INTEGRATED TECHNOLOGY WING STUDY

NAS1-16273

ORAL PRESENTATION APRIL 8, 1981

LOCKHEED-CALIFORNIA CO.
BURBANK, CALIFORNIA

PREPARED FOR NASA LANGLEY RESEARCH CENTER

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INTEGRATED TECHNOLOGY WING DESIGN
8 APRIL 1981

8:30 - 9:15 P.M.  OVERVIEW
    - TONY HAYS

9:15 - 10:00  AERODYNAMICS
    - ROGER FIELD/LUIS MIRANDA

10:00 - 10:30  ACTIVE CONTROLS/ADVANCED SYSTEMS
    - BRIAN PENROSE

10:30 - 10:45  BREAK

10:45 - 11:15  PROPULSION/PROPULSION INTEGRATION
    - BOB SKARSHAUG

11:15 - 11:45  STRUCTURES/MATERIALS
    - MARLON GUESS

11:45 - 12:15 P.M.  PRELIMINARY AEROELASTIC DESIGN OF STRUCTURES (PADS)
    - NICK RADOVCICH*

* NOT PART OF CONTRACT EFFORT; SUPPORTING ROLE
OVERVIEW OF PROGRAM

TONY HAYS
PROBLEM OBJECTIVE

TO DEVELOP A PLAN OF THE ORDERLY EFFORT REQUIRED BY A COMMERCIAL TRANSPORT MANUFACTURER TO INTEGRATE ADVANCED TECHNOLOGY INTO A NEW WING FOR A DERIVATIVE AND/OR NEW AIRCRAFT THAT COULD ENTER SERVICE IN THE LATE 1980s TO EARLY 1990s TIME PERIOD.

The purpose of this study is to answer the following question. If it is decided to develop a new wing for a derivative and/or new long-range commercial transport aircraft, what other technologies should be incorporated that are cost effective? The answer to this question will provide guidelines to NASA and industry as to the best allocation of research funds. It is particularly important that the limited money available for technology development be spent in the areas that offer the greatest benefits.
SPECIFIC OBJECTIVES

• COST/BENEFITS ASSESSMENT
• PLAN AND COST OF SUBSEQUENT TECHNOLOGY DEVELOPMENT PROGRAM
• RISK ASSESSMENT

At this presentation, cost/benefit assessment and preliminary plans and costs will be addressed. Risk assessment will not be discussed in detail at this point.
OVERVIEW OF PROGRAM
A flowchart for this study is shown above. Shaded areas are those parts of the plan that have been completed to date.
BASELINE CONCEPT
The conventional technology baseline airframe is derived from the L-1011-1 by the addition of a 120 in. fuselage plug forward of the wing and 160 in. plug aft of the wing. 62 in. wing root plugs are also added to increase wing area, together with 54 in. wing tip extensions in conjunction with maneuver load alleviation (MLA), as used on the L-1011-500. The aircraft represents the level of technology of current production aircraft.
BASELINE CONCEPT

DESIGN FEATURES
RANGE________________ 5000 N. MI.
CAPACITY___________ 350 PAX.
PAYLOAD___________ 73,500 LBS.
AVG. STAGE LENGTH___ 2500 N.MI.
CRUISE SPEED________ 0.80
FUEL RESERVES_______ INTERNATIONAL
G.E. CF6-50C_________ HIGH BYPASS TURBOFAN

DESIGN CONSTRAINTS
FIELD LENGTH________ 10,500 FT.
APPROACH SPEED_______ 145 KTS.
OPERATIONAL CEILING___ 42,000 FT.
CRUISE ALTITUDE (MIN.)_ 31,000 FT.

The design features are representative of a derivative of a high-capacity long-range wide-body trijet. The constraints are representative of current long-range wide-body aircraft.

Because of a change in the choice of engine from one that represents current technology to one that represents technology at the start of the E³ program, the original range requirement (shown above) has been revised downwards.
ECONOMIC ASSUMPTIONS

1980 DOLLARS

FUEL COST
FOR YEAR 2000 = $2.12/GAL
(INCREASING AT 3-1/2% ABOVE INFLATION)

1980 dollars are used in all economic calculations, but fuel costs are taken at the mid-life of an average production aircraft. The pessimistic assumption is made that fuel costs will continue to outpace inflation by about 3 1/2 percent.
A carpet plot is shown for a revised range of 4600 n.mi.
REFERENCE AIRCRAFT

TAKEOFF GROSS WEIGHT____ 608,647 LB
ZERO FUEL WEIGHT________ 376,650 LB
OPERATING WEIGHT EMPTY___ 303,150 LB
WING LOADING_____________ 138 LB/FT^2
THRUST/WEIGHT RATIO______ 0.26
THRUST/ENGINE____________ 52,749 LB
FLYAWAY COST___________ $69 MILLION
D.O.C.___________________ 5.66 \$/SM

Leading characteristics of the reference aircraft are shown above.
This drawing shows the general configuration of the baseline aircraft. Some small changes have been made to the nacelles and tail to reflect the CF6-50C engine.
The major technological elements that have been identified for this study are shown above.
TECHNOLOGY BENEFITS
For certification and entry into service by the end of 1990, technology development must be completed by the end of 1986. Plans and costs of technology development are addressed in this study.
This figure shows options, not requirements, associated with the application of an advanced airfoil to the reference configuration. The optimum choice of wing design and operating characteristics involves a complex interaction of these variables.
**TRANSONIC WING TECHNOLOGY DEVELOPMENT**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>WING 49</th>
<th>WING 53</th>
<th>WING 55</th>
<th>WING 56</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPECT RATIO</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>SWEEP AT 1/4 C</td>
<td>35°</td>
<td>35°</td>
<td>25°</td>
<td>25°</td>
</tr>
<tr>
<td>T/C</td>
<td>10%</td>
<td>10%</td>
<td>12%</td>
<td>14%</td>
</tr>
<tr>
<td>DESIGN MACH NO.</td>
<td>0.84</td>
<td>0.84</td>
<td>0.80</td>
<td>0.76</td>
</tr>
<tr>
<td>DESIGN C_L</td>
<td>0.40</td>
<td>0.50</td>
<td>0.60</td>
<td>0.75</td>
</tr>
<tr>
<td>Δ M L (GOAL)</td>
<td>0</td>
<td>5%</td>
<td>14%</td>
<td>25%</td>
</tr>
</tbody>
</table>

Wing 55 represents the level of technology that is close to technology readiness. This study uses a level of aerodynamic technology more advanced than Wing 55. The actual choice of aspect ratio, sweep, thickness and design lift coefficient will be determined through parametric analysis.

The M(L/D) benefit does not account for the penalty in increased wing weight associated with the higher aspect ratio wing.

Wing 49 represents the level of technology in the L-1011.
**MAXIMUM LIFT COEFFICIENT**

- LOCKHEED FLIGHT TEST AND WIND TUNNEL EXPERIENCE
- INDUSTRY AND NASA PUBLISHED DATA
- HIGH LIFT SYSTEM ANALYSIS

<table>
<thead>
<tr>
<th>TECHNOLOGY LEVEL</th>
<th>TRAILING EDGE FLAPS</th>
<th>LEADING EDGE DEVICE</th>
<th>TYPICAL CLMAX POTENTIAL 35° SWEEP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b1 / b</td>
<td>c1 / c</td>
<td>100% b, 15% c</td>
</tr>
<tr>
<td>L-1011</td>
<td>.50 - .55</td>
<td>.25 - .30</td>
<td>2 SLATS/KREUGERS</td>
</tr>
<tr>
<td>ADVANCED CONVENTIONAL</td>
<td>.55 - .65</td>
<td>.30 - .35</td>
<td>2 or 3 SHAPED KREUGER</td>
</tr>
<tr>
<td>ADVANCED CONCEPTS</td>
<td>.65 - .70</td>
<td>.30 - .35</td>
<td>2 or 3 ROTATING FLAP</td>
</tr>
</tbody>
</table>

Maximum lift coefficient is an important parameter in sizing an aircraft wing. Lockheed's flight test and wind tunnel experience with the L-1011, S-3A and the P-3C along with published data and high-lift research form a foundation for maximum lift predictions.
The active controls configuration includes the technology elements of relaxed static stability (RSS), fly-by-wire (FBW), multiplexing (MUX), and fuel management for c.g. position control. Addition of FBW flight controls to the baseline enables maximum benefit to be achieved from relaxing the static stability in the pitch axis. Unchanged from the baseline aircraft are the hydraulic, pneumatic, and electrical power and distribution systems, the environmental control system (ECS), and the avionics. The active controls technologies of gust alleviation (GA), maneuver load alleviation (MLA), and elastic mode suppression (EMS) are not included for this configuration as they are considered baseline technologies. Flutter mode suppression was found to be beyond the reach of 1986 technology readiness.
Shown is the "current wing" curve for trim drag vs. c.g. location. It shows that by shifting the c.g. range aft, and thus relaxing the static stability, the most trim drag benefit obtainable for current wing technology is about 2 percent. With the use of c.g. fuel management, pitch augmentation should not be required. An on-going Lockheed study for the ACEE program is investigating the benefits of RSS for current technology wings. The curve is the result of wind tunnel data for that study.
A greater amount of trim drag benefit is obtainable for the advanced wing by shifting the c.g. back beyond the neutral point. A benefit of 4 percent is shown above for implementation of relaxed static stability. With the c.g. range shifted back into the unstable regime the aircraft will require full FBW pitch augmentation.
ACTIVE CONTROLS SUMMARY

WEIGHT SAVINGS: 0.5% EMPTY WEIGHT

RSS PAYOFF: FUEL 4%

MAINTENANCE IMPROVEMENT
SYSTEMS DEFINITION,
ADVANCED SYSTEMS AND CONTROLS

- ADVANCED SECONDARY POWER SYSTEM (SPS)
- ADVANCED ELECTRICAL SYSTEM
- ADVANCED ENVIRONMENTAL CONTROL SYSTEM (ECS)
- MULTIPLEXED LOAD CONTROL
- ELECTRO-MECHANICAL ACTUATION SYSTEM (EMAS) FOR FLIGHT CONTROL AND SERVICES
- INTEGRATED AVIONICS
- POWERED WHEELS

HYDRAULIC AND PNEUMATIC
POWER/DISTRIBUTION SYSTEMS REMOVED

The "Advanced Systems and Controls" configuration eliminates engine bleed and the pneumatic distribution system. The hydraulic system is also removed. The electrical system is redesigned to generate and distribute the power needed for the functions and services of an all-electric aircraft.
ALL ELECTRIC AIRCRAFT

SECONDARY POWER SERVICES

GEN

STARTER

APU

EMPTY WEIGHT 2%
FUEL CONSUMPTION 4%
MAINTENANCE
AIRCRAFT COST

REDUCES
SFC COMPARISON
CF6-50C AND GE E³ ENGINES
35,000 FT 0.80 Mo

SFC levels are shown for the E³ FPS during cruise for both a separate flow and a mixed flow exhaust system. Without the exhaust system mixer the SFC improvement relative to the CF6-50C engine is approximately 11.5 percent.
<table>
<thead>
<tr>
<th>WING</th>
<th>ENGINE</th>
<th>EXHAUST FLOW</th>
<th>INSTALLED NACELLE DRAG % OF AIRCRAFT DRAG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>WITHOUT AIR/PROP INTEGRATION</td>
<td>WITH AIR/PROP INTEGRATION</td>
</tr>
<tr>
<td>CONV.</td>
<td>CF6-50C</td>
<td>SEPARATE</td>
<td>4.3%</td>
</tr>
<tr>
<td>CONV.</td>
<td>E³</td>
<td>SEPARATE</td>
<td>4.3%</td>
</tr>
<tr>
<td>CONV.</td>
<td>E³</td>
<td>MIXED</td>
<td>7.2%</td>
</tr>
<tr>
<td>ADV.</td>
<td>CF6-50C</td>
<td>SEPARATE</td>
<td>11.5%</td>
</tr>
<tr>
<td>ADV.</td>
<td>E³</td>
<td>SEPARATE</td>
<td>11.5%</td>
</tr>
<tr>
<td>ADV.</td>
<td>E³</td>
<td>MIXED</td>
<td>17.3%</td>
</tr>
</tbody>
</table>

*ALL ENG/NACELLES LOCATED WITH C.G. SAME AS FOR CF6-50C*
ADVANCED ALUMINUM ALLOYS

DEVELOP POWDER METALLURGY
ALUMINUM ALLOYS WITH:

OBJECTIVE:  • 15 PERCENT HIGHER STRENGTH
             • 20 PERCENT HIGHER FATIGUE STRENGTH
             • CORROSION RESISTANCE EQUAL TO CURRENT ALLOYS
             • 8-10 PERCENT REDUCTION IN DENSITY
             • 15-20 PERCENT INCREASE IN MODULUS

PROGRESS:   • 20 PERCENT FATIGUE IMPROVEMENT DEMONSTRATED
             • CORROSION RESISTANCE EXCELLENT
             • 10 PERCENT STRENGTH IMPROVEMENT
             • DENSITY AND MODULUS GOALS DEMONSTRATED

This chart shows structural objectives for advanced powdered alloys and progress on meeting these objectives. Advanced powdered alloys with significant improvements in strength, reduced density and increased modulus have been developed.
## PROJECTED BENEFITS OF ADVANCED ALUMINUM ALLOYS

<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>WEIGHT SAVING</th>
</tr>
</thead>
<tbody>
<tr>
<td>WING</td>
<td>13.4%</td>
</tr>
<tr>
<td>EMPENNAGE</td>
<td>13.3%</td>
</tr>
<tr>
<td>STRUCTURAL WEIGHT</td>
<td>5.6%</td>
</tr>
</tbody>
</table>

Weight savings for the wing and empennage are shown as a percentage of the weight of that component.
### Projected Benefits of Advanced Composites

<table>
<thead>
<tr>
<th>Structure</th>
<th>Weight Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>21.3%</td>
</tr>
<tr>
<td>Empennage</td>
<td>21.1%</td>
</tr>
<tr>
<td>Structural Weight</td>
<td>8.9%</td>
</tr>
</tbody>
</table>
SiC/Al ADVANTAGES

- 30-50% INCREASE IN STRENGTH
- 50-100% INCREASE IN STIFFNESS
- 12-20% REDUCTION IN STRUCTURAL WEIGHT
- POTENTIAL COST OF STRUCTURAL WEIGHT SAVED APPROXIMATELY $10-$20 PER POUND

This chart shows projected strength, modulus, weight and cost benefits of SiC/Al metal matrix composites.
## Projected Benefits of Metal Matrix Composites

<table>
<thead>
<tr>
<th>Structure</th>
<th>Weight Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>17.4%</td>
</tr>
<tr>
<td>Empennage</td>
<td>17.2%</td>
</tr>
<tr>
<td>Structural Weight</td>
<td>7.2%</td>
</tr>
</tbody>
</table>
PADS DESCRIPTION

PRELIMINARY AEROELASTIC DESIGN OF STRUCTURES
— A COMPUTER SYSTEM —

- The actual system does nothing — a skeleton
- Includes architecture to access any batch program — any data base system
- How programs & data are to be used in any sequence is under user control through use of macros
- Produces an uninterrupted computing sequence with logical branching capability
  (in one job submittal — executed over 300 batch modules — like 300 separate job submittals)
The upper and lower bounds show the variation in equations used by different aircraft manufacturers relating wing weight to aspect ratio.
The black dots show the wing designs for which PADS application has been funded. The white dot (aspect ratio 10 wing made of advanced aluminum) is the subject of a proposed study.
# LARGE COMPOSITE PRIMARY AIRCRAFT STRUCTURES - WING DEVELOPMENT

**OBJECTIVE:** TO PROVIDE VERIFICATION OF TECHNOLOGY READINESS FOR APPLICATION OF COMPOSITE WING STRUCTURE ON COMMERCIAL AIRCRAFT

<table>
<thead>
<tr>
<th>ADVANCED COMPOSITES FOR COMMERCIAL AIRCRAFT</th>
<th>'81</th>
<th>'82</th>
<th>'83</th>
<th>'84</th>
<th>'85</th>
<th>'86</th>
<th>'87</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCPAS - KEY TECHNOLOGY ($2 MIL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• FUEL CONTAINMENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• DAMAGE TOLERANCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• JOINTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCPAS - WING DEVELOPMENT ($38 MIL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I PRELIMINARY DESIGN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II DESIGN CONCEPTS AND MANUFACTURING DEVELOPMENT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III DESIGN AND MANUFACTURING VERIFICATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV FULL SCALE DEMONSTRATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This shows one example of plans that are in the process of development for each technical discipline.
FUTURE PLANS
The ASSET (Advanced Systems Synthesis and Evaluation Technique) program is a large computer program which is used to calculate both performance and costs of candidate configurations.
The table above lists the advanced technology elements that will be applied to the baseline aircraft in order to evaluate technology benefits. Configurations 13 through 16 will indicate whether synergistic benefits exist.
This figure shows a method of presenting results from the study. The application of technologies (1) and (3) show a synergistic benefit, whereas the application of (1) and (2) show a combined effect that is less than the sum of the benefits applied separately.
This study concentrates on the costs of technology development. Other costs associated with design and production are calculated by parametric analysis and/or using the ASSET model.
AERODYNAMICS

LUIS MIRANDA/ROGER FIELD
AERODYNAMIC WING DESIGN TECHNOLOGY

INDEPENDENT RESEARCH PROGRAM

+ COLLABORATIVE PROGRAM WITH NASA-AMES

+ COLLABORATIVE PROGRAM WITH NASA-LANGLEY

OBJECTIVE

DEVELOPMENT OF AERODYNAMIC WING DESIGN CONCEPTS, CRITERIA AND METHODS FOR PERFORMANCE MAXIMIZATION.
COLLABORATIVE WING TECHNOLOGY PROGRAM

NASA - AMES
- ADVANCED COMPUTER CODES
- WIND TUNNEL FACILITY
- TEST SUPPORT

LOCKHEED-CALIFORNIA
- PRACTICAL DESIGN APPLICATION
- WIND TUNNEL MODEL
- ANALYSIS AND DOCUMENTATION

- WING DESIGN DATA BASE
- EVALUATION OF THEORETICAL METHODOLOGY
- IDENTIFICATION OF PROBLEM AREAS
- IMPROVEMENT OF DESIGN METHODOLOGY
APPROACH

CONCEPTUAL
- SUPERCRITICAL AIRFOILS
- HIGH ASPECT RATIO
- RELAXED STATIC STABILITY
- ITERATIVE: CAS GEOMETRY + FLO-22.5
- OPTIMIZATION: CONMIN + CAS + FLO-22.5
- SHOCK-FREE REDESIGN
- PERTURBATION REDESIGN

COMPUTATIONAL

EXPERIMENTAL
- WIND TUNNEL TEST OF WING-BODY-TAIL CONFIGURATIONS
- FORCES, MOMENTS, PRESSURE DISTRIBUTIONS, OIL FLOWS
- AMES 14 FT, CALSPAN 8 FT, RYE CYN 4 FT
THE WING DESIGN PROCESS

1. DESIGN GOALS
2. CONCEPTS & CRITERIA
3. INVERSE SYNTHESIS
4. GEOMETRY
5. THEORETICAL ANALYSIS
6. WIND TUNNEL TEST
7. DESIGN INTEGRATION
8. ANALYSIS & CORRELATION
AIRFOIL TECHNOLOGY AND PRESSURE DISTRIBUTION CRITERIA

EARLY SUPERCritical ("PEAKy")

M_L > 1
M_L < 1

ADVANCED SUPERCritical
TRANSONIC CODES EVALUATED

FLO-22
• NON-CONSERVATIVE DIFFERENCES
• PARABOLIC CO-ORDINATES

FLO-28
• CONSERVATIVE DIFFERENCES
• JOUKOWSKY-PARABOLIC CO-ORDINATES

FLO-30
• CONSERVATIVE DIFFERENCES
• CYLINDRICAL WIND-TUNNEL CO-ORDINATES
FLO-22 CHOSEN FOR FURTHER WORK

WHY?

- FLO-28/FLO-30 6-TO-10 TIMES MORE EXPENSIVE
- MAJOR THEORY-EXPERIMENT DISCREPANCIES NOT RESOLVED BY FUSELAGE MODELLING
- VISCOSOUS EFFECTS PREDOMINATE
- FLO-22 EASIER TO USE AND MORE RELIABLE
MODIFICATIONS TO FLO-22 (FLO-22.5)

- VISCOUS CORRECTION
  3-D INTEGRAL BOUNDARY LAYER

- FUSELAGE SIMULATION
  LINEAR THEORY
  SPANWISE FLOW IMPOSED AT "PLANE-OF-SYMMETRY"
TRANSONIC WING TECHNOLOGY DEVELOPMENT PLAN

- 310
  - AR = 7°
  - θ = 30°
  - M₀ = 0.80

E. O. B. 030°
T.E. O. B. 030°
T.E. O. B. 030°

- 43
  - W378 GEOMETRY
  - DETACHABLE LEADING AND TRAILING EDGES
  - AR = 8
  - θ = 30°
  - M₀ = 0.80

- 51
  - NASA SUPERCRITICAL TECHNOLOGY
  - AR = 9
  - θ = 30°
  - M₀ = 0.80

- 53
  - CAS SUPERCRITICAL TECHNOLOGY
  - AR = 7
  - θ = 30°
  - M₀ = 0.85

- 55
  - AR = 14
  - θ = 20°
  - M₀ = 0.70

- 65
  - AR = 10
  - θ = 20°
  - M₀ = 0.80

NASA SUPERCritical TECHNOLOGY
AR = 9
θ = 30°
M₀ = 0.80

CAS SUPERCritical TECHNOLOGY
AR = 7
θ = 30°
M₀ = 0.85
TRANSONIC WING TECHNOLOGY DEVELOPMENT

<table>
<thead>
<tr>
<th>AR</th>
<th>W 49</th>
<th>W 53</th>
<th>W 55</th>
<th>W 56</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>7</td>
<td>10</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

| Δ   | 35°  | 35°  | 25°  | 25°  |

| T/C (%) | 10    | 10    | 12    | 1/6   |

| MD  | 0.84  | 0.84  | 0.80  | 0.74  |
| CLD | 0.45  | 0.50  | 0.60  | 0.75  |

| % Δ ML D | GOAL 0 | 5     | 14    | 25    |

ITW-189
**WING 55**

\[ C_1 = 380.930 \]

\[ C_2 = 267.562 \]

\[ C_3 = 111.484 \]

\[ S_{REF} = 3,456 \text{ SQ FT} \]

\[ b = 186 \text{ FT} \]

\[ AR = 10.0 \]

\[ \Delta c/4 = 25^\circ \]

\[ \text{ETA} = 0.103 \]

\[ \text{ETA} = 0.173 \]

\[ \text{ETA} = 0.200 \]

\[ \text{ETA} = 0.400 \]
COLLABORATIVE HIGH REYNOLDS NO. TEST PROGRAM

NASA - LANGLEY
- CRYOGENIC WIND TUNNEL
- NITROGEN
- TEST SUPPORT

LOCKHEED-CALIFORNIA
- AIRFOIL DESIGN: $C_{LD} = 0.65; \, t/c = 0.12$
- WIND TUNNEL MODELS
- ANALYSIS & DOCUMENTATION

- CRYOGENIC TESTING EXPERIENCE
- MODEL FABRICATION REQUIREMENTS
- REYNOLDS NUMBER EFFECTS
- REYNOLDS NUMBER SIMULATION
PERT DRAG

DRAG PERTURBATION METHOD. PREDICTS DRAG VARIATION DUE TO CHANGES IN:

- Wing area
- Aspect ratio
- Sweep
- Thickness ratio
- C.G. location
- Tail volume
- Fuselage length

DRAG BUILD-UP:

BASE DRAG POLAR + DRAG RISE VARIATION + DELTA TRIM DRAG + DELTA FRICTION DRAG = AIRPLANE DRAG
BASIC DRAG POLAR
MACH = SUBCRITICAL

\[ \frac{\Delta C_D^*}{\Delta C_l^2} = \frac{\Delta C_D}{\Delta C_l^2} \times \frac{AR}{AR^*} \times \frac{e}{e^*} \]

\[ e^* = 1 - (1 - e) \frac{\cos \Lambda}{\cos \Lambda^*} \]
\[ \Delta C_D = \frac{(M \cos \Lambda)^{2/3}}{(\frac{t}{C})^{5/3}} \Delta C_D \]

\[ \hat{C}_L = \frac{(M \cos \Lambda)^{4/3}}{(\frac{t}{C})^{2/3}} \hat{C}_L \]

\[ K = \frac{(M \cos \Lambda)^{2} - 1}{(M \cos \Lambda)^{4/3}(\frac{t}{C})^{2/3}} \]
PERT DRAG CALCULATION OF TRIMMED DRAG

\[ C_L \]

**CD**

\[ \frac{S_T}{S_W} C_{LT} \]

TAIL OFF

TRIMMED

\[ \epsilon, \text{CALCULATED AT DOWNSTREAM INFINITY} \]

ITW-198
MACH = 0.80

- PERT DRAG PREDICTION
- NASA WIND TUNNEL DATA
- Mach = 0.80
- AR = 7
- \( \Lambda = 35^\circ \)
- \( t/c = 0.10 \)
- AR = 12
- \( \Lambda = 27^\circ \)
- \( t/c = 0.14 \)
BENEFITS OF AERODYNAMIC WING TECHNOLOGY INTEGRATION

\[ C_L \]

\[ C_{DF} \]

\[ C_L^2 \]

\[ \frac{\pi}{AR} \]

ADVANCED TECHNOLOGY

ITW-200

63
For the past several years Lockheed has been conducting aerodynamic research in the areas of cruise wing technology and high-lift technology. Information from these on-going technology development programs is applied to the Integrated Technology Wing Design Program.
Application of advanced aerodynamic technology to wing thickness demonstrates, when compared to a "REF" L-1011 technology, a reduction in airplane drag or an increase in wing thickness for a comparable drag level.
Increasing aspect ratio reduces induced drag. The drag reduction of advanced wing technology combined with high aspect ratio is evident. L-1011 technology is shown as a "REF".
Advanced aerodynamic cruise technology allows for a reduction in wing sweep for the same cruise drag level as the "REF" L-1011 technology.
Advanced control system technology has introduced the concept of designing an aircraft for flight with a statically unstable c.g.. The effect of c.g. location, or trim drag, on total airplane drag shows significant benefits for aft c.g. positions. L-1011 technology is shown as a "REF".
HIGH LIFT SYNTHESIS

BASIC POLAR BUILD-UP, M = 0.25 AT SEA LEVEL

\[ C_{D_{FLAP}} = C_{D_{CLEAN}} + \Delta C_{D_{PSLAT}} + \Delta C_{D_{F}} + \frac{(C_{L_{CLEAN}} + \Delta C_{L_{F}})}{\pi AR} - \frac{C_{L}^2}{\pi AR} \]

- \( C_{D_{CLEAN}} \) L-1011 AND S-3A FLIGHT TEST
- \( \Delta C_{D_{PSLAT}} \) L-1011 FLIGHT TEST
- \( \Delta C_{D_{F}} \) L-1011 AND RAeS DATA
- \( \frac{(C_{L_{CLEAN}} + \Delta C_{L_{F}})}{\pi AR} \) L-1011 AND RAeS DATA
- \( \frac{C_{D}^2}{\pi AR} \) L-1011 AND RAeS DATA

High-lift drag polars are built-up from incremental data for selected slat and flap configurations. Lockheed's experience with L-1011 and S-3A aircraft, and data available in published documents form the data base for the high-lift polars.
Flap and slat incremental lift and drag data are computed assuming a constant angle-of-attack for the basic clean configuration and the flapped configuration. The high-lift increments are additive to the low speed cruise polar, forming the high-lift polar.
Improvements in maximum lift capability relative to current L-1011 technology are readily available by applying advanced conventional devices, such as shaped kreugers and triple slotted flaps. Advanced concepts, triple slotted equal segment flaps and rotating leading edge flaps, will provide maximum lift increments of 0.25 for takeoff and 0.80 for landing configurations.
Lockheed is currently investigating, in the wind tunnel, a rotating leading edge flap utilizing a rotating tube and a simple 4-bar linkage for actuation. The tube rotates the flap approximately 120 degrees until the bulb nose opens to form a smooth upper surface contour with a slat for flow control.
Correlation of calculated high-lift data with flight test data for two Lockheed aircraft indicates an acceptable level of correlation, particularly for the L/D critical takeoff realm.
Horizontal tail sizing data are summarized on a "notch" chart showing the variation of tail size requirement with specified center-of-gravity (c.g.) range. For a properly balanced airplane, the specified forward and aft c.g. limits lie at the stability and control boundaries indicated on the "notch" chart. Main landing gear location based on tip-up margin requirements is also an important consideration.
One of the primary considerations in sizing the vertical tail/rudder for multi-engined transports with wing-mounted engines is meeting the engine-out minimum control speed requirements in FAR Part 25 and BCAR:

Ground - Computed dynamically as time histories of lateral runway deviation following engine failure.

Air - Computed by 3-D static analysis to satisfy bank angle limitations at specified weight, thrust, flap deflection, c.g., etc.
The flight profile used in Lockheed's ASSET (Advanced System Synthesis and Evaluation Technique) model is representative of actual airline requirements. The alternate distance is 200 nautical miles with the alternate profile compatible with sections 121.645 and 121.647 of the Federal Aviation Regulations.
## Concept Development Costs

<table>
<thead>
<tr>
<th>Development of Technology</th>
<th>Year</th>
<th>Total Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>81</td>
<td>82</td>
</tr>
<tr>
<td>TRANSONIC AIRFOIL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANALYSIS</td>
<td>415,000</td>
<td>455,000</td>
</tr>
<tr>
<td>W/T TESTING</td>
<td>800,000</td>
<td>850,000</td>
</tr>
<tr>
<td>HIGH LIFT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANALYSIS</td>
<td>270,000</td>
<td>270,000</td>
</tr>
<tr>
<td>W/T TESTING</td>
<td>195,000</td>
<td>205,000</td>
</tr>
</tbody>
</table>

**PROJECT GO-AHEAD**

The aerodynamic development costs spread over a six year period indicates a peak level of expenditure in 1984 of approximately four million dollars. The 1984-85 time span includes transonic testing in the new NTF cryogenic wind tunnel and high Reynolds number low speed testing. The costs include facilities, manpower, models and computer usage.
### SUMMARY OF TECHNOLOGY COSTS & BENEFITS

<table>
<thead>
<tr>
<th>TECHNOLOGY APPLICATION</th>
<th>TECH. DEV. COST</th>
<th>M(L/D)%</th>
<th>OwE%</th>
<th>TECH READINESS DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transonic Airfoil Planform</td>
<td>Research To Date + 10,160,000</td>
<td>14.0%</td>
<td>—</td>
<td>1986</td>
</tr>
<tr>
<td>High Lift Planform</td>
<td>$4,170,000</td>
<td>—</td>
<td>—</td>
<td>1986</td>
</tr>
</tbody>
</table>

A total aerodynamic development expenditure of approximately $14 million in the next six years will provide a 7 percent improvement in M(L/D) relative to 1980. The total cost includes high-lift development which is an integral part of the wing design process.
ACTIVE CONTROLS/ADVANCED SYSTEMS

BRIAN PENROSE
SYSTEMS DEFINITION, ACTIVE CONTROLS

RELAXED STATIC STABILITY (RSS)
- FLY-BY-WIRE (FBW)
- MULTIPLEXING (MUX) FOR FLIGHT CONTROL
- C.G. FUEL MANAGEMENT

The active controls configuration includes the technology elements of relaxed static stability (RSS), fly-by-wire (FBW), multiplexing (MUX), and fuel management for c.g. position control. Addition of FBW flight controls to the baseline enables maximum benefit to be achieved from relaxing the static stability in the pitch axis. Unchanged from the baseline aircraft are the hydraulic, pneumatic, and electrical power and distribution systems, the environmental control system (ECS), and the avionics. The active controls technologies of gust alleviation (GA), maneuver load alleviation (MLA), and elastic mode suppression (EMS) are not included for this configuration as they are considered baseline technologies. Flutter mode suppression was found to be beyond the reach of 1986 technology readiness.
CONTRIBUTING STUDIES

Complete as well as on-going Lockheed studies in advanced system technologies applications are being utilized toward achieving the objectives of the "Integrated Technology Wing Design" study for the configurations of 'active controls' and 'advanced systems and controls.' These contributing studies are listed here.


"Terminal Configured Vehicle Program" (TCV), NASA-Langley Research Center.

"Development and Flight Evaluation of an Augmented Stability Active Controls Concept with a Small Tail (EET/ACT-II), NASA-Langley Research Center.

"Advanced Electromechanical Actuation System" Lockheed IRAD Study.
Shown in the diagram is a quadruplex FBW system that could be designed to give sufficient reliability by a combination of built-in test, on-line monitoring, and parallel voting. Four digital flight control computers each calculate a control signal for each surface independently. Each computer receives the signal from each of the others, rejects out-of-tolerance signals, and takes the median value as an output. Thus, each computer outputs the same value, avoiding force fights as the secondary actuators. The secondary actuators send a mechanically summed output to the primary servo-valves. The spoiler primary actuators are electrically linked to their computers. The spoiler electro-hydraulic valves utilize magnetic summing of the computer signals.
# Actuator Application Matrix

## Aircraft Energy Efficiency

<table>
<thead>
<tr>
<th>Service</th>
<th>Direct Drive</th>
<th>Hinge Link/Pwr Hinge</th>
<th>Elect. Rotary/Linear</th>
<th>Electric Actuator</th>
<th>Stored Energy</th>
<th>Traction Drive</th>
<th>IP</th>
<th>Digital Actuator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Flight Controls</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Slats and Flaps</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td></td>
<td></td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Spoilers</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td></td>
<td></td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Main Gear</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nose Gear</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>A</td>
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<tr>
<td>Cargo Door</td>
<td>B</td>
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<td>Inlet Door</td>
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<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swing Wing/Tail</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thrust Reverser</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td></td>
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</tr>
<tr>
<td>Nose Wheel Steering</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td></td>
<td>A</td>
<td>A</td>
<td></td>
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<tr>
<td>Brakes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td></td>
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</tr>
<tr>
<td>Tail Skid</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td></td>
<td>A</td>
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<td></td>
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<tr>
<td>Powered Wheels</td>
<td>B</td>
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<td></td>
<td></td>
<td></td>
<td>B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A Complete  B Advanced  C Preliminary
The direct drive actuator is one type of electro-hydraulic actuator that was investigated. "Direct drive" means that the main spool of the hydraulic actuator is driven without the need for a secondary spool stage for hydraulic amplification. In the above sketch, the main spool is driven by a quadredundant, torquer motor which gets its inputs from the flight control computer. This is one actuator which has been designed for FBW actuation of flight control surfaces.
This graph demonstrates the difference in drag between a current technology wing (L-1011 type) and an advanced wing (supercritical). The curves, which were made from recent wind tunnel data, indicate a 15 percent drag benefit for the advanced wing. The drag comparison is made for aircraft c.g. locations which produce zero loading of the horizontal tail, or a "tail-off" balancing condition. Drag benefit is in terms of range factor (M (L/D)) which is the product of mach number and lift-to-drag ratio.
ADVANCED WING BENEFIT
CONVENTIONALLY BALANCED

Now the c.g.'s have been moved forward to a range position which provides for conventional balancing of the aircraft, or stability without the need for FBW control augmentation. The aft limit of c.g. movement still provides for a positive static margin. The advanced wing shows a 13 percent drag benefit compared to the current wing. The reference c.g. position will be a point of departure for demonstrating the effect of RSS in the following charts.
Shown is the "current wing" curve for trim drag vs. c.g. location. It shows that by shifting the c.g. range aft, and thus relaxing the static stability, the most trim drag benefit obtainable for current wing technology is about 2 percent. With the use of c.g. fuel management, pitch augmentation should not be required. An on-going Lockheed study for the ACEE program is investigating the benefits of RSS for current technology wings. The curve is the result of wind tunnel data for that study.
A greater amount of trim drag benefit is obtainable for the advanced wing by shifting the c.g. back beyond the neutral point. A benefit of 4 percent is shown above for implementation of relaxed static stability. With the c.g. range shifted back into the unstable regime the aircraft will require full FBW pitch augmentation.
**DRAG BENEFIT COMPARISON**

<table>
<thead>
<tr>
<th></th>
<th>CONVENTIONAL BALANCING</th>
<th>RSS &amp; C.G. MANAGE. (ACEE)</th>
<th>RSS (FLY-BY-WIRE)</th>
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</thead>
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<tr>
<td>CURRENT WING</td>
<td>0</td>
<td>2%</td>
<td>N/A</td>
</tr>
<tr>
<td>ADVANCED WING</td>
<td>13%</td>
<td>15%</td>
<td>17%</td>
</tr>
</tbody>
</table>

In summary, and using the current wing with conventional balancing as a starting point, it has been shown that a 2 percent trim drag benefit is possible for the current wing with RSS and c.g. management. FBW pitch augmentation is not considered for the current wing as further movement of the c.g. range into the unstable region will only decrease the trim drag benefit. The advanced wing shows a 13 percent drag benefit over the current wing based upon superior aerodynamic qualities, a 15 percent benefit in drag with an RSS similar to that being done in our study for the ACEE program, and a 17 percent benefit for further RSS with full FBW augmentation.
ACTIVE CONTROLS
TECHNOLOGY DEVELOPMENT

MULTIPLEXING PROTOTYPE HARDWARE
MULTIPLEXING PROTOTYPE SYSTEM

ADVANCED RSS STUDY
(SEE SEPARATE SHEET)

FUEL MANAGEMENT SYSTEM
PRELIMINARY DESIGN

FAULT TOLERANT COMPUTER STUDY
FAULT TOLERANT SOFTWARE EXPERIMENTS
FAULT TOLERANT HARDWARE EXPERIMENTS

AERO STUDIES - WING PERFORMANCE
WIND TUNNEL
FLIGHT TESTS

1 MAN-YEAR (MY) = $80K

A plan for the "active controls" configuration has been developed which provides for technology maturity by 1986. Total cost for technology development comes to $34 million based on a man-year worth of $80,000.
### ADVANCED RSS TECHNOLOGY DEVELOPMENT

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<td>Control Systems Design and Analysis</td>
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</table>

1 MAN-YEAR = $80K
ACTIVE CONTROLS SUMMARY

WEIGHT SAVINGS: 0.5% EMPTY WEIGHT

RSS PAYOFF: FUEL 4%

MAINTENANCE IMPROVEMENT
The "Advanced Systems and Controls" configuration eliminates engine bleed and the pneumatic distribution system. The hydraulic system is also removed. The electrical system is redesigned to generate and distribute the power needed for the functions and services of an all-electric aircraft.
The figure shows the major areas within the conventional secondary power system (SPS) existing on the baseline aircraft.
<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>POWER SOURCE</th>
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<th>STORED</th>
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<tbody>
<tr>
<td>ELECTRIC</td>
<td>HYDRAULIC</td>
<td>PNEUMATIC</td>
<td>STORED</td>
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<tr>
<td>FLIGHT CONTROLS</td>
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<td>○</td>
<td>○</td>
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<tr>
<td>COMMUNICATIONS/NAVIGATION/AFC</td>
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<tr>
<td>INSTRUMENTATION/LIGHTING</td>
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<td>ENGINE START</td>
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<td>○</td>
<td></td>
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<tr>
<td>ENVIRONMENTAL CONTROL SYSTEM</td>
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<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>DEICING</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td></td>
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<tr>
<td>FUEL BOOST PUMPS</td>
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<td>○</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>GEAR/STEERING/ BRAKES</td>
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<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>APU/EPU START</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>THRUST REVERSERS</td>
<td>●</td>
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<td>○</td>
<td></td>
</tr>
<tr>
<td>CARGO DOORS</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
</tbody>
</table>

The advanced technologies to be developed in this configuration will allow functions and services traditionally powered by hydraulics and pneumatics to be electrically powered.
SECONDARY POWER

ENVIRONMENTAL CONTROL SYSTEM (ECS)
PRESSURIZATION
3 ECS PACKS AT 100 KVA EACH
COOLING AT 24 TONS
3 ECS PACKS ≈ 60 KVA (ON GROUND)

GALLEY
≈ 100 KW

LIGHTING (INTERNAL/EXTERNAL) ≈ 10 KW
AVIONICS ≈ 16 KW
FLIGHT CONTROL SYSTEM (FCS) ≈ 60 KW

DE-ICING
WINDSHIELDS ≈ 12 KW
WINGS (ELECTROTHERMAL) ≈ 60 KW
WINGS (ELECTRO-IMPULSE) = 5 KW

SECONDARY POWER SYSTEM (SPS)
3 x 250/300 KVA GENERATORS/ENGINE

The figure lists the secondary power requirements of the major aircraft functions for the "advanced systems and controls" configuration. Two generators per engine, producing a total of 250 kVA of electric power, will be used to provide power for all the functions of the aircraft. These samarium-cobalt generators will also be used in a starting mode to start the engine electrically.
Three Environmental Control System (ECS) packs are used to pressurize, heat, and cool the cabin. These are electrically driven, no bleed air is used. Each has:

- Air compressor for fresh air pressurization
- Heat exchanger and fan for cooling fresh air with ram air
- Freon compressor for refrigeration
- Heat exchanger and fan for cooling freon with ram air
- Freon evaporator for cooling fresh air
- Electric heater
ALL-ELECTRIC ECS: OBJECTIVES

- IMPROVE ENGINE SFCS/REDUCE BLOCK-FUEL
  → LOWER OEW/LOWER TOGW
- SIMPLIFY CONVENTIONAL ECS INSTALLATION
- PROVIDE MAJOR WEIGHT REDUCTION IN HARDWARE
  → ELIMINATE DUCTING IN ENGINES, PYLONS, WINGS
  → ELIMINATE SEPARATE START SYSTEM
- IMPROVE ECS PERFORMANCE
- IMPROVE LOGISTIC SUPPORT
- REDUCE ENGINEERING/PRODUCTION LABOR HOURS
- SIMPLIFY MAINTENANCE SUPPORT
- REDUCE SYSTEM/MOCK-UP TESTING
This photograph shows a hinge-line, electro-mechanical actuator that was designed and built by AiResearch. This actuator has dual redundancy in the motors and reduction gearing. "Power-hinge" type gearing at the center of the actuator outputs torque to the control surface. The samarium-cobalt motors are powered by 270 Vdc.
This is one of Sunstrand's hinge-line EMAS designs for application to a flight control surface. Power is transferred from the SmCo permanent magnet motor, through a no-back device and through three stages of planetary gearing to the output "slice" where the control surface is driven.
Plessey's linear screwjack EMAS employs a wrap-around SmCo motor concentric to the screwjack. The screwjack translates a nut which is a part of the hollow ram. The ram extends 'right' and retracts 'left'. The total actuator system is comprised of the actuator built by Plessey, the controller electronics by Boeing, and the SmCo motor by Inland Motors. These companies will soon be testing their design on the NASA "Quiet Short-Haul Research Aircraft" (QSRA).
TEST PLANS PLESSEY/BOEING/INLAND
JOINT RESEARCH PROGRAM

1ST GENERATION ACTUATOR (BREADBOARD VERSION)
JAN 1981 DELIVERY TO BOEING FOR NASA’S QSRA

INSTALLATION: INBOARD FLYING SPOILERS (2 EA)
OUTBOARD SPOILERS SHALL BE LEFT
WITH EH ACTUATORS FOR
PERFORMANCE COMPARISONS

DESCRIPTION: NON-CONCENTRIC MOTOR/SCREWJACK
ALL ELEMENTS ARE INLINE

EXPERIENCE: SIX MONTHS CONTINUOUS CYCLING IN LAB TESTS

2ND GENERATION ACTUATOR (SOPHISTICATED)
END OF 1981 INSTALLATION ON QSRA

INSTALLATION: REPLACE OB SPOILER EH ACTUATORS
WITH PROTOTYPE

DESCRIPTION: CONCENTRIC MOTOR/SCREWJACK

The Plessey linear actuator is currently the only EMAS, for actuation of a
primary flight control surface, that has advanced to the flight test stage
of its development program.
Bendix has designed a unique rotary actuator transmission which uses a single-stage epicyclic gearing arrangement. It can be driven by electric, hydraulic, or pneumatic power. The driven ring gear orbits and transfers power to the output gear. The gear ratio is determined by the difference in the number of teeth between the ring and output gears.
The Vought "Eccentuator" is basically a bent beam of fixed angle (θ) which is "motorized" at one end and "actuated" at the other. A special gearing arrangement at the motoring end produces a simultaneous rotation and circular translation of the beam end. The result is a planar actuating movement of the opposite end of the beam, through an angle four times that of the beam bend angle (θ).
Energy Storage Substations (ESS) utilize a high speed fly-wheel (100,000 rpm) for short term hydraulic or mechanical actuation loads on aircraft. Short term loads include functions such as actuation of landing gear or flaps. The flywheel's energy/rpm's are reduced during actuation, and regenerated during times of low power demand.
The traction drive overcomes the inertia problem during actuation, caused by rotation of the motor in one direction, stopping, and acceleration in the other direction. The motor driving the input shaft revolves at constant rpm in one direction only. Modulation and speed variation is accomplished by the toroid and roller arrangement shown in the figure. An electrical input "steers" or rotates the steerable rollers against the input and slave toroids. The fixed rollers introduce a constant counter-force which is reacted into the differential roller cage and output shaft. A special traction fluid within the servo provides efficient power transfer at the roller/toroid interface, with minimum slippage.
ALL ELECTRIC AIRCRAFT

SECONDARY POWER SERVICES

REDUCES
- EMPTY WEIGHT 2%
- FUEL CONSUMPTION 4%
- MAINTENANCE
- AIRCRAFT COST

STARTER
# TWO MAJOR ALL-ELECTRIC PAYOFFS

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<thead>
<tr>
<th>BLEED ELIMINATION</th>
<th>WT SAVINGS</th>
<th>COST SAVINGS</th>
<th>RISK</th>
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</thead>
<tbody>
<tr>
<td>BLEED ELIMINATION</td>
<td>STARTER/GENERATOR AND ELECTRIC ECS</td>
<td>60%</td>
<td>65%</td>
</tr>
<tr>
<td>HYDRAULICS ELIMINATION</td>
<td>FLY-BY-WIRE, EMAS</td>
<td>40%</td>
<td>35%</td>
</tr>
</tbody>
</table>
The figure shows relationship of several different technology development plans. The right end of each bar designates the technology maturity date. Electric actuators and computerized SPS control aren't expected to reach maturity by 1986 unless their development is stepped up significantly.
## Delay Reduction, Savings Potential

<table>
<thead>
<tr>
<th></th>
<th>Delay Minutes</th>
<th>Crew and Aircraft</th>
<th>Fuel and Weight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi Out (Electric Wheels)</td>
<td>5</td>
<td>0.37</td>
<td>0.98</td>
<td>1.35</td>
</tr>
<tr>
<td>SID Geometry</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RNAV</td>
<td>4</td>
<td>0.29</td>
<td>0.47</td>
<td>0.77</td>
</tr>
<tr>
<td>Loiter and Hold</td>
<td>5</td>
<td>0.37</td>
<td>0.49</td>
<td>0.86</td>
</tr>
<tr>
<td>Star Geometry</td>
<td>5</td>
<td>0.37</td>
<td>0.49</td>
<td>0.86</td>
</tr>
<tr>
<td>Taxi In (Electric Wheels)</td>
<td>0</td>
<td>0</td>
<td>0.49</td>
<td>0.49</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>19 Min</strong></td>
<td></td>
<td><strong>4.33%</strong></td>
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**Assumptions:**
Average U.S. Delays, 3000 NM Cruise, Wide Body Aircraft
# Technology Costs and Benefits Summary

<table>
<thead>
<tr>
<th>Technology Application</th>
<th>Tech Dev Cost</th>
<th>ΔSFC or ΔDrag</th>
<th>ΔEW</th>
<th>Tech Readiness Date</th>
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</thead>
<tbody>
<tr>
<td>RSS (Includes FBW, MUX)</td>
<td>$34M</td>
<td>4%</td>
<td>0.45</td>
<td>1986</td>
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<tr>
<td>All-Electric</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECS</td>
<td>$20M</td>
<td>4%</td>
<td>1.06</td>
<td>1985</td>
</tr>
<tr>
<td>EMAS</td>
<td>$50M</td>
<td></td>
<td>0.71</td>
<td>1986-90</td>
</tr>
<tr>
<td>Powered Wheels</td>
<td>$10M</td>
<td></td>
<td></td>
<td>1986</td>
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</tbody>
</table>
PROPULSION/PROPULSION INTEGRATION

BOB SKARSHAUG
PROPULSION SYSTEM TECHNOLOGY

• ADVANCED ENGINE CONCEPTS
• PROPULSION/AIRFRAME INTEGRATION
ADVANCED ENGINE CONCEPTS

OBJECTIVES

- TO DEFINE COST/BENEFITS OF ADVANCED PROPULSION SYSTEM TECHNOLOGY
- TO ASSESS THE TECHNICAL RISK ASSOCIATED WITH ACHIEVING DESIRED GOAL
- TO DEVELOP THE PLAN TO ESTABLISH THE REQUIRED TECHNOLOGY
- TO DEFINE THE COST OF THE TECHNOLOGY PROGRAM
TECHNOLOGY DATA BASE

- NASA E³ ENGINE PROGRAMS
- NASA E³ EXHAUST SYSTEM MIXER TESTS
- MODEL TESTS
- NASA - EET PROP/AIRFRAME INTEGRATION

ENGINE TECHNOLOGY

AIRCRAFT/PROPULSION INTEGRATION TECHNOLOGY

ADVANCED TECHNOLOGY PROPULSION SYSTEM
The approach being used in this study is to define the performance and weight increments for advanced engine concepts and propulsion system/airframe integration. These increments will be evaluated in terms of aircraft and economic parameters such as TOGW, DOC and life cycle cost.
The technology data base being used in the study draws from the NASA E³ engine program and exhaust system mixer testing. The aircraft propulsion system integration technology base is developed from conventional aircraft configuration model tests and NASA EET Propulsion System/Airframe Integration testing. Projections for advanced technology propulsion systems will be developed from these data sources.
**E³ PROGRAM GOALS**

- 12% REDUCTION IN INSTALLED SPECIFIC FUEL CONSUMPTION (SFC)
- 5% REDUCTION IN DIRECT OPERATING COST (DOC)
- 50% REDUCTION IN SFC DETERIORATION IN SERVICE
- MEET FAR 36 (MARCH 1978) ACOUSTIC STANDARDS WITH PROVISIONS FOR GROWTH
- MEET PROPOSED EPA (1981) EMISSIONS STANDARDS FOR NEW ENGINES

This study will use the performance and weight associated with the G.E. definition of the E³ Flight Propulsion System (FPS). The E³ engine program goals are provided as a reference; however, the E³ FPS will have approximately a 14.6% improvement in cruise SFC.
NACELLE

- TYPE – SEPARATE FAN/CORE EXHAUST FLOW
  MIXED FAN/CORE EXHAUST FLOW
- LOCATION – LONGITUDINAL, VERTICAL, & LATERAL
- CANT ANGLE – PITCH & YAW (TOE-IN OR TOE-OUT)
- SHAPE – INLET DROOP, LOCAL CONTOURING, ETC

PYLON

- CAMBER • AREA RULE • CANT ANGLE

WING CONTOURING

Identifies geometric variables affecting installed drag increments. Past efforts have allowed correlation of nacelle location parameters to installed drag data for specific nacelle configurations on conventional aircraft. In addition, effects on drag of nacelle cant and pitch angles and pylon shape have been investigated.

A comprehensive airframe/propulsion integration test is necessary to supplement the results obtained from the NASA LaRC tests for the advanced aircraft. In addition to establishing optimal nacelle/pylon location and orientation (and correlation the drag data to appropriate parameters) local contouring of the wing and/or nacelle may be necessary to eliminate the interference drag.
PROPULSION SYSTEM TECHNOLOGY

COST/BENEFIT ASSESSMENT
# COMPARISON OF E³ FPS AND CF6-50C

## COMPONENT EFFICIENCIES

35,000 FT/0.8M MAX. CRUISE

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>E³ Δ EFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAN BYPASS</td>
<td>+4.8 PTS</td>
</tr>
<tr>
<td>FAN HUB (BOOSTER)</td>
<td>+4.0 PTS</td>
</tr>
<tr>
<td>HIGH PRESSURE COMPRESSOR — ADIABATIC</td>
<td>−0.3 PTS</td>
</tr>
<tr>
<td></td>
<td>— POLYTROPIC</td>
</tr>
<tr>
<td>HIGH PRESSURE TURBINE</td>
<td>+0.8 PTS</td>
</tr>
<tr>
<td>LOW PRESSURE TURBINE</td>
<td>+1.1 PTS</td>
</tr>
</tbody>
</table>

The following chart identifies the component performance improvements achieved in the E³ FPS system relative to a CF6-50C.
Selected propulsion system configuration matrix provides for a systematic installation of the current and advanced technology engine/nacelle configurations, with and without airframe/propulsion technology, to both the conventional and advanced aircraft. This procedure allows comparison of the drag benefits that can be realized for configurations ranging from minimum modification of the conventional aircraft through that employing all identifiable advanced technology. Combining these results with appropriate program costs (technology development, engine acquisition, aircraft operation, etc.) allows evaluation of the most cost effective approach to further development.

Installation of advanced engines to either conventional or advanced aircraft is initially considered for the engine c.g. at the same location as the baseline CF6-50C engine to minimize changes to the aircraft. Application of airframe-propulsion technology results in relocation of the engine/nacelle, if required, and configuration/orientation changes to the nacelle/ pylons.
BASELINE PROPULSION SYSTEM

GENERAL ELECTRIC CF6-50C TURBOFAN ENGINE

- TAKEOFF THRUST ________________ 50,250 LB
- TAKEOFF FLAT RATED TEMP. ______ ISA + 15°C
- BYPASS RATIO (SLS) ____________ 4.35
- FAN DIAMETER ________________ 86.4 IN.
- ENGINE LENGTH ______________ 171.2 IN.
- BARE ENGINE WEIGHT ________ 8674 LB
- ENGINE CERTIFICATION DATE ______ NOV. 1973

The GE CF6-50C turbofan engine was selected as the baseline propulsion system to maintain consistency with the NASA-Lewis Research Center E³ engine studies. The CF6-50C is used in commercial service with the engine being certified in late 1973.
The CF6-50C installed propulsion weight is shown in the following chart. The propulsion system is configured similar to that used in commercial service.
The bare engine dimensions for the CF6-50C engine for a nominal takeoff thrust size of 50250 pounds are shown in the following figure.
A cutaway of the baseline propulsion system is shown in the following figure.
Characteristics of the GE E³ flight propulsion system are shown in the following chart. The engine information has been provided at a nominal takeoff rating of 46900 pounds (sea level static). The engine is flat rated at takeoff to ISA +15°C. The technology level in the engine is representative of the mid-1980's and with appropriate funding the engine could be certified by 1990.
The propulsion system weight buildup for the E³ flight propulsion system with a mixed flow exhaust system, at the reference thrust level of 46900 pounds, is shown in the following chart. The propulsion system includes the use of advanced technology fan reverser design and composites.
**COMPARISON OF E³ CYCLE TO CF6-50C**

<table>
<thead>
<tr>
<th></th>
<th>CF6-50C</th>
<th>E³</th>
</tr>
</thead>
<tbody>
<tr>
<td>• BYPASS RATIO</td>
<td>4.2</td>
<td>6.8</td>
</tr>
<tr>
<td>• FAN PRESSURE RATIO</td>
<td>1.76</td>
<td>1.65</td>
</tr>
<tr>
<td>• OVERALL PRESSURE RATIO</td>
<td>32</td>
<td>38</td>
</tr>
<tr>
<td>• TURBINE ROTOR INLET TEMP (°F) SLS, 86°F, TAKEOFF RATING</td>
<td>2445</td>
<td>2450</td>
</tr>
<tr>
<td>• INSTALLED CRUISE SFC 0.80, 35,000 FT, STD DAY</td>
<td>BASE</td>
<td>-14.6%</td>
</tr>
<tr>
<td>• ACTIVE CLEARANCE CONTROL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– COMPRESSOR</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>– H.P. TURBINE</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>– L.P. TURBINE</td>
<td>NO</td>
<td>YES</td>
</tr>
</tbody>
</table>

Significant differences are noted between the E³ FPS and the CF6-50C engine cycle. The E³ FPS has a significantly higher bypass ratio and a higher overall pressure ratio. These are major contributors to the 14.6 percent reduction in installed cruise SFC.
The following chart shows those areas of improvement in the engine which contribute to the overall 14.6 percent reduction in installed cruise SFC for the E³ FPS relative to the CF6-50C turbofan.
The following chart shows the difference in cruise SFC between the CF6-50C and the E³ FPS. The performance level shown in the chart for the E³ FPS includes the mixed flow exhaust system.
The following chart shows the performance improvement for the E³ FPS for a typical holding condition.
ADVANCED TECHNOLOGY ENGINE (E$^3$) 
ENGINE OUTLINE DIMENSIONS

DIMENSIONS SHOWN ARE BASE SIZE. $F_n$ SLS $T/O_{nom} = 46,900$ LB

The following charts show the dimensions for the E$^3$ FPS at a nominal takeoff thrust size of 46900 pounds.
INTEGRATED WING TECHNOLOGY STUDY

BASELINE E3 MIXED FLOW

NACELLE DIMENSIONS

\[ FN_{BASE} = 46,900 \text{ LB} \]

Diameter Scaling Factor: \( \left( \frac{FN}{FN_{BASE}} \right)^{0.50} \)

Nacelle Overall Length Scaling Factor: \( \left( \frac{FN}{FN_{BASE}} \right)^{0.48} \)

Nacelle dimensions are shown for the mixed flow E\(^3\) propulsion system rated at 46900 pounds of sea level static takeoff thrust. The inlet design is consistent with current L-1011 technology and has approximately a 4\(^\circ\) droop.
INSTALLED $E^3$ FPS FEATURES

- Composite Nacelle
- ECS Based Fuel Heater
- High Thermodynamic Efficiency
- Long Duct Mixed Flow Core Thrust Spoiling During Reverse
- Advanced Acoustic Bulk Absorber
- Slender Nacelle $D_{HL}/D_{MAX} = .86$
- Acoustic Blade-Vane Spacing
- T/R Blocker Doors Independent of Core Cowl
- Turbine Acoustic Treatment
The following chart shows the SFC benefit for the $E^3$ FPS system relative to a separate flow exhaust configuration. Data are provided for a range of flight Mach numbers and rated thrust levels.
### Mixed vs Separate Flow Exhaust System Weight

**Reference Thrust = 46,900 LB**

<table>
<thead>
<tr>
<th>Component</th>
<th>Mixed Flow</th>
<th>Separate Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare Engine</td>
<td>8,750 LB</td>
<td>8,750 LB</td>
</tr>
<tr>
<td>Inlet</td>
<td>470</td>
<td>470</td>
</tr>
<tr>
<td>Fan Reverser</td>
<td>1,270</td>
<td>1,532</td>
</tr>
<tr>
<td>Core Cowls</td>
<td>307</td>
<td>216</td>
</tr>
<tr>
<td>Primary Nozzle</td>
<td>154</td>
<td>137</td>
</tr>
<tr>
<td>Exhaust Nozzle</td>
<td>306</td>
<td>—</td>
</tr>
<tr>
<td>Engine Build Up</td>
<td>575</td>
<td>575</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11,832 LB</strong></td>
<td><strong>11,680 LB</strong></td>
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Propulsion system weights for a mixed and separate flow exhaust system are shown in the following chart.
PROPULSION SYSTEM CONFIGURATION

<table>
<thead>
<tr>
<th>BASELINE AIRCRAFT</th>
<th>ADVANCED AIRCRAFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CONVENTIONAL WING</td>
<td>• ADVANCED TECHNOLOGY WING</td>
</tr>
<tr>
<td>• CF6-50C SEPARATE FLOW TURBOFAN ENGINE</td>
<td>• CF6-50C SEPARATE FLOW TURBOFAN ENGINE</td>
</tr>
<tr>
<td>• CONVENTIONAL INSTALLATION</td>
<td>• CONVENTIONAL INSTALLATION</td>
</tr>
<tr>
<td>WITH E³ SEPARATE FLOW ENGINE</td>
<td>WITH E³ SEPARATE FLOW ENGINE</td>
</tr>
<tr>
<td>WITH AIRFRAME/PROPULSION INTEGRATION</td>
<td>WITH AIRFRAME/PROPULSION INTEGRATION</td>
</tr>
<tr>
<td>WITH E³ MIXED FLOW ENGINE</td>
<td>WITH E³ MIXED FLOW ENGINE</td>
</tr>
<tr>
<td>WITH AIRFRAME/PROPULSION INTEGRATION</td>
<td>WITH AIRFRAME/PROPULSION INTEGRATION</td>
</tr>
<tr>
<td>WITH AIRFRAME/PROPULSION INTEGRATION</td>
<td>WITH AIRFRAME/PROPULSION INTEGRATION</td>
</tr>
</tbody>
</table>
AIRFRAME/PROPULSION INTEGRATION VARIABLES

NACELLE
- TYPE – SEPARATE FAN/CORE EXHAUST FLOW
  MIXED FAN/CORE EXHAUST FLOW
- LOCATION – LONGITUDINAL, VERTICAL, & LATERAL
- CANT ANGLE – PITCH & YAW (TOE-IN OR TOE-OUT)
- SHAPE – INLET DROOP, LOCAL CONTOURING, ETC

PYLON
- CAMBER  •  AREA RULE  •  CANT ANGLE

WING CONTOURING

Identifies geometric variables affecting installed drag increments. Past efforts have allowed correlation of nacelle location parameters to installed drag data for specific nacelle configurations on conventional aircraft. In addition, effects on drag of nacelle cant and pitch angles and pylon shape have been investigated.

A comprehensive airframe/propulsion integration test is necessary to supplement the results obtained from the NASA LaRC tests for the advanced aircraft. In addition to establishing optimal nacelle/pylon location and orientation (and correlating the drag data to appropriate parameters), local contouring of the wing and/or nacelle may be necessary to eliminate the interference drag.
WING/PYLON/NACELLE INTERFERENCE DRAG

INSTALLED DRAG

$$\Delta D_{\text{INST}} = D_{\text{TOTAL AIRCRAFT}} - D_{\text{FUSELAGE CLEAN WING}}$$

INTERFERENCE DRAG

$$\Delta D_{\text{INTERFERENCE}} = D_{\text{TOTAL AIRCRAFT}} - D_{\text{FUSELAGE CLEAN WING}} - D_{\text{PYLON/NACELLE FRICTION}}$$

Defines "installed" and "interference" drag increments associated with engine/nacelle installation on aircraft. The installed drag increment includes external cowl friction drag penalties and allows comparison between alternate configurations. The interference drag increment excludes the isolated external cowl friction drag. For a given nacelle shape the airframe/propulsion integration goal is to eliminate the interference drag increment.
The GE CF6-50C separate flow engine/nacelle installed on the conventional aircraft is defined as a baseline configuration. The location of the nacelle relative to the wing is such that interference drag is zero and the installed nacelle drag of 4.3 percent aircraft drag is equivalent to the isolated nacelle external cowl friction drag.

Consistent with current technology designs the pylon shape is symmetrical and canted inboard, with the nacelle at approximately 2 degrees. The engine/nacelle is pitched up 2 degrees relative to the fuselage reference line. The inlet is drooped 4 degrees to account for flow upwash angle.
Installed nacelle drag used in this study for the conventional aircraft installation is shown typically in the adjacent chart. The correlating parameter for drag due to nacelle position is $h/x$, the ratio of the minimum channel width between the wing and nacelle (or fan exhaust streamtube) to the distance of the core exhaust from the wing leading edge. At values of this parameter about 0.8 the interference drag is estimated to be zero and the installed nacelle drag is equal to the cowl friction drag of the isolated nacelle. This latter drag is higher for the mixed flow nacelle because of the greater wetted area of the cowl compared to the separate flow cowl.

The effect on drag of cambering the pylon is estimated to reduce the drag by 0.8 percent of the aircraft drag.
CONVENTIONAL AIRCRAFT WITH E³ SEPARATE FLOW ENGINE (CONFIGURATION 3)

Installation of the GE E³ separate flow nacelle on the conventional aircraft, with the c.g. at the same location as that for the CF6-50C engine, results in a nacelle position relative to the wing for which the interference drag is zero. The nacelle dimensions are based on the design provided by General Electric for the 83-inch fan diameter E³ engine and subsequently scaled to the 94 inch fan diameter engine for which the performance data are based.
CONVENTIONAL AIRCRAFT WITH E³ SEPARATE FLOW ENGINE AND AIRFRAME/PROPULSION INTEGRATION (CONFIGURATION 4)

Pylon camber/area rule for the E³ separate flow/conventional aircraft is estimated to provide a favorable interference drag effect, reducing the installed nacelle drag to 3.5 percent of aircraft drag.
Installation of the E3 mixed flow engine/nacelle on the conventional aircraft at the same c.g. location as that for the CF6-50C engine/nacelle results in an unfavorable position of the nacelle relative to the wing and a penalty in drag due to interference. In addition to this penalty, the external cowl friction drag is greater than that for the separate flow CR6-50C engine, resulting in an installed nacelle drag equal to 7.3 percent of aircraft drag. The nacelle dimensions are based on the design provided by General Electric for the 83-inch fan diameter E3 engine and subsequently scaled to the 94-inch fan diameter engine for which the performance data are based.
CONVENTIONAL AIRCRAFT WITH E³ MIXED FLOW ENGINE AND AIRFRAME/PROPULSION INTEGRATION (CONFIGURATION 6)

![Diagram of conventional aircraft with E³ mixed flow engine and airframe/propulsion integration.]

<table>
<thead>
<tr>
<th>NACELLE LOCATION PARAMETERS</th>
<th>INSTALLED DRAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>h/X₂ = 0.800</td>
<td>ΔD_INST = 5.4%</td>
</tr>
<tr>
<td>X₂/C = 0.133</td>
<td>ΔD/A/C</td>
</tr>
<tr>
<td>Z/D = 0.709</td>
<td></td>
</tr>
<tr>
<td>D/C = 0.385</td>
<td></td>
</tr>
<tr>
<td>XCG/C = 0.393</td>
<td></td>
</tr>
</tbody>
</table>

Relocation of the E³ mixed flow engine forward relative to the wing leading edge results in a position that eliminates the interference drag penalty associated with a common CF6-50C c.g. location. In addition, camber/area rule of the pylon provides a favorable interference effect, reducing the installed drag by 0.8 percent of the aircraft drag.
Installed nacelle drag test data from the NASA LaRC airframe/propulsion tests are presented. The effect on drag of engine/nacelle location is shown for configurations including pylon camber/area rule, zero degree nacelle cant and 2 degree pylon cant (outboard). Also shown are the incremental effects on drag resulting from pylon camber and area rule, and nacelle/ pylons cant. The effect of pylon area rule (with camber) was shown to result in a 0.8 percent reduction in drag. The effect of pylon camber on drag was not isolated in back to back tests; however, using the identified effects of area rule and pylon cant, was estimated to result in a 2.9 percent reduction in drag. The combined effect of a nacelle/ pylon cant change from 0 degrees/2 degrees (for which the nacelle location tests were conducted) to -2 degrees/ -2 degrees of the selected configuration was established as resulting in a 1.1 percent reduction in drag.
The installed nacelle drags used in this study for the advanced aircraft configurations are presented. These data are corrected, based on the incremental drag effects derived from the LaRC tests, to correspond to the configurations identified herein with no airframe/propulsion integration, i.e., symmetrical pylon and 2 degree inboard cant of the pylon/nacelle.
Installation of the CF6-50C engine/nacelle on the advanced aircraft results in an installed nacelle drag increment of 11.5 percent of aircraft drag. The symmetrical pylon cant and nacelle cant and pitch are identical to those selected for the baseline conventional aircraft.
ADVANCED AIRCRAFT WITH E³
SEPARATE FLOW ENGINE
(CONFIGURATION 8)

With the GE E³ separate flow engine installed on the advanced aircraft the installed nacelle drag increment is 11.5 percent of the aircraft drag.
The goal of airframe/propulsion integration program is to eliminate the interference drag of the E³ separate flow engine/nacelle installed on the advanced aircraft. Achieving this goal will reduce the installed nacelle drag associated with the current technology design of 11.5 percent to 4.3 percent of aircraft drag. Data from the NASA LaRC tests indicate a reduction in drag of 3.7 percent can be realized through pylon camber/area rule. These tests also show that the nacelle/pylon cant angle of 2 degrees inboard, selected herein, results in the lowest drag of the angles tested. To achieve the goal of eliminating interference drag, a further drag reduction of approximately 3 percent is required through optimizing nacelle location, cant and pitch angle and local contouring of the wing/pylon/nacelle.
For the GE E\textsuperscript{3} mixed flow engine/nacelle installed on the advanced aircraft at the same c.g. location as that for the CF6-50 engine the installed drag is estimated as 17.3 percent of aircraft drag. This estimate includes a 4.4 percent drag penalty resulting from an unfavorable nacelle location.
For the E³ mixed flow engine/nacelle installed on the advanced aircraft the goal of the airframe/propulsion integration program is to reduce the installed nacelle drag level to 6.2 percent of the aircraft drag (isolated nacelle friction drag). Based on LaRC test data, the best nacelle location tested for this configuration resulted in an installed drag of 12.9 percent of aircraft drag. These tests also show a reduction in drag of 3.7 percent resulting from pylon camber/area rule. To achieve the goal of eliminating interference drag, an additional drag reduction of 3 percent is required through optimizing nacelle location, cant and pitch angle and local contouring of the wing/ pylons/nacelle.
A summary of the installed nacelle drag levels for the conventional and advanced aircraft is presented. For the conventional aircraft, engine/nacelle installation can be accomplished with no penalty in drag due to interference effects. An airframe/propulsion technology program for this aircraft would substantiate that a 0.8 percent reduction in nacelle drag could be achieved through the favorable effects resulting from pylon camber/area rule.

For the advanced aircraft using a highly loaded supercritical wing, the installed nacelle drag is an appreciable percent of total aircraft drag. The goal of the airframe/propulsion integration program is reduce the nacelle drag to that associated with isolated nacelle friction, through elimination of the interference drag penalty. Achievement of this goal requires a reduction aircraft in drag of approximately 3 percent from the levels demonstrated in the NASA LaRC tests.
## PROPELLION SYSTEM TECHNOLOGY

### COST/BENEFIT SUMMARY

<table>
<thead>
<tr>
<th>NO.</th>
<th>ENGINE</th>
<th>EXHAUST</th>
<th>AIRCRAFT/WING</th>
<th>Δ SFC</th>
<th>Δ DRAG</th>
<th>FUEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CF6-50C</td>
<td>SEPARATE</td>
<td>CONVENTIONAL</td>
<td>BASE</td>
<td>BASE</td>
<td>BASE</td>
</tr>
<tr>
<td>2</td>
<td>CF6-50C</td>
<td>SEPARATE</td>
<td>CONVENTIONAL</td>
<td>BASE</td>
<td>- 0.8%</td>
<td>- 0.8%</td>
</tr>
<tr>
<td>3</td>
<td>E3</td>
<td>SEPARATE</td>
<td>CONVENTIONAL</td>
<td>-11.5%</td>
<td>0.0%</td>
<td>-11.5%</td>
</tr>
<tr>
<td>4</td>
<td>E3</td>
<td>SEPARATE</td>
<td>CONVENTIONAL</td>
<td>-11.5%</td>
<td>- 0.8%</td>
<td>-12.3%</td>
</tr>
<tr>
<td>5</td>
<td>E3</td>
<td>MIXED</td>
<td>CONVENTIONAL</td>
<td>-14.6%</td>
<td>+ 2.9%</td>
<td>-11.7%</td>
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*NOTE - DOES NOT INCLUDE ASSOCIATED WEIGHT INCREMENTS*
PROPULSION SYSTEM TECHNOLOGY

PROGRAM PLAN
Phase I and II of the $E^3$ engine program are shown in the following chart. Phase I consisted of definition studies and component design activities. Phase II involved full scale component testing, core design and test, and the integrated core low spool system integration test.
**E³ PROGRAM MILESTONES**

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Program milestones for the E³ program are shown in the following chart.
## E3 Program Milestones

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ADVANCED AIRFRAME/PROPULSION INTEGRATION TECHNOLOGY PLAN

EXPERIMENTAL DATA BASE (ACEE/EET ADVANCED TRANSPORT DATA BASE)
- REPEAT CONFIGURATION
- ISOLATE CONF. EFFECTS
- EXTEND DATA BASE - POSITIONS/CAMBERING
- NACELLE
- WING/PYLON/NACELLE

ANALYTICAL METHODS (BOPPE CODE)
- SWEEP PYLON
- REALISTIC NACELLE → 3D
OVERALL PROPULSION/AIRFRAME INTEGRATION PROGRAM SCHEDULE

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ITW-102
The $E^3$ program has a 90 percent chance of achieving the 12 percent reduction in cruise SFC. The $E^3$ FPS system has approximately 85 to 90 percent chance of achieving the 14.6 percent reduction in cruise SFC.
The $E^3$ FPS has approximately an 80 percent chance of coming in 400 pounds heavier than the design weight with only approximately a 10 percent chance of achieving the design weight.
ADVANCED ENGINE TECHNOLOGY
- COST ~ $193M + $24M (G.E. FPS)
- PAYOFF ~
  - 14% REDUCTION IN CRUISE SFC
  - 5% REDUCTION IN DIRECT OPERATING COST
  - 50% REDUCTION IN SFC DETERIORATION
  - MEET FAR 36 ACOUSTICS STANDARDS
  - MEET PROPOSED EPA (1981) EMISSION STANDARDS
- TECHNOLOGY READINESS ~ 1986

PROPULSION SYSTEM/AIRFRAME INTEGRATION
- COST
- PAYOFF ~ TO INSTALL AN ADVANCED TECHNOLOGY, MIXED FLOW PROPULSION SYSTEM FOR ZERO INTERFERENCE DRAG
- TECHNOLOGY READINESS ~ 1986
OBJECTIVES:

TO DEVELOP TECHNOLOGY PLANS, PAYOFFS AND COSTS REQUIRED FOR IMPLEMENTATION OF:

- ADVANCED ALUMINUM AND METAL MATRIX COMPOSITE MATERIALS
- ADVANCED TITANIUM TECHNOLOGY
- ADVANCED COMPOSITE MATERIALS

The objectives of the materials and structures studies are to develop technology plans, establish potential payoffs and determine the costs for advanced materials, structural concepts and manufacturing techniques. Advanced aluminum alloys, metal matrix composites, titanium and graphite epoxy composite are being evaluated.
Advanced aluminum alloys and metal matrix composite developments are covered in this section.
ADVANCED ALUMINUM ALLOYS

DEVELOP POWDER METALLURGY
ALUMINUM ALLOYS WITH:

OBJECTIVE:
• 15 PERCENT HIGHER STRENGTH
• 20 PERCENT HIGHER FATIGUE STRENGTH
• CORROSION RESISTANCE EQUAL TO CURRENT ALLOYS
• 8-10 PERCENT REDUCTION IN DENSITY
• 15-20 PERCENT INCREASE IN MODULUS

PROGRESS:
• 20 PERCENT FATIGUE IMPROVEMENT DEMONSTRATED
• CORROSION RESISTANCE EXCELLENT
• 10 PERCENT STRENGTH IMPROVEMENT
• DENSITY AND MODULUS GOALS DEMONSTRATED

This chart shows structural objectives for advanced powdered alloys and progress on meeting these objectives. Advanced powdered alloys with significant improvements in strength, reduced density and increased modulus have been developed.
This chart shows the development schedule of an advanced aluminum alloy payoff study being funded by NASA Langley under Contract NAS1-16434. Preliminary plans and development costs have been established for initial Integrated Technology Wing (ITW) studies. Results from the above study will be incorporated into the ITW studies during the final study phase.
METALLURGICAL DEVELOPMENTS

- ALLOY MODIFICATIONS
- THERMAL MECHANICAL TREATMENT
- POWDER METALLURGY TECHNIQUES

Metallurgical developments which make possible the development of advanced aluminum alloys with significant property improvements are shown above.
These charts show the effects of lithium in aluminum alloys. An 8 to 10 percent reduction in density with a 15-20 percent increase in modulus is projected with 3 to 4 percent lithium by weight.
A schematic diagram of the aluminum powder metallurgy (P/M) method is shown. The sequence consists of: 1) rapid solidification (10^6°F/sec) of molten aluminum alloy by quenching in inert gas, one of several methods available in the industry, 2) collection and sizing of fine powders, 3) cold compaction, 4) canning, 5) vacuum de-gassing and hot compaction to full density ingot, and 6) extrusion, forging or rolling of ingots into structural products. Potential microstructural advantages include: 1) fine grain size, 2) elimination of segregated phases, and 3) fine particle dispersion.

Schematic diagram of aluminum ingot metallurgy (I/M) method, sequence consists of: 1) casting of aluminum alloy ingot with slow cooling rate (10°F/sec), and 2) fabrication of wrought aluminum products into structural products.
This chart shows development thrusts for advanced aluminum alloys at the Lockheed-California Company, alloy development goals and potential applications.
A preliminary development plan is shown for advanced aluminum alloys. This five year plan was established to permit incorporation of aluminum alloys using powder, lithium alloying or silicon carbide metal matrix technology. The plan covers thirteen (13) major tasks with an estimated development cost of $7 million dollars to develop an alloy for the Advanced Technology Aircraft (assuming concurrent development of similar technology for military aircraft). The development plan outline includes: Establishment of target property goals (currently being defined under NASA contract NASA-16434 "Systems Study of Transport Aircraft Using Advanced Aluminum Alloys"), alloy development, material characterization, design properties, and structural testing.
BACKGROUND: SiC/AL METAL MATRIX COMPOSITES

Silicon carbide whiskers are made from rice hulls. The hulls are first ground and then heated in a coke oven. An attractive feature of this product is its extremely low cost of $5-10 per pound. A 1000X magnification of silicon carbide whiskers is shown on the right.
Silicon carbide/aluminum (SiC/Al) metal matrix composites (MMC) are processed similar to aluminum powder except that a mixing phase combining the SiC and aluminum is conducted prior to compacting. Fabrication processes are expected to be similar to existing aluminum techniques.
SiC/Al ADVANTAGES

- 30-50% INCREASE IN STRENGTH
- 50-100% INCREASE IN STIFFNESS
- 12-20% REDUCTION IN STRUCTURAL WEIGHT
- POTENTIAL COST OF STRUCTURAL WEIGHT SAVED APPROXIMATELY $10-$20 PER POUND

This chart shows projected strength, modulus, weight and cost benefits of SiC/Al metal matrix composites.
A general development plan for hybrid structures is shown above. The development plan and development costs for SiC/Al is expected to be similar to that shown earlier for advanced aluminum alloys. This plan covers other hybrid developments. No cost estimates are provided since they will depend on the specific material mix and applications under consideration.
Developments in advanced titanium materials and producibility methods are reviewed in this section.
This chart shows the technology base being developed for titanium. NASA Langley has studies under way on superplastic forming, diffusion bonding and the low cost beta alloys. DoD also has several programs in this area. The Lockheed-California Company is under contract to NASA Langley to characterize the low cost beta alloys and is conducting independent research work as well.
LOW COST TITANIUM DEVELOPMENT

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This chart shows a five year development plan for low cost titanium. Although the use of titanium in current commercial aircraft is limited and none other than fasteners is used in structural wing applications, a change in engines could trigger the use of advanced titanium technology for the wing pylons and center engine support structure.
Plans for large composite primary aircraft structures (LCPAS) is shown in this section. The plans covered include the LCPAS key technology program and the wing development program.
This chart shows the advanced composites programs which have been funded by NASA Langley. Small secondary structures such as the L-1011 aileron, the 727 elevator and the DC-10 rudder as well as small primary structure developments have led to the initiation of developments for large primary structures. Lockheed independent research and development studies are also underway to accelerate composite applications.
A preliminary development plan is shown for advanced composites materials application to primary aircraft structures. This plan is a multi-phased program extending over a six year time period. The wing structure development program encompasses engineering and manufacturing studies, manufacturing development, and development testing to generate composite primary structure design data, to support concepts development, and for design verification. The program culminates in the manufacturing and test of full-scale demonstration articles of representative primary structure. The four technical phases encompass: Phase I - Preliminary Design, Phase II - Design Concepts and Manufacturing Development, Phase III - Design and Manufacturing Verification and Phase IV - Full-Scale Demonstration.
LOW COST COMPOSITES MANUFACTURING

PROBLEM: CURRENT METHOD EMPLOYING HAND LAY-UP FOR COMPOSITES MANUFACTURING IS NOT COST EFFECTIVE

SOLUTION: MATERIALS AND MANUFACTURING ENGAGED IN JOINT PROGRAM TO DEVELOP AUTOMATED MANUFACTURING TECHNIQUES

This chart discusses a current manufacturing technology program at the Lockheed-California Company. Lockheed feels it is essential to develop low cost producibility techniques if composites are to find increased applications in air frame structures.
This chart illustrates an automated continuous roll forming technique being developed by the Lockheed-California Company for structural shapes. Development work is currently being conducted on composite hat stiffeners for the L-1011 vertical fin which was developed under NASA Langley sponsorship.
### SUMMARY OF TECHNOLOGY COSTS AND BENEFITS

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*ESTIMATED COST COVERS DEVELOPMENT OF TWO ALLOYS

ITW-130
Preliminary Aeroelastic Design of Structures (PADS)

Nick Radovcich

Copies of this presentation are in a separate brochure.