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**NASA TECHNICAL  
MEMORANDUM**

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(NASA-TM-X-73557) COST/BENEFIT ASSESSMENT  
OF THE APPLICATION OF COMPOSITE MATERIALS TO  
SUBSONIC COMMERCIAL TRANSPORT ENGINES (NASA)  
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**COST/BENEFIT ASSESSMENT OF THE APPLICATION OF COMPOSITE  
MATERIALS TO SUBSONIC COMMERCIAL TRANSPORT ENGINES**

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16. Abstract <p>Results from a number of studies concerned with the cost and benefits of applying advanced composite materials to commercial turbofan engines are summarized. For each application area the optimistic and pessimistic benefit projections were averaged to arrive at a projected yearly percentage fuel savings for a commercial fleet of advanced technology transport aircraft. Engine components included in the summary are the fan section which includes fan blades, fan frame/case, and the blade containment ring; the nacelle; and the high pressure turbine blades and vanes. The projected fuel savings resulting from the application of composites are 1.85 percent for the fan section, 1.75 percent for the nacelle, and 2.35 percent for the high pressure turbine.</p>			
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**SUMMARY**

The recent demands for lightweight, more efficient, turbine powered, commercial transport aircraft have presented a challenge to the materials technology industry. Not only must new materials be more structurally efficient, but they must also be capable of being developed at reasonable cost, manufactured at a competitive price, and perform throughout the life cycle of the aircraft without requiring undue maintenance. The requirement, therefore, is not simply for new and better materials but for cost effective applications of materials in a demanding environment.

In order to best satisfy the requirement for composite materials technology, a number of studies have been conducted to identify the most promising composite application areas in commercial aircraft. This report summarizes the cost/benefit data from the studies which have addressed composite materials applications in turbofan engines. Most of the information contained herein has been obtained from reports published within the last 5 years and has been converted, where necessary, to be applicable to the engines of a medium range, 180 to 200 passenger aircraft for 1985 service. This reference aircraft has come to be known as the ATT, or Advanced Technology Transport.

Three areas of composite application are identified and benefits are expressed in terms of reduced fuel consumption. One area is the fan section, another is the nacelle, and the third is the high pressure turbine (HPT). The average projected fuel savings are 1.85 percent, 1.75 percent, and 2.35 percent respectively. Composite components for these applications

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(except HPT blades) are also expected to cost less to manufacture as compared to current materials. These benefits are substantial, when converted to monetary savings based on use of \$3 billion worth of fuel annually by the commercial aircraft fleet, and in light of the government Research and Development development cost for these materials which is estimated to be \$117 million.

## INTRODUCTION

For a number of years both NASA and the U. S. Air Force have been investigating potential applications of composite materials to aircraft. A primary objective has been to identify those components in both the airframe and the engine where redesign using advanced composite materials can be cost effective or cost competitive. Definition of cost effectiveness can be a complex subject, especially for military aircraft, but simply stated for commercial aircraft, the amortized cost of development including checkout and testing, plus any net increase in materials cost, should not exceed the expected net decrease in direct operating costs (DOC), or net increase in return on investment (ROI). A number of studies have been performed and reported by various commercial organizations and Government agencies, and it is the purpose of this report to consolidate and summarize the available information against a consistent baseline for cost effectiveness. Using this information, overall guidelines for development program emphasis can be developed by comparing the potential cost/benefit ratios of the specific technology application areas.

The information contained in this report is that which relates to the application of advanced composites to high-bypass-ratio gas turbine engines and is based on the findings presented in the referenced reports. A number of technology areas and materials have been evaluated in these reports, but the technologies selected and summarized herein represent the major applications for advanced composites. The components selected are indicated in figure 1 and include the fan frame, the fan blades, and the fan containment

ring which make up the fan section of the engine. The benefits of composites as applied to the nacelle were also summarized from the available reports. The nacelle and the fan section combine to make up the cold section of the engine. Cost/benefit data for the turbine vanes and the turbine blades of the high pressure turbine section, or the hot section of the engine, are also presented. The aircraft selected for this summary is the Advanced Technology Transport (ATT), since most of the reports included benefits based on the ATT and it was possible to reduce the limited non-ATT results to ATT benefits through suitable trade factors. The basic ATT aircraft specified for the studies was a 180 to 200 passenger conventional take-off and landing (CTOL) aircraft having a 3000 nautical mile range with a cruise speed of Mach 0.8. As such, the ATT probably is the best current representation of the next new aircraft to be manufactured for the U.S. commercial fleet. Another reason for selecting the ATT as the reference aircraft was that the projected time of introduction (1985-1990) for an aircraft like the ATT is compatible with the development time required for the necessary composite materials and structures technology. Changes in various engine and aircraft operating parameters (SFC, engine weight, engine and spare parts cost, and maintenance cost) have a fixed relationship to the percent change in take-off gross weight, direct operating cost, return on investment, and block<sup>1</sup> fuel usage for this three-engine aircraft. These relationships were used to convert all benefits to an equivalent SFC improvement or percentage reduction in fuel consumed by the engines during the block mission. The total benefits of the technology are based on a projected fuel consumption of ten billion gallons per year for the U.S. commercial fleet with a fuel cost of 30 cents per gallon. For example, if the application of composite fan blades would provide a projected fuel savings of 1 percent, then this would mean that there would be a total fuel savings of 1 percent of 10 billion gallons, or 100 million gallons per year at 30 cents per gallon this converts to a savings of 30 million dollars per year.

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<sup>1</sup>Total quantity of fuel required to go from point A to point B including warm up, taxi, take off, and flight.

## COST BENEFIT PROJECTIONS

Each of the referenced documents was screened to obtain available cost/benefit projections for composite applications in the fan section, nacelle, and for the high pressure turbine areas. Benefit values were recorded along with the type of aircraft and mission profile for which the projections were made. All values were then converted to benefits based on the trade factors shown for the projected ATT aircraft and the mission profile of figure 2. For those cases where there was insufficient information to convert a benefit value to the ATT aircraft, that specific benefit projection was discarded. The maximum and minimum projected benefits resulting after the conversion process had been applied to each composite application area were then averaged to obtain the benefits reported herein.

### SUMMARY OF PROJECTED AVERAGE BENEFITS

Results of the averaging process are shown in figure 3. The fuel savings projected for the fan section is shown to be 100 million gallons per year for the fan blades, 50 million gallons per year for the fan frame, and 35 million gallons per year for the containment ring. This is a total of 185 million gallons with a projected value of 55.5 million per year at 30 cents per gallon. In the case of the hot section, the high pressure turbine blades result in a projected savings of 110 million gallons per year. The turbine vanes represent a projected savings of 125 million gallons per year. Adding these, the projected savings for the turbine section is 235 million gallons or 70.5 million dollars yearly. The composite benefit for the nacelle is projected to be 175 million gallons or 52.5 million dollars per year. The total engine sum of these composite application benefits is 595 million gallons per year or 178.5 million dollars.

Figure 4 shows a graphical representation of these figures and includes an approximate 200 million gallons per year benefit attributable to improved aerodynamic and mixing characteristics of a composite long duct, mixed-flow

nacelle. The total yearly benefits projected for composite applications is thus shown to be approximately 800 million gallons including the total long duct benefits. Inclusion of the long duct aerodynamic benefits with the composite benefits is reasonable since a number of the airline companies have indicated that the long duct, mixed-flow exhaust would not be used if made with conventional materials because of excessive weight. Thus, the benefits of improved aerodynamics would not be available unless the nacelle were manufactured with advanced composites technology. This figure includes these aerodynamic related benefits only for information purposes. However, the basic conclusions of this report are developed around the composite benefits only and do not include the aerodynamic benefits of the long duct nacelle. Figure 5 shows a bar chart of the benefits of composites for all of the engine applications cited as compared to the projected government Research and Development cost. For each technology area, the development costs include duplicate contract efforts through design, laboratory tests and ground engine testing, and a single contract for flight engine testing. Using this approach to costing, it has been estimated by NASA that \$57 million for fan section development, \$30 million for nacelle development and \$30 million for turbine development will be required. Adding these three, the total one-time government R&D investment is \$117 million. This compares with a minimum yearly return projected to be \$114 million and a maximum projected yearly return of \$243 million (\$300 million if the total benefit of the composite long duct nacelle is included).

Figures 6 to 16 provide a breakdown of the benefits attributable to each of the various technology areas as obtained from the reports that were summarized herein. These figures show the benefits in percent and both a high estimate and a low estimate are given. These highs and lows were averaged to obtain the numerical values shown in figure 3.



## FAN SECTION BENEFITS

Figure 6 is the summary benefit chart for the composite fan blades and includes the benefits in terms of specific fuel consumption, reduction in weight, reduced fuel consumption, direct operating cost, return on investment, and fabrication cost. It should be noted that the numbers shown for specific fuel consumption are effective numbers that are calculated from the block fuel savings. Weight savings related to use of composites in a fan or nacelle section of the engine generally overshadow any direct engine efficiency improvements. Thus, the specific fuel consumption data shown are calculated from the block fuel savings attributable to the weight reductions effected by use of composites in place of heavier metal structures. The effective SFC benefit is that value which would be required to provide block fuel benefits equivalent to those projected due to the weight savings.

In the case of the fan blades, the block fuel savings is projected to be between 0.6 percent for the low value and 1.4 percent for the high value. This variation is consistent with the concern of the respective companies doing the studies over the ability to solve the bird ingestion foreign object damage problems of composite fan blades. The weight savings is seen to vary from a minimum of 25 percent reduction in blade weight to a maximum of 40 percent reduction. In addition, it should be noted that there is an important benefit that does not show up in the yearly projected savings, either in fuel or dollars. It is the simplification of the containment structure attributable to use of composite fan blades. If a bird is ingested into an engine and the blades should fail, composite blades tend to fragment and break up into smaller and lighter pieces than would titanium blades. The composite blade fragments contain less energy and thus less containment material is required to prevent their escaping radially through the engine shroud and doing further damage to the aircraft or its passengers.

Figure 7 is a listing of the composite fan frame benefits as obtained from the General Electric studies (refs. 1 and 2). As can be seen in figure 7, the fuel saving is projected to vary from a low value of 0.4 percent to a high value of 0.6 percent. The Pratt and Whitney study (ref. 3) considered a fan

exit case instead of a fan frame to support the engine weight and thrust loads. However, both the structural function and weight of the fan exit case and fan frame are similar and Pratt & Whitney shows similar benefit numbers for the fan exit case. In general, the frame/case weight savings are projected to be between 30 and 45 percent.

Figure 8 is a summary of the composite containment ring benefits and shows block fuel savings projected to be between 0.3 percent and 0.4 percent. The fabrication cost numbers on the containment ring are not shown in figure 8 because they have not been included in the projections by the companies that conducted the studies.

Figure 9 is a summary of the composite fan section benefits and shows block fuel savings to vary between a low of 1.3 percent and a high of 2.4 percent. This would result in a maximum yearly fuel savings of 240 million gallons or 72 million dollars. Assuming that cost reduction similar to the frame/case can be achieved for the containment ring, the expected fabrication cost benefits for the fan section range from a low of 10 percent reduction in cost to a high of 25 percent reduction in cost. The maximum increase in the return on investment in this area would be 1.05 percent with a direct operating cost improvement of 2.2 percent. Weight reductions for the composite fan section are expected to vary between 30 and 45 percent.

### NACELLE BENEFITS

Figure 10 is a summary of the composite nacelle benefits and it should be noted that the numbers listed are for wide body aircraft and not the ATT. This technology area is somewhat more complex than the fan section because the composite nacelle benefits include aerodynamic effects in addition to the material improvement effects. There are various ways of building the nacelle. It can be either a long duct or a short duct type or somewhere in between. A short metal duct which is currently being used on most commercial aircraft is the baseline case as shown in figure 10. Also shown are

projected benefits for three alternate types of nacelles. The baseline metal short duct could be replaced by a composite short duct nacelle with little or no effect on other engine or aircraft operating parameters. However, there are currently a number of study programs evaluating the benefits and effects of a long duct nacelle which would include exhaust flow mixing from the fan and the turbine section and also include a thrust reverser section. The long duct nacelle could be built with all-metal construction or with composites. Two companies have been very active in evaluating composites for nacelle applications. These are Lockheed California Company (CALAC) and McDonnell Douglas Aircraft Corp. (MDAC). Figure 10 compares the projected benefits in terms of weight, fuel, and cost advantages as a function of nacelle concept and also compares the projections of the two contractors. As compared to the short duct metal baseline case, the composite short duct is seen to have a projected benefit of between 12 and 15 percent in weight and a fuel benefit of 0.3 percent. For this case there is very close agreement between the MDAC and the CALAC studies. In the case of the metal long duct nacelle, a difference can be seen. The MDAC projection shows a 13 percent weight increase for a metal long duct nacelle, but because of the aerodynamic efficiencies resulting from flow mixing in the long duct a fuel savings of 1.7 percent is projected. The CALAC projection is more conservative and shows a 39 percent increase in weight which tends to overshadow the fuel savings attributable to the aerodynamic benefits of the long duct. Consequently, an increase of 0.1 percent in block fuel consumption is projected by CALAC. When composites are applied to the long duct nacelle, MDAC projects a 29 percent weight reduction or a 16 percent weight improvement over the metal short duct. However, CALAC expects only a 20 percent reduction and thus still has a 19 percent weight penalty. This is partly attributed to the fact that the CALAC metal long duct nacelle is so much heavier than the equivalent MDAC nacelle. This leads to fuel savings projected by MDAC of 4.75 percent while the CALAC fuel saving is only 0.3 percent for the composite long duct nacelle.

As previously stated, the values shown in figure 10 were based on wide body type of aircraft. The nacelle benefits can be projected to the ATT type

of aircraft by using the weight and fuel consumption figures of references 5 and 7 and the trade factors of figure 2. Figure 11 presents the results of this conversion process as applied to the minimum fuel nacelle configurations and includes the total long duct benefits as compared to a short duct metal nacelle. In this case, for the ATT type of aircraft, the block fuel savings can be seen to vary between 1.6 percent and 4.4 percent. This percentage difference is still attributable to the weight differences for the long duct as projected in the CALAC and MDAC reports, but the total difference is decreased due to the fact that the ATT is a new aircraft while the wide bodies are redesigns only. Based on the limited ATT estimates available, the projected fabrication cost reduction attributable to composites is seen to be between 10 and 25 percent. In this case the SFC is an effective number which is attributable to both the cycle efficiency and the reduced weight of the long duct composite nacelle. The composite benefits are shown for the long duct ATT application in figure 12. This figure presents the benefits attributable to composites alone (no aerodynamic effects), and this value can be seen to range between 1.5 and 2 percent block fuel savings. Fabrication cost benefits ranging between 20 and 36 percent are projected on the basis of the limited data from the ATT studies. Once again, the SFC numbers shown are effective numbers since they are strictly due to reduced weight of the composite long duct nacelle. The numbers presented in figure 12 were used to calculate the averages shown previously to describe the benefit of composite nacelles.

A summary of the benefits of composites in the cold section of the engine which includes both the fan section and the nacelle is shown in figure 13. The block fuel saving is seen to vary between 2.8 percent as a minimum and 4.4 percent as a maximum. This maximum block fuel savings would result in a 440 million gallon (\$132 million) savings per year as projected for the total aircraft fleet. The weight saving shown for the cold section of the engine varies between 26 and 35 percent.

## HIGH PRESSURE TURBINE BENEFITS

Figures 14 and 15 reflect the application of higher temperature materials to the high pressure turbine (HPT). The original studies were based on the increased temperature capability resulting from directionally solidified eutectics for HPT blades and ceramics for HPT vanes. However, recent work at NASA Lewis Research Center suggests that an equivalent temperature advantage can be obtained through the use of tungsten-wire/superalloys. The fabrication costs shown in figure 14 are based on DS eutectic technology. This cost penalty which is projected to vary between 50 and 150 percent would be greatly reduced or negated by the use of tungsten-wire/superalloys. The benefits shown are basically attributable to the high temperature strength of these composites and the higher efficiencies which come about as a result of the higher allowable turbine operating temperatures. As can be seen, fuel savings vary between 0.7 and 1.5 percent. This is a fairly wide difference which is attributable mainly to the cooling flow requirements assumed for 1985 baseline technology and the philosophy of the companies making the individual projections. In the case of the turbine blades, the specific fuel consumption numbers are directly attributable to engine performance improvements; since weight is projected to be equivalent to current technology there is no particular weight improvement due to composites in the turbine blades.

Figure 15 shows the projected benefits of the composite turbine vanes. The block fuel saving is estimated to be between 0.3 and 2.2 percent. This shows the widest difference between any of the numbers given. It is due basically to two things: (1) the way that cooling flow is factored into engine performance, and (2) the material selected for the baseline technology against which the higher temperature vanes were compared. In the case of the lower number, an advanced alloy was chosen as a baseline against which the improved materials were compared. In addition, for the lower benefits case, reduction of cooling flow was considered to be of secondary importance in improving engine performance. In the case of the high projected benefits, a conservative approach was taken in projecting the 1985

bill-of-materials for the HPT and consequently, a current state-of-the-art material was used for the baseline turbine vane material. Thus, the higher temperature turbine vane materials provided a great deal of improvement in allowable turbine inlet temperature. Also, for this case, reduction of cooling flow requirements was considered to be very important to engine performance. The true answer is expected to lie somewhere between the high and low values given in figure 15 and, thus, very probably reflects something close to the average value that was used in the overall benefit calculations (figs. 3 and 4). The fabrication cost projections shown in figure 15 are valid for both ceramic materials or for tungsten wire reinforced superalloys. As was the case for the turbine blades, recent work at the NASA Lewis Research Center indicates that the turbine inlet temperature increases (on which the performance improvements were based) are also achievable with tungsten-wire/superalloy composites.

Figure 16 is a summary of the composite HPT airfoil benefits and shows a maximum projected fuel saving of 370 million gallons per year or \$111,000,000 per year.

#### ADDITIONAL BENEFITS OF COMPOSITE APPLICATIONS

The numbers shown for engines in the summary have not included a number of other potential benefits. The benefits discussed are based on savings in block fuel consumption attributable to reduced structural weight or higher allowable turbine inlet temperature. The additional benefits that are shown in figure 17 include the reduced manufacturing costs compared to current usage which are in the range of 25 percent for most applications except the high pressure turbine blade area where cost reductions are not expected for tungsten wire/superalloys. In addition, a greater number of noise reduction options are available through the application of composites. In the case of the fan section, high tip speed fans can be designed with composites and this leads to a lower number of blades and better air flow conditions, elimination of midspan shrouds, and reduced noise. In addition, the fan blade containment

problem is eased as was mentioned earlier. It is also possible to eliminate the typical clam shell type of thrust reverser which is used in most commercial aircraft today. This can be achieved through the use of a variable pitch fan blade. The latter can only be made effectively through the application of high strength/low density composites. The variable pitch blades require large tip chord and wide blade-to-blade spacing. A metal blade designed to the variable pitch aerodynamic specifications thus would have to be very thick (and heavy) to meet the dynamic requirements. Also, the total number of engine compressor and turbine stages can possibly be reduced since higher tip speed stages and higher pressure ratios per stage can be achieved through application of composite materials technology. And, as a final item, it should be noted that the weight savings attributable to the composites as summarized in this report have included only nominal weight savings due to the specific redesign of a particular section using composites together with some secondary effects in the engine achieved by reducing the total engine weight. They do not include a detailed weight ripple effect. For example, when the fan blade weight is reduced it should also be possible to design a lighter weight shaft, lighter bearings, and lighter engine support sections. This weight reduction has been accounted for only by using ratio factors to scale down the overall engine weight. However, if the weight ripple effects were actually designed in detail through the entire engine, it is expected that even greater weight savings and higher block fuel savings could be achieved. None of these additional potential benefits show up in the block fuel savings which have been summarized in this report. Therefore, it is believed that the average values shown are somewhat conservative and when the additional benefits would be applied these values would increase substantially.

### CONCLUDING REMARKS

Based on the review reported herein of previously published cost/benefit studies, it is shown that substantial benefits can be obtained from the application of composite materials to aircraft engine components.

Based on the application of composites to fan blades, frame/case, containment ring, nacelles, and high pressure turbine blades and vanes, an average fuel savings of approximately 600 million gallons per year can be obtained. This fuel savings is based on applying composite engine component benefits to a commercial fleet consuming 10 billion gallons of fuel per year. The fuel savings represents 180 million dollars per year with a fuel cost of 30 cents per gallon. These benefits are large compared with the costs of research programs proposed to make possible the application of composites to aircraft engines and indicate that the composites research and development efforts now underway should be continued.

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**FIGURE 1. - AREAS FOR APPLICATION OF COMPOSITES  
IN ADVANCED AIRCRAFT ENGINES**

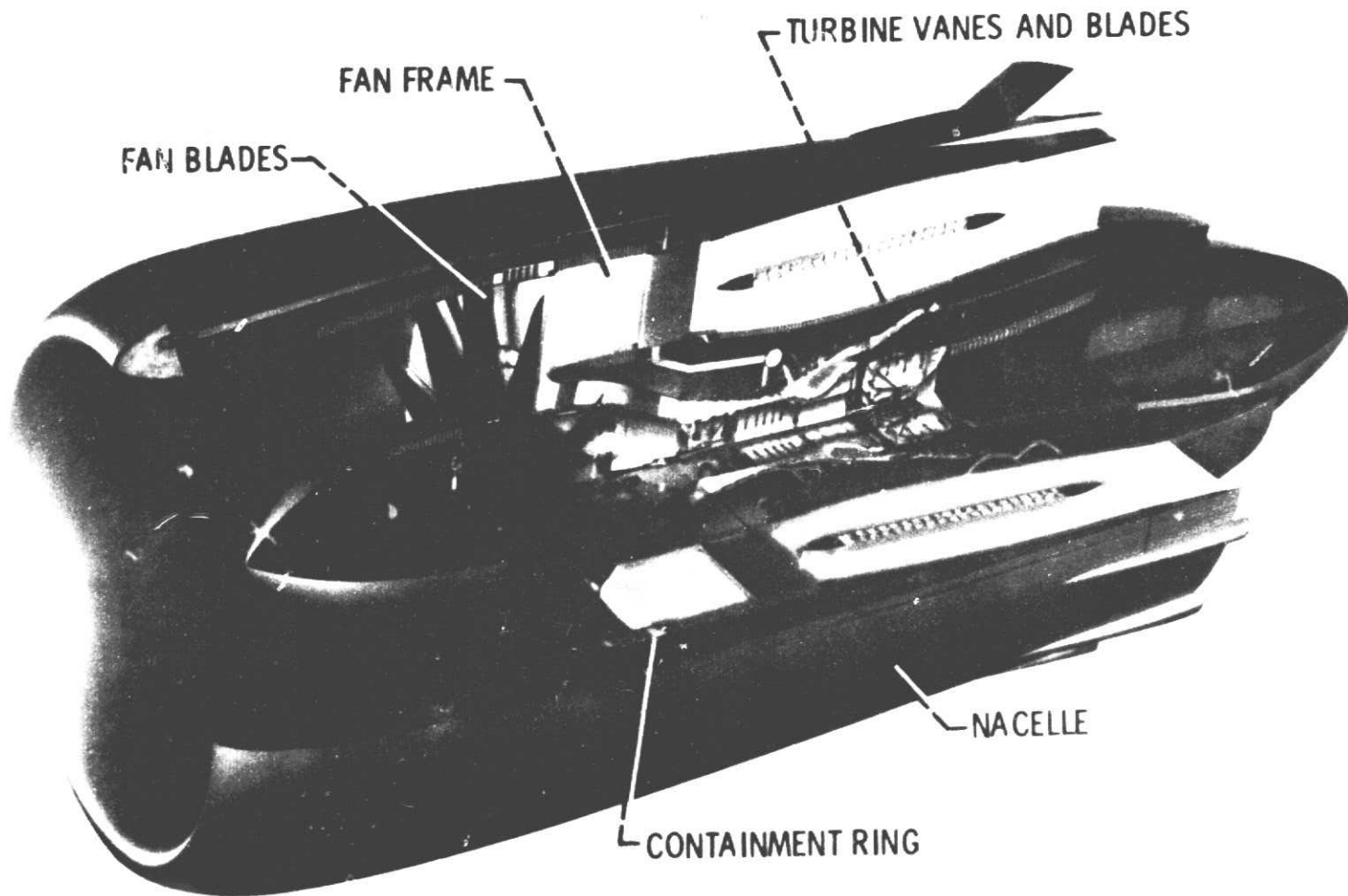


FIGURE 2 - TRADE FACTORS FOR ADVANCED TECHNOLOGY TRANSPORT AIRCRAFT

1985 180-200 PASSENGER CTOL - 3000 NM TRIJET - MACH .8

MODIFIED 1967 ATA FORMULA FOR DOC AND ROI CALCULATIONS

<u>DECREASE IN ENGINE PARAMETER</u>	<u>PERCENT CHANGE</u>			
	TOGW	DOC	ROI	FUEL
1% SFC	-.56	-.52	+.16	-1.36
500 POUNDS/ENGINE	-1.55	-.80	+.28	-1.15
\$10,000 BASIC ENGINE PRICE	X	-.065	+.043	X
\$10,000 ENGINE SPARE PARTS SELLING PRICE	X	-.054	+.010	X
0.1 MAN HR./BLOCK HR. ENG. MAINT. LABOR	X	-.045	+.088	X

BENEFITS BASED ON COMMERCIAL FLEET FUEL

CONSUMPTION OF 10,000,000,000 GALLONS PER YEAR AT 30¢ PER GALLON

**FIGURE 3 - AVERAGE BENEFITS OF COMPOSITE MATERIALS FOR ENGINE APPLICATIONS IN SUBSONIC COMMERCIAL TRANSPORT FLEET**

<u>APPLICATION AREA</u>	<u>YEARLY FUEL SAVING (X 10<sup>-6</sup>)</u>	
	<u>\$</u>	<u>GAL</u>
FAN BLADES	30.0	100
FAN FRAME	15.0	50
CONTAINMENT RING	10.5	35
	<u>\$</u>	<u>GAL</u>
<u>FAN SECTION SUM</u>	55.5	185
TURBINE BLADES	33.0	110
TURBINE VANES	37.5	125
<u>TURBINE SECTION SUM</u>	70.5	235
<u>NACELLE</u>	52.5	175
<u>ENGINE SUM</u>	178.5	595

**FIGURE 4 - AVERAGE BENEFITS OF COMPOSITE MATERIALS  
 IN COMMERCIAL AIRCRAFT FLEET OPERATIONS**

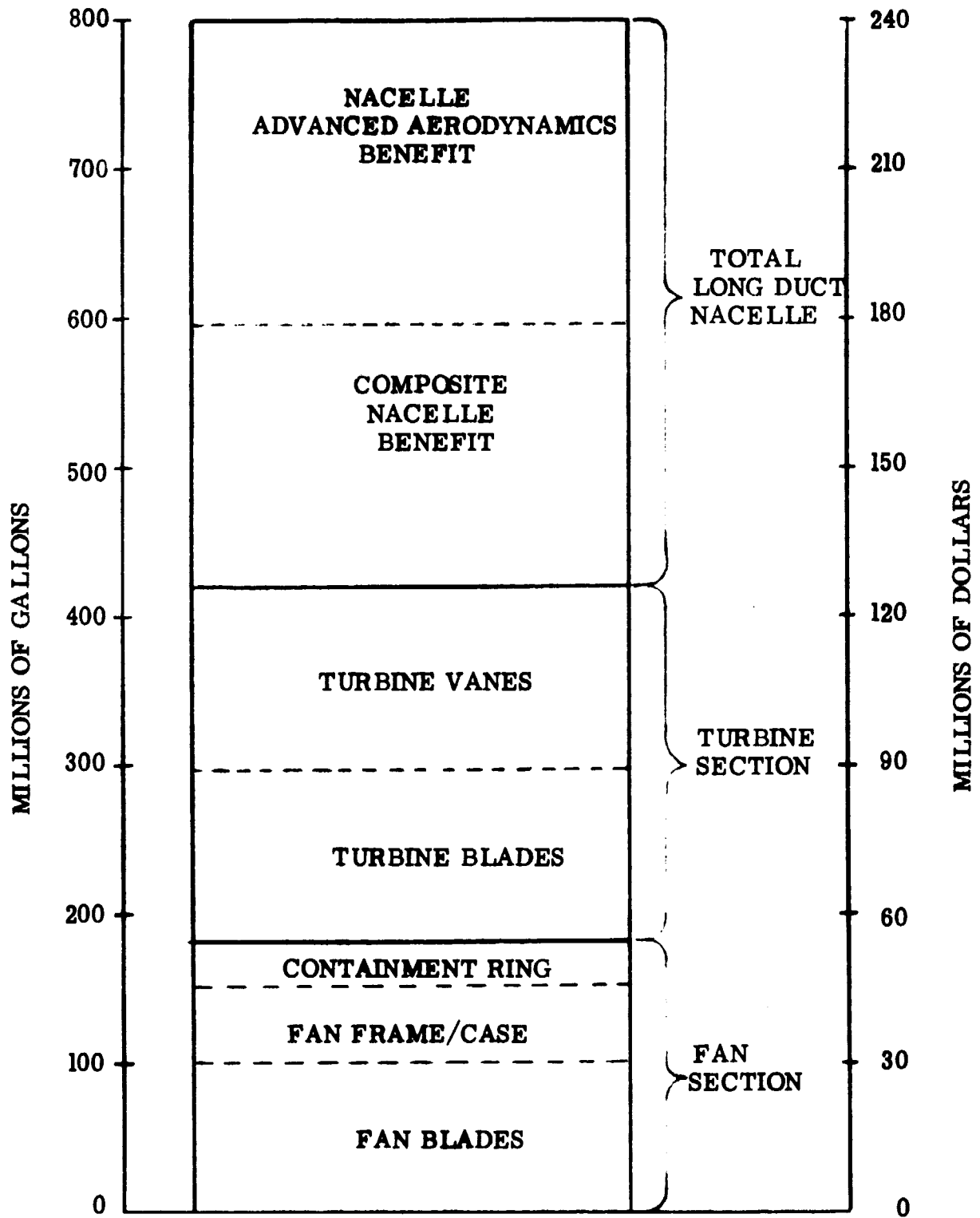


FIGURE 5 - COMPARISON OF COSTS TO BENEFITS OF  
COMPOSITE MATERIALS IN ENGINE APPLICATIONS

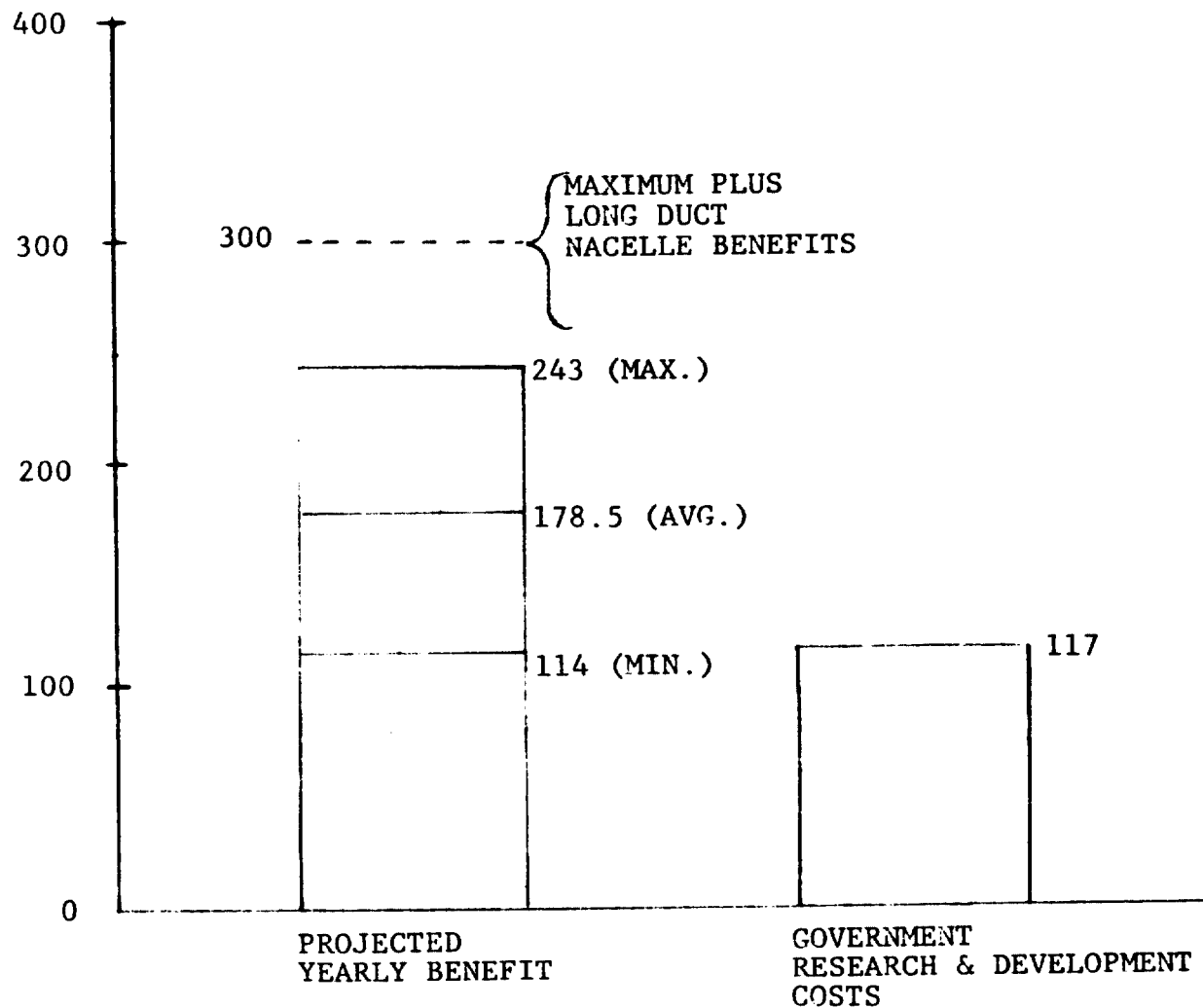


FIGURE 6 - COMPOSITE FAN BLADE BENEFITS

BENEFIT IN PERCENT

	SFC*	WEIGHT	FUEL	DIRECT OPERATING COSTS	RETURN ON INVESTMENT	FAB COST
HI	(1.0)	40	1.4	1.3	.6	25
LO	(.4)	25	.6	.2	.1	0
YEARLY FUEL SAVINGS (MAX.):			GALLONS	140,000,000		
			\$	42,000,000		

WIDE VARIATION IN NUMBERS DUE TO DISPARITY IN ATTITUDES OF COMPANIES DOING STUDIES

CONTAINMENT SIMPLIFIED WITH COMPOSITE BLADES

\* EFFECTIVE SFC IMPROVEMENT DUE TO REDUCED WEIGHT, NOT IMPROVED ENGINE CYCLE EFFICIENCY

FIGURE 7 - COMPOSITE FAN FRAME BENEFITS

BENEFIT IN PERCENT

	SFC *	WEIGHT	FUEL	DIRECT OPERATING COSTS	RETURN ON INVESTMENT	FAB COST
HI	(.45)	45	.6	.6	.3	25
LO	(.3)	30	.4	.4	.2	10
YEARLY FUEL SAVINGS (MAX.):			GALLONS	60,000,000		
			\$	18,000,000		

\* EFFECTIVE SFC IMPROVEMENT DUE TO REDUCED WEIGHT, NOT IMPROVED ENGINE CYCLE EFFICIENCY



FIGURE 8 - COMPOSITE CONTAINMENT RING BENEFITS

BENEFIT IN PERCENT

	SFC*	WEIGHT	FUEL	DIRECT OPERATING COSTS	RETURN ON INVESTMENT	FAB COST
HI	(.3)	50	.4	.3	.15	?
LO	(.2)	40	.3	.2	0	?

YEARLY FUEL SAVINGS (MAX.):    GALLONS    40,000,000  
   \$        12,000,000

\* EFFECTIVE SFC IMPROVEMENT DUE TO REDUCED WEIGHT, NOT IMPROVED ENGINE CYCLE EFFICIENCY



FIGURE 10 - BENEFIT COMPARISONS FOR COMPOSITE NACELLES  
IN WIDE BODY TRANSPORT AIRCRAFT

	BENEFIT IN PERCENT					
	WEIGHT		FUEL		COST	
	CALAC*	MDAC**	CALAC	MDAC	CALAC	MDAC
METAL SHORT DUCT	0	0	0	0	0	0
COMPOSITE SHORT DUCT	15	12	0.3	.3	15	12
METAL LONG DUCT	- 39	- 13	- 0.1	1.7	- 39	- 13
COMPOSITE LONG DUCT	- 19	16	.3	4.75	- 19	23

\* CALAC = LOCKHEED CALIFORNIA STUDY (REFERENCE 7)

\*\* MDAC = McCONNELL DOUGLAS AIRCRAFT CORPORATION (REFERENCE 5)

FIGURE 11 - TOTAL LONG-DUCT ATT NACELLE BENEFITS AS COMPARED  
TO SHORT-DUCT METAL NACELLES

BENEFIT IN PERCENT

	SFC	WEIGHT	FUEL	DIRECT OPERATING COSTS	RETURN ON INVESTMENT	FAB COST
HI	(3.4) *	30	4.4	2.5	2.0	25
LO	(1.2)	-10	1.6	2.2	1.5	10

YEARLY FUEL SAVINGS (MAX.): GALLONS 440,000,000  
 \$ 132,000,000

\* EFFECTIVE SFC IMPROVEMENT DUE TO BOTH CYCLE EFFICIENCY AND REDUCED WEIGHT.

FIGURE 12 - COMPOSITE ATT LONG-DUCT, MIXED FLOW NACELLE BENEFITS

BENEFIT IN PERCENT

	SFC*	WEIGHT	FUEL	DIRECT OPERATING COST	RETURN ON INVESTMENT	FAB COST
HI	(1.5)	30	2.0			36
LO	(1.1)	20	1.5			20

\* EFFECTIVE SFC IMPROVEMENT DUE TO REDUCED WEIGHT, NOT IMPROVED ENGINE CYCLE EFFICIENCY

FIGURE 13 - SUMMARY OF COMPOSITE FAN SECTION AND NACELLE BENEFITS

BENEFIT IN PERCENT

	SFC*	WEIGHT	FUEL	DIRECT OPERATING COSTS	RETURN ON INVESTMENT	FAB COST
HI	(3.25)	35	4.4			25
LO	(2.0)	26	2.8			15

YEARLY FUEL SAVINGS (MAX.):    GALLONS 440,000,000  
   \$        132,000,000

\* EFFECTIVE SFC IMPROVEMENT DUE TO REDUCED WEIGHT, NOT IMPROVED  
ENGINE CYCLE EFFICIENCY

FIGURE 14 - COMPOSITE TURBINE BLADE BENEFITS

BENEFIT IN PERCENT

	SFC	WEIGHT	FUEL	DIRECT OPERATING COSTS	RETURN ON INVESTMENT	FAB COST
HI	1.0	5	1.5	.8	.23	- 50
LO	0.5	0	0.7	0	0	-150
YEARLY FUEL SAVINGS (MAX.):			GALLONS	150,000,000		
			\$	45,000,000		

WIDE DISPARITY IN NUMBERS REFLECTS COST UNKNOWNNS ALONG WITH ASSUMED 1985 BASELINE COOLING FLOW REQUIREMENTS AND COMPANY'S PHILOSOPHY.

FIGURE 15 - COMPOSITE TURBINE VANE BENEFITS

BENEFIT IN PERCENT

	SFC	WEIGHT	FUEL	DIRECT OPERATING COSTS	RETURN ON INVESTMENT	FAB COST
HI	1.6	7	2.2	1.7	.51	50
LO	.17	0	.3	.83	.24	50
YEARLY FUEL SAVINGS (MAX.):			GALLONS	220,000,000		
			\$	66,000,000		

WIDE DISPARITY IN NUMBERS DUE TO MATERIALS SELECTED FOR BASELINE AND EFFICIENCY PENALTIES ATTRIBUTED TO COOLING.



FIGURE 16 - SUMMARY OF COMPOSITE HPT AIRFOIL BENEFITS

BENEFIT IN PERCENT

	SFC	WEIGHT	FUEL	DIRECT OPERATING COSTS	RETURN ON INVESTMENT	FAB COST
HI	2.6	6	3.7	2.5	.74	- 40
LO	.67	0	1.0	.83	.24	-100
YEARLY FUEL SAVINGS (MAX.):			GALLONS	370,000,000		
			\$	111,000,000		

FIGURE 17 - ADDITIONAL POTENTIAL BENEFITS FROM APPLICATION  
OF COMPOSITES TO ENGINES

REDUCED MANUFACTURING COST (EXCEPT FOR HPT BLADES)

GREATER NUMBER OF NOISE REDUCTION OPTIONS

FAN BLADE CONTAINMENT PROBLEM EASED

ELIMINATION OF THRUST REVERSER THRU VARIABLE PITCH  
FAN DESIGN

REDUCTION OF ENGINE COMPRESSOR AND TURBINE STAGES

WEIGHT RIPPLE EFFECTS