reinforced TiAl, using fibers composed of titanium diboride and alumina).

The consortium was funded in March 1988 at a budget of $150 million for a 30-month period. Recently, a subsystems consortium was formed to develop some 11 different systems including avionics and instrumentation, crew escape, slush hydrogen technology, and turbomachinery. As in the Materials Consortium, work in the subsystems consortium is being done on a nonproprietary basis. Both the NASP JPO and contractors appear highly satisfied with the consortium arrangement.

NASP Materials[1]

The X-30 airframe will utilize noninsulated, load-bearing hot structures without the thermal protection tiles of the shuttle. Where necessary, these hot structures will be cooled with hydrogen using several active cooling schemes. The projected structural designs for all areas of the vehicle call for high-stiffness, thin-gauge product forms that can be fabricated into efficient load-bearing components. These in turn require high strength, low density materials that can retain their properties up to temperatures beyond the capabilities of present day commercially available materials.

Current challenges center around scaling up laboratory production processes of advanced materials; developing fabrication and joining techniques to form lightweight sandwich and honeycomb structures; and forming materials and coatings that can withstand thermal cycling of the sort that would be seen in a flight vehicle. In addition, concerns about the possibility of material fatigue must be resolved (see discussion of transient thermal fatigue in footnote **30).**

The major classes of materials with promise for the X-30 are rapid solidification technology titanium aluminide alloys (RST Ti), metal matrix composites based on reinforced titanium aluminizes (Ti-Aluminide MMC), high thermal conductivity materials, carbon-carbon (C-C) composites, and ceramic matrix composites.

Titanium-based materials are candidates for large portions of the X-30 external and internal structure. Currently available titanium alloys are lightweight and can withstand temperatures of 1,100 “F but in the X-30 even greater temperature tolerance is desirable to minimize active cooling requirements. Higher temperature, titanium-based materials are possible using recently developed rapid solidification technology. RST Ti-aluminide is produced when molten titanium and aluminum are dropped on a spinning disk that sprays small droplets of the material into a region of cold helium gas. The material cools at an extraordinary rate-up to one thousand degrees in one millisecond-and is transformed into a fine powder with unique properties. In particular, RST materials are not contaminated with oxygen and the sudden cooling produces a material without stratification or other nonuniformities.

At room temperature, RST aluminum displays similar strength to conventional aluminum. However, RST Ti-aluminides exhibit much higher strength and stiffness at high temperatures compared to conventional titanium alloys while having only one-half the weight of the material previously used at these temperatures. Alloy systems based on Ti_3Al can withstand about 1,500 “F and alloys based on TiAl can withstand about 1,800 “F. They are also lighter than the currently available high-temperature nickel alloys.

TiA1-based alloys are the most desired of the Ti-aluminides because of their combination of high-

[1]The material in this section draws extensively on Terence M. F. Ronald, “Materials Challenges For The National Aero-Space Plane,” *Review of Progress in Quantitative Non-Destructive Evaluation (New York, NY:* Plenum Press, May 1989). See also: Ned Newman and Richard Pinckert, “Materials for NASP,” *Aerospace America, May 1989 pp. 24-26,* 31; Alan S. Brown, “Taming Ceramic Fiber,” *Aerospace America,* May 1989, pp. 14-22; and Jay G. Baetz, “Metal Matrix Composites: Their Time Has Come,” *Aerospace America, November* 1988, pp. 14-16.

temperate tolerance, light weight, and greater resistance to hydrogen embrittlement. Their drawback has been that their brittleness makes it difficult to roll them into sheets, a necessary step to fashion sandwich panels. Some recent progress has been reported, but currently Ti_3Al-based alloys figure more prominently in near-term plans for the X-30 because of their greater ductility. Use of Ti_3Al-based alloys instead of TiAl would cause some increase in vehicle weight because their density is about 10 percent higher than TiA1. In addition, Ti_3Al is more susceptible to hydrogen embrittlement and would therefore require barrier coatings if actively cooled with hydrogen.

Metal matrix composites of titanium use embedded silicon carbide fiber to produce a material that is much stronger and stiffer than the unreinforced metal. Silicon carbide reinforced titanium can reportedly withstand temperatures of 1,500 “F and is a candidate material for thin panel structures that will form parts of the X-30’S skin. There are several technology challenges associated with incorporation of the fibers into the matrix. Among them is the thermal expansion mismatch between fiber and matrix, leading to a propensity for cracks to appear in the low ductility matrix during formation of the composite or on thermal cycling.

One solution being pursued is the development of alternative reinforcing fibers that have a better thermal match, such as titanium diboride and titanium carbide. NASP is also setting up pilot plants to explore Ti-MMC composites formed with rapid solidification plasma deposition methods. Some success has been reported with Ti_3A1-matrix materials and work is underway to extend this to TiA1-based composites. A challenge for all Ti-MMC materials will be to develop methods for evaluating the presence of cracks in the fiber/matrix bond without compromising the integrity of the material. In addition, there is a concern with all fiber reinforced materials related to their reactivity at high temperatures with the host material.

Carbon-carbon composites (carbon fibers embedded in a carbon matrix) are candidate materials for heat shields and large portions of the X-30’S skin. Carbon-carbon is one-third lighter than aluminum, retains its *strength* to very high temperatures, and has been used on the Space Shuttle leading edges and nose. On the Shuttle, carbon-carbon on the wing leading edge and the nose cap is exposed to temperatures as high as approximately 2,750 ‘F. Mission lifetimes of Shuttle C-C wing panels are currently 65 to 85 flights, but new sealant coatings are being introduced that will increase this figure to 100 flights. The challenge for NASP materials researchers is to create a material that is able to withstand repeated thermal cycling during the specified minimum of 150 X-30 flights.

At very high temperatures, untreated carbon-carbon would react with oxygen and form carbon dioxide. Researchers are testing a large number of protection schemes for carbon-carbon, including the application of special coatings that can form a barrier to oxygen, and the addition of oxidation inhibitors to the carbon matrix. The oxidation problem is exacerbated by the necessity on the X-30 to make carbon-carbon structures and oxidation coatings very thin to save weight. Although tests on samples of carbon-carbon materials during simulated NASP temperature-pressure cycles demonstrate increasing longevity, the durability of the composite is not yet equal to the materials used on the Shuttle.* The advanced carbon-carbon composites being developed for NASP are expected to provide greater strength than the C-C used on the Shuttle. With appropriate oxygen barrier coatings, temperature resistance to over 3,000 “F should be possible.[3]

Some parts of the X-30, such as leading edges and the nose cap, would exceed the temperature limits of carbon-carbon. In addition, these sections of the vehicle would be exposed to very high heat loads. Researchers are investigating the use of alternative composites that would be actively cooled as one solution to this problem. Ablative coatings of carbon-carbon are still another option; however, their use would increase maintenance and support costs.

On the Shuttle, carbon-carbon is placed on top of a metal load-bearing substructure. However, to save weight, carbon-carbon would be used at some locations in the X-30 as a load-bearing structure. Engineers have a particular concern with the use of C- C as a load-bearing structure because of the potential for cracks to form as a result of thermal cycling. Finding coating materials whose thermal expansion coefficient is close to that of the carbon-carbon substrate will be necessary to prevent cracks and subsequent oxidation of the substrate.

Joining of carbon-carbon is another area of concern. Close fitting of parts and control of surface finish is necessary because at hypersonic speeds small irregularities in surface smoothness, or gaps where materials are joined, could generate hot spots that would be sufficient to burn through surface materials. On the Shuttle, dimensional tolerances of carbon-carbon can be now be

[2]Recent tests with *small* samples of specially prepared carbon-carbon have withstood some 200 hours (roughly equivalent to 100 flights) of simulated NASP temperature and pressure flight profiles. However, researchers have not yet fabricated large structures with this material and there is some concern that the material will not retain its characteristics when fabricated in full-scale pieces. In addition, the material is relatively heavy because of its thick coating. Other types of carbon-carbon do not suffer from these problems, but they have not demonstrated as long a lifetime under simulated NASP flight profiles.

[3]Garland B. Whisenhunt, Director Carbon-Carbon Technology Applications, LTV Cap., briefing to OTA, May 30, 1989.

controlled to 0.010 inches.[4] Researchers expect similar performance will be available on the advanced carbon-carbon composites that would used on the X-30.

For operation above about 2,500 ‘F designers are also investigating the possibility of ceramic-matrix composites. These materials could form lightweight structures with better oxidation resistance than carbon-carbon. Historically, a problem with ceramic materials has been their brittleness and propensity to develop cracks. Researchers are attempting to find a reinforcement material for the ceramic matrix that will help alleviate this problem. Ceramic-composites are candidate materials for selected airframe applications, such as surfaces adjacent to the nose cap and leading edges of the X-30, and also for engine components and panels.

Two classes of ceramic-matrix materials are being studied. Glass-ceramic composites may be useful up to about 2,200 “F and can be fashioned into honeycomb-core panels and other complex shapes. They are a possible alternative to some titanium aluminizes. Advanced ceramic-matrix composites, such as silicon carbide fiber inbedded in a silicon carbide matrix (SiC-SiC), are not as well developed as the glass-ceramics, but their resistance to hydrogen embrittlement makes them an attractive material for actively cooled hot structures, Again, the potential for cracking is a concern with all Ceramic-matrix materials.

Graphite reinforced copper matrix composites are being studied for structures that will be actively cooled. This material is expected to be durable and it exhibits higher thermal conductivity (in the direction of the fiber), lower density, and higher strength than pure copper. NASP is exploring production methods for this material and is also investigating the possibility for creating other reinforced high thermal conductivity copper composites.

[4] Ibid.