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BROADENED APPLICATIONS OF ADVANCED COMPOSITES*

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Abstract

The superior structural performance of boron composites predicted ten years ago has been repeatedly demonstrated. It is deemed necessary to assess the current status and look to the future of this emerging technology to broaden its acceptance by industry. Numerous opportunities in systems applications as well as the major inhibiting factors are identified. The cost and market volume of boron tapes are also illustrated.

I. Introduction

A joint industry-government study of the status of composite technology was initiated in December 1971 by Air Force Materials Laboratory with the National Aeronautics and Space Administration (NASA) participation. Nicknamed COMPOSITES RECAST, primary objectives of this study were to identify (1) current technological deficiencies, (2) barriers to the transition of composite technology to systems application, and (3) future opportunities.

The study was not intended to evaluate performance or effectiveness of research and development programs of the past. Instead, information obtained was to be used to provide a data base for a joint USAF master plan for exploitation of advanced composites in the next decade.

To achieve a high level of objectivity in this study and to cover diversified viewpoints to balance various biases, participants included authorities on military and commercial aerospace systems, aerospace materials suppliers and users, universities, industry and government.

It is the purpose of this paper to present the major findings of COMPOSITES RECAST with emphasis on broadened applications and future opportunities in the use of advanced composites.

II. Major Findings

COMPOSITES RECAST concluded that the technology required for application of composites to systems has matured to the point of readiness for much expanded exploitation. As a result, major thrust of the study centered on approaches to overcoming identified barriers to increased utilization; confidence and cost. Lack of confidence is recognized as a primary inhibiting factor in widespread use of advanced composites. Confidence in the performance and reliability of composite structures is, of course, the primary requirement. An additional confidence factor identified relates to the lack of manufacturing/life cycle cost data and methodology.

The approach to increased confidence centered on the necessity to demonstrate the service performance of composite structures in various types of missions and under realistic environmental exposures. In this respect, technological advances in accelerated testing, proof testing and other laboratory simulation of anticipated loads, chemical environments, and foreign object damage are very much needed. More aggressive design criteria also should be developed to fully exploit the unique properties of composites neither possible nor available with metals. Composites offer a combined safe-life and fail-safe feature which will result in a higher level of structural reliability than that provided by metals. Thus, in effect, it may be worthwhile to re-invest some of the demonstrated structural weight savings made possible by composites into increased structural reliability. Far-reaching programs of service evaluation are also of primary importance in building confidence. Such service experience on large numbers of structures will generate much-needed manufacturing and service life cost data; components on commercial cargo aircraft will rapidly accumulate flight hours, at minimum risk; and effective utilization of prototypes will demonstrate systems

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performance improvements. Effective means must be devised to accumulate, disseminate and retrieve data on materials properties, manufacturing methods and service experience.

The next most visible barrier is cost. While cost is a highly volume-sensitive item, some cost reductions will be possible even at the current relatively constant volume consumption. These reductions will come from materials and fabrication innovations such as use of hybrid composites which consist of high and low-cost filaments, quick curing processes for organic-matrix composites, low pressure bonding for metal-matrix composites, less complicated tooling concepts, a better design-manufacturing interface, automation, relaxed tolerance and inspection standards, and reduction of the number of materials such as graphite filaments (through more stringent specifications).

Future opportunities for composites in systems under development are emerging. The fan blade for a high-bypass-ratio engine and the airframe for VTOL are such examples. The space shuttle, helicopters, remotely piloted vehicles, high performance aircrafts and advanced technology transports are further examples of the need for composites. Unfortunately, use of composites in these product opportunities is rare under current unfavorable economic environment and procurement practices. Thus, if composites are to be incorporated into systems, a more aggressive campaign must be waged. Two strong messages resulted from COMPOSITES RECAST. First, performance requirements of systems should not be frozen without due consideration of the potential benefits of advanced technologies. The speed of fighters for example should not be fixed until at least one iteration against available materials technology, such as advanced composites. Secondly, systems analysis on use of composites must be carried out in-depth to achieve credibility; the NASA sponsored study on Advanced Technology Transport (ATT), as a good example, should be extended to assembly drawings to properly assess the benefits of composites.

III. Fan Blades

Aircraft engines have the basic requirement of performance, reliability and cost. Composites have a significant impact on all three. Performance is measured by specific thrust (thrust/weight) where weight is a prime consideration. Fan blades have the highest payoff in that they generate additional benefits such as reduced disk weight, reduced containment requirement, and reduced supporting structure. In new aircraft design these engine weight savings are further multiplied in determining aircraft weight. Shroudless fan blades made possible by composites have a significant performance benefit due to elimination of flow path obstructions. Advanced, large by-pass, quiet engines have the requirement of large, low speed fan blades where composite construction is a logical, low risk application. Very-high-tip-speed fans are being developed for advanced systems where the blading should be made using advanced composites because of the high strength/density requirement.

Major inhibiting factors are as follows:

A. Confidence

Numerous current programs are directed at demonstrating fan blade technology, which not only involves structural and rig testing but rigorous engine testing. A significant amount of successful field experience must be added to provide confidence to commit complex parts to composite designs.

B. Cost

Cost/weight trade-offs of composites are dependent on the engine application and the functional requirement being satisfied. Although most composite parts are projected to have higher cost, there are some, notably large fan blades, which are projected to be cost competitive with their metal counterparts. Generally speaking a composite component is worth considering if it can be manufactured for up to $200 per pound of finished part.

C. Technical Performance

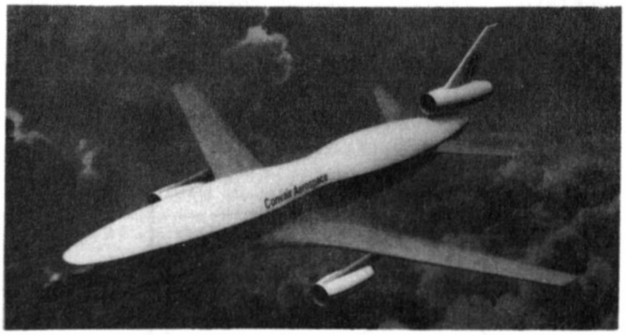
Reliability, comparable to traditional materials, must be attained to assure wide acceptance of composites. In addition, repairability and inspectability must be assured.

Engine components operate in an environment of high stress, high temperature and high air flow and are subject to fatigue, corrosion, and damage by foreign objects. They must operate for 20 years service including up to 20,000 take-off and landing cycles and up to 50,000 hours with a minimum of down-time for repair. Vast experience by both commercial and military operators, where in recent times reliability has increased an order of magnitude, has made operators skeptical of change and has made it much more difficult to introduce new technology without substantial service testing.

IV. Transports

The most obvious and frequently cited pay-off resulting from use of composites is weight reduction. However, when the total system is considered the weight-saving can be translated into performance gains, better structural integrity and safety, economic gains, and the possibility of permitting problems in other technologies (such as noise reduction) to be solved with minimal total systems weight increase.

Many of the potential pay-offs, such as greater structural integrity with accompanying reduced maintenance costs, have yet to be defined in detail. However, the NASA ATT (Advanced Technology Transport) system studies have indicated economic benefits such as shown by Figure 1. The comparison of a specific aircraft configuration with conventional aluminum construction to the same aircraft with extensive utilization of composites shows reductions in acquisition costs and direct operating costs (DOC) which are significant enough to produce a 20 per cent increase in return on investment (ROI). It must be pointed out that there is not unanimous agreement that acquisition costs will be lower. However, there is concurrence that direct operation costs will be decreased and return on investment increased.



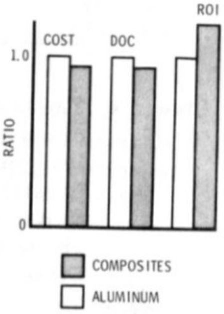


Figure 1. Advanced Technology Transport (ATT) showing 5 to 10 per cent lower direct operating cost (DOC) and about 20 per cent higher return on investment (ROI) when composites are used instead of aluminum, as reported by Boeing, and General Dynamics. The optimum use of composites is at 50 per cent (both minimum DOC and maximum ROI).

Major inhibiting factors can be stated as follows:

A. Confidence

One of the principal factors inhibiting greater utilization of composites in transport aircraft is the lack of general acceptance of this advanced materials technology at all technical levels (i.e., design and engineering, manufacturing, operations, and maintenance). Lack of acceptability can be related to reluctance to depart from tradition, composites technology deficiencies, or simply inexperience.

Experience with composites technology to date has been largely concentrated in relatively small fighter-type aircraft and is not totally transferable to transport aircraft. The transport is 10-15 times larger than the fighter, has different load histories (more cycles of lower loads), and has different mission and utilization requirements. Table I indicates typical fighter/transport size relation. When the wings are redesigned with composites, a 22 per cent savings in weight is assumed. The resulting wings contain 65 per cent composites by weight. The size factor is also a good indicator of the greater amount of composites utilization expected in transport aircraft.

TABLE I COMPOSITES UTILIZATION POTENTIAL

SYSTEM	WING AREA (FT^2)	WING WEIGHT (LBS)	REDESIGNED WITH COMP. (LBS)	COMP. USED (LBS)
TRANSPORT	6,200	35,870	27,800	18,100
FIGHTER	538	2,337	1,825	1,178
RATIO	11.6			15.4

Another significant difference is in structural detail. This is graphically illustrated by Figures 2 and 3. The most striking difference is the extensive truss-type structure of the transport wing as opposed to the full-depth rib construction of the fighter wing.

B. Cost

As in any endeavor, cost is a deciding factor. Composites costs must be considered from two viewpoints. One viewpoint is the actual cost per pound of the manufactured composite component or system. The second viewpoint is the effective cost per pound when all the synergistic benefits of weight savings, systems resizing, lower operational costs, greater structural integrity, etc., are considered.

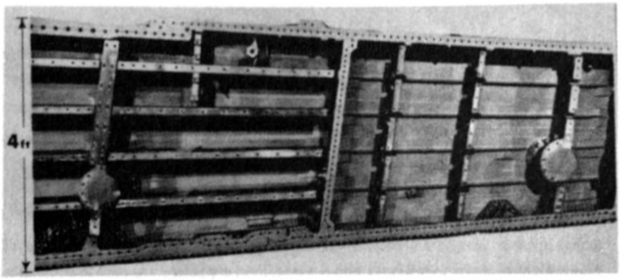


Figure 2. An exposed view of a section of fighter wing (North American F-100) showing the dimension and internal full-depth rib construction.

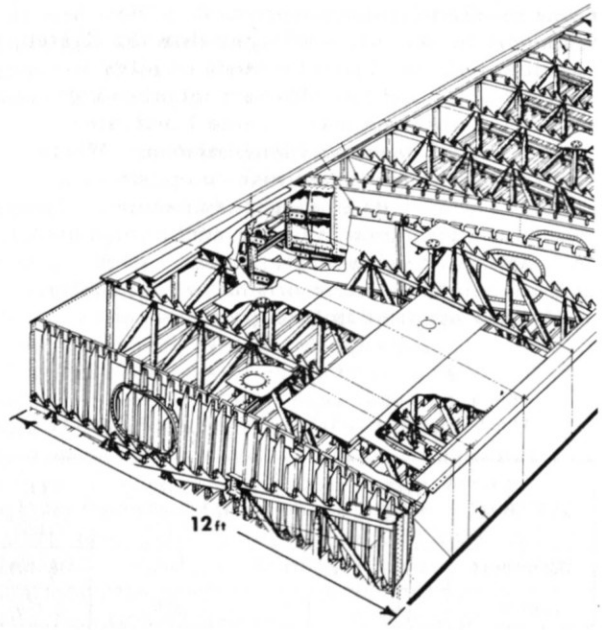


Figure 3. An exposed view of a section of a large transport (Lockheed C-5A) wing showing the dimension and internal truss-type construction. Composites demonstration to date has not dealt with large structures like this.

Although there are sufficient cost data on composite materials, very little meaningful data has been generated on manufacturing, operations, and maintenance costs. The absence of such data makes it difficult to determine acquisition and life-cycle costs. For this reason, those economic studies which have been accomplished often lack credibility.

C. Technical Performance

There have been few instances in the past where a definite need for composites has been demonstrated. When this has occurred, composites have been readily accepted. However, greater utilization of composites can be enhanced by appropriate systems studies. These studies can include various aspects of composites such as costs, extent of utilization, structural configurations, interaction of composites with other systems, etc.

Application of composites to transports creates a requirement of long-life that is not encountered in other applications. A 20 year life with the capability of 30,000 to 50,000 flight hours is necessary. Furthermore, typical airline type operations means that the composite structures must have a higher degree of maintainability and damage tolerance.

V. VTOL

The weight saving "escalation factor" for most helicopters is about 3. That is, the addition (or savings) of one pound in the airframe will result in the increase (or reduction) of gross weight by about 3 pounds. Particularly high leverage is available in the helicopter rotor blade, since this component has an additional multiplying factor of 2. That is, a pound saved in the blade saves another pound in the rotor hub area, and these escalate into 6 pounds of gross weight saved. Weight saved can be translated into increased payload, increased fuel capacity (range), higher operating speed or reduced size, depending upon the mission to be performed. For example, Figure 4 shows that the direct operating cost (DOC) can be reduced 30 per cent in case of a medium inter-city helicopter transport if composite rotor blades are used.

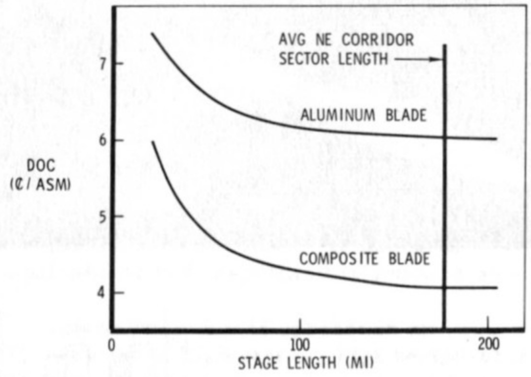


Figure 4. The lower direct operating cost (DOC) of composite blade for an intercity helicopter. A 30 per cent decrease is possible over an average Northeast United States corridor stage length of 180 miles, as estimated by Sikorsky Division of United Aircraft.

Composites offer very high fatigue strain allowables. This means that increased structural reliability can be achieved in the fatigue critical structures of the helicopter as an intrinsic property of composites. In addition, composites can be selected which exhibit "soft" or forgiving failure modes, enhancing the fail safety of the vehicle.

The complex shapes and close tolerances desired to optimize aerodynamic and aeroelastic properties of helicopter rotor blades are extremely difficult to achieve in metal blade designs. Composites can give the designer a freedom to achieve these desired shapes at reasonable cost.

Figure 5 shows the impact in vehicle size on a medium STOL transport owing to use of composites. For the same mission, the aluminum plane (in shaded area) can be significantly reduced by taking advantage of the lighter-weight composites.

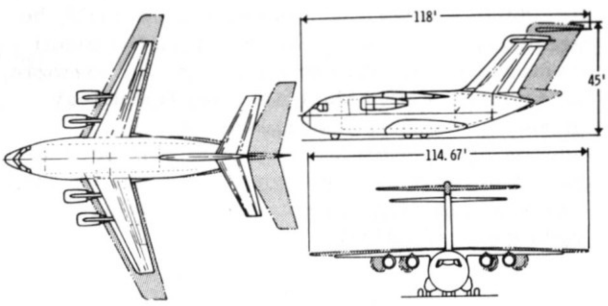


Figure 5. Medium STOL transports made of aluminum can be substantially reduced in size by using composites. Shaded area represents the reduction, as estimated by McDonnell Douglas. Detail study of such payoff must be made before a credible assessment can be achieved.

Major inhibiting factors are:

A. Confidence

Most engineers and managers are, by nature, conservative. Until substantial and successful service experience is gained, there will be a great reluctance to commit composites to widespread production use.

Lack of confidence (fear of failure) is a factor which embodies elements of the concerns described above; lack of proven design concepts, lack of knowledge of costs, and lack of service experience.

In new programs, fear of technical, schedule, or cost failure is so acute that "high risk" approaches which may offer a performance benefit are ignored. In more mature programs, emphasis is typically strong on field problem solving. Neither of these situations, in themselves, offer much encouragement to technical "reaching out" unless a need exists.

B. Costs

The lack of knowledge of raw material costs, coupled with a general lack of confidence in the ability of sheet metal-oriented shops to fabricate composite components, leads to concern over potentially high costs. Although raw material prices have been reducing more rapidly than projected, high cost and cost uncertainties remain as major inhibitors.

The composites advocate is often tempted to use the argument that, although initial (acquisition) costs are increased, the system life cycle costs are reduced. In today's environment the customer is not receptive to this argument. He is budgeted for acquisition cost. Overhead and maintenance costs are incurred in later fiscal years, paid from another account and, at best, are nebulous to document. As a result, composite structures must hold the line on acquisition costs or else be rejected by the decision makers as uneconomical, in spite of potentially lower life cycle costs.

VI. Spacecraft

The space environment coupled with the requirement for extremely light weight structures makes utilization of advanced composites a natural and convenient solution to space problems. In this era of precision optics, high frequency communications and sophisticated sensors operating in space, graphite/organic composites may provide the only practical or economical method of providing the zero coefficient of thermal expansion required to meet mission goals.

Typical spacecraft can afford a finished cost of approximately $10,000/lb. Cost is not the driving factor. Spacecraft have a unique requirement for confidence in that things "have to be right the first time" because the spacecraft is launched into space and is either a success or a failure. In addition return on investment is directly related to time in space. There is no access to repair or replace components. A complete and methodical test program, coupled with very close confirmation of the analysis, is always required. The acceptance level is high at present, but full trust is not yet evident primarily because there is not that much composite hardware in orbit.

VII. High Performance Aircrafts

Potential pay-off of advanced composites materials in high performance aircraft is perhaps the greatest of any class of aircraft, military or civil. A great premium is placed on reduced weight, great strength, resistance to fatigue, redundant load paths, and many of the. other features. Weight saved may be traded for range (fuel), payload, or excess energy-maneuverability. Figure 6 shows the effect on take-off weight as a function of percent utilization of composites. Major factors inhibiting wider application of composites to high performance aircraft fall within the realm of confidence builders, rather than high performance requirements or reduced cost. Even so, these factors - particularly cost - are highly significant in certain air vehicle systems.

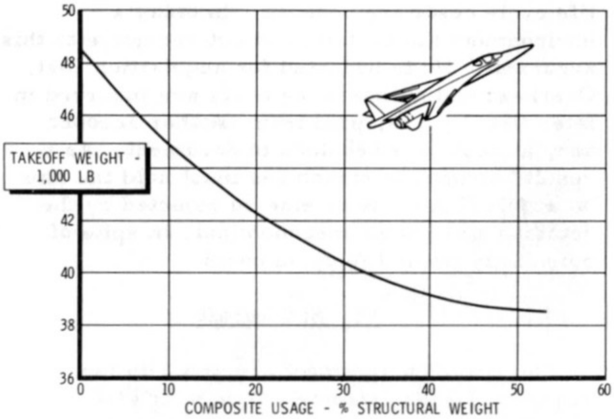


Figure 6. High performance aircrafts can be made 20 per cent lighter in take-off weight if composites are used in 50 per cent of the structures, shown by a study made by McDonnell Douglas.

VIII. Space Shuttle

The physical size alone of the space shuttle is so staggering that significant opportunity for weight reduction exists, due just to this fact alone. In addition, the payload fraction of this vehicle is on the order of 1% of the gross weight of the vehicle, and it is not difficult to visualize that with a very small growth rate during the design process the entire payload might disappear.

The current concept for the vehicle is for a primary structure which does not exceed 350°F. This allows the consideration of organic materials which are currently in inventory. Some specific areas in which composites have application are in rib, spar, and thrust structure; longerons; reinforced frames and bulk heads; and over-wrapped propellant tanks.

A. Confidence

A consistent theme has developed where confidence seems to be directly proportional to the amount of flight and service experience that the user has witnessed; and the shuttle program is no exception. NASA interest and confidence has been building rapidly in the past 2 years, but the remaining road block is the demonstration of full-scale hardware under operating conditions.

B. Cost

The basic problem is that the development or acquisition cost for the system is the over-riding factor in any cost decisions for this program. Studies have been run which indicate that the value of a pound saved on the Orbiter is $15,000 to 20,000. Composites can actually be applied at a lower absolute cost than the metal counterpart. The thrust structure, for example, has this potential. Manufacturing technology developments for reducing cost and demonstrating confidence must be continued so that when overweight problems develop, we will have the capability to apply this technology rapidly and effectively.

C. Technical Performance

The orbiter as presently conceived is a primary structure which operates at or below 350°F. Therefore, the majority of applications are within the capability of the materials which have been characterized and developed. For boron/epoxy, long-term environmental problems and additional work in vibration and sonic fatigue, cryogenic effects, and material compatability will have to be conducted. For materials such as graphite/epoxy and boron/aluminum, considerable work on standardization and development of allowables need to be done in addition to the items mentioned for the boron/epoxy material. Higher temperature materials such as polyimides will require longer and much more extensive development in the next 3 to 5 years so that they might impact advanced shuttle versions sometime downstream.

IX. Cost of Boron Tapes

Cost of boron-epoxy tapes at 50 per cent volume fraction has dropped from $1,500 per pound in 1965 to $100 in 1972. The price will continue to drop as volume increases. The drop in boron has been at a faster rate than the most optimistic projection of the past. Cost and market volume between 1965 and 1975 are shown in Figure 7. Economic behavior of glass and graphite fibers follows the same pattern. During the same period, beginning in 1965, significant improvements in quality of the filament and the resulting tape have been made.

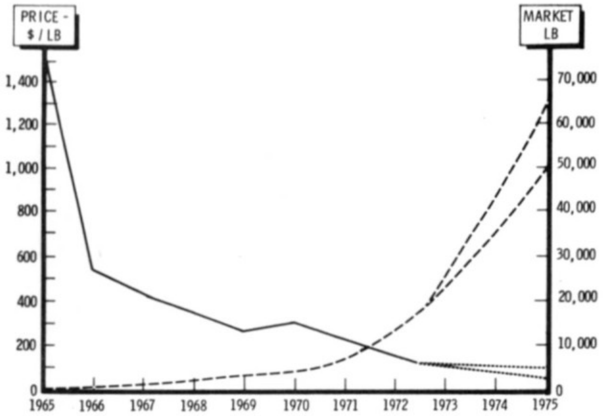


Figure 7. Cost of boron/epoxy tape and market volume from 1965-1975, as a composite picture of views by Avco, Hamilton Standard Division of United Aircraft, 3M, and numerous users. No technological breakthrough is believed necessary in order to lower the cost - volume usage is the biggest driver.

X. Conclusions

Advanced composites are emerging as engineering materials. While production commitments are increasing, aggressive plans for the future must be formulated and pursued. Effort to date has been on a substitutional basis; i.e., replacing metals with composites while keeping the geometry and function constant. The benefit of the use of composites can be increased substantially if a total design can be exercised. The constraints imposed by traditional metallic structures should be removed.

While increased use of composites may not call for further improvement in properties, higher performance material systems should continue to be exploited. Research and development should place emphasis on reduction of cost as well as increase in reliability and durability equal to that on the increase in static properties.

The "high technology" of composites developed primarily for the aerospace industry can have equal significance to much broader industrial applications. As machines run at higher speed, lower power or less tolerance, composites may provide the best answer. Thus, the future is there for composites, but innovations in technology and management are needed along the way.

Acknowledgment

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