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NASA Contractor Report 166197

Application of Advanced Technologies to Derivatives of Current Small Transport Aircraft

Final Report

By P. P. Renze and J. E. Terry

July, 1981

Prepared under Contract NAS2-105
by
BEECH AIRCRAFT CORPORATION
Wichita, Kansas

for

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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APPLICATION OF ADVANCED TECHNOLOGIES TO DERIVATIVES OF CURRENT SMALL TRANSPORT AIRCRAFT

FINAL REPORT

By P. P Renze and J. E. Terry

July 1981

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16 Abstract

This study analyzes the application of advanced technologies to a derivative of a current technology small transport aircraft. Mission requirements of the derivative design were the same as the baseline to readily identify the advanced technology benefits achieved. Advanced technologies investigated were in the areas of Propulsion, Structures and Aerodynamics and a direct operating cost benefit analysis conducted to identify the most promising. Engine improvements appear most promising and combined with propeller, airfoil, surface coating and composite advanced technologies give a 21-25% DOC savings. A 17% higher acquisition cost is offset by a 34% savings in fuel used. Recommendations are made for continued research and development in the areas of Propulsion, Aerodynamics and Structures.

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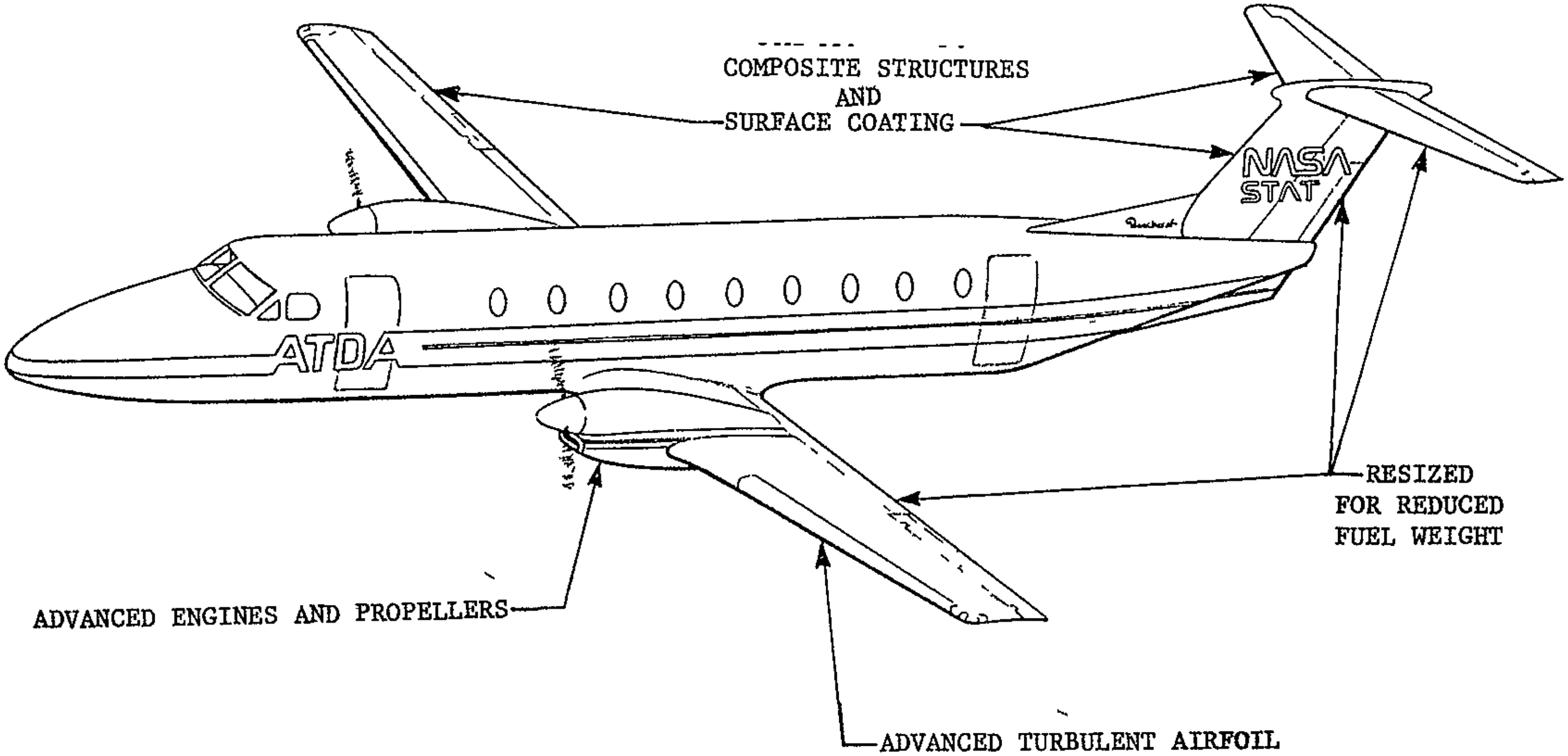

COMPOSITE STRUCTURES
AND
SURFACE COATING
NASA
STAT
ATDA
RESIZED
FOR REDUCED
FUEL WEIGHT
ADVANCED ENGINES AND PROPELLERS
ADVANCED TURBULENT AIRFOIL

1.0 SUMMARY

Beech Aircraft Corporation under Contract NAS2-10571 undertook the study of advanced technologies applications to a derivative of a current small short-haul transport aircraft. A derivative is defined as the baseline aircraft with an unchanged or slightly modified fuselage with possible changes to engines, systems, wing and empennage.

The results of this study complement the previous NASA STAT studies in which the baseline aircraft was designed to a defined set of configuration and mission specifications.

Mission requirements of the derivative design were the same as the baseline aircraft, to readily identify the advanced technology benefits achieved.

Advanced technologies selected for application to the baseline aircraft are

- Advanced turboprop engines
- Advanced propellers
- Surface Coating
- Composite Structures
- Advanced Turbulent Flow Airfoils

The key improvements in the Advanced Technology Derivative Aircraft (ATDA) compared to the current technology baseline are·

- 14% reduction in takeoff gross weight
- 14% reduction in wing area
- 14% reduction in total cruise drag
- 17% reduction in engine power

Since the ATDA was constrained to the range and cruise speed of the baseline aircraft, the performance differences are minimum. The most important differences are in the 34% reduction in block fuel used and corresponding DOC reduction of 21% for the 100 n. mi. stage length and $1.75/gal fuel cost.

1.0 SUMMARY (Cont'd.)

Evaluation of the ATDA shows that the 21%-25% DOC reduction potential comes at a 17% higher acquisition cost due to the development costs of the baseline aircraft being fully amortized. The additional acquisition cost is justified by the operating cost savings which allows a payback period of just under a year. A potential market capture rate of 40% is indicated for the 1990's.

Recommended research areas to evolve advanced technology for application to small transport derivative aircraft are as follows.

1) Improved aerodynamics including advanced airfoils, propeller-nacelle-wing integration and surface coatings.
2) Advanced propulsion systems including low SFC turboprop engines and advanced propeller concepts.
3) Graphite/epoxy structures in lightly loaded areas with emphasis on fabrication methods for low cost.
4) Control system technology for active controls for relaxed static stability and ride improvement.

2.0 INTRODUCTION

Since the advent of deregulation, the commuter or short stage length air carrier has grown in numbers and service areas. The operational environment that these aircraft are subject to has created a demand for an aircraft specifically designed for this market segment.

Design of a new aircraft is a lengthy and costly process. To reduce costs manufacturers will enhance or modify an existing aircraft design to meet a particular need. These derivative aircraft utilize the basic airframe, systems, avionics, etc., of the current aircraft thus reducing tooling and development costs.

Utilization of advanced technology from NASA-sponsored and independent research may further reduce both manufacturing and operating costs. Once the technology is available, application to a derivative aircraft will aid its introduction to the market.

As a complement to the recently completed NASA Small Transport Aircraft Technology studies, this study will investigate the application of advanced technology to a baseline aircraft similar to a current 19-passenger design. The study is divided into four tasks:

Task I - Baseline Aircraft and Mission Definition
The baseline aircraft is similar to a current technology aircraft with a 19-passenger seating capacity. The mission requirements will follow those defined by this design.

Task II - Application of Advanced Technology
The NASA developed computer analysis program, General Aviation Synthesis Program (GASP), is used to evaluate the influence of advanced technologies, both individually and in combination, on the baseline aircraft. Baseline payload/range and cruise speed were held constant. Those advanced technology items identified as most promising were then applied to the baseline aircraft to design an advanced technology derivative aircraft which would accomplish the baseline mission more efficiently.

Task III - Evaluation

Comparisons of the ATDA with the baseline aircraft were made in the areas of configuration, performance and economics. Market potential of the ATDA versus present and future market requirements and available aircraft was also accomplished.

Task IV - Recommendation for Future Research

Recommendations for continued and new research of the advanced technologies evaluated in Task III.

Definitions of the baseline aircraft and computer program methods are presented in Sections 4.1 - 4.3. Identification and selection of the potential advanced technologies are discussed in Section 4.4. Application of the selected technologies is discussed in Section 4.5. Evaluation of the ATDA and comparison with the baseline are contained in Section 4.6. Section 5 0 lists recommendations for future research.

3.0 ABREVIATIONS AND SYMBOLS

ACEE	Aircraft Energy Efficiency Program
AR	Aspect Ratio
ASNM	Available seats-nautical miles
ATDA	Advanced Technology Derivative Aircraft
BLK	Block
c	Local chord
C_d	Section drag coefficient
C_D	Total drag coefficient
C_ℓ	Section lift coefficient
$C_{\ell_{max}}$	Section maximum lift coefficient
C_L	Total lift coefficient
$C_{L_{max}}$	Total maximum lift coefficient
DEG	Degree
DOC	Direct Operating Cost
FPM	Feet per Minute
ft	Feet
gal	Gallon
GASP	General Aviation Synthesis Program
hr	Hour
kts	Knots
L	Lift or length
lbs	Pounds
L/D	Lift to Drag Ratio
M	Mach number
NLF	Natural Laminar Flow
NM	Nautical mile
n. mi.	Nautical mile
no.	Number
psi	Pounds per square inch
R/C	Rate of climb
RN	Reynolds number
ROI	Return on investment
RPM	Revolutions per minute

3.0 ABBREVIATIONS AND SYMBOLS (Cont'd.)

SFC	Specific fuel consumption
SHP	Shaft horsepower
S.L.	Sea level
SQ. FT.	Square Feet
STAT	Small Transport Aircraft Technology
X	Distance along the X axis
Z	Distance along the Z axis
2-D	Two dimensional
α	Angle of attack
λ	Taper Ratio
Δ	Incremental Value

4.0 DISCUSSION AND RESULTS

Summary. Major data analysis for this study was done using the General Aviation Synthesis Program (GASP) developed by NASA. A current technology small transport aircraft was selected as the basepoint configuration Close match of the performance estimated by normal preliminary design methods was accomplished by GASP methods. Various advanced technologies are identified and evaluated for application to the baseline with the goal of achieving fuel efficiency and lower operating costs. A cost analysis method was developed to assess the cost of the new technologies in a derivative aircraft versus the benefits obtained.

The most promising technologies are incorporated into the baseline aircraft to obtain a final derivative aircraft design.

4.1 General Aviation Synthesis Program (GASP)

NASA's Ames Research Center has developed the General Aviation Synthesis Program (GASP). This computer program performs tasks generally associated with aircraft preliminary design and allows an analyst the capability of performing parametric studies in a rapid manner.

The program is comprised of modules representing the various technical disciplines integrated into a computational flow. This ensured that the interacting effects of design variables are continuously accounted for in the aircraft sizing procedure. By utilizing the computer model the impact of various aircraft requirements and design factors may be studied in a systematic manner with benefits measured in terms of overall aircraft performance and economics.

4.1 General Aviation Synthesis Program (GASP) (Cont'd.)

The synthesis program consists of a control module and several technology submodules which perform the various independent studies required in the design of general aviation or small transport aircraft. Each of the six technology modules (Figure 1) is composed of one or more computer subroutines and the input to each module may be either the output of another module or it may be input directly to the module.

This integrated approach ensures that results contain the effects of design interactions among the various modules. For example, a change in wing loading affects wing area, tail size, lift, drag, propulsion system size, cruise altitude, structural weight, range and other parameters A typical flow chart is shown in Figure 2.

A complete description of the total program and detailed discussion of each technology module may be found in Reference 1.

Upgrading and modification of the various modules has been occurring since the publication of Reference 1 in coordination with NASA Ames Research Center personnel Beech has modified the propulsion module to accept power tables as used at Beech and made the complete program compatible with IBM equipment and systems.

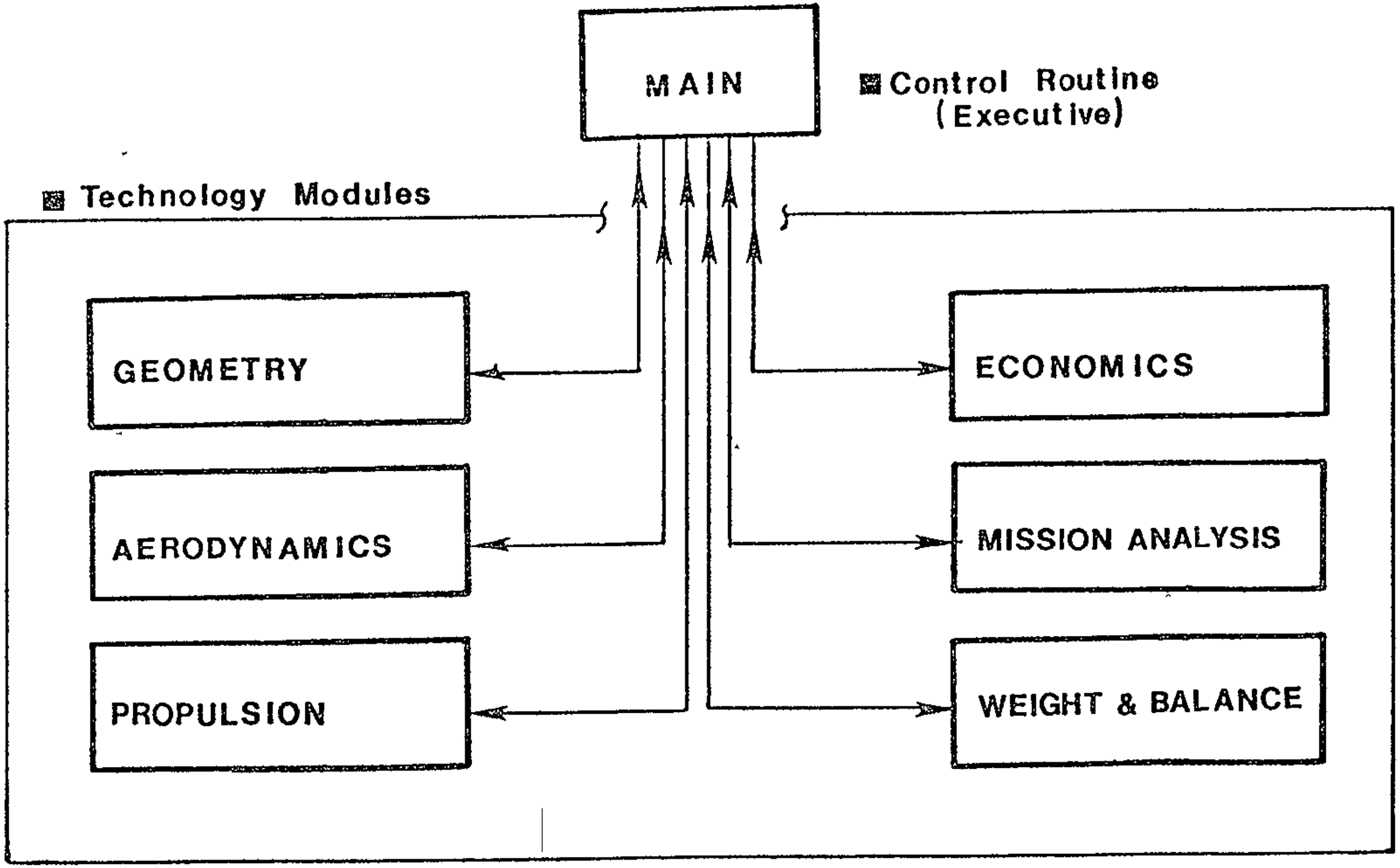


FIGURE 1. GASP MODULE FLOW CHART

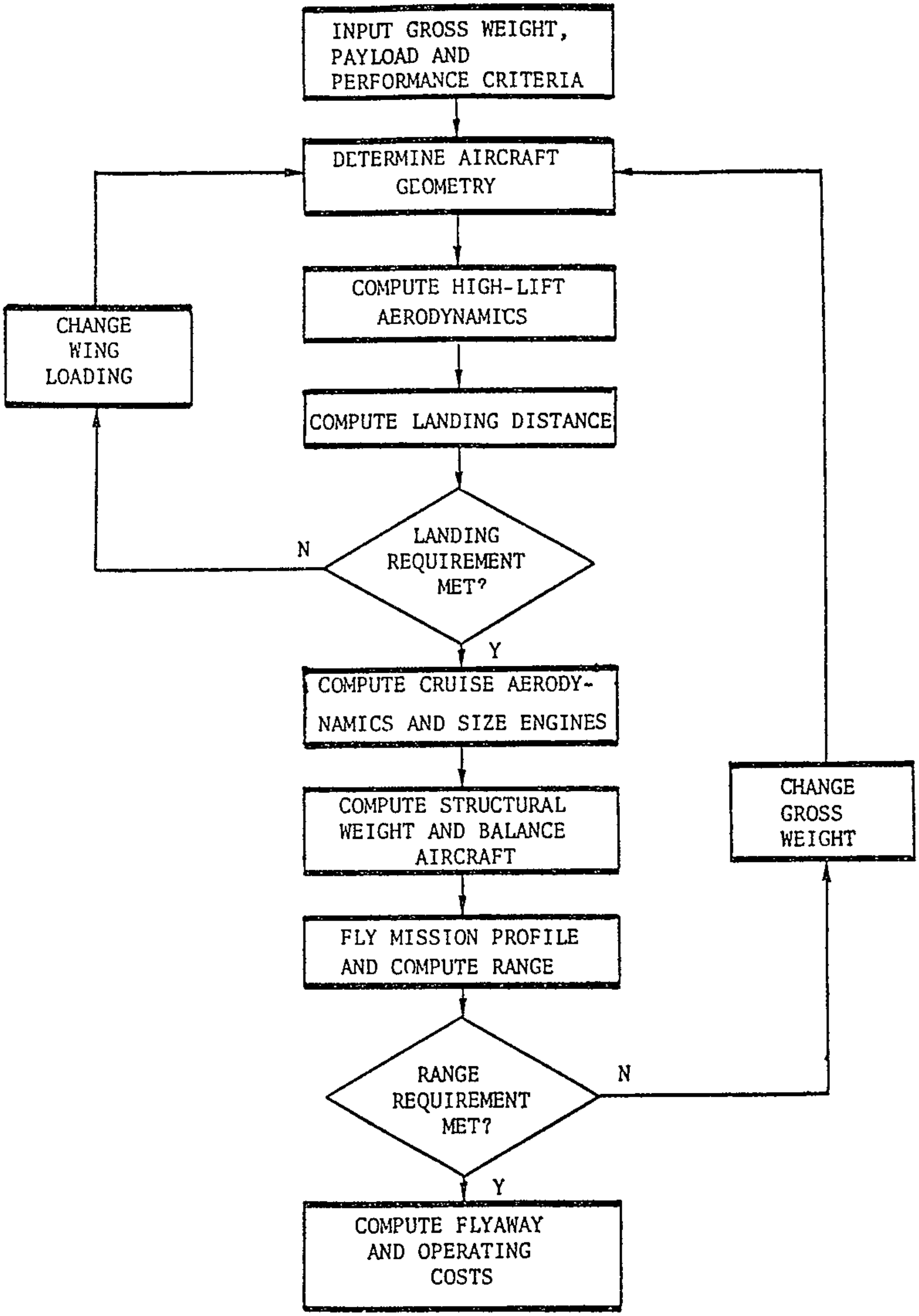


FIGURE 2. GASP CALCULATION FLOW CHART

4 2 Baseline Definition

The aircraft selected for the baseline of this study is representative of a current technology aircraft that will soon be entering commuter operations. It is a twin turboprop, low-wing, T-tail design with two crew and 19 passengers.

The basic mission is defined as a one leg mission with a max rate of climb to 10,000 foot altitude, cruise at normal power and descent with reserve fuel at full payload. Figure 3 depicts the complete mission profile.

This aircraft is defined in more detail in the following sections.

4.2.1 General Arrangement - Three-View

A three-view drawing of the baseline aircraft is shown in Figure 4 .

4.2.2 Inboard Profile

A drawing showing the general arrangement of the interior of the baseline aircraft is shown in Figure 5 .

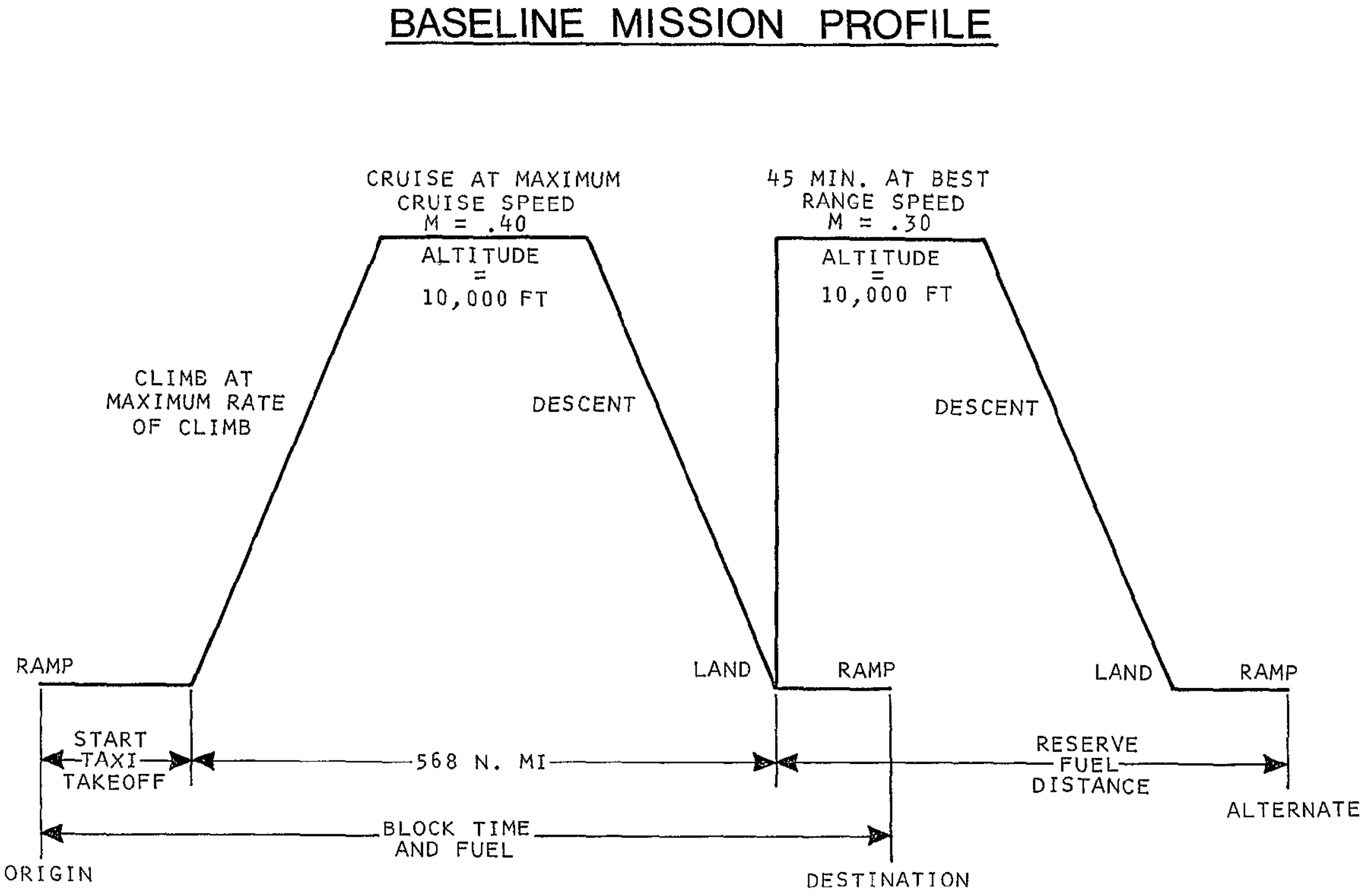

BASELINE MISSION PROFILE

Figure 3. Baseline Mission Profile

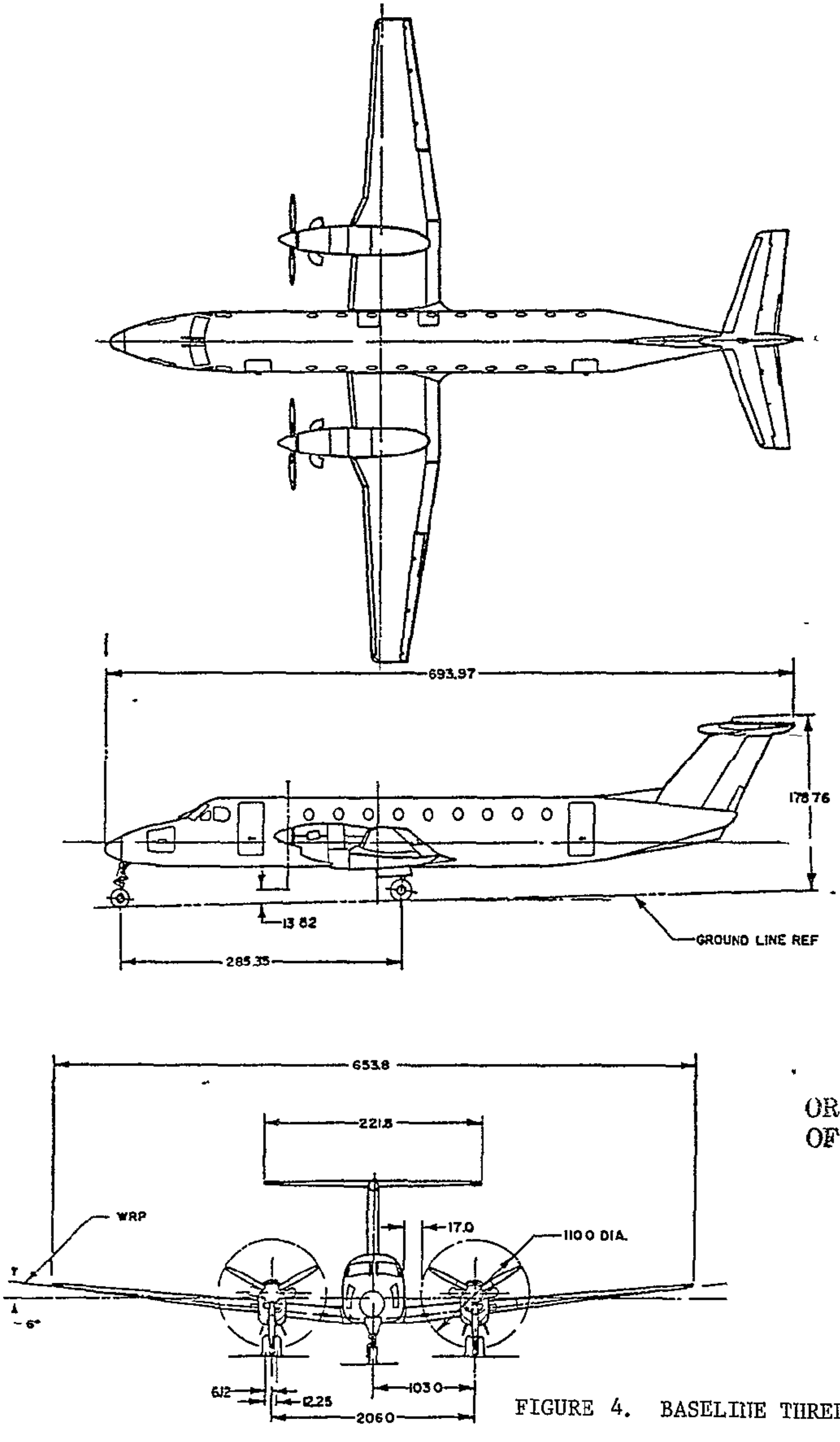
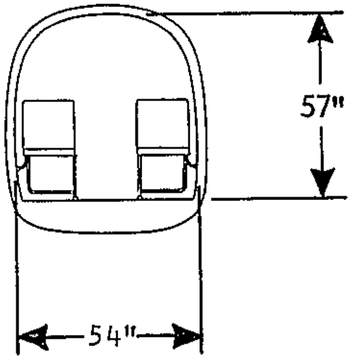


FIGURE 4. BASELINE THREE-VIEW

BASELINE SEATING ARRANGEMENT

19 PASSENGER

AISLE WIDTH	19"
SEAT PITCH	30"
SEAT WIDTH	16"
UNDER SEAT STORAGE	13"x18.5"x6"
PRELOADED BAGGAGE	6.2 cu. ft. per passenger



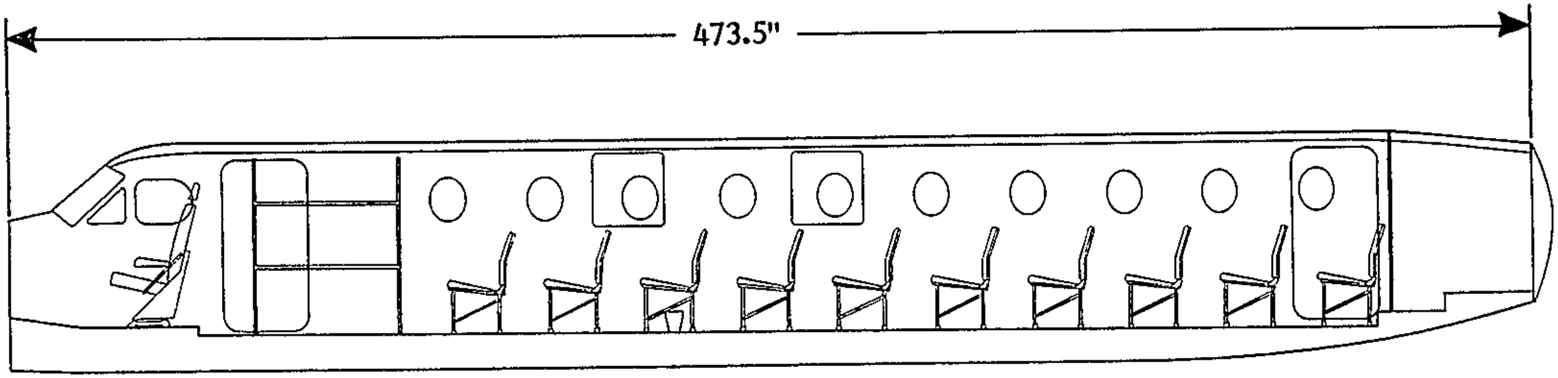


Figure 5. Baseline Inboard Profile

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.2 Baseline Definition (Cont'd.)

4 2.3 Characteristics

Maximum Ramp Weight			15,355 lbs.
Fuel for Start, Taxi, Run up			110 lbs.
Maximum Takeoff and Landing Weight			15,245 lbs.
Standard Empty Weight			8,400 lbs.
Useful Load			6,955 lbs.
Useable Fuel 426 Gal.			2,855 lbs
Payload			4,100 lbs.
19 Passengers @ 170 lbs.		3,230 lbs.	
Baggage		530 lbs.	
Pilot & Copilot		340 lbs.	
Baggage Stowage Volumes & Arrangement			118 ft.^{3}
Forward Nose Baggage	(Max 150 lbs.)	100 lbs.	14 ft.^{3}
Cabin Compartment Baggage	(Max 540 lbs.)	315 lbs.	48 ft.^{3}
Aft Compartment Baggage	(Max 630 lbs.)	115 lbs.	56 ft.^{3}
Nose Equipment Compartment	(Radios, etc.)		14 ft.^{3}
Aisle or Cabin Height			57 in.
Aisle Width (below 25" above floor)			18.3 in
(above 25" above floor)			19 in.
Seat Width			16 in.
Seat Pitch			30 in.

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.2 Baseline Definition (Cont'd)

4 2.4 Performance

Cruise Speed @ 10,000 ft.	263 kts.
Range at Max. CR Speed with Full Payload	555 NM
Engine Out Service Ceiling (50 FPM)	16,600 ft.
Terminal Area Speed Capability (Gear Down)	182 kts.
Stall Speed Landing $\delta_f = 35^o$	85 kts.
R/C 2 Engine FPM	2,280/S.L.
R/C 1 Engine RPM	490/S.L.
Service Ceiling 100 FPM 2 Engine	30,000 ft.
Landing Distance (15,245 lbs. max landing weight sea level, standard day over 50 ft.)	3,250 ft.
Takeoff Distance (15,245 lbs. sea level, standard day over 50 ft.)	3,088 ft.

Cockpit and Passenger Cabin Details·

170 lb passenger weight, 198 lb. passenger + baggage
2-man crew, no cockpit observer jump seat
No flight attendant (19 passengers)
57-inch (4.75 ft.) interior aisle height
30-inch seat pitch, 16-inch seat width (no armrests)
18 5 - 19 inch aisle width
10-inch garment stowage area @ .53 inches width/passenger
Underseat stowage for carry-on baggage of 13" x 18.5" x 6" per passenger
Easy loading of preloaded baggage @ 5.47 $ft.^3$/pass. interior, to 6.21 ft^3/pass. interior + exterior
No beverage service provision (optional)
No lavatory
Cabin pressurization - 4.8 psi

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.3 Baseline Match With GASP

Matching of baseline parameters to GASP is done in a four-step procedure outlined below.

4.3.1 Geometry

Geometric parameters are input as length/diameter ratios for the fuselage and thickness/chord ratio for the wing and empennage. These parameters are varied until the values match the baseline geometry. Figure 6 presents the GASP output for the baseline geometry with the actual values written in for comparison.

4.3.2 Aerodynamics and Propulsion

Aerodynamic matching is accomplished by matching of the airplane drag polar at the takeoff, climb and cruise conditions. Profile drag is matched by inputting form factors for the various components of the aircraft such as wing, fuselage, nacelle, horizontal tail and vertical tail. Profile drag of the wing as a function of lift coefficient is also input. Figure 7 presents the GASP output for the baseline aerodynamics with actual values written in for comparison.

High lift device lift and drag are calculated as incremental values to the basic drag polar. These calculations are based on the methodology of Reference 2. The various types of high lift devices are referenced to a reference wing and the lift and drag increments are modified by correction factors dependent on the wing geometry being analyzed. Figure 8 presents the flap performance summary of the GASP output.

Engine input is in the form of tables of corrected engine data for various flight conditions Propeller data are input in the form of number of blades, activity factor, integrated lift coefficient rotational speed and diameter. GASP uses Hamilton Standard methods

```
          SMALL TRANSPORT AIRCRAFT BASELINE, 1981

GROSS WEIGHT =    15555.        PASSENGERS =  19. PLUS CREW

FUSELAGE       LENGTH                (ELF)          51.82    FT     54.24
               WIDTH                 (SWF)           5.55    FT     5.13
               WETTED AREA           (SF)           773.     SQFT   763.
               DELTA P               (DELP)          4.60    PSI    4.8

WING           ASPECT RATIO          (AR)            9.80             9.8
               AREA                  (SW)          303.0     SQFT   303.
               SPAN                  (B)            54.5     FT     54.5
               GEOM. MEAN CHORD      (CBARW)         5.88    FT
               QUARTER CHORD SWEEP(DLMC4)            0.0     DEG
               TAPER RATIO           (SLM)           0.416
               ROOT THICKNESS        (TCR)           0.160
               TIP THICKNESS         (TCT)           0.113
               WING LOADING          (WGS)          50.7     PSF
               WING FUEL VOLUME      (VFW)         661.8     GAL

HOR. TAIL      ASPECT RATIO          (ARHT)          5.00             5.0
               AREA                  (SHT)          68.0     SQFT   67.99
               SPAN                  (BHT)          18.44    FT     18.44
               MEAN CHORD            (CBARHT)        3.82    FT     3.82
               THICKNESS/CHORD       (TCHT)          0.100
               MOMENT ARM            (ELTH)         30.9     FT     30.9
               VOLUME COEFF.         (VBARH)         1.181            1.181

VERT. TAIL     ASPECT RATIO          (ARVT)          1.18             1.18
               AREA                  (SVT)          48.7     SQFT   48.75
               SPAN                  (BVT)           7.59    FT     7.59
               MEAN CHORD            (CBARVT)        6.53    FT     6.53
               THICKNESS/CHORD       (TCVT)          0.120
               MOMENT ARM            (ELTV)         26.5     FT     26.5
               VOLUME COEFF.         (VBARV)         0.078            078

ENG.NACELLES   LENGTH                (ELN)          12.20    FT     10.91
               MEAN DIAMETER         (DBARN)         3.11    FT     3.11
               NUMBER ENGINES        (ENP)           2.0              2.0
               WETTED AREA           (SN)          226.40    SQFT   147.56
               LOCATION              8.6 FT. FROM A/C CENTERLINE      8.6

ENGINE         POWER/ENGINE          (HPMSLS)      1163.     SHP
               STATIC THRUST/WT.     (TOW)           0.376

PROPELLER      DIAMETER              (DPROP)         9.17    FT
               RPM                   (PRPM)        1700.
               MAX. TIPSPEED         (TIPSPD)       816.     FPS
               NO. BLADES            (BL)            3.
               ACT.FACT./BLADE       (AF)          110.0
               INT.LIFT COEFF.       (CLI)           0.500
```

FIGURE 6. GASP BASELINE GEOMETRY COMPARISON

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          SMALL TRANSPORT AIRCRAFT BASELINE, 1981

CRUISE MACH = 0.300          CRUISE ALTITUDE =  10000.          CRUISE Q (PSF) = 91.83

CRUISE RE.NUM. PER FT.   = 1.606E 06    FLATPLATE CF AT RE=10EX7 IS 0.00269

AERODYNAMIC DATA

                          FLATPLATE                 WETTED
DRAG BREAKDOWN            AREA(SQFT)      CDO      AREA(SQFT)

     WING                   2.0921      0.00691      521.32     568.7
     FUSELAGE               2.3192      0.00765      772.56     762.8
     VERT.TAIL              0.3202      0.00106       97.49     108.9
     HOR. TAIL              0.4713      0.00156      135.97     138.3
     ENGINE NAC.            0.8692      0.00287      256.40     147.56
     TIP TANKS              0.0         0.0            0.0
     INCREMENTAL            4.9366      0.01630        0.0       23.23

         TOTAL             11.0105      0.03634     1765.75     1742.5

         MEAN SKIN FRICTION COEF.= 0.006236

AERODYNAMIC COEFF.
    A1                                                 0.7067
    A2                                                -0.1159
    A3                                                 0.0669
    A4=.75X(T/C)                                       0.1162
    A5=CDO--                                           0.0294
    A6                                                 2.5883
    A7=1/(PI.SEE.AR)                                   0.0463
    3-D LIFT SLOPE AT CRUISE MACH        (CLALPH)      5.3264     PER RADIAN
    OSWALD FACTOR                        (SEE)         0.7016

CRUISE CD = 0.0363 +  0.0463 CL2  (ASSUMES MINIMUM WING PROFILE DRAG)

RETRACTABLE LANDING GEAR CD INC.=0.02359

LOW SPEED LIFT/DRAG-GR.UP(IF R)D.G.E.
                             FLAPS UP                               TAKEOFF                                 LANDING
      ALPHA        CL         CD         L/D         CL         CD         L/D         CL         CD         L/D
   -2.00000    0.01111    0.03617    0.30730    0.47222    0.06003    7.86635    0.79129    0.10147    7.79840
    0.0        0.19183    0.03799    5.04970    0.65294    0.06681    9.77339    0.97201    0.11001    8.83591
    2.00000    0.37255    0.04283    8.69741    0.83565    0.07668   10.87215    1.15273    0.12192    9.45457
    4.00000    0.55327    0.05070   10.91160    1.01437    0.08967   11.31205    1.33344    0.13724    9.71623
    6.00000    0.73398    0.06162   11.91169    1.19509    0.10579   11.29665    1.51416    0.15596    9.70662
    8.00000    0.91470    0.07560   12.09964    1.37580    0.12504   11.00330    1.69488    0.17808    9.51773
   10.00000    1.09542    0.09264   11.82435    1.55652    0.14741   10.55904    1.87560    0.20339    9.21250
```

FIGURE 7. GASP BASELINE DRAG COMPARISON

```
**************************************************************************************************

                     FLAP PERFORMANCE SUMMARY (OUT OF GROUND EFFECT)
                 CLMAX      VSTALL,KTS  FLAP ANGLE   LE ANGLE     DELTA CL     DELTA CD

FLAPS UP         1.2952 1.296  107.6 107.   0.0          0.0      0.0          0.0
T.O. CONFIG      1.7404 1.754   92.9  92.  15.0          0.0      0.4611       0.0194
LDG. CONFIG      2.0460 2.046   85.7  85.  35.0          0.0      0.7602       0.0563

                   SINGLE SLOTTED FLAPS
                  OPT ANGLE     DELCL AT OPT    DELCD AT OPT     AREA(FT2)      WEIGHT(LB)

FLAPS               40.0          0.9860          0.1400           45.4            78.7
**************************************************************************************************
```

FIGURE 8. GASP BASELINE FLAP CONFIGURATION

as described in NASA CR-2066 to calculate propeller efficiency through generalized propeller performance tables. Corrections are applied to account for differences between the reference geometry and the input geometry. Engine power, SFC and propeller efficiency were matched within 1%.

4.3 3 Weights

Weights of the aircraft are divided into several groups, propulsion group, structures group and flight controls group. Fixed equipment, fixed useful load, payload and fuel complete the components of the total gross weight. Weight coefficients in the weight trend equations are adjusted to define weights closely matched to the baseline. Figure 9 presents the GASP output of the group weight statement.

4.3.4 Performance

Matching of the performance was mainly concerned with cruise speed and range matching. Takeoff and landing distances are paced by the matched low speed drag polars. Accelerate-stop distance is within 5% and landing distance is within 1%. A slightly higher takeoff and landing max gross weight due to differences in GASP calculations was used for these values (Figures 10 and 11). In GASP ramp weight is used for the max landing weight. Also two landing distances are calculated in GASP, one without idle thrust in the ground run and one with idle thrust in the ground run. Since the preliminary design method used in the baseline calculation does not provide for idle thrust, in GASP it is matched to the first landing distance calculation. Due to the ground maneuvering time constraint applied to the DOC calculations (See Section 4.3.5), the taxi and takeoff fuel allowance is slightly less than the original baseline allowance.

```
          SMALL TRANSPORT AIRCRAFT BASELINE, 1981

VDIVE =  322. KTS   VMO =  275. KTS   MMO = 0.562
ULT. LF =  6.60   MAN. LF =  4.40   GUST LF =  2.91

PROPULSION GROUP
   PRIMARY ENGINES              (WEP)         971.
   PRIMARY ENGINE INSTL.        (WPEI)        166.
   FUEL SYSTEM                  (WFSS)        315.
   PROPULSOR WEIGHT             (WPROP)       330.
   TOTAL PROP.GROUP WT.         (WP)         1782.

STRUCTURES GROUP
   WING                         (WW)         1200.
   HOR. TAIL                    (WHT)         164.
   VERT. TAIL                   (WVT)         140.
   FUSELAGE                     (WF)         1704.    (INCL.    0.0 LBS A.T.W.)
   LANDING GEAR                 (WLG)         631.
   PRIMARY ENG. SECTION         (WPES)        383.
   GROUP WEIGHT INC.            (DELWST)        0.
   TOTAL STRUC.GROUP WT.        (WST)        4221.

FLIGHT CONTROLS GROUP
   COCKPIT CONTROLS             (WCC)          34.
   FIXED WING CONTROLS          (WCFW)        201.
   SAS                          (WSAS)          0.
   GROUP WEIGHT INC.            (DELWFC)        0.
   TOTAL CONTROL WT.            (WFC)         235.

WT. OF FIXED EQUIPMENT          (WFE)        2162.

WEIGHT EMPTY                    (WE)         8400.

FIXED USEFUL LOAD               (WFUL)        870. (INC. CREW )

OPERATING WEIGHT EMPTY          (OWE)        9270.

PAYLOAD                         (WPL)        3230. (PAX.VOL.= 19.    DESIGN PAX= 19.)

FUEL                            (WFA)        2855. (WFW= 2855.) (WFTP=    0.)

GROSS WEIGHT                    (WG)        15355.
```

FIGURE 9.   GASP BASELINE WEIGHTS

```
************************************************************************************************************
            TEMP.=  518. DEG.STD.+ 0.
  LANDING ELEVATION=    0. FT.
  LANDING WING LOADING=  50.62 PSF.
  LANDING WEIGHT =    15355. LBS.

  LANDING DISTANCE FROM 50. FT.=   3270. FT.   3257 FT.

  F.A.R. FACTORED FIELD LENGTH =   5450. FT.

                    APPROACH                TRANSITION                 DELAY                   ROLL

                 DIST=         978.     DIST=          66.     DIST=          499.     DIST=        1727.
                 R/S=          575.     XLFMX=       1.200     TDELAY=        3.00     MUB=       0.2500
                 VAPEAS=     111.09     SINKTD=      3.000     TIDLE=           0.     TR/TIDLE=  0.0
                 VAPTAS=     111.17     VSTEAS=      65.40     VTDTAS=       98.34     ABAR(G)=   0.2482
                 THETA=        2.93     CLMX=       2.0460
                 THRUST=      1127.     HFLAR=         6.4
************************************************************************************************************
```

FIGURE 10. GASP BASELINE LANDING DISTANCE

4.3.4 Performance (Cont'd.)

Time, fuel and distance in climb are matched, but rate of climb is lower in GASP (Figure 11). This is apparently due to drag polar calculation differences in climb and in the calculation of propeller efficiency resulting in lower thrust and drag. Total range is matched within 2.3% including descent credit not taken in the baseline range calculated with Beech preliminary design methods (Figure 12).

4.3.5 Initial and Direct Operating Costs

Initial and direct operating costs are calculated in GASP using a computer routine provided by NASA Ames. The methods are based on SAWE papers 1071 and 1098 with modifications (References 3 and 4). A summary of the equations used is presented in Table 1 . Direct Operating Cost (DOC) assumptions for this study are listed in Table 2 .

In the calculation of initial cost, airframe cost is computed within the GASP whereas engine and propeller costs are input as dollars/SHP and dollars/lb, respectively

GASP computed results are shown in Figure 13. The $/block hour DOC's are matched within 1%.

```
  36.0  4927.0    92.1  15262.    28.0  110.8   110.8 0.167    0.01 1.1906 0.1510   5.96   0.80    158.9  1.00    2131.      642.  5.70
  37.0  5114.1    92.3  15262.    30.8  110.8   110.8 0.167    0.02 1.1903 0.1514   5.96   0.77    150.2  1.00    2131.      642.  5.73
  38.0  5301.2    92.4  15262.    33.0  110.8   110.8 0.167    0.00 1.1988 0.1526   6.06   0.75    146.3  1.00    2131.      642.  5.81
DISTANCE TO 35 FT.=    5452.4     TAS=    110.8 EAS=    110.8 V35/VS=   1.1987
  39.0  5488.3    92.6  15262.    35.5  110.8   110.8 0.167    0.03 1.1895 0.1520   5.96   0.73    142.4  0.99    2131.      642.  5.69
  40.0  5675.4    92.8  15262.    37.8  110.8   110.8 0.167    0.00 1.1982 0.1531   6.06   0.72    141.1  1.00    2131.      642.  5.78
  41.0  5862.6    93.0  15261.    40.2  110.8   110.8 0.167    0.02 1.1691 0.1525   5.96   0.71    139.5  0.99    2130.      642.  5.67
  42.0  6049.8    93.2  15261.    42.5  110.8   110.8 0.167    0.02 1.1890 0.1526   5.96   0.70    136.9  0.99    2130.      642.  5.66
  43.0  6236.9    93.5  15261.    44.7  110.8   110.8 0.167    0.00 1.1979 0.1536   6.06   0.69    135.8  1.00    2130.      642.  5.75
  44.0  6424.1    93.5  15261.    47.0  110.8   110.8 0.167    0.00 1.1978 0.1538   6.06   0.69    134.5  1.00    2130.      642.  5.75
  45.0  6611.3    93.7  15261.    49.2  110.9   110.8 0.167    0.00 1.1978 0.1539   6.06   0.68    133.1  1.00    2130.      642.  5.74

    ACCELERATE - STOP DISTANCE =    4526.6 FEET.    4333 FT.

   ENGINE OUT DISTANCE TO 35 FT.=     5452.4 FEET

 ALL ENGINE DISTANCE TO 35 FT. (L) =      3383.1 FEET
 FAR 25 T.O. DISTANCE (1.15XL) =       3890.5 FEET
 ALL ENGINE DISTANCE TO 50 FT. =       3579.3 FEET    3088 FT.

   AT END OF TAKEOFF PHASE
 TIME=  0.182 HRS   FUEL USED=       97. LBS   WEIGHT=   15257. LBS   ALT.=     500. FT.

   ACCELERATE TO MACH NO. =0.209

                    FUEL                                                                   FUEL
  TIME    RANGE     USED     WEIGHT    ALT.     TAS    EAS     MACH  MACH     THRUST       FLOW
  (HRS)   (NM)     (LBS)     (LBS)     (FT)    (KTS)  (KTS)     NO.   DIV      (LBS)      (LB/HR)

  0.182    0.0      97.0    15257.     500.    131.    130. 0.199 0.605     3867.      1273.
  0.182    0.09     98.1    15256.     500.    138.    137. 0.209 0.614     3778.      1272.

  END OF ACCELERATION SEGMENT
  TIME= 0.182 HRS   FUEL USED=    98.1 LBS   WEIGHT=  15256. LBS   RANGE=    0. NM

    CLIMB TO   10000. FT. AT MAXIMUM RATE OF CLIMB

                    FUEL                                                                                   FUS.                              FUEL
  TIME    RANGE     USED     WEIGHT    ALT.     TAS    EAS     MACH   MACH     CL      CD     ALPHA GAMMA ANGLE    R/C     THRUST       FLOW
  (HRS)   (NM)     (LBS)     (LBS)     (FT)    (KTS)  (KTS)     NO.    DIV                    (DEG) (DEG) (DEG)   (FPM)    (LBS)      (LB/HR)        η
                             15245      500    142.5  142.5                  .7805  .0682   5.60  8.97  13.57    2280     3804.                   .789
 INTEGRATED DESIGN CL ADJUSTMENT NOT WORKING PROPERLY FOR CT DEFINITION
 INTEGRATED DESIGN CL ADJUSTMENT NOT WORKING PROPERLY FOR CT DEFINITION
  0.182      0.       98.   15256.     500.    138.    137. 0.209 0.616 0.7839 0.0652  6.48   6.52 12.00   1591.    2983.     1083.          .75
  0.188      1.      104.   15251.    1000.    139.    137. 0.211 0.616 0.7836 0.0651  6.47   6.53 12.00   1604.    3027.     1073.
  0.198      2.      115.   15240.    2000.    141.    137. 0.215 0.616 0.7830 0.0651  6.46   6.54 12.00   1631.    3029.     1070.
  0.208      4.      126.   15229.    3000.    143.    137. 0.219 0.616 0.7824 0.0651  6.45   6.55 12.00   1658.    3031.     1069.
  0.218      5.      137.   15218.    4000.    146.    137. 0.223 0.616 0.7818 0.0650  6.43   6.57 12.00   1687.    3034.     1070.
  0.228      7.      147.   15207.    5000.    148.    137. 0.227 0.616 0.7813 0.0650  6.42   6.58 12.00   1716.    3042.     1074.
  0.235      8.      158.   15197.    6000.    150.    137. 0.231 0.616 0.7807 0.0649  6.41   6.59 12.00   1745.    3050.     1077.
  0.247      9.      168.   15187.    7000.    152.    137. 0.236 0.616 0.7801 0.0649  6.39   6.61 12.00   1776.    3052.     1080.
  0.257     11.      178.   15177.    8000.    155.    137. 0.240 0.616 0.7799 0.0649  6.38   6.36 11.74   1735.    2989.     1058.
  0.266     12.      188.   15166.    9000.    157.    137. 0.245 0.616 0.7800 0.0649  6.35   5.98 11.36   1659.    2868.     1030.
  0.276     14.      198.   15156.   10000.    160.    137. 0.250 0.616 0.7799 0.0649  6.37   5.61 10.98   1581.    2769.     1001.

    END OF CLIMB TO    10000. FT
 TIME=  0.276 HRS   FUEL USED=     198. LBS   WEIGHT=   15156. LBS   RANGE=      14. NM  R/C AT 10000. FT = 1581. FPM

 ALTITUDE=       10000. FT     TAS=      262.94 KTS    MACH NO=       0.4115
 EXTRAPOLATION NOT PERMITTED (UPPER) 10000.000     0.0      465.025      0.412    262.651     961.983    912.686    521.612     45.119
```

FIGURE 11. GASP BASELINE TAKEOFF DISTANCE COMPARISON

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                                             DESIGN CASE
                                             CRUISE PERFORMANCE SUMMARY
                                                        FOR
                                             ***** DESIGN PAYLOAD *****
                                             **** MAXIMUM PAYLOAD *****
                                             FUEL AVAILABLE=    2855.

                               AT                         AT                        AT
                         SPECIFIED SPEED           NORMAL POWER           BEST SPEC. RANGE
                          START     END            START     END           START     END
                          CRUISE    CRUISE         CRUISE    CRUISE        CRUISE    CRUISE
                          -------   -------        -------   -------       -------   -------
 TIME            HRS.      0.0       0.0            0.304     2.328         0.281     3.476
 RANGE           N.MI        0.         0.            20.      552.           15.      638.
 FUEL USED       LBS.        0.         0.           250.     2314.          203.     2303.
 WEIGHT          LBS.        0.         0.         15124.    13040.        15151.    13051.
 ALTITUDE        FT.         0.         0.         10000.    10000.        10000.    10000.
 TAS             KTS.       0.0        0.0          262.9     262.9         194.9     194.9
 EAS             KTS.       0.0        0.0          226.0     226.0         167.5     167.5
 MACH NO.                 0.0       0.0            0.4115    0.4115        0.3051    0.3051
 DIV. MACH                0.0       0.0            0.6752    0.6778        0.6456    0.6541
 ANGLE ATTACK    DEG.      0.0       0.0            0.879     0.463         3.541     2.756
 FUSE. ANGLE     DEG.      0.0       0.0           -0.121    -0.537         2.541     1.756
 CL                       0.0       0.0            0.2893    0.2492        0.5272    0.4542
 L/D                       0.0       0.0            7.398     6.543        10.690     9.683
 FUEL FLOW       LB/HR      0.0        0.0         1042.7    1020.7         671.5     644.8
 BREG. FACTOR    N.MI.       0.         0.          3816.     3361.         4401.     3948.
 SPEC. RANGE     NM/LB  0.0       0.0              0.25217   0.25760       0.29029   0.30233

 DESCENT FROM CRUISE AT NORMAL POWER CONDITION

                    FUEL                                                                           FUS.                         FUEL
 TIME    RANGE      USED     WEIGHT    ALT.     TAS    EAS    MACH  MACH    CL       CD    ALPHA GAMMA  ANGLE     R/S    THRUST    FLOW
 (HRS)   (NM)      (LBS)     (LBS)     (FT)    (KTS)  (KTS)    NO.   DIV                  (DEG) (DEG)  (DEG)    (FPM)   (LBS)   (LB/HR)

 2.334    554.     2318.    13037.   10000.    248.    213. 0.388 0.675 0.2772 0.0398  0.78 -5.78 -6.00     2532.    550.     483.  A
 2.341    556.     2321.    13033.    9000.    244.    213. 0.381 0.675 0.2769 0.0398  0.78 -5.78 -6.00     2495.    551.     496.  A
 2.348    557.     2324.    13030.    8000.    241.    213. 0.374 0.675 0.2766 0.0398  0.79 -5.79 -6.00     2460.    551.     509.  A
 2.355    559.     2328.    13026.    7000.    237.    213. 0.367 0.675 0.2764 0.0398  0.79 -5.79 -6.00     2425.    551.     522.  A
 2.362    561.     2332.    13023.    6000.    233.    213. 0.359 0.675 0.2778 0.0399  0.81 -5.81 -6.00     2391.    539.     532.  A
 2.369    562.     2335.    13019.    5000.    229.    212. 0.351 0.674 0.2791 0.0399  0.84 -5.84 -6.00     2357.    527.     542.  A
 2.376    564.     2339.    13015.    4000.    225.    212. 0.344 0.674 0.2804 0.0399  0.86 -5.86 -6.00     2325.    515.     550.  A
 2.383    565.     2343.    13011.    3000.    221.    211. 0.337 0.674 0.2816 0.0400  0.88 -5.88 -6.00     2292.    504.     557.  A
 2.390    567.     2348.    13007.    2000.    217.    211. 0.330 0.674 0.2830 0.0400  0.90 -5.90 -6.00     2261.    491.     564.  A
 2.394    568.     2350.    13005.    1500.    215.    210. 0.327 0.674 0.2839 0.0400  0.91 -5.91 -6.00     2245.    464.     568.  A

    END OF DSCNT TO      1500. FT
TIME=  2.394 HRS    FUEL USED=     2350. LBS    WEIGHT=    13005. LBS    RANGE=     568. NM
```

555 NM

```
      RESERVE FUEL(LBS)           0.                  505.                  505.
        (FIXED AMT.)

 ***************************************************************************

      RANGE =  568.    BLOCK TIME= 2.394     USED FOR DESIGN RANGE AND COST

 ***************************************************************************

 ************************************************************************************

             TEMP.=  518. DEG°STD.+ 0.
   LANDING ELEVATION=     0. FT.
   LANDING WING LOADING=  50.66 PSF.
```

FIGURE 12. GASP BASELINE MISSION COMPARISON

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TABLE 1

DOC MODULE EQUATIONS

Aircraft Initial Cost

Total Aircraft Cost = 400.4 (weight of airframe)$^{.8936}$ x inflation factor + cost of engines + cost of propellers

Flying Operations

Flight Crew = (2.5 x no. of seats) x block time

Fuel, Oil and Taxes = fuel used x fuel cost ($/gal) x 1.045 x block time

Insurance = aircraft cost x percentage rate x block time/utilization hours per year

Direct Maintenance

Airframe Labor = labor rate x .0115 x airframe weight$^{.575}$ x block time

Airframe Material = .115 x airframe weight$^{.575}$ x block time

Engine Labor = labor rate x .00246 x SHP$^{.66}$ x block time x no. of engines

Engine Material = .0984 x SHP$^{.66}$ x block time x no. of engines

Total Airframe = airframe labor + airframe material

Total Engine = engine labor + engine material

Maintenance burden = percent burden rate x (airframe labor rate + engine labor)

Depreciation = aircraft cost x spares factor x (1 - residual) x block time/depreciation years/utilization hours

Total DOC = flight crew + fuel, oil and taxes + insurance + total airframe maintenance + total engine maintenance + maintenance burden + depreciation

DOC in cents per available seat per statute mile (¢/assm)

DOC = total DOC/no. of seats/stage length x 1.15

TABLE 2

DIRECT OPERATING COST GROUND RULES

1. 1981 dollars
2. Utilization - 2800 hrs.
3. Crew Cost - 2.5 x 19 = $47.50/blk. hr.
4. Fuel Cost - $1.75/gal. 1981

   - $3.50/gal. 1990
5. Maintenance Labor and Burden -

   Based on study of comparable aircraft

   Labor Rate = $13/hr.

   Burden Rate = 80% Labor Cost
6. Insurance - 1.5%/year of total aircraft price
7. Spares factor - 6% of total aircraft price
8. Depreciation - straight line over 12 years to 15% residual value
9. Nonproductive maneuvering time - 10 minutes
10. Block time = flight time + 10 minutes

```
                                   --- COST DATA ---
                                GASP SHORTHAUL METHOD
                    ENGINES       NUMBER =      2.  TYPE=      0                    TOTAL MAN. TIME= 10.9 MIN.
 EMPTY WEIGHT=  8400.     AIRFRAME WEIGHT=  7099.     WEIGHT OF 1 ENGINE=   486.     CRUISE SPEED= 264. KTS
 HORSEPOWER/ENGINE=    1163.
 TOTAL AIRCRAFT COST=  1805729.     AIRFRAME COST=  1450607.     COST OF 1 ENGINE=   170961.     COST OF 1 PROP.=      6600.
         DESIGN MISSION
              OPERATING COST FOR NOR.RATED POWER AND  10000. ALTITUDE
 ****************************************************************************************************
                    RANGE=      50. N.M.    BLOCK FUEL=      322. LBS    BLOCK TIME=  0.4250 HRS.

   UTILIZATION                                 2800.
 FLYING OPERATIONS
    FLIGHT CREW                               20.186
    FUEL,OIL,AND TAXES(1.750$/G)              67.969
    INSURANCE                                  4.111
 DIRECT MAINTENANCE
    AIRFRAME                                  18.417
    ENGINE                                    11.692
 MAINTENANCE BURD.                            10.622
 DEPRECIATION                                 20.577

   TOTAL DOC ($/TRIP)                        173.574
             ($/B.HR.)                       408.445
             ($/N.MI.)                         3.471
             (C/ASSM)                         15.868    ( 19. SEATS)

          REVNUE/PAX=      8.775 DOL.   TOTAL OPER.COST=   190.931 DOL.   IOC/DOC=    0.100     STEW= 0.
          YIELD=  15.561 C/RPSM         TOC BREAKEVEN PAX=  21.76    TOC BREAKEVEN L.F.= ****** PERCENT
                                        DOC BREAKEVEN PAX=  19.78    DOC BREAKEVEN L.F.= ****** PERCENT

 ****************************************************************************************************
                    RANGE=     100. N.M.    BLOCK FUEL=      516. LBS    BLOCK TIME=  0.6151 HRS.
                                                                        $3.50/Gal.
   UTILIZATION                                 2800.
 FLYING OPERATIONS                                                        29.215
    FLIGHT CREW                               29.216                     283.011
    FUEL,OIL,AND TAXES(1.750$/G)             141.526                       5.95
    INSURANCE                                  5.950
 DIRECT MAINTENANCE                                                       26.656
    AIRFRAME                                  26.656                      16.922
    ENGINE                                    16.923                      15.373
 MAINTENANCE BURD.                            15.375                      29.782
 DEPRECIATION                                 29.735
                                                                         406.909
   TOTAL DOC ($/TRIP)                        265.456                     661.576
             ($/B.HR.)                       431.520                       4.069
             ($/N.MI.)                         2.654                      18.623
             (C/ASSM)                         12.141    ( 19. SEATS)

          REVNUE/PAX=     17.560 DOL.   TOTAL OPER.COST=   291.979 DOL.   IOC/DOC=    0.100     STEW= 0.
          YIELD=  15.130 C/RPSM         TOC BREAKEVEN PAX=  16.76    TOC BREAKEVEN L.F.= 88.314 PERCENT
                                        DOC BREAKEVEN PAX=  15.25    DOC BREAKEVEN L.F.= 80.269 PERCENT

 ****************************************************************************************************
```

FIGURE 13. GASP BASELINE INITIAL AND OPERATING COSTS

```
                    RANGE=     200. N.M.    BLOCK FUEL=     909. LBS    BLOCK TIME=  0.9954 HRS.

   UTILIZATION                               2800.
FLYING OPERATIONS
   FLIGHT CREW                               47.265
   FUEL,OIL,AND TAXES(1.750$/G)             248.640
   INSURANCE                                  9.629
DIRECT MAINTENANCE
   AIRFRAME                                  43.140
   ENGINE                                    27.386
MAINTENANCE BURD.                            24.881
DEPRECIATION                                 48.200

   TOTAL DOC ($/TRIP)                       449.159
             ($/B.HR.)                      451.221
             ($/N.MI.)                        2.246
             (C/ASSM)                        10.276    ( 19. SEATS)

          REVNUE/PAX=    34.650 DOL.   TOTAL OPER.COST=   494.075 DOL.   IOC/DOC=   0.100    STEW= 0.
          YIELD=  15.065 C/RPSM        TOC BREAKEVEN PAX=  14.26   TOC BREAKEVEN L.F.= 75.048 PERCENT
                                       DOC BREAKEVEN PAX=  12.96   DOC BREAKEVEN L.F.= 68.225 PERCENT

   ******************************************************************************************

                    RANGE=     400. N.M.    BLOCK FUEL=    1693. LBS    BLOCK TIME=  1.7561 HRS.

   UTILIZATION                               2800.
FLYING OPERATIONS
   FLIGHT CREW                               83.413
   FUEL,OIL,AND TAXES(1.750$/G)             462.867
   INSURANCE                                 16.987
DIRECT MAINTENANCE
   AIRFRAME                                  76.105
   ENGINE                                    48.313
MAINTENANCE BURD.                            43.893
DEPRECIATION                                 85.031

   TOTAL DOC ($/TRIP)                       816.607
             ($/B.HR.)                      465.024
             ($/N.MI.)                        2.042
             (C/ASSM)                         9.345    ( 19. SEATS)

          REVNUE/PAX=    69.150 DOL.   TOTAL OPER.COST=   898.267 DOL.   IOC/DOC=   0.100    STEW= 0.
          YIELD=  15.025 C/RPSM        TOC BREAKEVEN PAX=  12.99   TOC BREAKEVEN L.F.= 68.369 PERCENT
                                       DOC BREAKEVEN PAX=  11.61   DOC BREAKEVEN L.F.= 62.154 PERCENT

   ******************************************************************************************

                    RANGE=     568. N.M.    BLOCK FUEL=    2350. LBS    BLOCK TIME=  2.3942 HRS.

   UTILIZATION                               2800.
FLYING OPERATIONS
   FLIGHT CREW                              113.725
   FUEL,OIL,AND TAXES(1.750$/G)             642.592
   INSURANCE                                 23.160
DIRECT MAINTENANCE
   AIRFRAME                                 103.766
   ENGINE                                    65.869
MAINTENANCE BURD.                            59.645
DEPRECIATION                                115.929

   TOTAL DOC ($/TRIP)                      1124.675
             ($/B.HR.)                      469.638
             ($/N.MI.)                        1.981
```

FIGURE 13. GASP BASELINE INITIAL AND OPERATING COSTS (Cont'd.)

```
        (C/ASSM)                       9.067    ( 19. SEATS)
          REVNUE/PAX=    98.094 DOL.   TOTAL OPER.COST=  1237.362 DOL.   IOC/DOC=   0.100     STEW= 0.
          YIELD=  13.023 C/RPSM        TOC BREAKEVEN PAX=  12.61   TOC BREAKEVEN L.F.= 66.390 PERCENT
                                       DOC BREAKEVEN PAX=  11.47   DOC BREAKEVEN L.F.= 60.333 PERCENT

  *****************************************************************************************
 ALTITUDE=       1000. FT   TAS=     252.79 KTS   MACH NO=      0.3831

 PROPELLER NOISE FOR  2. ENGINES AT  233.0 KTAS AND AT  1000.0 FEET
     REF.LEVEL= 93.23  DIA.AND BLADE CORT.=  3.68  DIST.CORR.= -6.02  NO.ENGINE CORR.=  3.01  PNL ADJUST=  3.20

  TOTAL=  97.09 PNDB  OR   85.09 DB(A)
```

FIGURE 13. GASP BASELINE INITIAL AND OPERATING COSTS (Cont'd.)

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies

Through independent studies, literature searches and consultations with NASA, promising advanced technologies have been identified. These technologies include laminar flow and low speed improved turbulent airfoils, composite structures, advanced turboprop engines, advanced propellers and active control systems.

4.4 1 Advanced Airfoils

4.4.1.1 Laminar Flow

Laminar flow on aircraft wings to achieve a low profile drag has been studied and applied for many years. A summary of past experiences is presented in Reference 30. Extensive laminar flow is dependent on accurate, wave-free surfaces free of roughness and other disturbances such as propeller slipstreams, insects, dirt and wing sweep Of course, rain, frost and ice are also detrimental to laminar flow achievement. These problems are covered more extensively in Reference 30.

A two-dimensional analysis of several airfoils was conducted as an independent study by Beech utilizing the Eppler Analysis Program (References 5 and 6). This computer program calculates the lift and drag characteristics of a given airfoil while checking upper and lower pressure gradients to determine separation points.

Airfoils considered were the NACA 23015 as a baseline, the NACA 65A415, the NASA Ames/STAT NLF and a fourth airfoil generated by Beech utilizing the COPES computer program (Reference 7).

This airfoil, shown in Figure 14, designated the Beech Advanced Laminar Airfoil, is designed with reduced aft loading and hinge moment constraints to provide minimum drag for each C_ℓ and to delay separation as long as possible. This airfoil has a lower drag over a wider C_ℓ range but has a reduced $C_{\ell_{max}}$ compared to the NASA Ames/STAT NLF airfoil shown in Figure 15.

4.4 Identification of Potential Technologies (Cont'd.)

4.4.1 Advanced Airfoils (Cont'd.)

4.4.1.1 Laminar Flow (Cont'd.)

Analysis of these airfoils was conducted at a Reynolds Number of 7.45 x 10^6 and transition was allowed to be determined by the computer program.

Figure 16 presents a comparison of the 2-D drag polars without a cruise flap. The Beech Advanced Turbulent airfoil is discussed in Section 4.4.1.2.

The NACA 23015 is the baseline airfoil with little laminar flow. Therefore, the minimum drag is relatively high, which increases the cruise drag. However, for a typical climb C_ℓ of .8 the drag is relatively low. The NACA 65A415 airfoil shows low minimum drag but the points of low drag are in a narrow range of C_ℓ's. The analysis program failed for the airfoil in the C_ℓ = .8 to 1.1 range indicating fully separated flow on the upper surface. The NASA Ames/STAT airfoil has a low minimum drag over a wider C_ℓ range than the NACA 23015 although at C_ℓ = .8 the drag is higher than the NACA 23015.

Figure 17 presents a comparison of the 2-D drag polars with the addition of a 30% chord ratio cruise flap which improved the drag for all airfoils while increasing $C_{\ell_{max}}$. Flap deflection was variable with C_ℓ according to a schedule set for each airfoil. The NASA Ames/STAT NLF airfoil has a definite advantage over the other airfoils and the results indicate a lower drag at climb C_ℓ's than at cruise C_ℓ's although low drag is maintained through the C_ℓ range up to a C_ℓ of 1.4 with flap deflections of -5° to $+34^\circ$. The Beech Advanced Laminar Flow airfoil gained little in reduced drag at the low C_ℓ's but did have substantial gains in C_d and $C_{\ell_{max}}$ for the higher C_ℓ's. If transition does occur early, the resultant drag is not as high nor does the $C_{\ell_{max}}$ decrease as much as the Ames/STAT NLF airfoil. This loss of laminar flow in the high C_ℓ region may be caused by the insect and dust problems discussed earlier and is a cause for concern in the use of natural laminar flow.

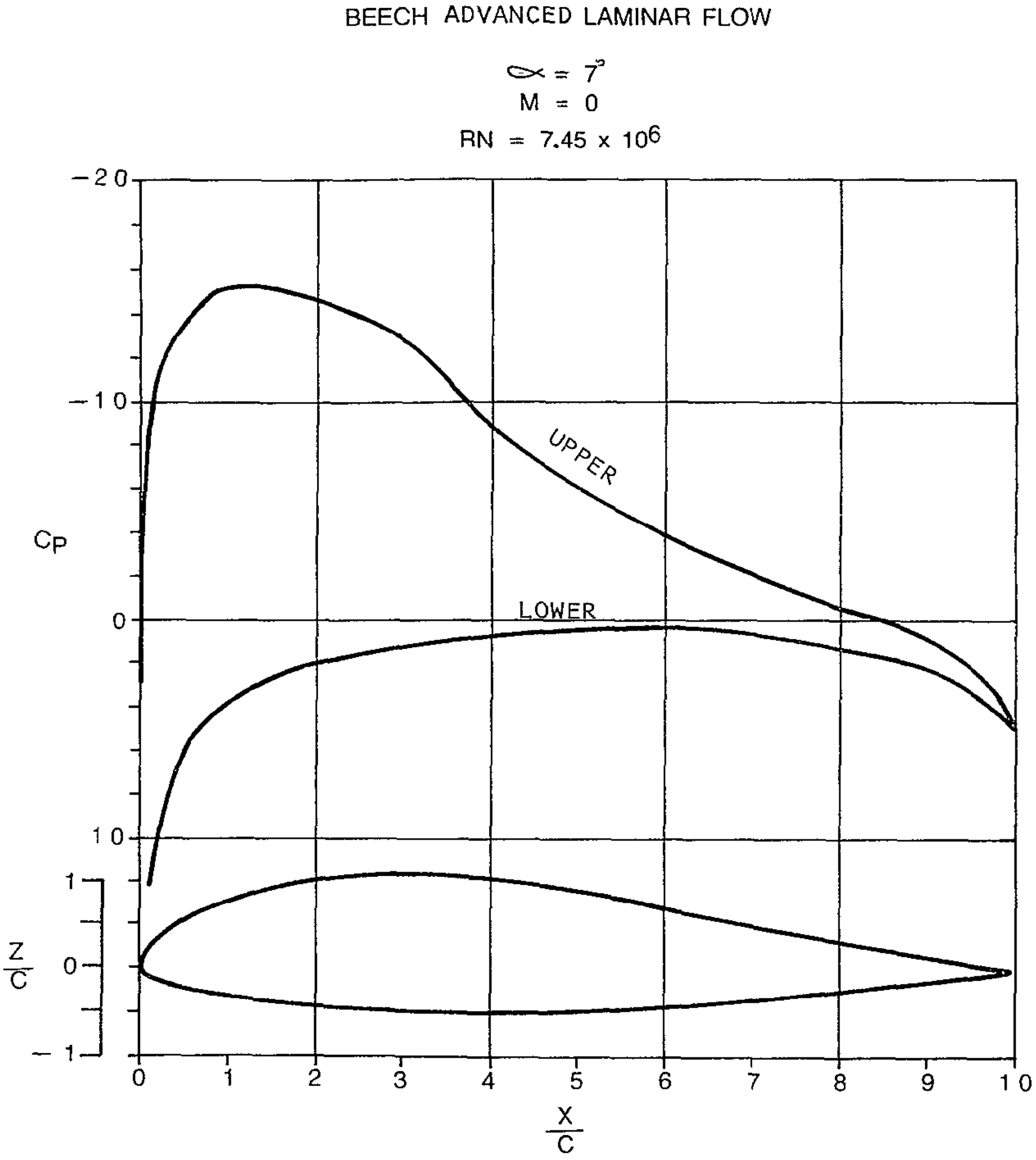


FIGURE 14 BEECH ADVANCED LAMINAR FLOW AIRFOIL PRESSURE DISTRIBUTION AND CONTOUR

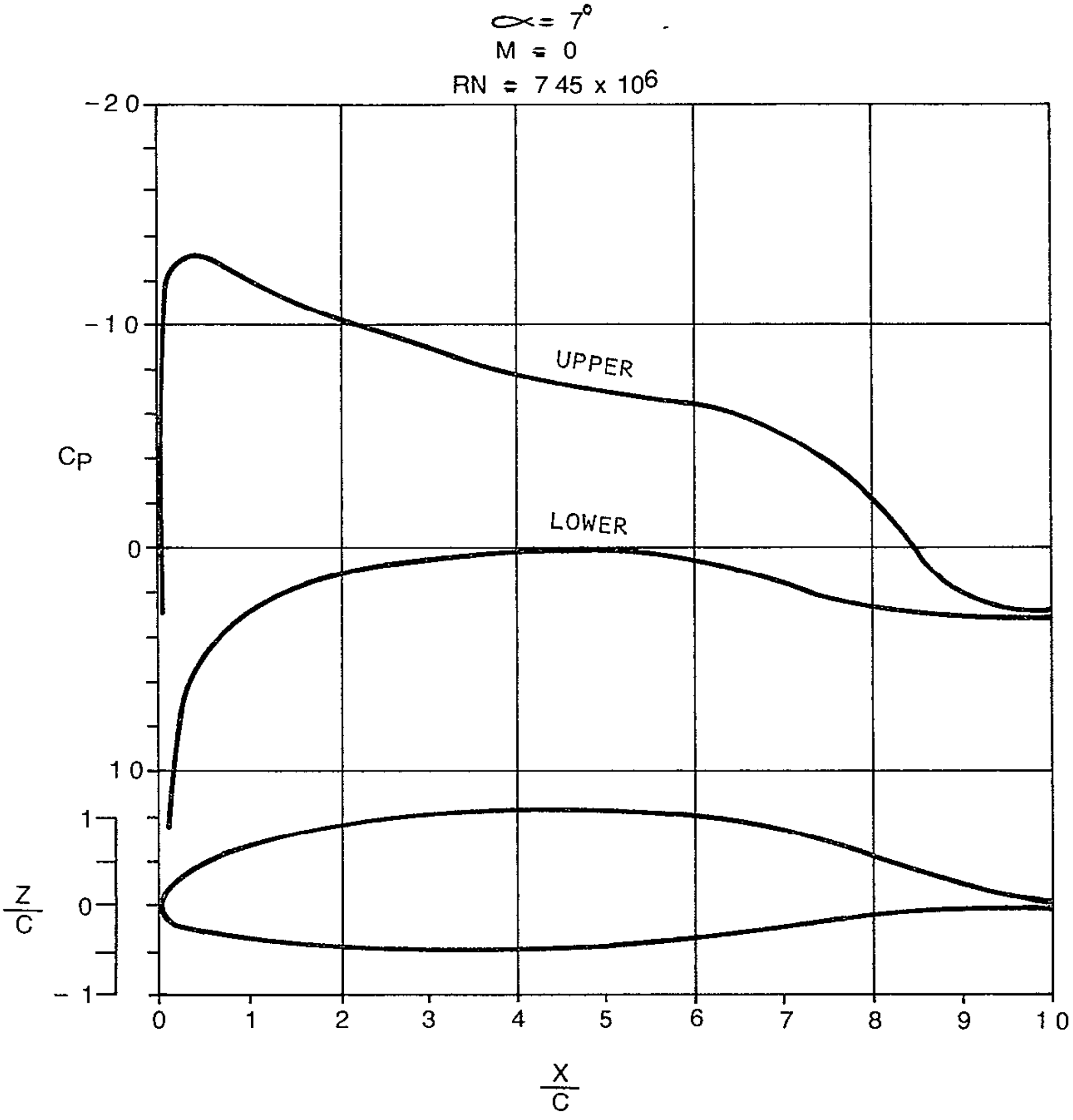


FIGURE 15 AMES/STAT NLF AIRFOIL PRESSURE DISTRIBUTION AND CONTOUR

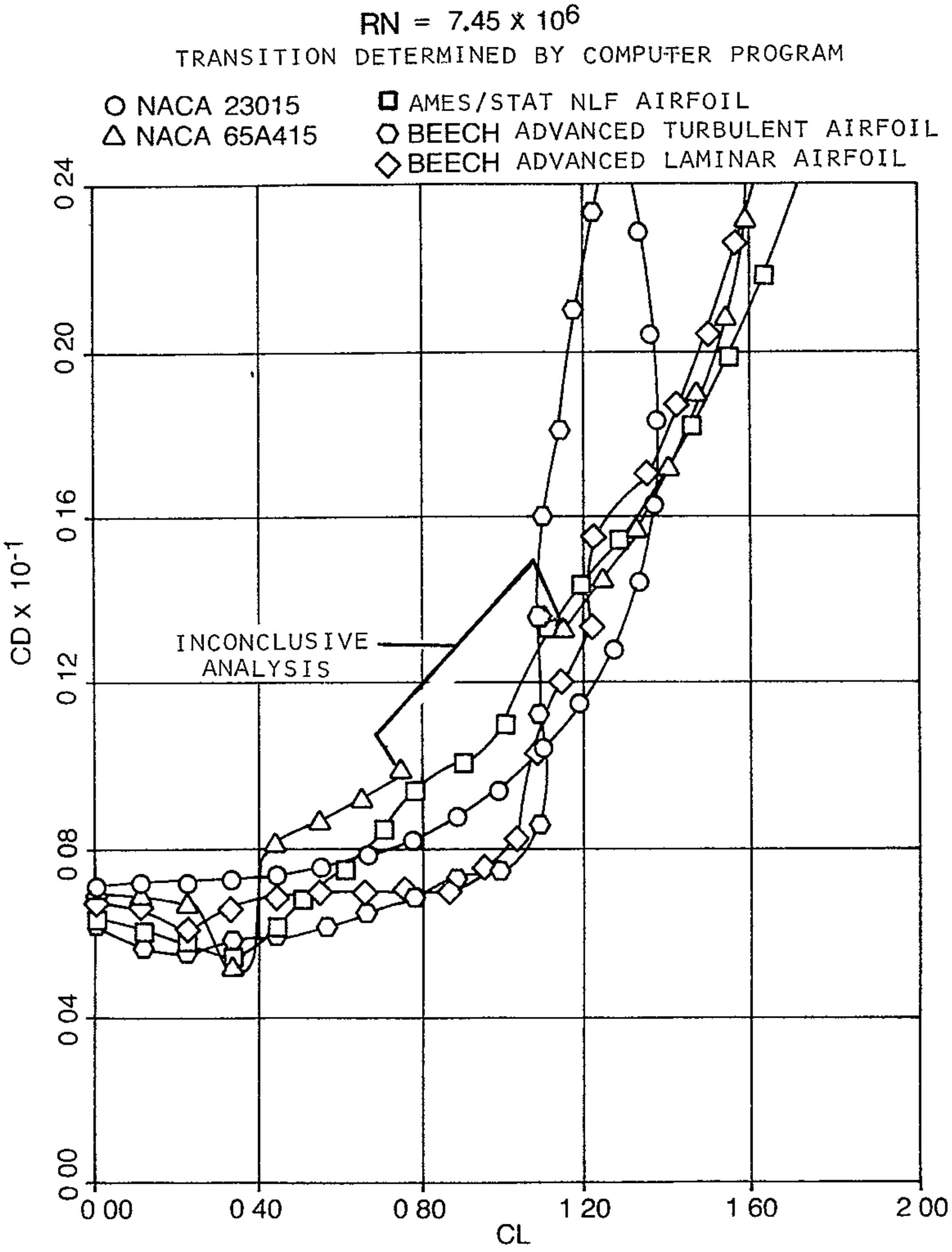


FIGURE 16. AIRFOIL 2-D DRAG POLAR
COMPARISON WITHOUT CRUISE FLAP

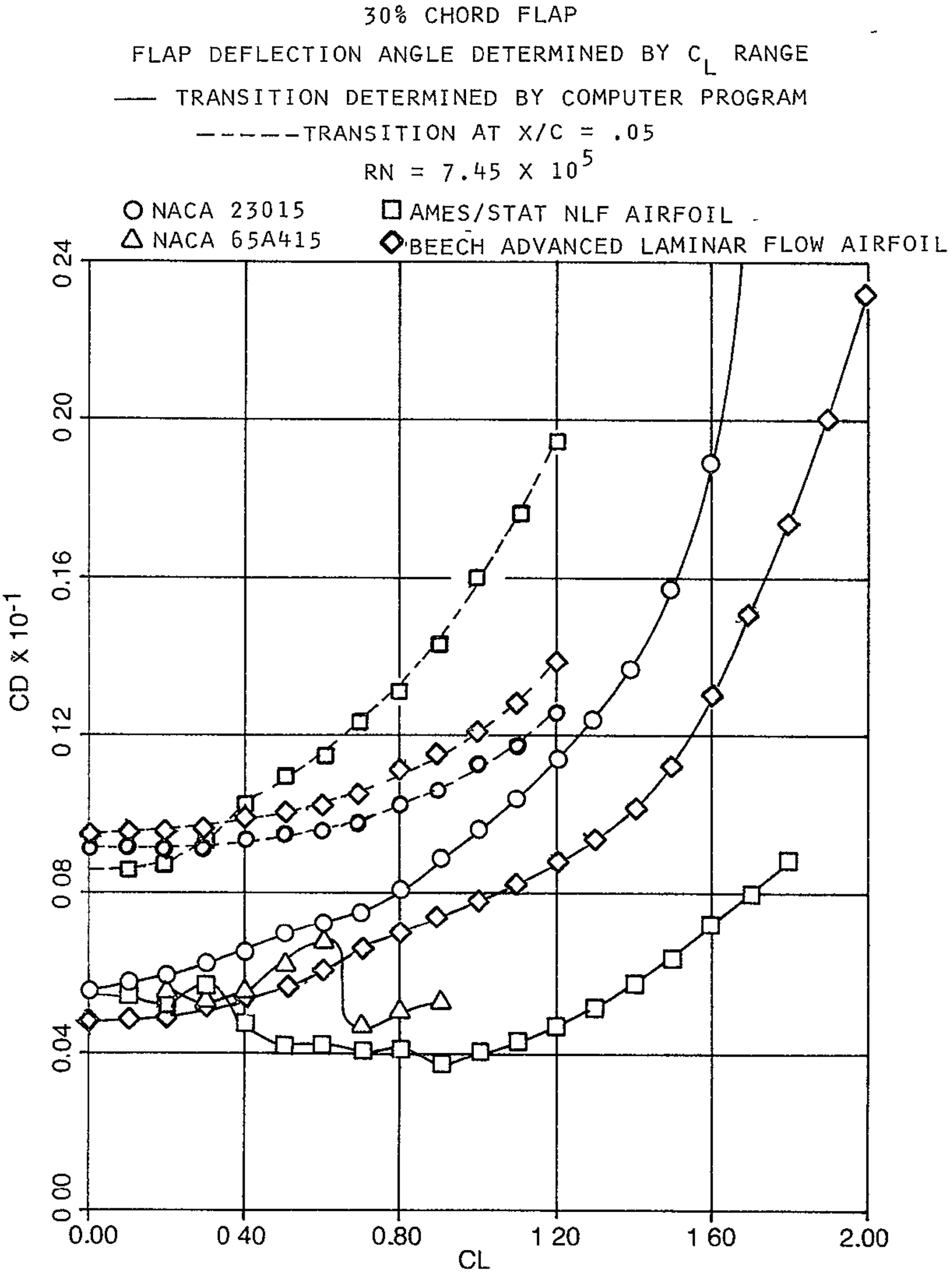


FIGURE 17. AIRFOIL 2-D DRAG POLAR COMPARISON WITH CRUISE FLAP

4.4.1.2 Improved Turbulent Airfoils

Previous studies (References 31 and 32) have shown that improved turbulent airfoils may be designed with lower cruise drag and improved climb L/D than the earlier NACA five-digit series airfoils.

An independent study by Beech of an improved turbulent airfoil which would have a lower drag over the C_ℓ range of interest resulted in the shape presented in Figure 18. This airfoil should result in improved performance without the attendant problems associated with maintaining laminar flow at all conditions. In fact, as seen in Figure 16, the drag variation is better than the NASA/Ames NLF airfoil without cruise flap.

Figure 16 presents the variation of C_ℓ versus C_d for the Beech Advanced Turbulent Airfoil against the airfoils previously described in Section 4.4.1.1. The Beech Advanced Turbulent Airfoil has a lower drag over the C_ℓ range of 0 to .8 than the NACA 23015 and is equal to the Beech Advanced Laminar Airfoil over the .8 to .11 C_ℓ range.

Figure 19 presents the section C_ℓ versus C_d and C_m variation for a Reynolds Number of 6×10^6. Figure 20 presents the C_ℓ versus α variation both two-dimensionally and three-dimensionally based on the baseline wing planform

4.4.1.3 Surface Coatings

Surface coatings on the wing and tail surfaces have been the object of study since 1977 (Reference 8). The objective of these studies is to reduce the drag of transport aircraft by maintaining smooth lifting surfaces and as an added benefit reducing maintenance by providing surface protection (Reference 9). This study narrowed the three types of coatings (liquid, film, adhesive) to three liquid spray-on elastomeric polyurethanes.

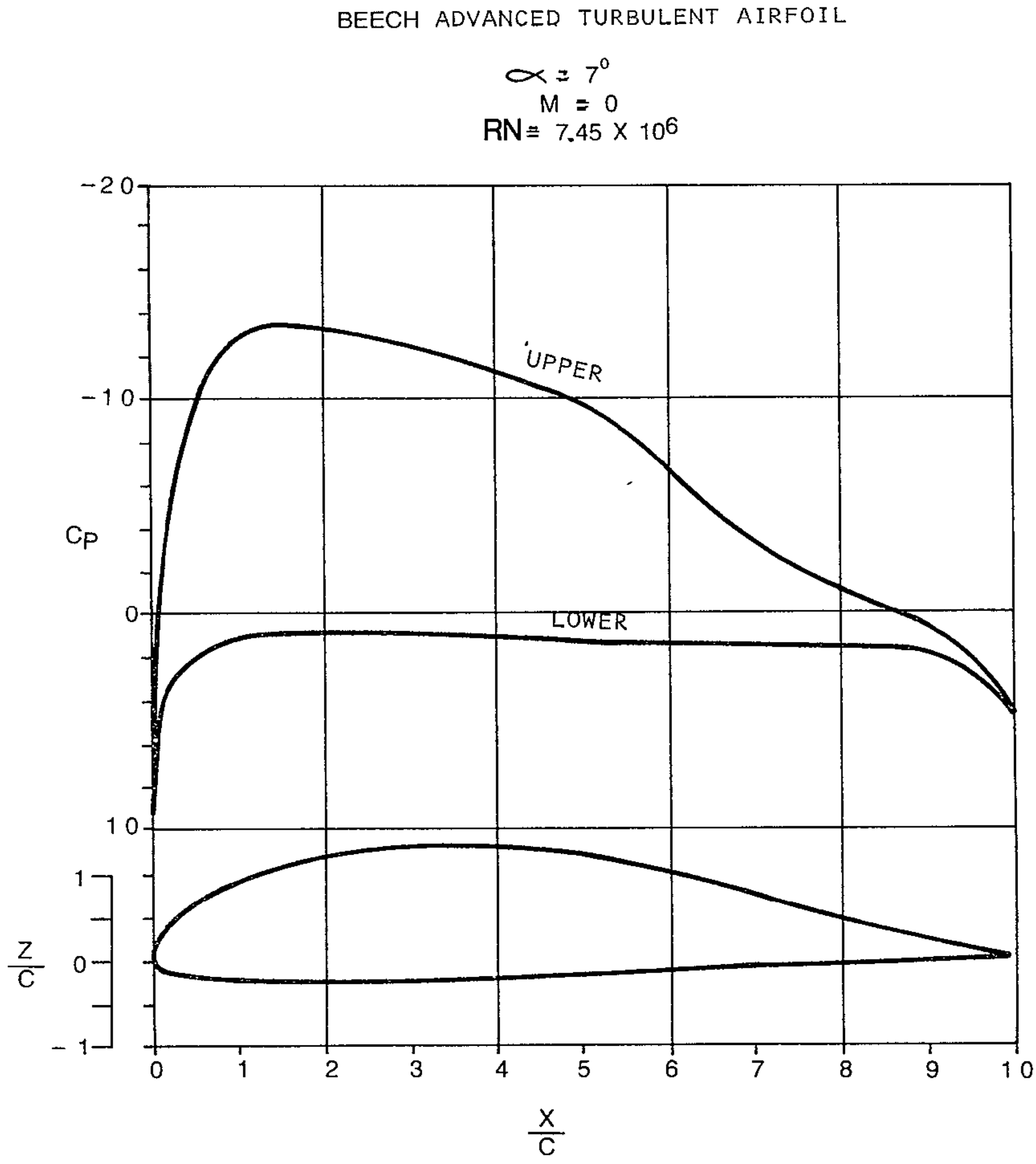


FIGURE 18 BEECH ADVANCED TURBULENT AIRFOIL PRESSURE DISTRIBUTION AND CONTOUR

BEECH ADVANCED TURBULENT AIRFOIL
SECTION CHARACTERISTICS
RN = 6,000,000
M = 0

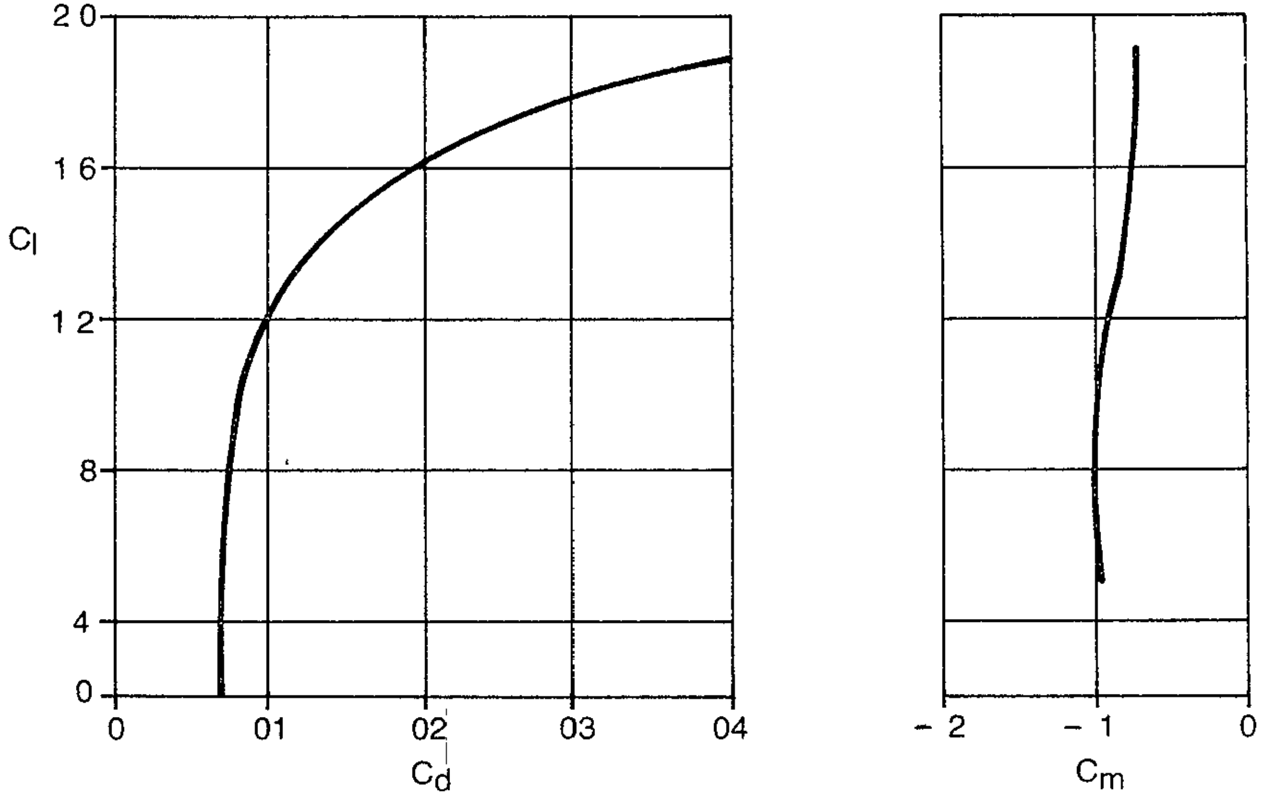


FIGURE 19 BEECH ADVANCED TURBULENT AIRFOIL SECTION CHARACTERISTICS

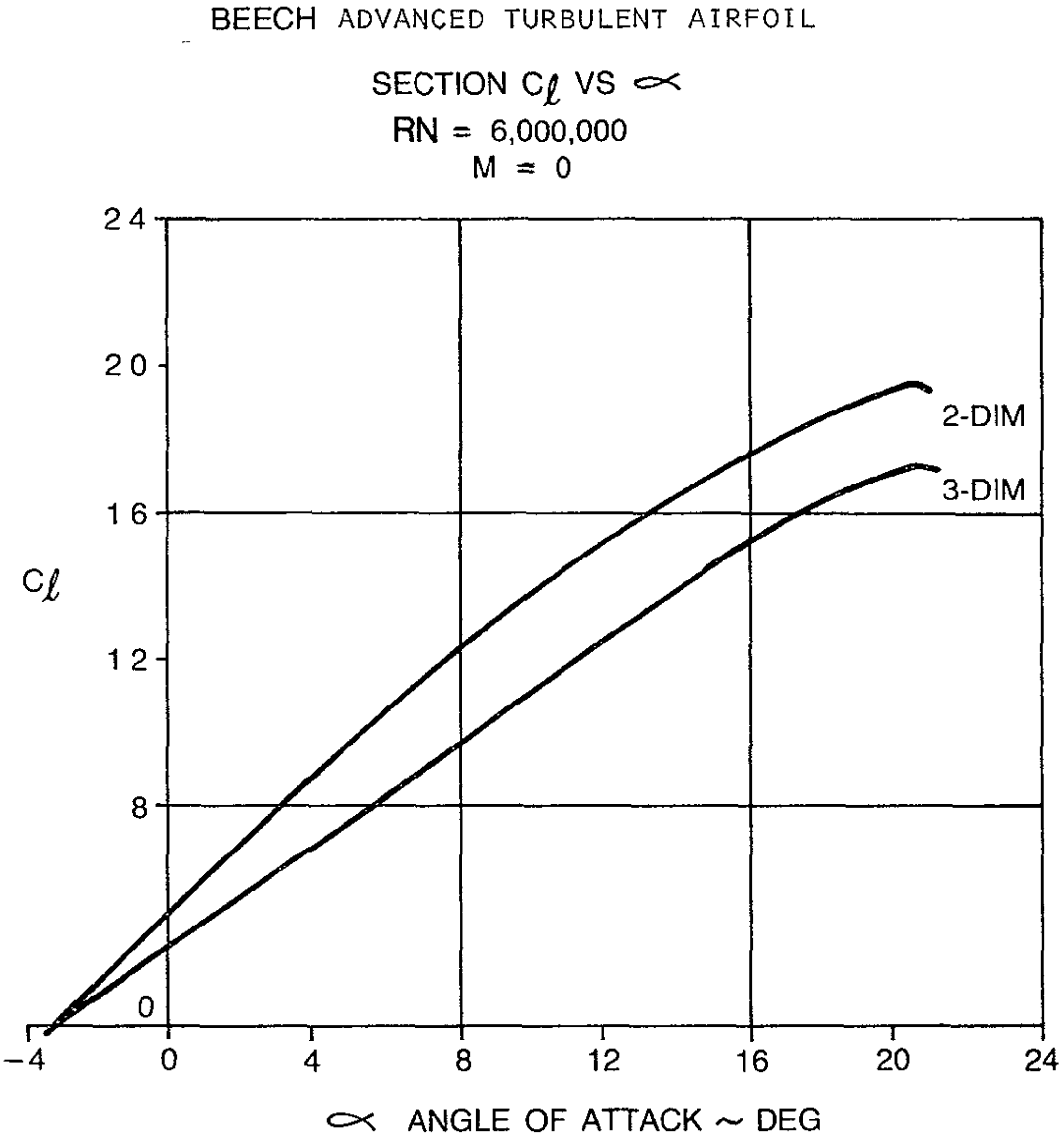


FIGURE 120 BEECH ADVANCED TURBULENT AIRFOIL SECTION Cℓ VS α

In a follow-on study this selection was further verified (Reference 10). Although drag reduction benefits are not verified as yet by testing, estimates of the potential drag reduction were made. For a medium sized transport aircraft a drag reduction in the cruise condition of 2% was estimated (Reference 8). A cost/benefit analysis showed that for a surface coating applied from leading edge to rear spar of the wing and empennage a drag reduction greater than .3% would be a potential benefit to the operator.

4.4.2 Wing Geometry Variation (AR, λ)

Parametric studies of the effects of aspect ratio (AR) and taper ratio (λ) on Direct Operating Cost (DOC) were conducted utilizing GASP.

Range and cruise speed are held constant and wing area is varied for a constant taper ratio and aspect ratio. This process was done for three taper ratios and three aspect ratios for nine combinations.

Carpet plots of empty weight versus wing area with constant values of DOC and aspect ratio and 4000 ft. accelerate-stop distance line were generated. Cross plotting to obtain a variation of DOC versus taper ratio for constant aspect ratio results in the curves presented in Figure 21.

These curves show that for a constant taper ratio the differential in DOC for aspect ratios 10 and 12 is less than .5%. For a constant aspect ratio over the range of taper ratios .27 to .44 the differential in DOC is .6% for 564 n. mi. stage length and 1.3% for 100 n. mi. stage length.

EFFECT OF ASPECT RATIO AND TAPER RATIO ON DOC
4000 FT ACCELERATE-STOP DISTANCE
20° FLAPS

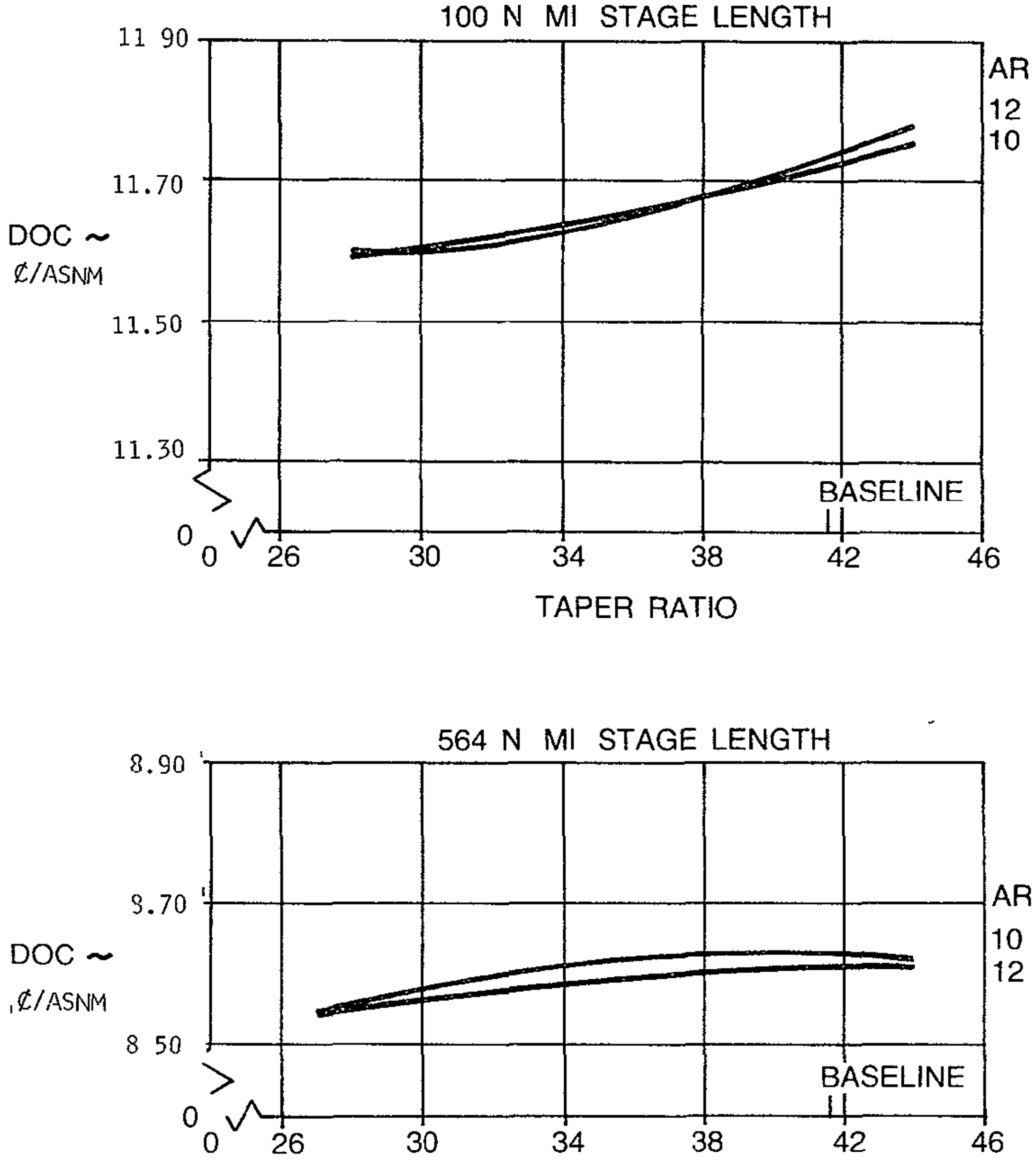


FIGURE 21
EFFECT OF ASPECT RATIO AND
TAPER RATIO ON DOC

4.4.2 Wing Geometry Variations (AR, λ) (Cont'd.)

The difference in design range from the baseline given in Section 4.3.4 is because these studies were done before modification to the GASP for engine out drag inclusion and DOC guideline changes. These changes do not affect the study results since they are complete in themselves and the trends and differentials are between similarly calculated quantities.

4.4.3 Improved High Lift Devices

Improvement in high lift devices has reached a high level when applied to large transport aircraft. These double-slotted and triple-slotted flaps are not readily scaled down to small transports with the associated complexity and increased weight they add. Previous studies (References 11 and 12) indicated that the small transports need area increasing flap systems to achieve the lift required for takeoff distance and climb gradient requirements set in those studies.

In an independent study, Beech analyzed a single-slotted Fowler flap with 87% chord lip location and 25% chord ratio (Figure 22) This flap has a 22% chord extension before translating down at about 10° deflection. The flap is designed to conform to the aft portion of the advanced turbulent airfoils with their increased aft camber. A similar type flap was tested on a NASA LS(1)-0413 airfoil and reported on in Reference 33. This flap has a 33% increase in two-dimensional $C_{\ell_{max}}$ over a single-slotted flap arrangement.

When applied to an aircraft similar to the baseline, the $C_{\ell_{max}}$ increase is 5% for a Fowler flap of the same semi-span and 28% for a single-slotted Fowler flap at 89% semi-span both at 20 degree flap deflection (See Figure 23). In terms of ΔC_L and ΔC_D due to flap deflection Figure 24 shows a comparison of the single-slotted flap and the single-slotted Fowler flap with about a 74% increase in ΔC_L and 66% increase in ΔC_D for the 20° takeoff flap setting.

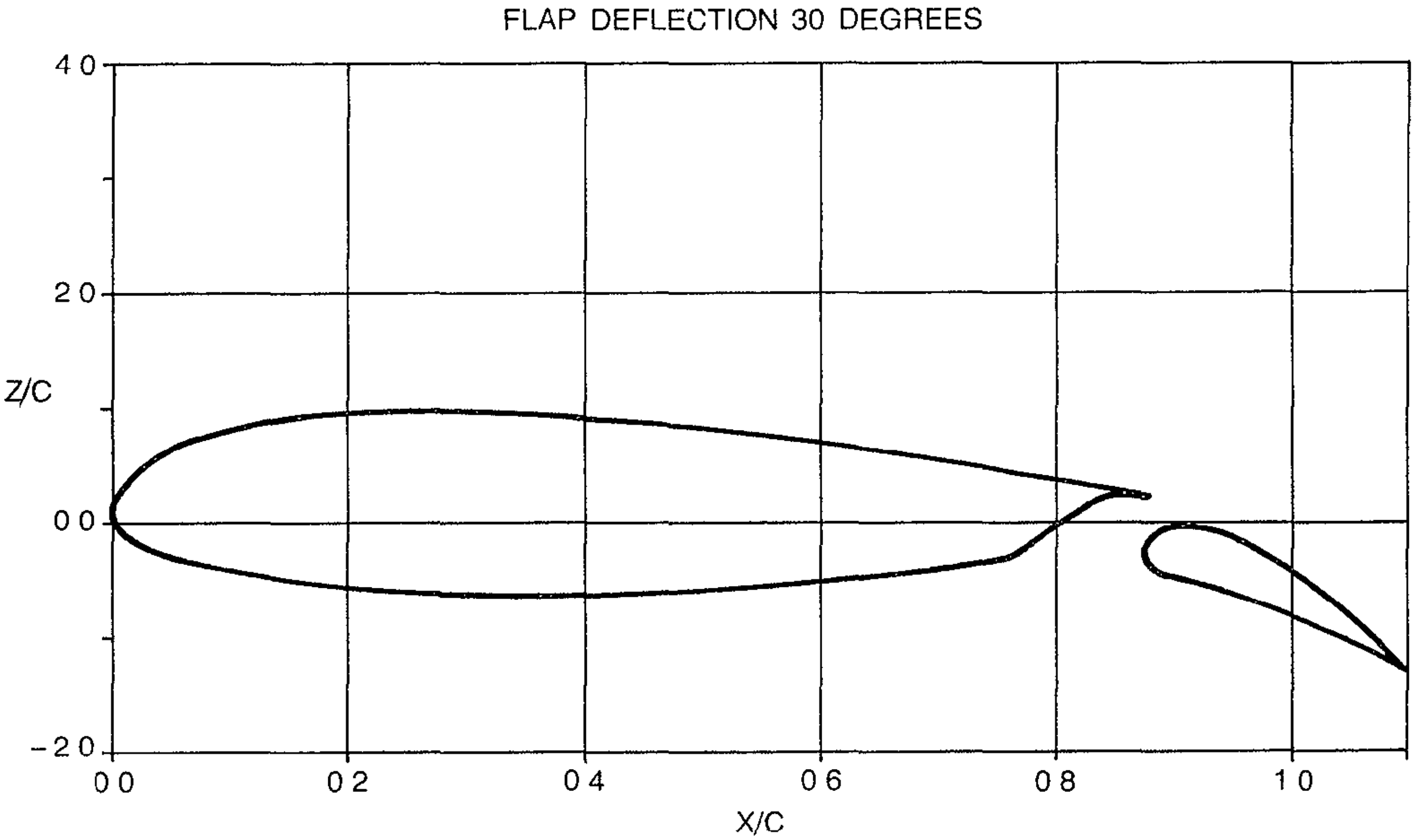


FIGURE 22 BEECH SINGLE-SLOTTED FOWLER FLAP CONTOUR

REFERENCE AREA = 303 SQ. FT.

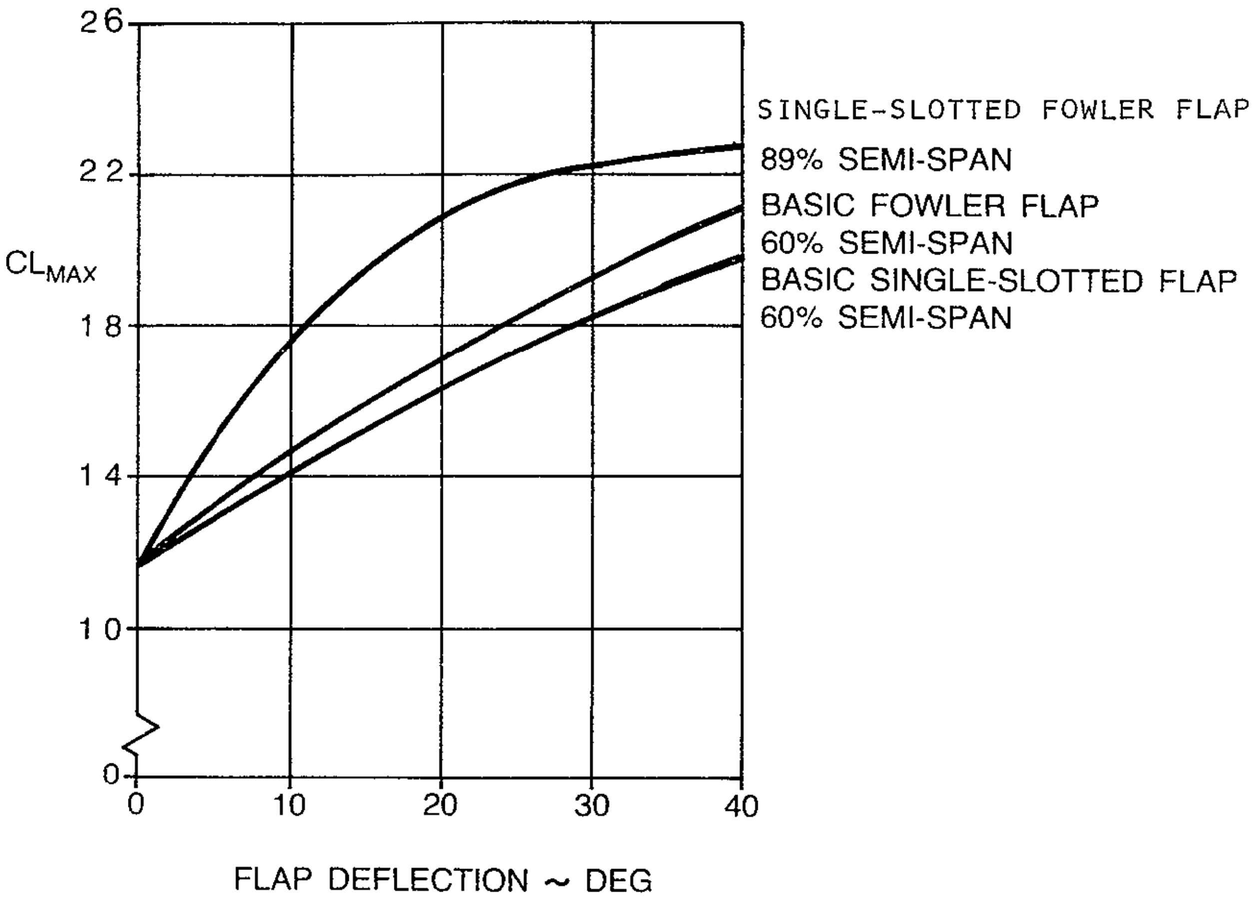


FIGURE 23 FLAP PERFORMANCE CL_{MAX} COMPARISON

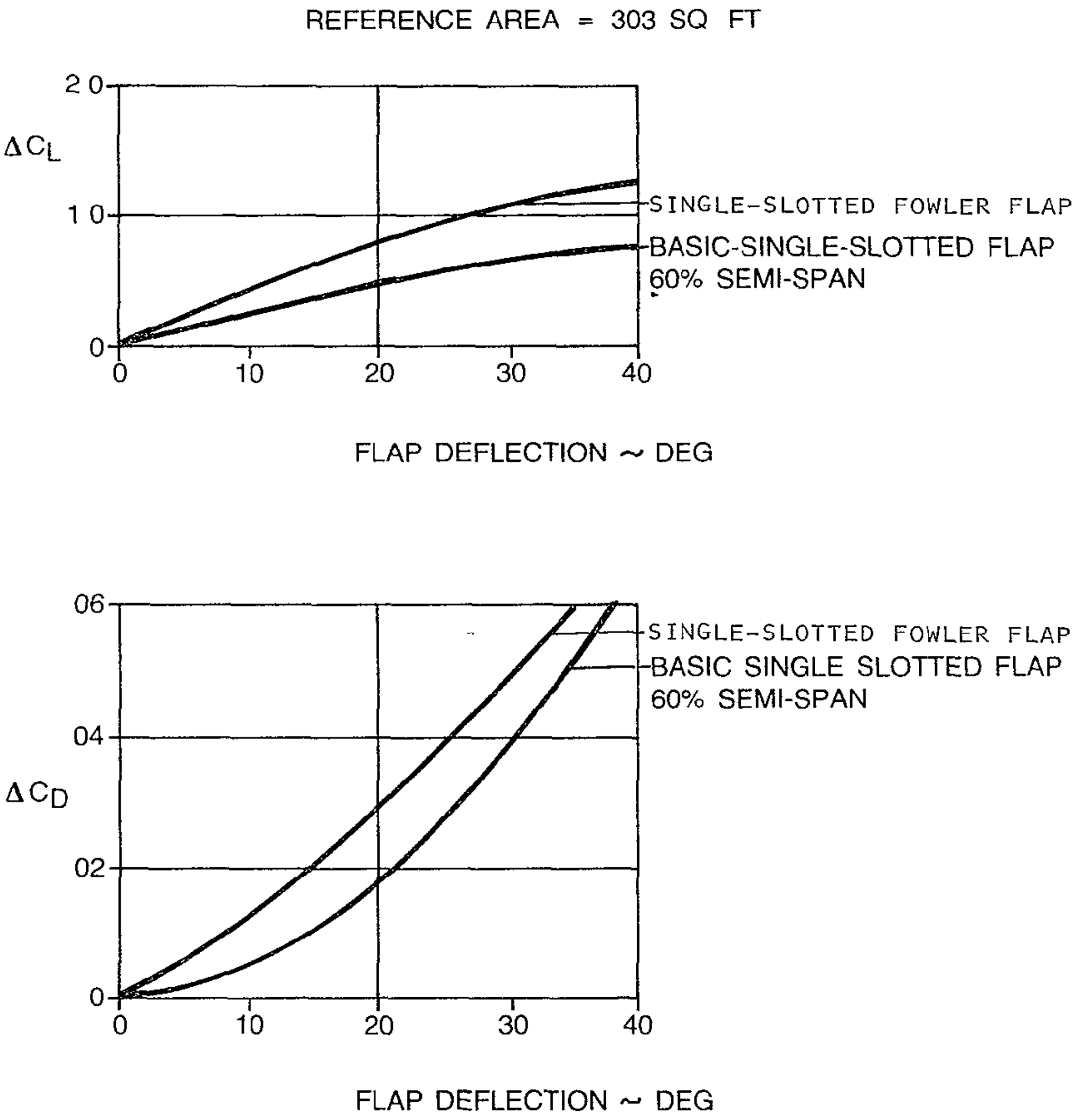


FIGURE 24
ΔC_L AND ΔC_D DUE TO
HIGH LIFT DEVICES

4.4.4 Composite Structures

Advanced structures have the potential of weight savings benefits that have been clearly demonstrated in large aircraft secondary structures (References 13, 14, 15, 16, 17, 18). These component weight savings have been in the 20 to 30 percent range, largely due to the use of graphite/epoxy materials. One comparison from Reference 14 is shown in Figure 25 Here a composite fin for a large transport aircraft has a weight savings of 28% and a reduction in parts and fasteners of 73% and 84%, respectively. Other primary and secondary structures and their associated weight savings now under development in the ACEE program are summarized in Figure 26. These large transport wings and empennage are highly loaded and hence tend toward heavy structure. Due to light loadings, the empennage and control surfaces of the general aviation or small transport type aircraft tend to be minimum thickness necessary to maintain stiffness. This aspect of applying composite structures has not been researched completely. Quantification of minimum ply requirements for stiffness, weight reduction, manufacturing costs and methods still needs to be accomplished.

One author (Reference 19) has stated that the greatest payoff in new materials will be derived from use in new design with associated resizing of the aircraft as shown in Figure 27. With a wing-only substitution on a derivative aircraft, the resulting fuel savings of 3% is said to not justify development costs. In Section 4.4.9 sensitivity studies and cost analysis of a baseline derivative aircraft will quantify this conclusion.

What price these new materials will bring is still being resolved. Converting from aluminum would require new facilities and lowering of the cost of graphite construction. "The issue of cost remains one of much less certainty and predictability. Tooling costs for composites are high, and many composite parts currently are labor-intensive. However, improved manufacturing technology now under development is expected to reduce fabrication costs." (Reference 20). The Development of the technology, personnel training and equipment costs

	METAL BOX	COMPOSITE BOX
WEIGHT (LB)	838	622
% COMPOSITE MATERIAL	-	77
WEIGHT SAVED (LB)	-	236 (28 4%)
NO OF RIBS	17	11
NO OF PARTS	716	191
NO OF FASTENERS	40,371	6 311

FIGURE 25COMPARISON OF COMPOSITE FIN
TO ALUMINUM FIN

COMPONENT	L-1011 AILERON	DC-10 RUDDER	B-727 ELEVATOR
SIZE m	1 2 × 2 4	0 8 × 4 0	0 9 × 5 8
BASELINE METAL MASS kg	63 5	41 4	117 0
COMPOSITE MASS kg	45 4	30 3	89 4
MASS SAVING %	28 5	26 8	23 6
QUANTITY TO BE FABRICATED	22	11*	11*
CERTIFICATION	MID-1980	YES	YES
PRODUCTION	UNCERTAIN	PENDING	UNCERTAIN

*FABRICATION COMPLETED

COMPONENT	L-1011 VERT FIN	DC-10 VERT STAB	B-737 HORIZ STAB
SIZE m	2 7 × 7 6	2 4 × 7 6	1 2 × 5 2
BASELINE METAL MASS kg	389 2	453 6	118 9
COMPOSITE MASS kg	272 2	350 3	91 6
PROJECTED MASS SAVINGS %	30 1	22 8	22 9
QUANTITY TO BE FABRICATED	3	7	11

FIGURE 26 COMPONENT WEIGHT SAVINGS
DUE TO COMPOSITE STRUCTURE

	FUEL SAVING	WEIGHT SAVING
WING SUBSTITUTION ONLY		
WING		25%
AIRFRAME (INCLUDES WING)		8%
TAKEOFF WEIGHT	3%	3%
ALL NEW RESIZED DESIGN		
AIRFRAME (INCLUDES WING)		33%
TAKEOFF WEIGHT	18%	18%

FIGURE 27 WEIGHT AND FUEL SAVINGS DUE TO COMPOSITE STRUCTURE

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd.)

4.4.4 Composite Structures (Cont'd.)

have not been taken into account in the studies done previously (References 11 and 12). These costs amortized over an aircraft production run may increase the total cost of manufacturing.

Another application of graphite/epoxy has been investigated as part of this study. Fatigue damage is generally not a design problem if the composite part has satisfied the static strength requirements. In fact, tests have repeatedly shown a higher static residual strength after fatigue testing than in unfatigued specimens (Reference 21). Hence the use of graphite/epoxy material in the replacement of fatigue critical aluminum structure is a possibility.

Analyzing the spar caps only of the baseline aircraft wing; substitution of strength critical requirements for fatigue requirements resulted in a 79% weight savings (Figure 28). This is about 2% in gross weight savings which again may not be enough to justify the development costs.

One result apparent in the NASA sponsored studies is that much of the required technology and experience gained in designing and working with graphite/epoxy structure is not readily transferable from one company to another. Therefore, each manufacturer will require a similar but smaller development effort (Reference 13).

4.4.5 Propulsion Improvements

4.4.5.1 Engine Technology

Recent STAT propulsion studies (References 22 and 23) have indicated a 10 to 20 percent improvement in specific fuel consumption (SFC) and an 18 to 23 percent reduction in engine weight. Engine initial cost has not been as well quantified in these studies. For this study it is assumed

	Aluminum	Graphite-Epoxy
σ/g (psi)	5700	15 000
ρ (lb/in^3)	0 100	0 055
Cap Wt (lb)	437	91
Wt Savings (lb)	--	346
% Wt Savings on Item	--	79%
% Wt Savings on Gross	--	2 0%
Possible fuel savings	--	2 0%

FIGURE 28 BASELINE SPAR CAP WEIGHT
SAVINGS DUE TO GRAPHITE/EPOXY MATERIAL

that a large increase in engine initial price is justified in order to obtain the SFC improvement indicated. Sensitivity studies in Section 4.4.7.3 will verify this assumption and show the effect of engine price on DOC.

Some of the advanced technologies mentioned in References 22 and 23 to achieve the reduction in weight and SFC are summarized in Table 3.

4.4.5.2 Propeller Technology

Advances in propeller technology have been made recently with the use of fiberglass or Kevlar composite propellers on current commuter aircraft and the projected use on some mid-'80's new commuter aircraft (References 24 and 25).

More advanced technology is being studied in other NASA sponsored studies (Reference 26). This study indicated a reduction in blade weight for Kevlar/foam blades of 50% from aluminum but with a 30% increase in cost. An 80% increase in cost is indicated for a graphite/epoxy composite blade.

These weight savings are for a direct blade replacement only. Hence, no estimate of the weight reduction in the hub area has been documented. Advances in this area may offset weight increases due to diameter increases, number of blades or sweep.

Performance of advanced propellers is projected to increase efficiency in cruise 3%. This includes 1% for propeller/nacelle integration and 2% for advanced airfoils, decrease thickness ratio and improved surfaces finish (due to composite structure). (Reference 26 and verbal communication with NASA.)

TABLE 3

ENGINE ADVANCED TECHNOLOGY IMPROVEMENTS

COMPRESSORS

Highly Loaded Axial Stages
Multi-Blade Impeller
Advanced Diffuser
12·1 Single-Stage Centrifugal
20.1 Two-Stage Centrifugal

COMBUSTOR

Air Blast Nozzles
Machined Ring Fabrication
Photo-Etched Fabrication
Improved Pattern Factor
Nonstrategic Materials
Thermal Barrier Coating

HIGH PRESSURE TURBINE

Improved Cooled Blades
Active Clearance Control
Single-Stage
Advanced Materials

LOW PRESSURE TURBINE

Three-Stage Inserted Blades
Tip Treatment
Advanced Materials
Integrally Cast Blade
High Modules Shaft

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd.)

4.4.5 Propulsion Improvements (Cont'd.)

4.4.5.2 Propeller Technology (Cont'd.)

4.4.5.2.1 Interior Noise Study

The effect of nacelle/propeller location on interior noise was studied to ascertain the degree of acoustic treatment needed to meet reasonable requirements of interior noise levels. Figure 29 presents the predicted noise level as a function of fuselage station location and prop-tip to fuselage clearance location. In the propeller plane at the baseline 17-inch prop tip to fuselage clearance location the interior noise level is estimated to be 110 dB(A) using standard Hamilton Standard predication methods (Reference 27). Movement of the nacelles outboard 30 inches results in a 6 dB(A) drop. The first row of seats is 20 inches aft of the propeller plane where the noise level is 108 dB(A) for the 17-inch prop-tip to fuselage clearance location and 103 dB(A) for the 47-inch prop-tip to fuselage clearance.

Moving the nacelles outboard on the wings results in structural changes and corresponding changes in airframe weight. Maintenance of the baseline V_{M_C} speed would require changes in the vertical tail area. For a 30-inch outboard movement the vertical tail area increases 17 square feet. Table 4 outlines the additional structural weight increase due to outboard nacelle movement.

A proposed acoustic treatment method, shown in Figure 30, should reduce the interior noise level 10 dB(A) per 2.6 lb/ft^2 for the prop plane area and 10 dB(A) per 1.0 lb/ft^2 for the remainder of the fuselage cabin area. For an 85 dB(A) noise level at the first seat location (lower noise levels at the other seat locations), the total aircraft acoustic treatment weight is 1030 pounds for the 17-inch prop-tip to fuselage clearance. Moving the nacelles outboard 30 inches from the baseline location requires an acoustic treatment weight of 788 pounds and structural weight increase of 102 pounds for a total weight of 944 pounds.

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd.)

4.4.5 Propulsion Improvements (Cont'd.)

4.4.5.2 Propeller Technology (Cont'd.)

4.4.5.2.1 Interior Noise Study (Cont'd.)

The interior noise study gives an indication of the weight penalty involved if the baseline aircraft were to conform to the desired levels set in previous STAT studies. Within the ground rules of this study, the fuselage of the baseline was held constant; therefore, the effects of interior noise reduction will not be considered any further in this study.

TABLE 4

PRELIMINARY WEIGHT VARIATION
DUE TO PROP FUSELAGE CLEARANCE VARIATION

D = PROPELLER DIAMETER = 110 in
Y = PROPELLER TIP FUSELAGE CLEARANCE

Y/D	.155	.250	.350	.450
Y-IN	17	27	37	47
VERTICAL TAIL AREA (FT^2)	48 75	55 6	60 8	66
VERTICAL TAIL WEIGHT @ 3 0 LB/FT^2 (LB)	146	167	182	198
Δ WEIGHT VERTICAL TAIL (LB)	0	21	36	52
Δ WEIGHT FUSELAGE (LB)	0	2	3 5	5
Δ WEIGHT WING (LB) { INCREASED REAR SPAR LOADS LONGER GEAR STRONGER WING JOINTS	0	18	31	45
TOTAL WEIGHT INCREASE DUE TO OUTBOARD NACELLE MOVEMENT (LB)	0	41	71	102

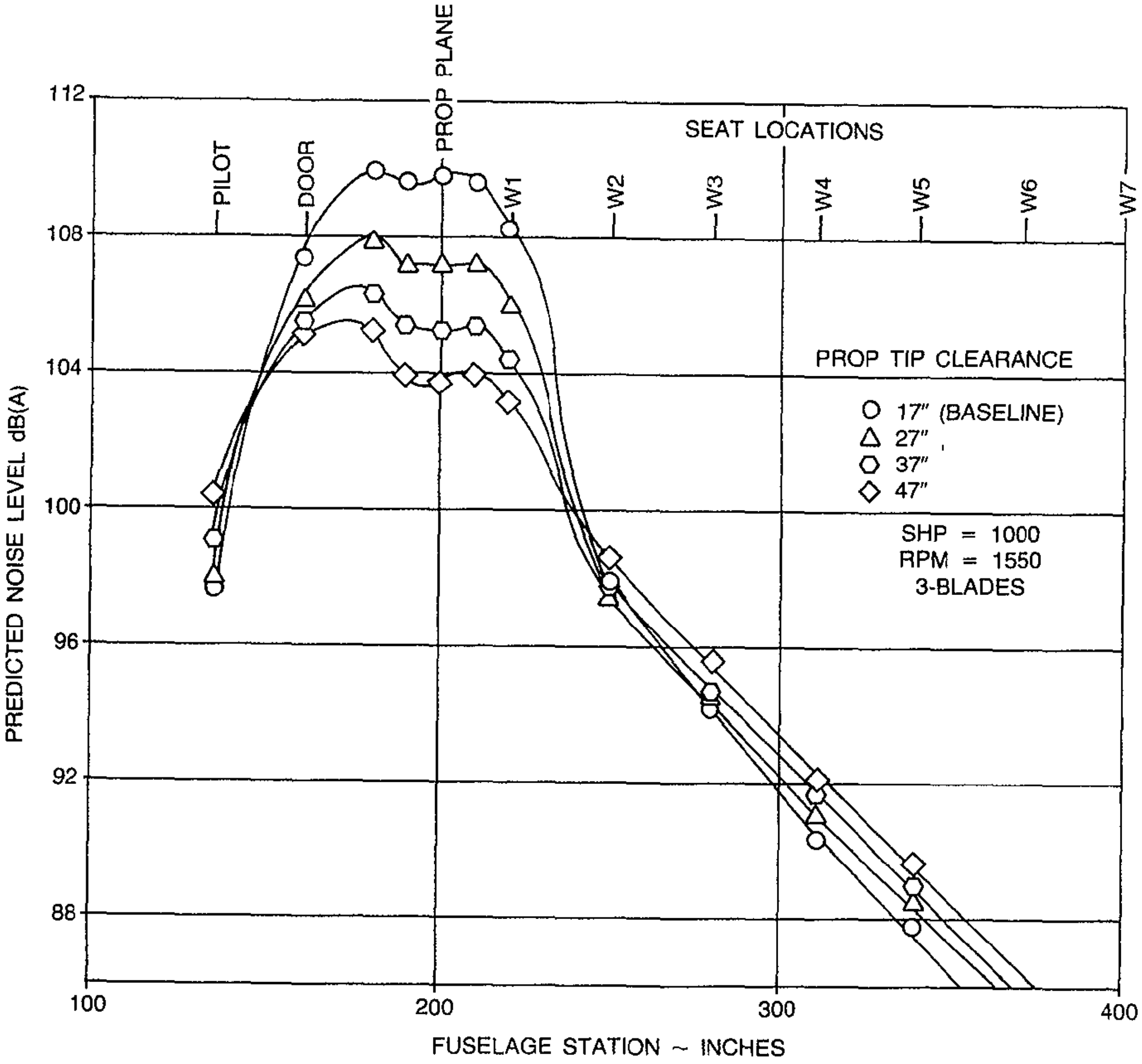
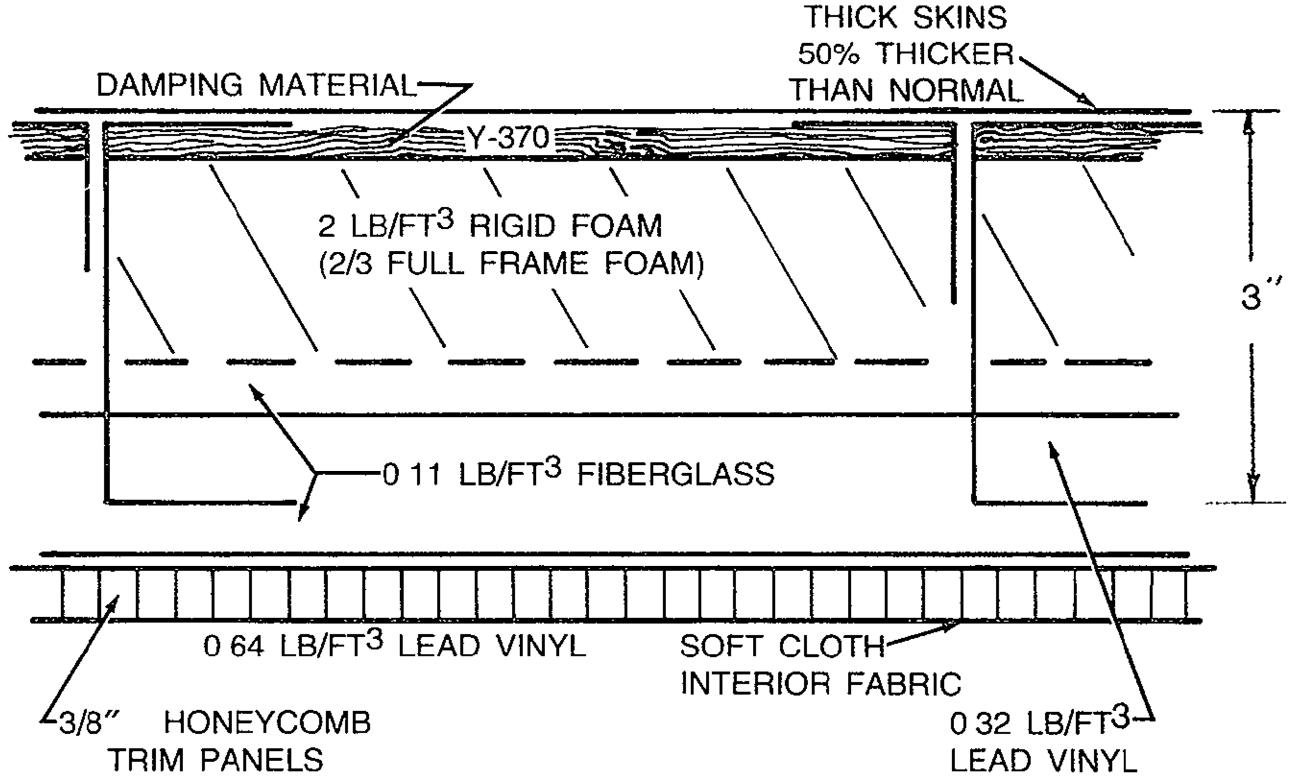


FIGURE 29 INTERIOR NOISE LEVEL VERSES FUSELAGE STATION

PROP PLANE ACOUSTIC TREATMENT
(STATION 140 THROUGH 290)



FUSELAGE ACOUSTIC TREATMENT
(USE FOR FWD 140 AND AFT OF STA 290)

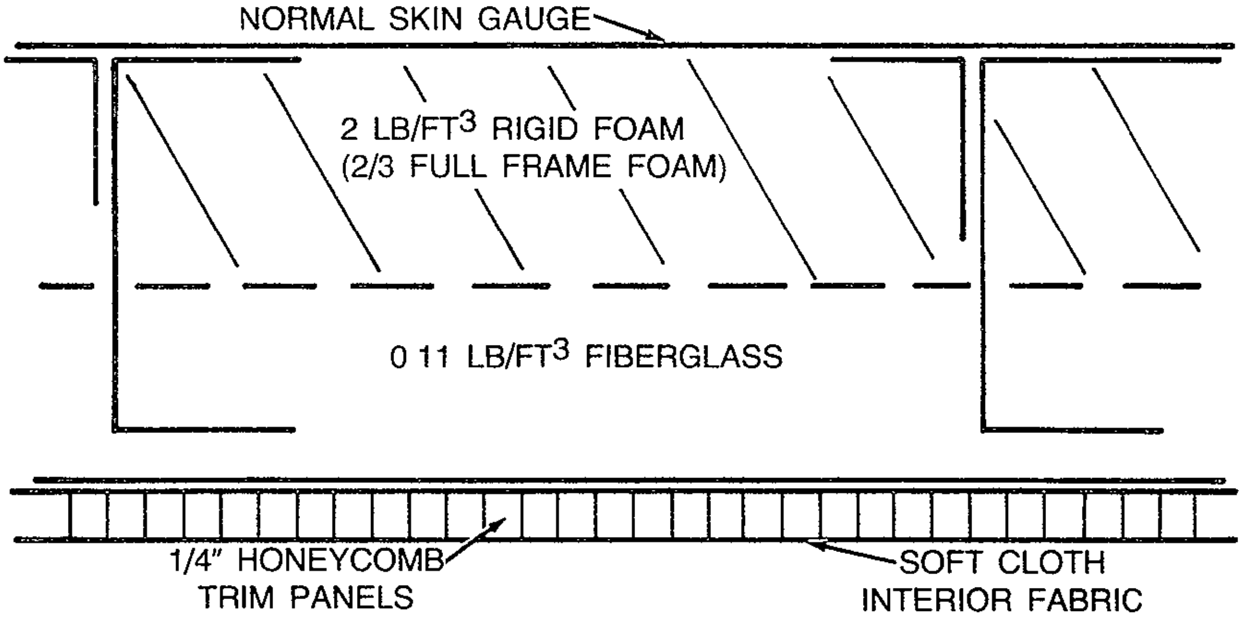


FIGURE 30 FUSELAGE ACOUSTIC TREATMENT METHOD

4.4.6 Aircraft Systems

Incorporation of advanced systems such as improved cockpit displays, electrical systems and advanced avionics are considered beyond the scope of this study. Active control technology has been considered previously in References 11. 12, and 29 for gust load alleviation, ride controls and relaxed static stability. Because of the wide range of loading requirements for a small transport aircraft in a commuter environment advanced technology for relaxed static stability is of interest in this study.

4.4 6.1 Active Controls - Relaxed Static Reliability

A promising benefit from active controls is drag reduction due to relaxed static stability. The active control system would augment the passive stability of the aircraft. Therefore, an aft C.G. location that would normally result in negative static margin would be compensated for by the active control system.

One study (Reference 28) has predicted a 4.5 percent improvement in cruise L/D due to reduced tail size (hence reduced parasite drag and induced drag) and minimum trim drag. This study also indicates that the maximum benefit from augmented relaxed static stability is available when it is incorporated into a new aircraft with an advanced airfoil wing. This is due to the more aft loading of the advanced airfoils (as described in section 4.4.1) which shifts the center of pressure aft necessitating an aft C.G. shift to minimize trim drag. Fuel savings of 5 to 10% have been predicted for the large transport aircraft analyzed in Reference 28. Benefits to the small transport aircraft have not been quantified in previous studies. In Section 4.4.7 it is shown that a 4.5% drag reduction gives approximately a 1% DOC savings.

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd.)

4.4.7 Sensitivity Studies - Influence of Advanced Technologies on the Baseline

In order to determine the effect of the various advanced technologies on direct operating cost, sensitivity studies were conducted with GASP utilizing the baseline aircraft. A summary of the advanced technology candidates and their benefits is shown in Figure 31 . The baseline configuration and mission profile were held constant and resizing due to the changed parameter was not allowed. This method isolates the change in DOC to the influence of the changed parameter only. Baseline aircraft resizing due to the application of the advanced technology will be presented in Section 4.5.

4.4.7 1 Effect of Drag Reduction

The advanced technologies that affect drag are advanced airfoils and surface coatings. The effect of the drag reduction was calculated in GASP by incrementing the total profile drag and calculating the resultant DOC for 100 and 568 n. mi stage lengths. Although only profile drag is changed for the whole mission, the change in drag is referenced to the total cruise drag. As a percent of cruise drag reduction for 10,000 ft. altitude and M = 41 the range of values is 1.5% for turbulent airfoils to 9% for a combination of laminar airfoils and surface coatings.

Since takeoff gross weight was held constant, aircraft empty weight changes as GASP adjusts structure weight for the change in fuel weight. DOC calculations affected by airframe cost (which is a function of airframe weight) were adjusted so that a constant empty weight was maintained. This ensures that only the change in drag affects DOC.

The variation of DOC with change in total cruise drag is shown in Figure 32. A 1% DOC change for a 4.5% drag change is indicated.

ADVANCED TECHNOLOGY CANDIDATES

Technology	Benefit
● Airfoils	
-Natural laminar flow	7% Cruise drag reduction
-Improved turbulent flow	1.5% Cruise drag reduction
● Long span Fowler flaps	18.5% $C_{L_{max}}$ increase
● Surface coatings	2% Cruise drag reduction
● Composite structures	25% Component weight savings
● Advanced turboprop engines	20% SFC reduction
● Advanced propeller concepts	3% Cruise prop efficiency increase
● Active controls	4.5% Cruise drag reduction

Figure 31 Advanced Technology Candidates

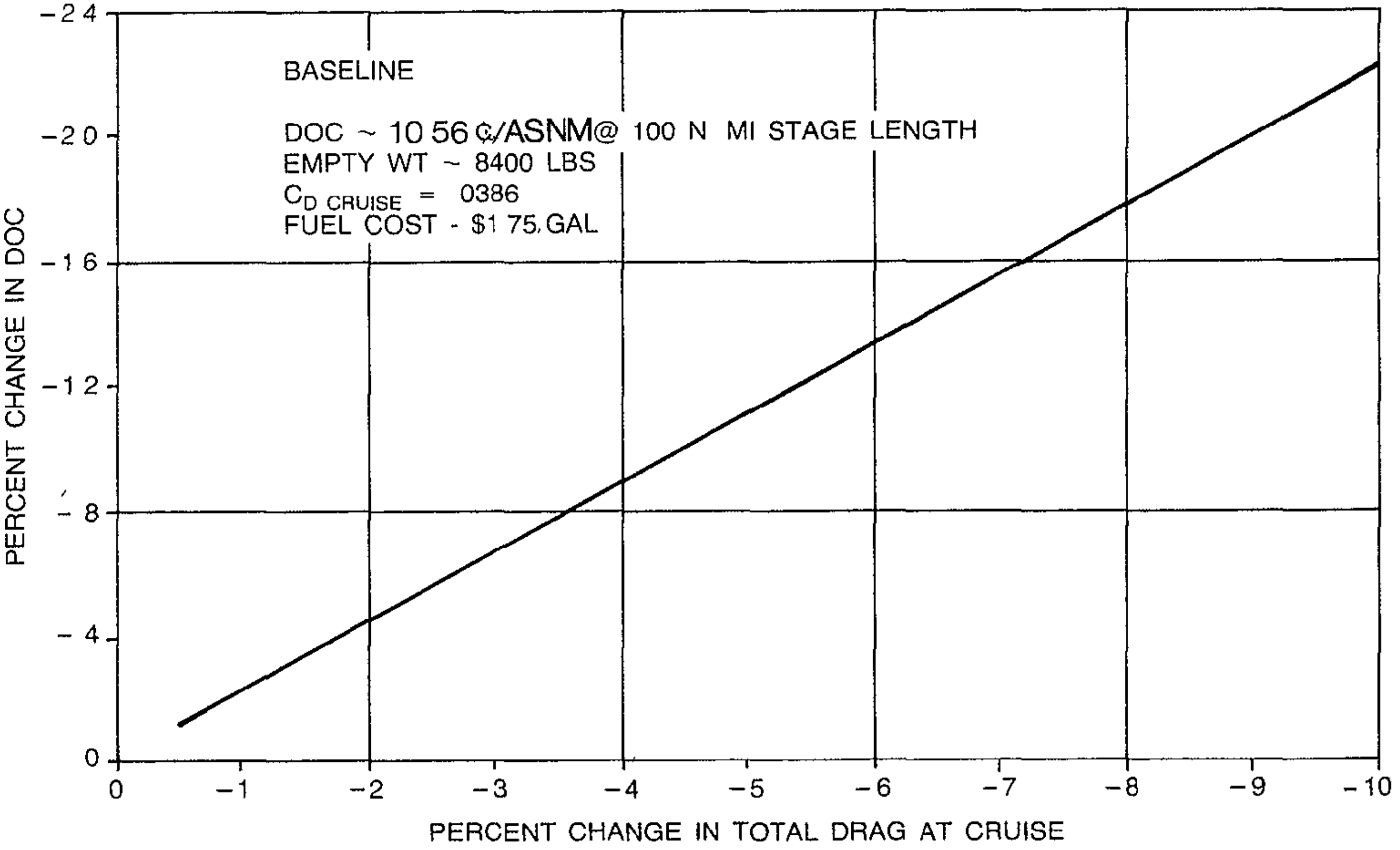


FIGURE 32 EFFECT OF DRAG REDUCTION ON DOC

4.4.7.1 Effect of Weight Reduction

Weight reduction due to advanced material use in airframe construction was calculated by incrementing the total structures group weight of the baseline aircraft. As noted in Section 4.4.4 , up to a 25% decrease in component structural weight may be effected through the use of composites. Since the variation is in empty weight, no adjustment to the DOC calculations is needed. The variation of percent change in empty weight and DOC with the percent change in structural weight is shown in Figure 33. A 1% DOC change for a 7% structural weight change is indicated.

4.4.7.3 Effect of Propulsion Improvements

Advanced engine effects were limited to a reduction in specific fuel consumption (SFC) with no attempt to resize the engine for decreased engine and aircraft weight. Engine tables were generated with 10, 15 and 20% SFC reduction from the baseline engine table with shaft horsepower and exhaust thrust held to baseline values. DOC calculations were adjusted to maintain a constant empty weight since the GASP adjusts the structure weight due to fuel weight change. The change in DOC and fuel used variation for a change in engine SFC is shown in Figure 34. A 1% DOC change for a 2% SFC change is indicated.

A point check of the effect of engine weight reduction was made to establish a reference. Applying a 20% SFC reduction the engine weight was decreased 20% with all other parameters held constant; for a 1% change in DOC a 28.5% change in engine weight would be required.

The effect of propeller efficiency improvement on DOC was calculated holding propeller geometry constant. Figure 35 presents the effect on DOC of a percent change in propeller efficiency. A 1% change in DOC requires a 2.9% change in propeller efficiency or a 2.6 percentage point improvement.

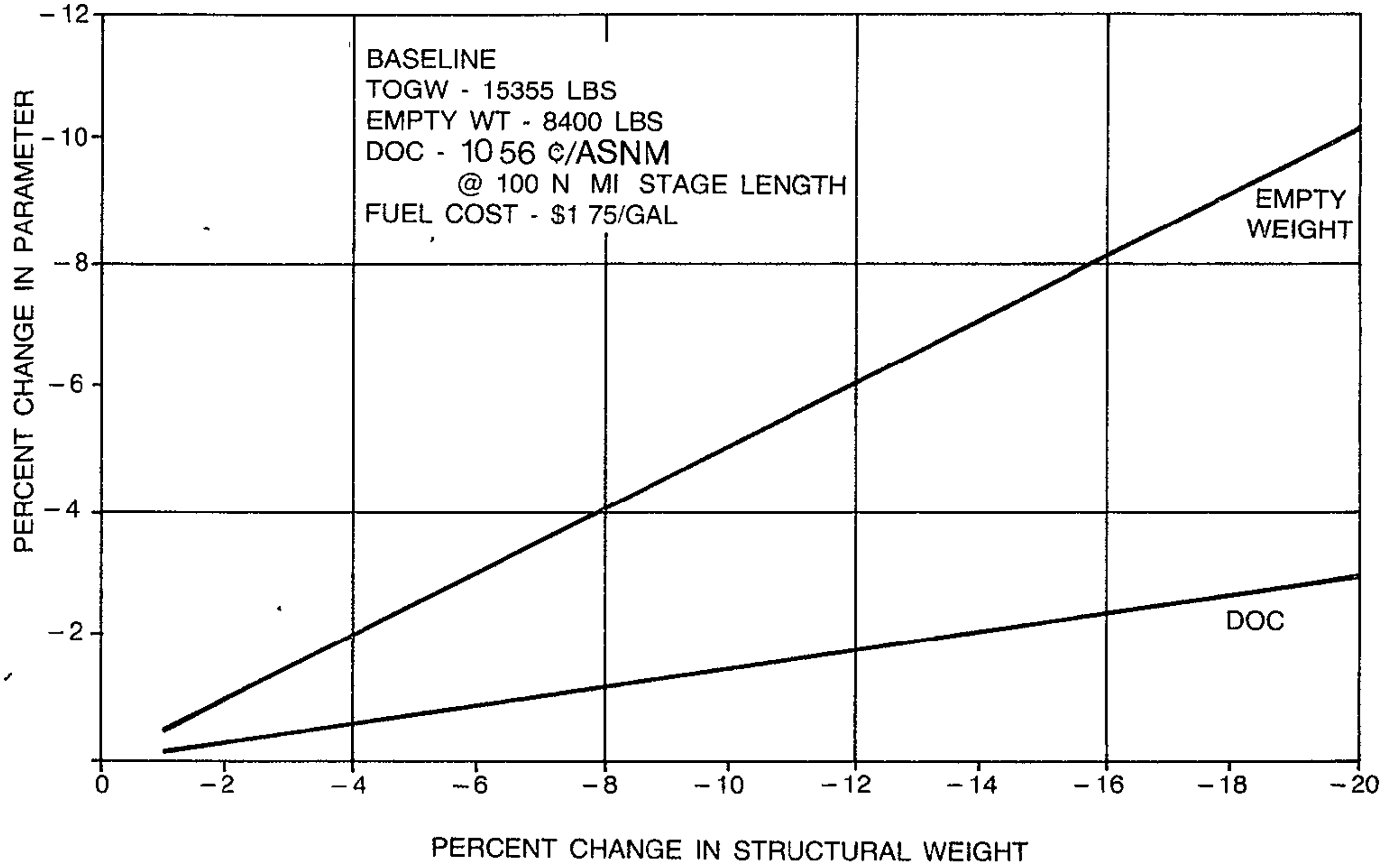


FIGURE 33 EFFECT OF STRUCTURAL WEIGHT REDUCTION ON EMPTY WEIGHT AND DOC

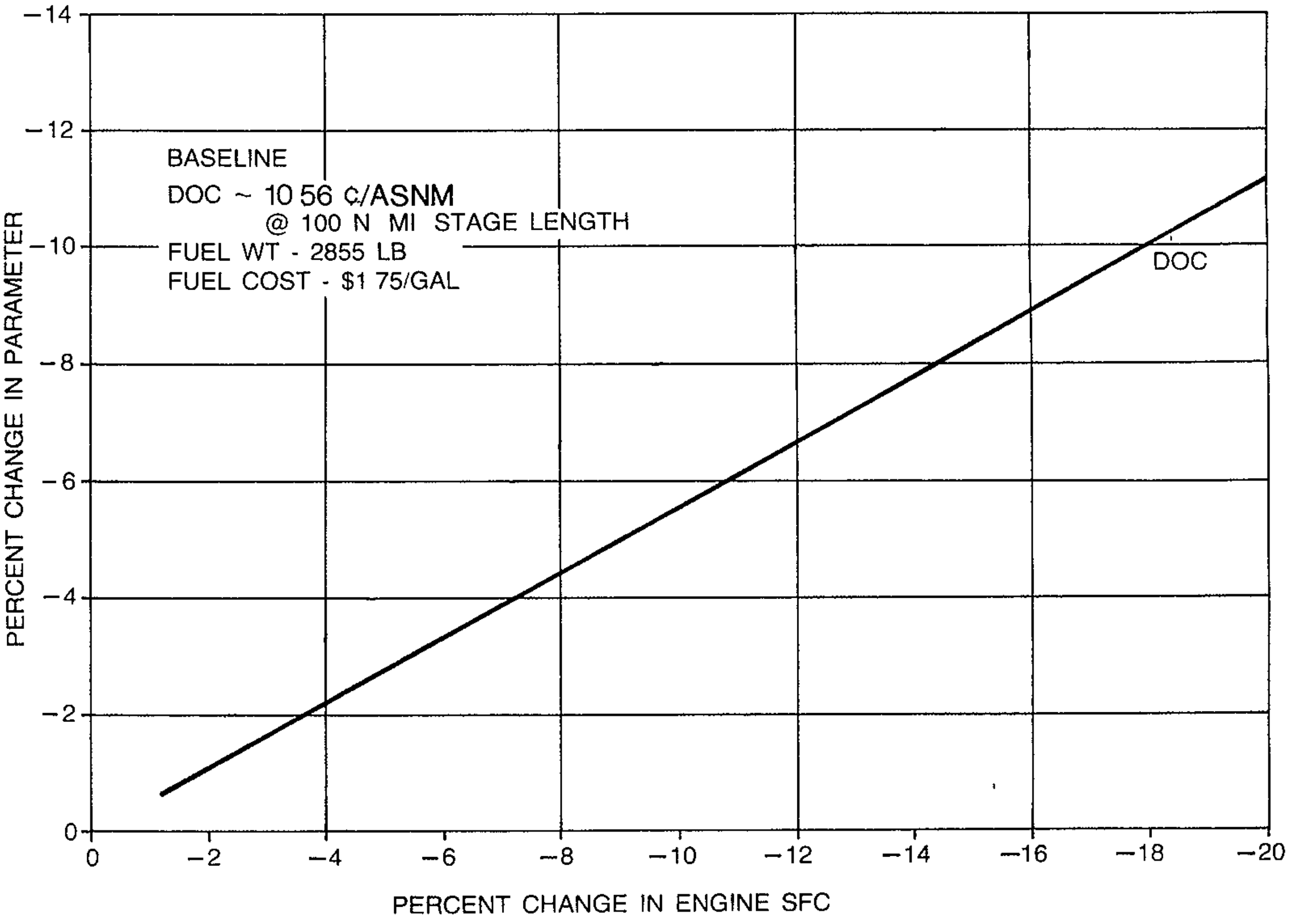


FIGURE 34 EFFECT OF SFC REDUCTION OÑ DOC

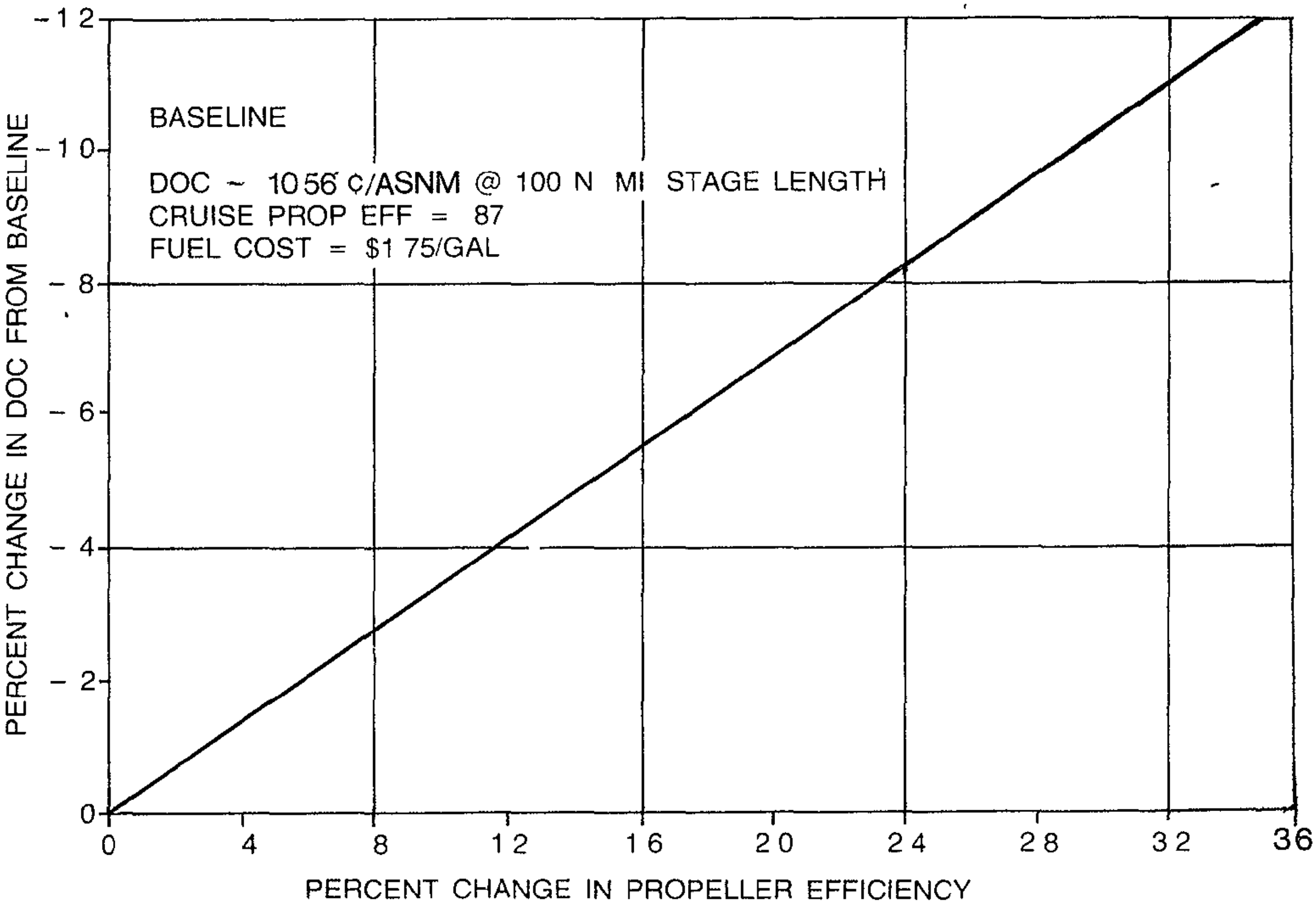


FIGURE 35 EFFECT OF PROPELLER EFFICIENCY IMPROVEMENT ON DOC

4.4.7.4 Effect of High Lift Devices

A single-slotted Fowler flap of 89% semi-span with an 18.5% increase in takeoff $C_{L_{max}}$ was substituted for the 60% semi-span single slotted flaps. There was a 6.0% increase in wing structural weight, as calculated by GASP, with a 94% increase in flap weight. Although there was a DOC increase of .25%, the balanced field length and landing distances decreased 20% and 24%, respectively. It should be noted that the use of full span flaps will probably necessitate spoiler roll control and trim ailerons which may increase wing structural weight. The effect of these controls are not accounted for in the GASP calculation.

4.4.8 Acquisition Cost Analysis Methodology

In order to ascertain the economic benefit of the advanced technologies as applied to a derivative design of the baseline aircraft a detailed recurring cost analysis is conducted. From this analysis an aircraft initial cost may be derived that is more detailed than is calculated in the DOC module of GASP.

A cost analysis method was developed for this study using manufacturer's experience and historical data and coded for desk top computer calculation. The method is divided into three basic parts: development cost, labor cost and material cost. These are combined and a reasonable markup for manufacturer's return on investment applied to obtain an aircraft selling price.

The method and assumptions used are described more fully in the following sections.

4.4.8.1 Assumptions

- 1981 Dollars
- Costs based on airframe weight
- Equipment costs unchanged from baseline costs
- Avionics cost constant (no variation with weight or engines)
- Original aircraft development costs fully recovered
- Derivative aircraft amortization over 250 units
- Certification costs based on Part 25 requirements
- 1981 production methods

4.4 8.2 Development Cost

Development cost of applying advanced technology to the baseline aircraft is estimated with an equation of the form:

$$D = C_1 + K_1 C_2 W_{N\&C}$$

where:

C_1 = minimum certification cost to FAR Part 25 - \$/lb.

C_2 = cost of new and changed weight - standard program \$/lb.

K_1 = complexity factor for a new type program

= 1 Standard Program

> 1 Higher than normal costs

< 1 Lower than normal costs

$W_{N\&C}$ = weight of new or changed components affected by the advanced technology application.

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd.)

4.4.8 Acquisition Cost Analysis Methodology (Cont'd.)

4.4.8.2 Development Cost (Cont'd.)

The certification cost is based on a minimum cost without any airframe changes. The estimate is increased 50% if a fatigue test is required as in a gross weight increase or a wing change. Cost of adding or changing components is based on 1981 methods of production. Application of advanced technologies (such as long-span Fowler flaps or composite structures) may require different production methods and tooling The complexity factor modifies the cost for these advanced technologies.

4.4.8.3 Material Cost

Material cost is composed of four basic elements, airframe materials, equipment, avionics and propulsion. Historical manufacturer's data is indexed to 1981 costs using a 15% annual inflation rate.

Airframe materials cost is a combination of baseline cost and new and changed cost. For a baseline type aircraft, basic structure materials make up approximately 42% of the total airframe material cost. Product supply (small nuts, bolts, rivets, etc.) make up the next largest part of the total at approximately 24%. These percentages are noted here because they would be directly affected by any structural advanced technology such as composites. Total airframe material cost is calculated by an equation of the form:

$$M_{AF} = C_3 \; (W_o + K_2 W_{N\&C})$$

where:

C_3 = airframe material cost baseline - \$/lb.

K_2 = nonstandard material factor for materials other than aluminum

W_o = unchange baseline airframe weight

$W_{N\&C}$ = weight of new or changed components affected by advanced technology application.

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd.)

4.4.8 Acquisition Cost Analysis Methodology (Cont'd)

4.4.8.3 Material Cost (Cont'd.)

As noted previously, equipment and avionics costs are assumed constant.

Propulsion costs, which includes engines, propellers and associated equipment, are obtained from the GASP cost module output for each case analyzed.

The total materials cost is then calculated by an equation of the form:

$$M = M_{AF} + E + A + P$$

where:

$M_{AF} = C_3\ (W_o + K_2 W_{N\&C})$

E = equipment cost

A = avionics cost

P = propulsion cost

4.4.8.4 Labor Cost

Labor costs are divided into two parts: unchanged weight with the same manhours cost per pound as the baseline and new and changed weight with a new amortization and learning curve.

The manhours per lb. of unchanged weight is based on a stabilized production rate assuming 500 units of the baseline aircraft have been produced. It is assumed that labor hours are stabilized and no further reductions are considered. Rates based on manufacturing experience were adjusted to reflect the slower rate for small transport aircraft and for the installation of options.

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont)

4.4.8 Acquisition Cost Analysis Methodology (Cont'd.)

4.4.8.4 Labor Cost (Cont'd.)

Labor hours on new and changed weight are amortized over 250 units in accordance with the ground rules of this study. The labor hours to produce an aircraft are based on a learning curve where the time to produce unit two is a percentage of the time to produce unit one. 80% is assumed for this study. The general equation is:

$$y = CX^{-N}$$

where:

y = labor hours at unit X

X = units

C = labor hours at unit 1

$$N = \frac{2.0 - \text{Log}_{10}(P)}{\text{Log}_{10}(2.0)}$$

P = percentage

The cumulative average hours to produce an aircraft is calculated by an equation of the form:

$$\bar{y} = \frac{C}{1-N} \; \frac{(X + .5)^{(1-N)} - .5^{(1-N)}}{X}$$

here:

C = labor hours at unit 1

X = total units

$$N = \frac{2.0 - \text{Log}_{10}(P)}{\text{Log}_{10}(2.0)}$$

P = learning percentage

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd.)

4.4.8 Acquisition Cost Analysis Methodology (Cont'd.)

4.4.8.4 Labor Cost (Cont'd.)

The baseline acquisition costs are based on actual unit labor cost after the 500th unit. At this point development and startup costs are assumed to be fully amortized. The rules of this study set a production run of 250 units to fully amortize the development costs. Assuming that the derivative aircraft is priced based on cumulative average labor costs over 250 units, labor costs for the new and changed weight portion of the new aircraft are 82% higher than baseline labor costs (80% learning curve).

$$\frac{\bar{y}_{\text{unit } 250}}{y_{\text{unit } 500}} = 1.82$$

In addition, advanced technology may require more or less labor per pound of new and changed weight, therefore another complexity factor is introduced. The total labor cost is therefore given by an equation of the form:

$$L = C_4(W_o + 1.82\ K_3 W_{N\&C})$$

where:

C_4 = baseline labor rate - \$/lb.

W_o = unchanged airframe weight

K_3 = complexity factor = $\dfrac{\text{unit 1 hours for new type construction}}{\text{unit 1 hours for baseline}}$

$W_{N\&C}$ = new and changed weight due to advanced technology application

4.4.8.5 List Price

The list price or selling price of the derivative aircraft is the sum of the development cost, material cost and labor cost marked up by an appropriate factor. This factor takes into account selling expenses, marketing costs and a reasonable profit to the manufacturer.

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd.)

4.4.8 Acquisition Cost Analysis Methodology (Cont'd.)

4.4.8.5 List Price (Cont'd.)

Additional acquisition cost to the operator of the aircraft would be the difference between the list price of the advanced technology derivative aircraft and the baseline aircraft.

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd)

4.4 9 Acquisition Cost Analysis

Using the previously described methodology, the additional operator acquisition cost for a derivative aircraft is compared to the DOC savings each advanced technology contributes to the derivative aircraft. Thus the number of years the operator will need to recover the additional cost due to advanced technology may be determined. This payback period will give a rough indication of the advance technologies worthy of further investigation.

Because this analysis is for a derivative aircraft with aircraft cost based on a fully amortized baseline aircraft, the initial cost for an aircraft using baseline technology is lower than the original baseline cost as given by GASP cost module calculation. In order to use comparable values the baseline DOC parameters in GASP affected by initial cost (Depreciation and Insurance) are adjusted to obtain DOC and initial cost on the same basis.

The sensitivity study curves of section 4.4.7 are used to obtain the DOC reduction due to each advanced technology. These reductions are referenced to the adjusted yearly DOC of the baseline for the 100 n. mi. stage length.

4.4.9.1 Drag Reduction

The NASA Ames/Stat NLF airfoil with cruise flap has a 7% reduction in total cruise drag which, from Figure 32, results in a 1.6% decrease in DOC. The acquisition analysis shows a 13% increase in initial cost assuming a standard program of production. This is a rather extensive modification of an existing design. The close tolerances and smoothness necessary to achieve laminar flow may require new tooling, materials and increased labor. Therefore, a more realistic acquisition cost would include these increases. An increase in initial cost of 16% is obtained with complexity factors increasing labor and development costs 20%. For the 100 n. mi. stage length the payback period for laminar flow airfoils is in excess of ten years for $1.75/gal. and in excess of 5 years for $3.50/gal. fuel cost.

Application of the Beech Advanced Turbulent Airfoil has similar results. A 1.4% reduction in cruise drag has a DOC benefit of .3% as seen from Figure 32. For an initial cost increase of 13% the payback periods for $1.75/gal. and $3.50/gal. fuel cost are each in excess of ten years.

Surface coatings on wing and empennage are evaluated slightly differently. Using coating costs from Reference 8 adjusted to 1981 dollars, the cost difference between coating and painting was calculated Manufacturer's data for painting similar size aircraft is used for paint material and labor cost. As noted in Reference 10 coating is applied from leading edge to rear spar and finished on the top surfaces with a polyurethane enamel topcoat for hydraulic fluid protection. CAAPCO B274 was selected as the coating with the best potential. Assuming a new production run of 250 units of the baseline aircraft with only coatings applied, the initial cost increase will be the sum of the (coating-paint) cost and the initial cost increase of the new production run. For an initial cost increase of .8% the payback periods are 2.0 years for $1.75/gal fuel cost and 1.0 year for $3.50/gal fuel cost. The weight differential between coating and painting is negligible. See Table 5.

Due to manpower and time restraints, a detailed analysis of the application of active controls to the baseline aircraft was not accomplished. Applying the results of Reference 28 (a 4.5% improvement in cruise drag from a 3% improvement for reduced tail size and 1.5% improvement for trim drag reduction due to relaxed stability) to Figure 32, the DOC improvement is 1%.

TABLE 5

SURFACE COATING - PAINT COMPARISON

	Material Cost ($)	Labor Cost ($)	Weight (lbs)
Coating			
Primer	69.00	--	15
CAAPCO B274	960.00	--	3
Polyurethane enamel	33.00	--	2
TOTAL	1062.00	3490.00	20
Paint			
Primer	69.00	--	3
Polyurethane enamel	259.00	--	10
TOTAL	328.00	1663.00	13
(Coating-Paint)	734.00	1827.00	7

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd.)

4.4.9 Acquisition Cost Analysis (Cont'd.)

4.4.9.1 Drag Reduction (Cont'd.)

In this case the increased avionics necessary for augmentation and active control monitoring are not accounted for. Complexity factors of 10% for increased materials and 20% for increased development are used. The payback period is calculated as 9 years for $1 75/gal. fuel cost and 6 years for $3.50/gal. fuel cost. It is expected that the increased system cost and maintenance cost would increase the payback period significantly.

4.4 9.2 Propulsion Improvements.

References 22, 23 and 24 indicate that an average SFC reduction of 20% is attainable in advanced technology engines.

From Figure 34, an 11% reduction in DOC is indicated when engine size and horsepower are held constant at the baseline values.

It is assumed in this study that an SFC decrease of this magnitude will be at an increased engine price. Figure 36 shows that a 1% decrease in the savings results from a 40% increase in engine initial price. To ascertain the effect of engine price on payback period in conjunction with a 20% SFC reduction a sensitivity study was conducted.

As mentioned previously, an engine change is assumed to have no effect on the airframe weight. The new and changed weight is assumed to be zero

From Figure 36 a 10% DOC savings for 20% SFC and 40% engine initial cost increase shows a payback period of 1.6 years. For no engine initial cost increase the payback period is nil.

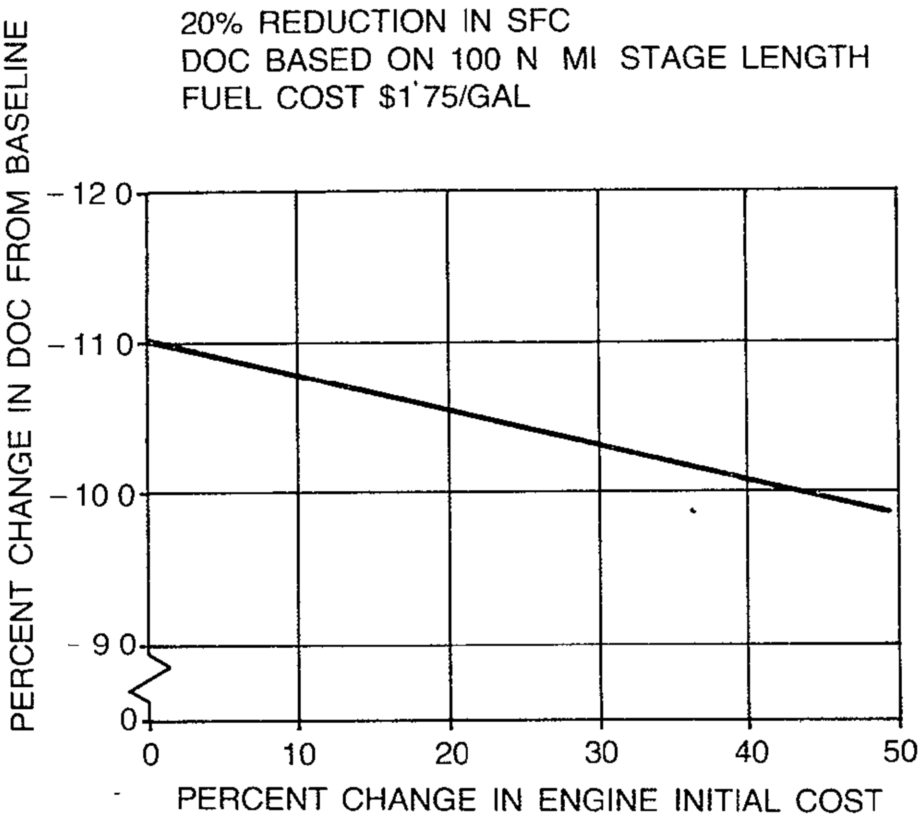


FIGURE 36 EFFECT OF ENGINE INITIAL COST ON DOC

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.4 Identification of Potential Technologies (Cont'd.)

4.4.9 Acquisition Cost Analysis (Cont'd.)

4.4.9.2 Propulsion Improvements (Cont'd.)

Figure 37 presents the percent cash flow versus years. The point of zero investment is the payback period in years. It is seen that even with a high engine initial cost increase the payback period is less than 5 years.

Propeller improvements are assumed to change propeller efficiency 3.5%. From Figure 35 the DOC savings is 1.2%. Payback period is 1.5 years for $1.75/gal. fuel cost and 1.0 years for $3.50/gal. fuel cost, with propeller weight held constant and cost increased 80%.

4.4.9.3 Structural Weight Reduction

Use of composite structures for weight reduction will result in different methods of construction, higher development costs for tooling and engineering plus labor and material costs may increase. These can all be accounted for in the use of the complexity factors

Before application of any complexity factors, an analysis of applying composites to wing structure only was done without factors. A payback period in excess of ten years was obtained for an assumed 25% wing weight reduction. This is a 7% reduction in structural weight which, from Figure 33, is a 1% DOC reduction. To obtain a more realistic cost estimate, complexity factors were applied to the analysis for the use of advanced graphite/epoxy composite structure. Complexity factors include increases of 40% in development costs for tooling, etc., 600% for material costs and a 10% decrease in labor costs for reduced parts count. Material costs are based on a 20 $/lb. graphite/epoxy material cost in 1985. Application of these factors increases the payback period to in excess of 15 years.

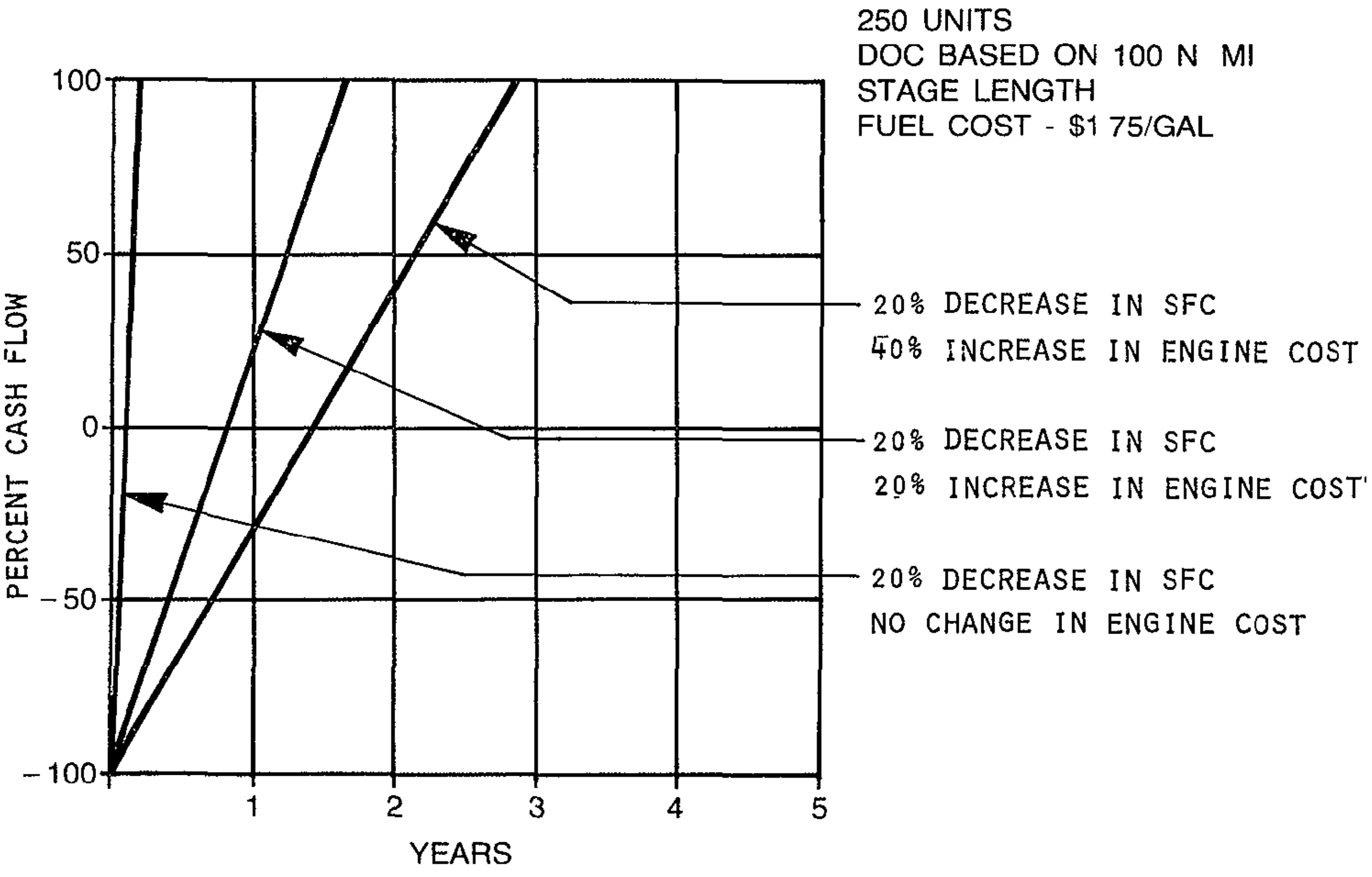


FIGURE 37 EFFECT OF ENGINE INITIAL COST ON RETURN ON INVESTMENT

4.5 Advanced Technology Derivative Aircraft

4.5.1 Selection of Technologies

Selection of the advanced technologies applicable to the baseline aircraft takes into account the results presented in section 4.4. Those studies were conducted with engine and airframe size held constant for a fixed payload/range.

In the final selection process, sizing studies were conducted with the GASP engine sizing option. Engine and airframe are resized to optimize the benefits obtained from advanced technologies for a fixed payload range and cruise speed. The engines are sized to the required cruise speed and then the airframe is sized by the fuel weight needed for the range requirement.

Advanced technologies are applied individually and in combination to the baseline aircraft design and the resulting DOC's compared to the baseline value. A summary of the results is shown in Table 6 .

The most promising technology is in the propulsion area where a 20% SFC reduction over the operating range of the engine was selected as representative of expected potential advances in engine technology. Resizing of the aircraft design resulted in an additional 3% DOC improvement for the \$1.75/gal. fuel cost and no change in engine initial cost With a 20% increase in engine \$/SHP this savings is reduced .4%. Due to resizing, the shaft horsepower required was reduced to the point where the actual engine initial cost decreased 1%.

Propeller advances are assumed to have a 3% efficiency increase utilizing advanced airfoils and prop-nacelle integration. A 50% weight reduction is assumed for the use of carbon/epoxy composite blades and lightweight hub with an 80% increase in propeller cost to use this technology. The effect of resizing is a 2.6% DOC savings which is an additional 1.4% DOC savings over the unresized aircraft for $1.75/gal. fuel cost.

Application of surface coatings to the wing and empennage surfaces from leading edge to rear spar in combination with an advanced turbulent airfoil shape results in a 2.4% DOC savings; an additional 1.6% DOC savings over unresized aircraft.

Graphite/epoxy material in wing and empennage structure resulted in a 2.6% DOC savings over the unresized aircraft.

A combination of the above advanced technologies results in a resized aircraft with an additional 6.8% DOC savings over a similar unresized aircraft. Table 7 presents the fuel savings due to the advanced technologies.

4.5.2 Advanced Technology Derivative Aircraft (ATDA).

The final derivative design utilizes the baseline aircraft fuselage and applies advanced technologies to the wing, empennage, engines and propellers. Engine size is determined from cruise condition and indexed back to a sea level static shaft horsepower. Wing, empennage and landing gear are resized to account for the change in fuel weight and corresponding structural weight. Direct operating costs are calculated for 50, 100, 200, 400 and 568 n. mi. stage lengths. Acquisition cost and payback period analyses are also conducted.

The ATDA design features a smooth surfaced wing with integrated propeller-nacelle-wing arrangement at approximately mid-wing. Figure 38 presents the general arrangement three-view drawing.

TABLE 6

DOC SAVINGS - ADVANCED TECHNOLOGIES

ADVANCED TECHNOLOGY	RESIZED AIRCRAFT				UNRESIZED AIRCRAFT	
	$1.75/Gal.		$3.50/Gal.		$1.75/Gal.	
	ΔDOC%	ΔDOC% Combined	ΔDOC%	ΔDOC% Combined	ΔDOC%	ΔDOC% Combined
Baseline	0	0	0	0	0	0
20% SFC Reduction	-13.66	-13.66	-17.16	-17.16	-11.1	-11.1
Propeller	- 2.60	-16.26	- 3.02	-20.18	- 1.18	-12.28
Surface Coating +Advanced Airfoil	- 2 35	-18.61	- 2.71	-22.89	- .75	-13.03
Wing & Empennage Composite Structure	- 2.56	-21.17	- 2.52	-25.41	- 1.34	-14.37
All Combined		-21.17		-25.41		-14.37
All Combined 20% $/SHP Engine Cost Increase		-20.75		-25.14		-14.08

TABLE 7

FUEL SAVINGS - ADVANCED TECHNOLOGIES

Block Fuel - 100 N. Mi. Stage Length

ADVANCED TECHNOLOGY	RESIZED AIRCRAFT		UNRESIZED AIRCRAFT	
	Δ Fuel %	Δ Fuel % Combined	Δ Fuel %	Δ Fuel % Combined
Baseline	0	0	0	0
20% SFC Reduction	-23.79%	-23.79%	-20.65%	-20.65%
Propeller	- 3.87%	-27.66%	- 1.54%	-22.19%
Surface Coating + Advanced Airfoil	- 3.29%	-30.95%	- .58%	-22.77%
Wing + Empennage Composite Structure	- 2.51%	-33.46%	- .58%	-23.35%

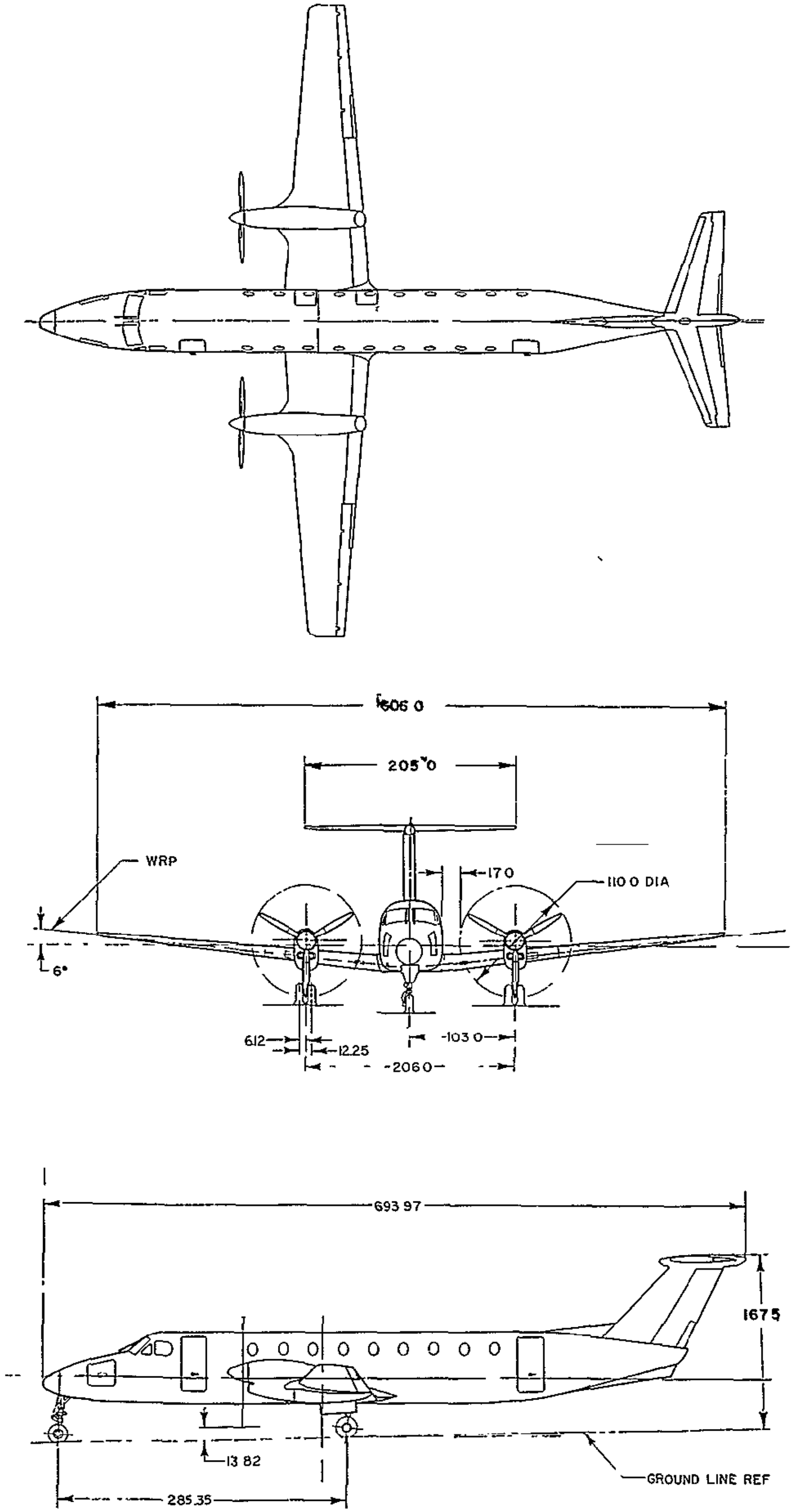


FIGURE 33. ADVANCED TECHNOLOGY DERIVATIVE AIRCRAFT GENERAL ARRANGEMENT

4.5.2.1 Inboard Profile

Interior arrangement of the ATDA is similar to the baseline configuration as the fuselage structure is unchanged. Figure 39 presents an inboard profile of the ATDA.

4.6 Evaluation of Derivative Aircraft

Evaluation of the ATDA in comparison to the baseline aircraft results in the following percent changes: A 14% total cruise drag reduction, a 14% reduction in gross weight, a 34% block fuel reduction, a 14% wing area reduction, a 21% DOC reduction for $1.75/gal. fuel cost and 25% DOC reduction for $3.50/gal. fuel cost. Operator acquisition cost is increased 17% which, based on the operating costs for the 100 n. mi. stage length, may be recovered in .9 years. Detailed comparisons are shown in the following sections.

4.6.1 Comparison with Baseline - Configuration, Weights, Performance

A geometric comparison of the ATDA and baseline is presented in Table 8. In accordance with the study guidelines, the fuselage is unchanged. Wing area is reduced 14% and the span slightly shortened. Empennage areas and span are correspondingly reduced. Engine nacelles are reduced slightly for the reduced horsepower engines. Total wetted area is reduced 8.5%. Combined with surface coating and advanced airfoils the total drag reduction in cruise is 14%.

Weight comparisons are presented in Table 9. The propulsion group weight is reduced by the assumed weight reductions of engines and propeller due to advanced technology which are 24% for engines and 50% for propellers. The structures and flight controls group weights are calculated in GASP and reflect the total fuel required weight reduction of 28%. Empty weight is reduced 16% and takeoff weight reduced 14% to meet the same design mission as the baseline.

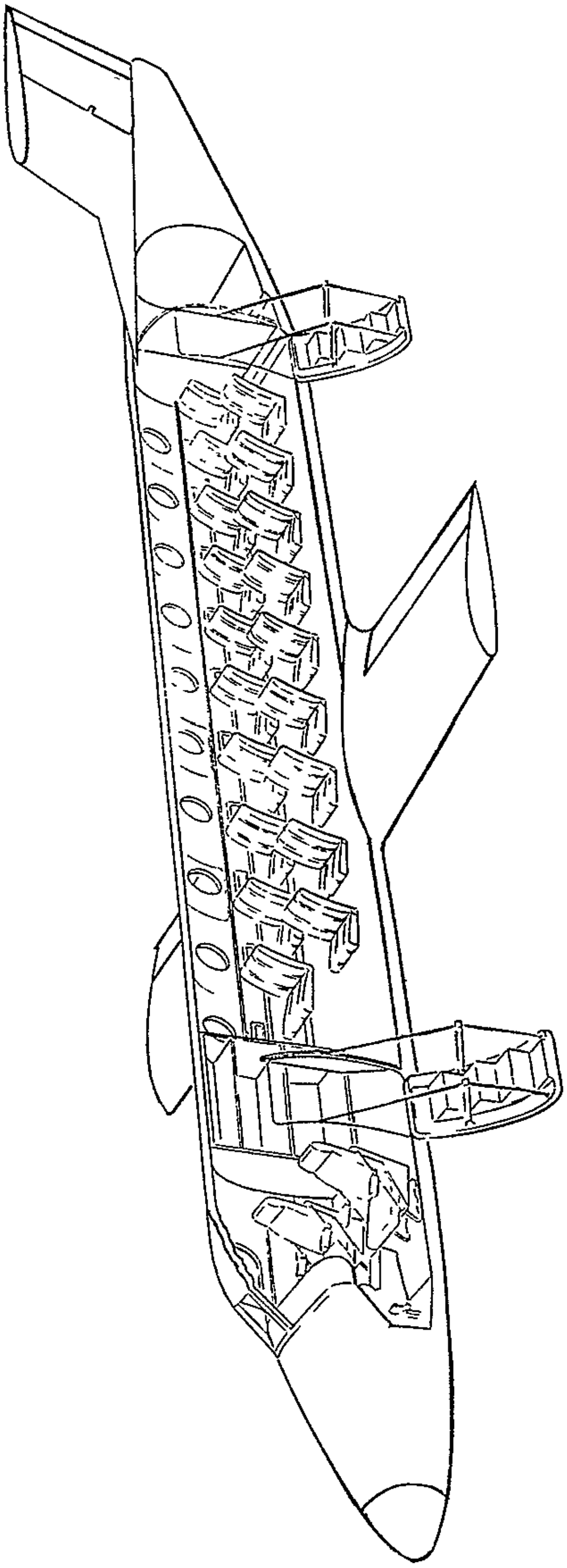


FIGURE 39. ADVANCED TECHNOLOGY DERIVATIVE AIRCRAFT INBOARD PROFILE

TABLE 8

GEOMETRY COMPARISON

	Baseline	Advanced Technology
Fuselage		
length - feet	51.82	51.82
width - feet	5.55	5.55
wetted area - square feet	773.	773.
Wing		
aspect ratio	9.8	9.8
area - square feet	303.	260.5
span - feet	54 5	50.5
taper ratio	.416	.416
wetted area - square feet	521.	443.
Horizontal Tail		
aspect ratio	5.0	5.0
area - square feet	68.0	58.4
span - feet	18.44	17.09
moment arm - feet	30.9	28.7
volume coefficient	1.181	1.181
wetted area - square feet	136.	117.
Vertical Tail		
aspect ratio	1 18	1.18
area - square feet	48.7	41.9
moment arm - feet	26.5	24.6
volume coefficient	.078	.078
wetted area - square feet	98.	84.
Engine Nacelles		
length - feet	12.2	11.23
mean diameter - feet	3.1	2.8
wetted area - square feet	283.	200.

TABLE 9

WEIGHT COMPARISON

Design Weights (pounds)	Baseline	ATDA
Max Ramp	15355.	13200.
Max Takeoff	15273.	13146.
Max Landing	15273.	13146.
Zero Fuel	12500.	11134.
Basic Operating Weight Empty	8740.	7375.
Fuel	2855.	2066.
Payload	3760.	3760.

Group Weight Comparison (pounds)	Baseline	ATDA
Propulsion Group		
Engines	971.	738.
Engine Instl	166.	126.
Fuel System	315.	228.
Prop Weight	330.	161.
Total	1782.	1253.
Structures Group		
Wing	1200.	696.
Horizontal Tail	164.	104.
Vertical Tail	140.	87.
Fuselage	1704.	1663.
Landing Gear	631.	543.
Engine Section	383.	322.
Total	4221.	3415.
Flight Controls Group		
Cockpit Controls	34.	32.
Fixed Wing Controls	201.	173.
Total	235.	204.
Fixed Equipment	2162.	2162.

TABLE 9

WEIGHT COMPARISON

(Continued)

Group Weight Comparison (pounds) (Continued)	Baseline	ATDA
Weight empty	8400.	7035.
Basic Operating Items	340.	340.
Operating Weight Empty	8740.	7375.

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.6 Evaluation of Derivative Aircraft (Cont'd)

4.6.1 Comparison with Baseline - Configurations, Weights and Performance (Cont'd.)

Performance comparison of the baseline aircraft and the ATDA is presented in Table 10. Fuel savings of 34% allow a reduction in gross weight of 14% with a subsequent 17% reduction in engine power required. Field lengths are reduced as a result of the reduction in gross weight.

4.6.2 Economic Comparisons

Economic comparisons are presented in Table 11. The advanced technology application will be at a 17% increase in acquisition price due to higher development and material costs and amortization of this cost over 250 units instead of 500 units. Direct operating cost comparisons for five stage lengths show a consistent savings from the baseline of 20-21% for $1.75/gal. fuel cost and 24-25% for $3.50/gal. fuel cost. An example of the individual component contribution to the direct operating cost reduction for the 100 m. mi. stage length is also shown in Table 11.

Illustrations of the breakdown of DOC are shown in Figures 40 and 41 for 100 n. mi. stage length at the two fuel costs considered. The large contribution of fuel, oil and their associated taxes is evident in these charts.

TABLE 10

PERFORMANCE COMPARISON

	Baseline	ATDA	Benefit
Takeoff Gross Weight (Lbs)	15273	13146	-14%
Engine Power (SHP) Flat Rating	1000	826	-17%
Range at Full Design Payload + Reserves (n. mi.)	568	568	Held Constant at Baseline Values
Cruise Speed @ 10,000 Ft (KTAS)	263	263	
Runway Length (Ft)			
Sea Level ISA	4980	4360	-13%
Sea Level 90°F	5686	4950	-17%
Offload for Off-design Field Lengths (Lbs)			
1000 foot less than Sea Level 90°F Baseline Runway	1003	198	-80%
7000 foot runway at 6000 Ft. 90°F	2033	1033	-49%
Block Fuel (Lbs)			
100 n mi. stage length	518	341	-34%
568 n. mi. stage length	2350	1561	-34%
Approach Speed (KTAS)	111	108	- 3%
Landing Stall Speed (KTAS)	86	83	- 4%

TABLE 11

ECONOMIC COMPARISON

ATDA	Δ% from Baseline
Unit Price (250 units 1981 $)	+17%
Engine price	- 1%
Propeller Price	+80%

Direct Operating Cost at Stage Length - n. mi.	Δ% from Baseline Fuel Cost	
	$1.75/gal.	$3.50/gal.
50	-20%	-24%
100	-21%	-25%
200	-21%	-25%
400	-21%	-25%
568	-21%	-25%

Direct Operating Cost Component Breakdown for 100 n. mi. stage length	Δ% from Baseline $1.75/gal. or $3.50/gal.
Crew	2%
Fuel and Oil	-34.0%
Insurance	17.0%
Maintenance	
Airframe	- 8.0%
Engine	-12.0%
Maintenance Burden	- 9.0%
Depreciation	17.0%

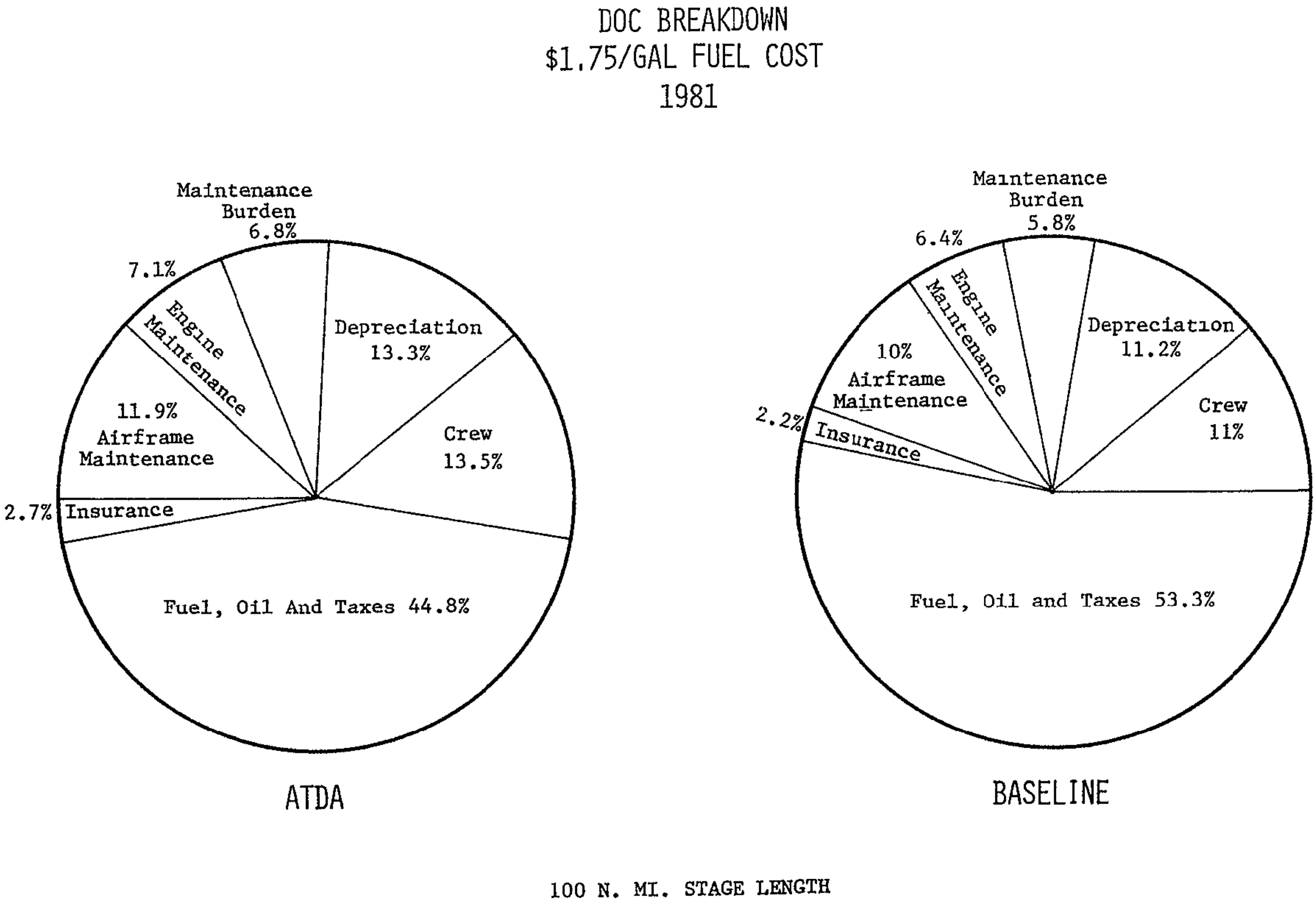


Figure 40. DOC Breakdown 1.75 $/gal. Fuel Cost

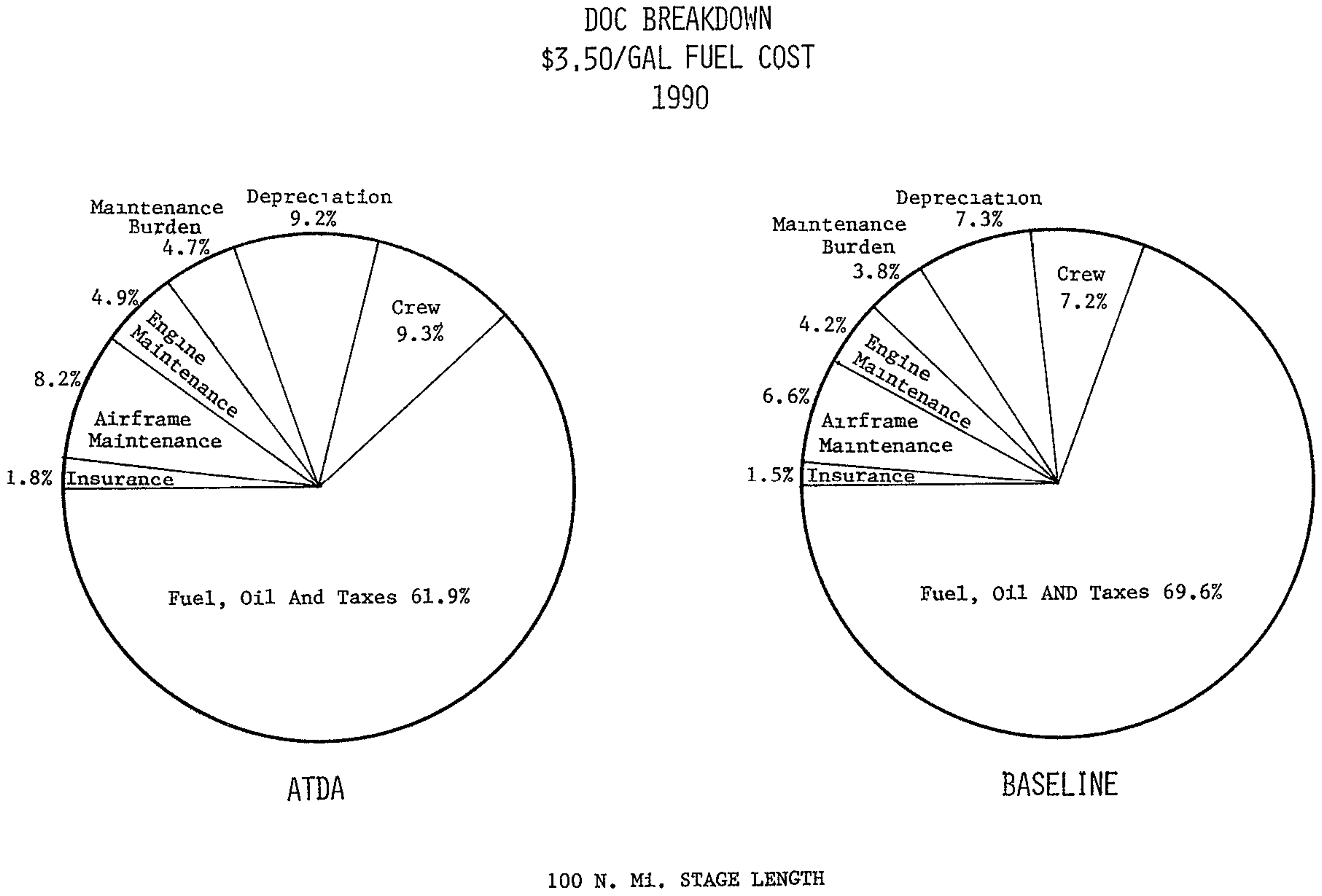


Figure 41. DOC Breakdown 3.50 $/gal. Fuel Cost

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.6 Evaluation of Derivative Aircraft (Cont'd.)

4.6.3 Market Potential

As an indication of the market potential of the ATDA, a worldwide projected demand for this type of aircraft was accomplished using standard market research methods. In the coming decade a demand of 1280 aircraft in the 15-19 passenger seating capacity is projected to be needed. Table 12 presents the aircraft demand for each year with the higher seating capacities shown for comparison.

These aircraft will supplement established operators as they open new routes and start new fleets for operators opening new markets. Domestically, new market development will be the prime area of growth in the commuter industry as route abandonment by major carriers continue and industry diversification accelerates. The demand for large equipment will be limited to commuter carriers serving large metropolitan hubs. The major growth in these major hub markets will be complete by 1987-88, and will be severely constrained by lack of gate access and A.T.C. limitations. New route growth outside the major hubs will be the strong growth areas for the later half of the decade and the first half of the 90's.

Internationally, demand for small transport aircraft will be at least as strong as in the U.S. However, the full potential for this market may not be realized as developing countries defer the development of an air transportation infrastructure. This deferral will be the result of continually escalating negative foreign balances. The willingness of international financing institutions to continue extending large loans to the third world is, in light of these negative balances, deeply in doubt and could present real difficulties in selling to the third world. The developed nations of Western Europe represent at best a weak market as a commuter type route structure is not viable and intercity transportation is more than adequately served by the more energy efficient rail transport mode.

4.0 DISCUSSION AND RESULTS (Cont'd.)

4.6 Evaluation of Derivative Aircraft (Cont'd.)

4.6.3 Market Potential (Cont'd.)

The small short haul aircraft needed in all capacities totals over 2000 aircraft. Based on the projected demand, a 40% capture rate was established for the ATDA. The resulting requirement of 50-60 aircraft per year is consistent with the five aircraft per month production rate used in the acquisition cost analysis and development cost recapture point of 250 units.

TABLE 12

PROJECTED ANNUAL AIRCRAFT DEMAND

WORLDWIDE

1981-1990

YEAR	15-19	20-25	26-35	36-40
1981	70	14	20	15
1982	85	16	20	15
1983	100	18	25	20
1984	125	18	30	20
1985	130	24	30	25
1986	140	25	30	25
1987	150	25	35	25
1988	160	25	35	30
1989	160	25	40	30
1990	160	30	40	30
TOTALS	1280	220	305	235

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- For payback periods of less than five years, advanced engines with low SFC's have the greatest potential for operating cost reductions. Although turboprop engines were examined in this study, other advanced engine concepts giving the same benefits may also have potential.

- Advanced high lift systems have the potential of reducing field lengths but will increase DOC's if the wing is not being resized Simpler mechanism and lightweight structures are required so as not to penalize climb and cruise performance.

- Graphite/epoxy composite structures do not in themselves have short payback periods in derivative aircraft due to the high development and production costs involved.

- Acquisition costs may be lower and the payback periods shorter for some combinations of advanced technologies. For example a wing resizing due to fuel efficiency may also incorporate new airfoils and materials since tooling, drawings, etc., may be changed concurrently.

- Advanced technologies have the potential of lowering operating costs significantly when applied to a derivative aircraft. Although the initial price is higher than the original aircraft, development costs are less than an all-new design.

5.2 Recommendations for New or Continued Research

5.2.1 Propulsion

- Highest priority should be given to research and development as projected in the recent STAT studies. Other advanced engine concepts such as rotary engines, diesel, stratified charge, etc., need further study. Emphasis on fuel efficiency and low maintenance requirements should be maintained in this development.

5.2 Recommendations for New or Continued Research (Cont'd.)

5.2.1 Propulsion

- Propeller development should be continued with full-scale testing of concepts developed in earlier general aviation propeller studies. Application of advanced materials research to propeller/hub combinations should be developed concurrently.

- Research in slipstream effects and propeller-nacelle-wing integration should be continued and large-scale powered wind tunnel tests conducted to quantify analytic results.

5.2 2 Aerodynamics

- Verification of drag benefits due to surface coatings and development of their application and maintenance methods should be continued

- Quantification of natural laminar flow and turbulent flow airfoil concepts should be conducted in three-dimensional full-scale tests.

5 2.3 Structures

- Based on the current and completed ACEE programs continued development of carbon filament/epoxy material application should be conducted with emphasis on lightly loaded structure application Development of fabrication methods with emphasis on low cost tooling and reduced labor costs should be accomplished.

- Compilation of previous and on-going research and test efforts in composites into a composite design guide for manufacturers of small transport aircraft should be accomplished.

5.2.4 Systems

- Conduct research on control system technology for active controls for relaxed stability and ride improvement. Emphasis should be on lightweight, small and reliable systems tailored to the small transport aircraft

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