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NASA/LOCKHEED

AIRCRAFT ENERGY EFFICIENCY

INTEGRATED TECHNOLOGY WING STUDY

NAS1-16273

MID-TERM ORAL PRESENTATION APRIL 8, 1981

LOCKHEED-CALIFORNIA CO.
BURBANK, CALIFORNIA

PREPARED FOR NASA LANGLEY RESEARCH CENTER

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X83-10073#

MID-TERM ORAL SCHEDULE

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

K

NASA/LOCKHEED

AIRCRAFT ENERGY EFFICIENCY

OVERVIEW OF PROGRAM

TONY HAYS

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NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

PROGRAM 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.

ITW-2

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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

SPECIFIC OBJECTIVES

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

ITW-3

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.

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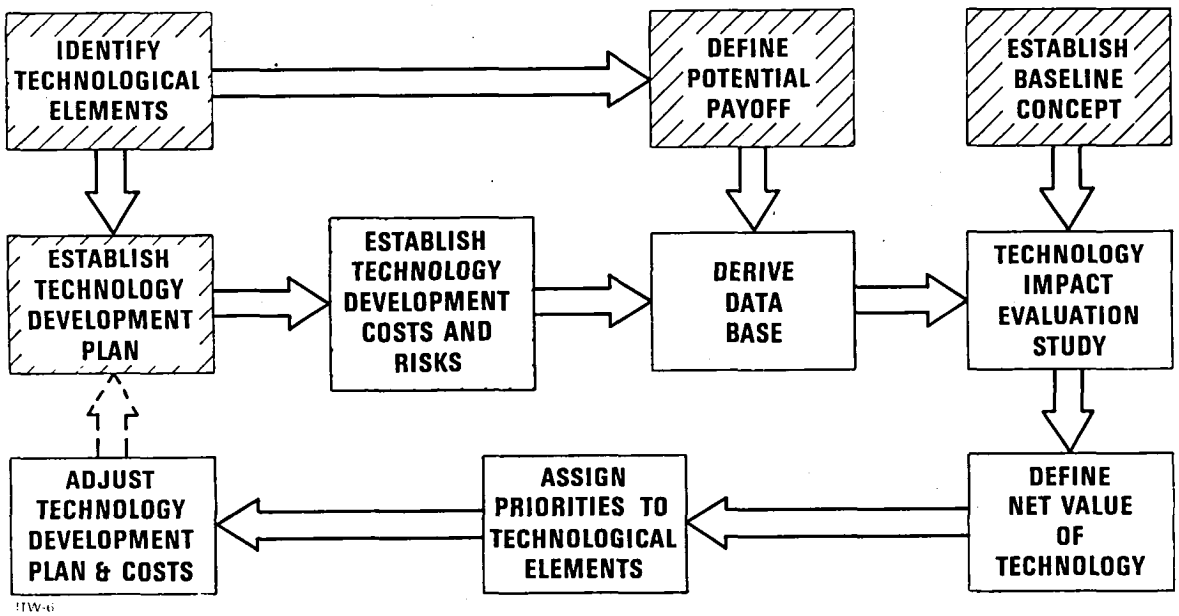
AIRCRAFT ENERGY EFFICIENCY

OVERVIEW OF PROGRAM

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

INTEGRATED TECHNOLOGY WING STUDY
FLOW CHART



A flowchart for this study is shown above. Shaded areas are those parts of the plan that have been completed to date.

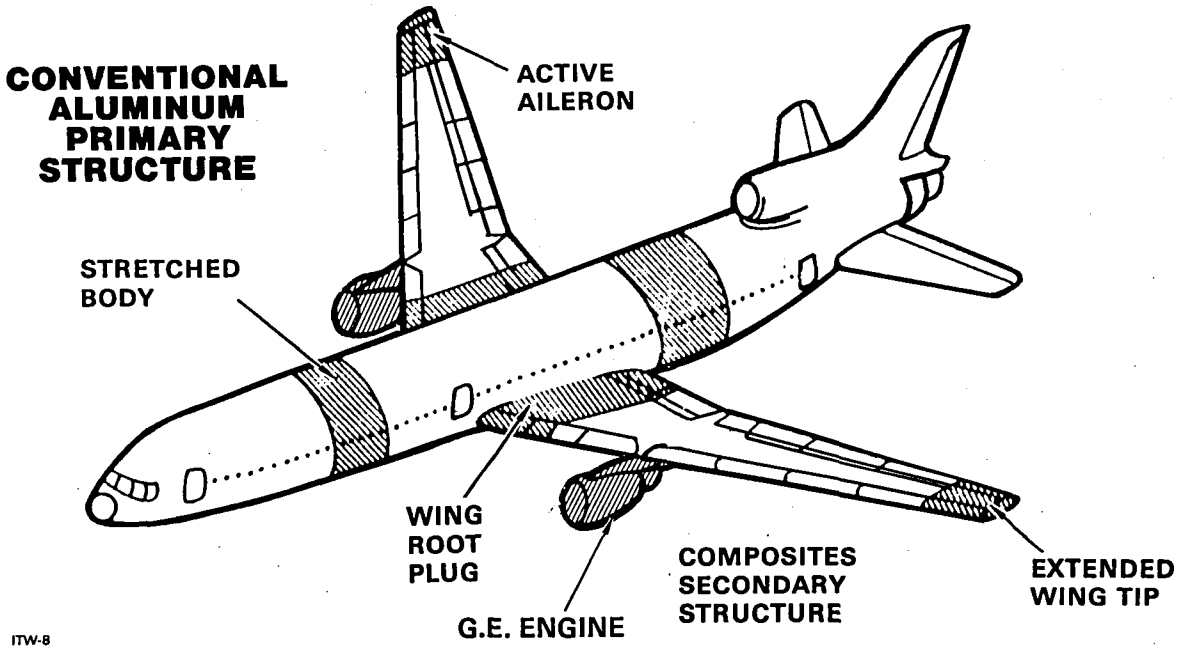
NASA LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

BASELINE CONCEPT

ITW-7

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

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.

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BASELINE CONCEPT

DESIGN FEATURES		DESIGN CONSTRAINTS	
RANGE	5000 N. MI.	FIELD LENGTH	10,500 FT.
CAPACITY	350 PAX.	APPROACH SPEED	145 KTS.
PAYLOAD	73,500 LBS.	OPERATIONAL CEILING	42,000 FT.
AVG. STAGE LENGTH	2500 N.MI.	CRUISE ALTITUDE (MIN.)	31,000 FT.
CRUISE SPEED	0.80		
FUEL RESERVES	INTERNATIONAL		
G.E. CF6-50C	HIGH BYPASS TURBOFAN		

ITW-9

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 E^3 program, the original range requirement (shown above) has been revised downwards.

NASA LOCKHEED AIRCRAFT ENERGY EFFICIENCY

ECONOMIC ASSUMPTIONS

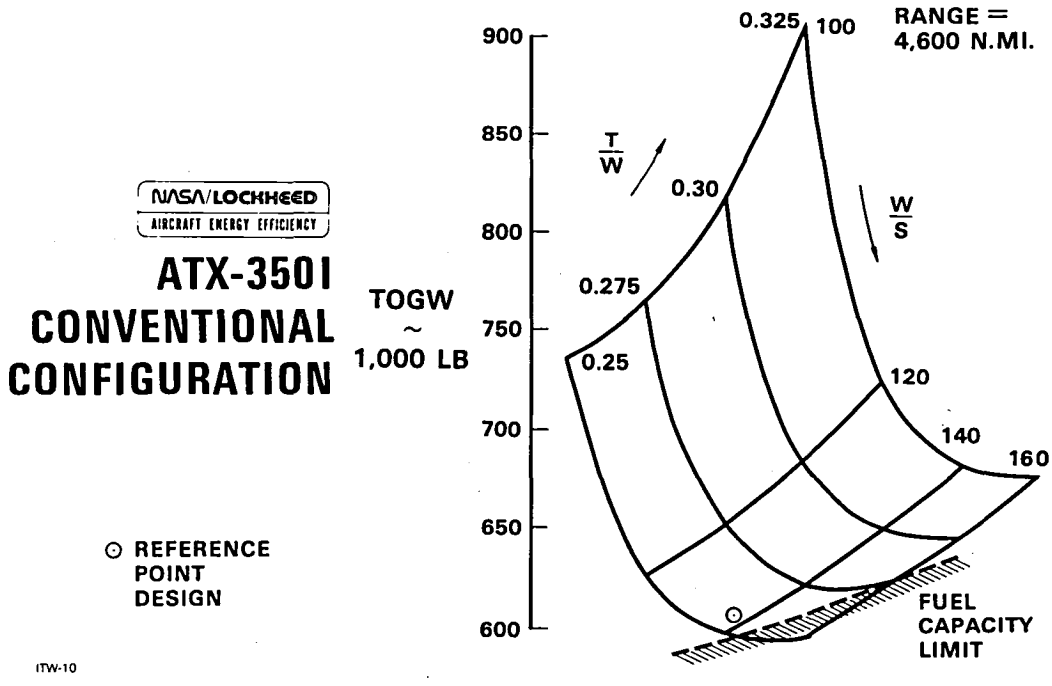
1980 DOLLARS

FUEL COST
FOR YEAR 2000 = $2.12/GAL

(INCREASING AT 3-1/2% ABOVE INFLATION)

ITW-158

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.

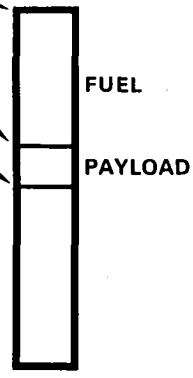


A carpet plot is shown for a revised range of 4600 n.mi.

NASA LOCKHEED AIRCRAFT ENERGY EFFICIENCY

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



ITW-11

Leading characteristics of the reference aircraft are shown above.

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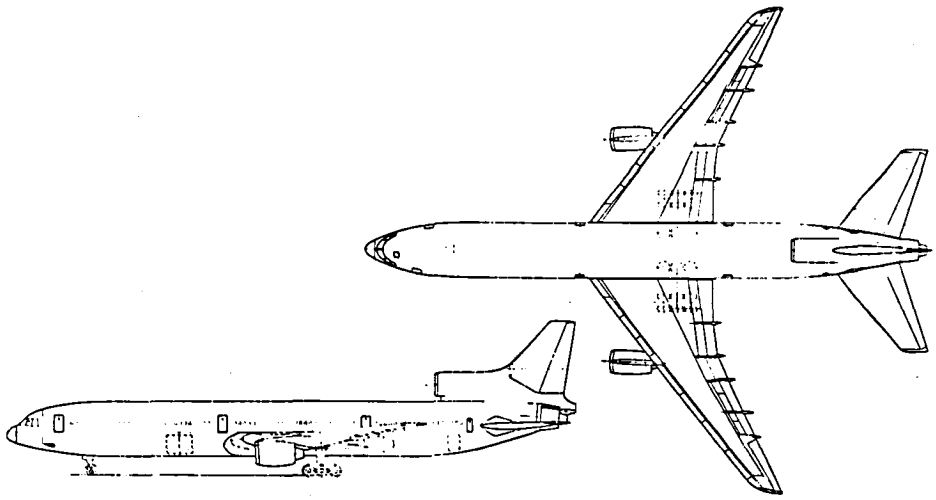
BASELINE CONCEPT



ITW-12

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.

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AIRCRAFT ENERGY EFFICIENCY

IDENTIFY TECHNOLOGICAL ELEMENTS

AERODYNAMICS
- AIRFOIL TECHNOLOGY
- PLANFORM PARAMETERS
- HIGH LIFT TECHNOLOGY

SYSTEMS AND CONTROLS
- ACTIVE CONTROLS
- ADVANCED SYSTEMS AND CONTROLS

PROPULSION
- ADVANCED PROPULSION
- AIRFRAME/PROPULSION INTEGRATION

STRUCTURES AND MATERIALS
- COMPOSITES
- ADVANCED ALUMINUM ALLOYS
- TITANIUM ALLOYS
- HYBRID STRUCTURES

ITW-13

The major technological elements that have been identified for this study are shown above.

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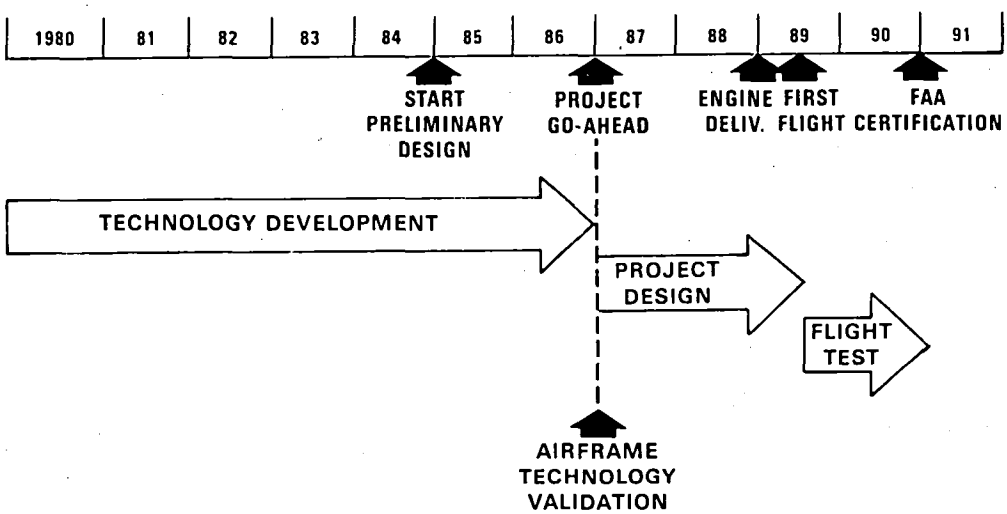
AIRCRAFT ENERGY EFFICIENCY

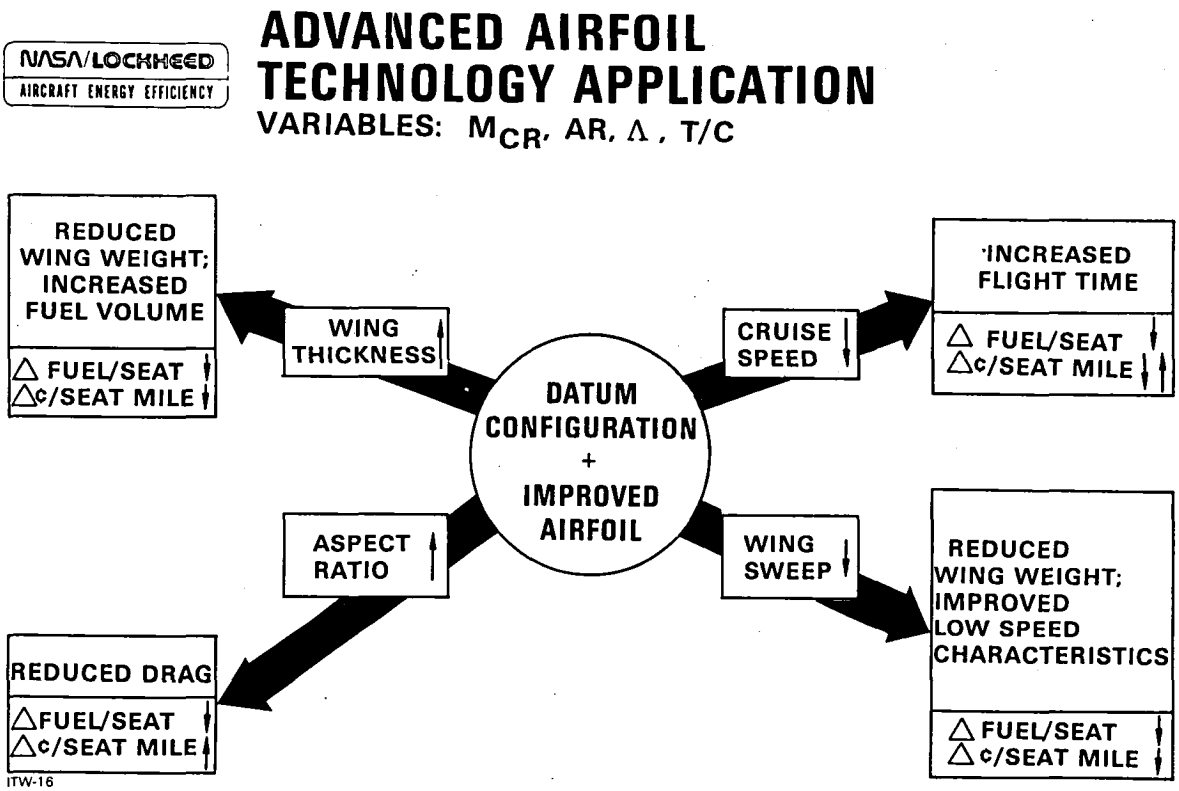
TECHNOLOGY BENEFITS

ITW-14

NASA LOCKHEED AIRCRAFT ENERGY EFFICIENCY PROGRAM SCHEDULE



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.

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TRANSONIC WING TECHNOLOGY DEVELOPMENT

PARAMETER \ DESCRIPTOR	WING 49	WING 53	WING 55	WING 56
ASPECT RATIO	7	7	10	14
SWEEP AT 1/4 C	35°	35°	25°	25°
T/C	10%	10%	12%	14%
DESIGN MACH NO.	0.84	0.84	0.80	0.76
DESIGN C_L	0.40	0.50	0.60	0.75
Δ M $\frac{L}{D}$ (GOAL)	0	5%	14%	25%

ITW-17

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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

HIGH LIFT SYNTHESIS

MAXIMUM LIFT COEFFICIENT

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

TECHNOLOGY LEVEL	TRAILING EDGE FLAPS			LEADING EDGE DEVICE	TYPICAL $C_{L_{MAX}}$ POTENTIAL 35° SWEEP
	$\frac{b_f}{b}$	$\frac{c_f}{c}$	SLOTS	100% b, 15% c	
L-1011	.50 - .55	.25 - .30	2	SLATS/KREUGERS	2.6
ADVANCED CONVENTIONAL	.55 - .65	.30 - .35	2 or 3	SHAPED KREUGER	3.0
ADVANCED CONCEPTS	.65 - .70	.30 - .35	2 or 3	ROTATING FLAP	3.4

ITW-26

Maximum lift coefficient is an important parameter in sizing an aicraft 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.

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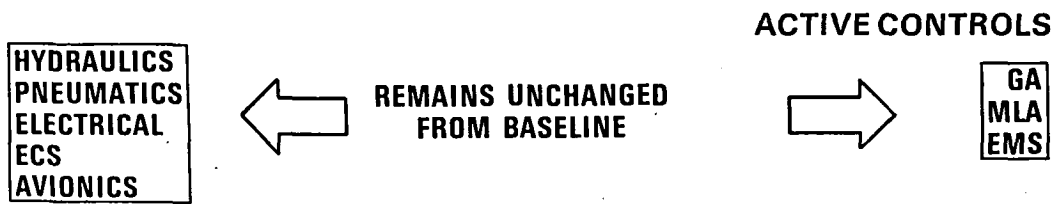
AIRCRAFT ENERGY EFFICIENCY

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.

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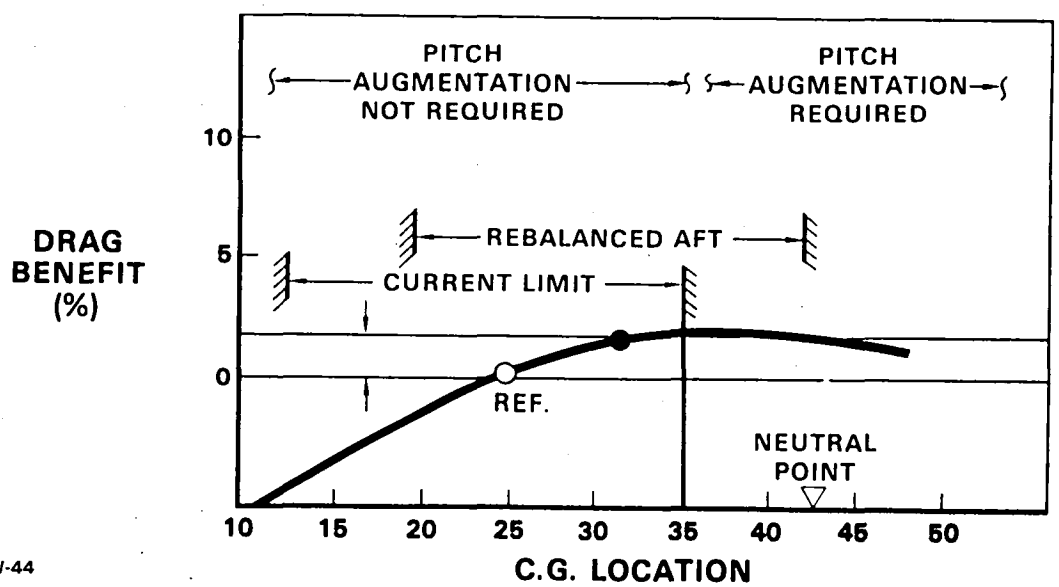
AIRCRAFT ENERGY EFFICIENCY

RELAXED STATIC STABILITY, CURRENT WING



ITW-44

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.

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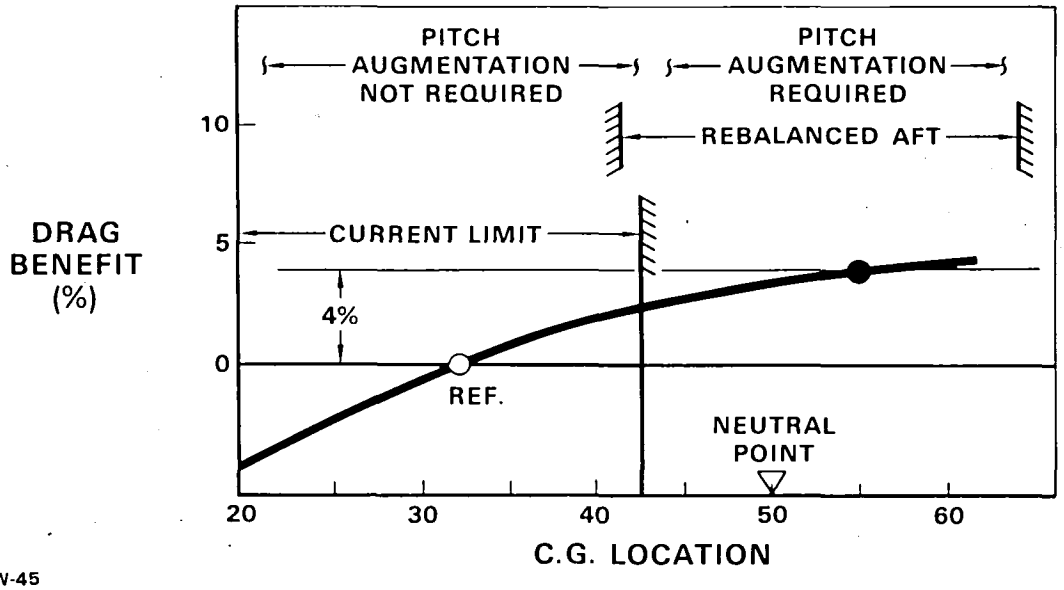
AIRCRAFT ENERGY EFFICIENCY

RELAXED STATIC STABILITY, ADVANCED WING



ITW-45

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.

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ACTIVE CONTROLS SUMMARY

WEIGHT SAVINGS: 0.5% EMPTY WEIGHT

RSS PAYOFF: FUEL 4%

MAINTENANCE IMPROVEMENT

ITW-48

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AIRCRAFT ENERGY EFFICIENCY

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

ITW-49

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.

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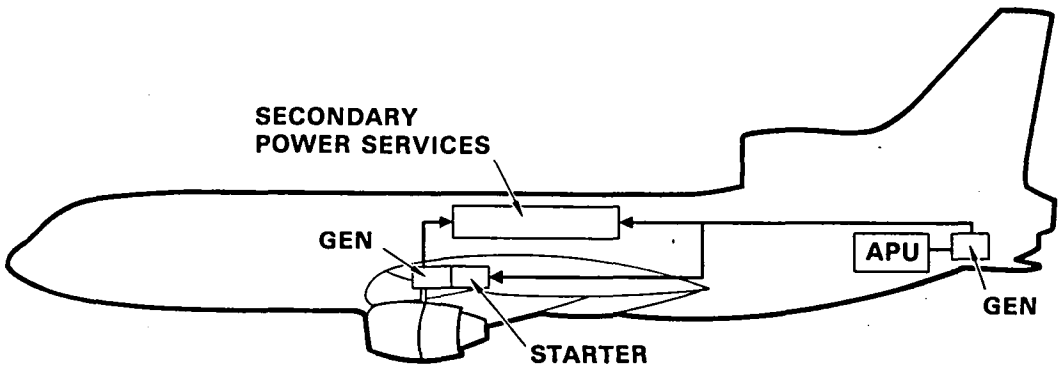
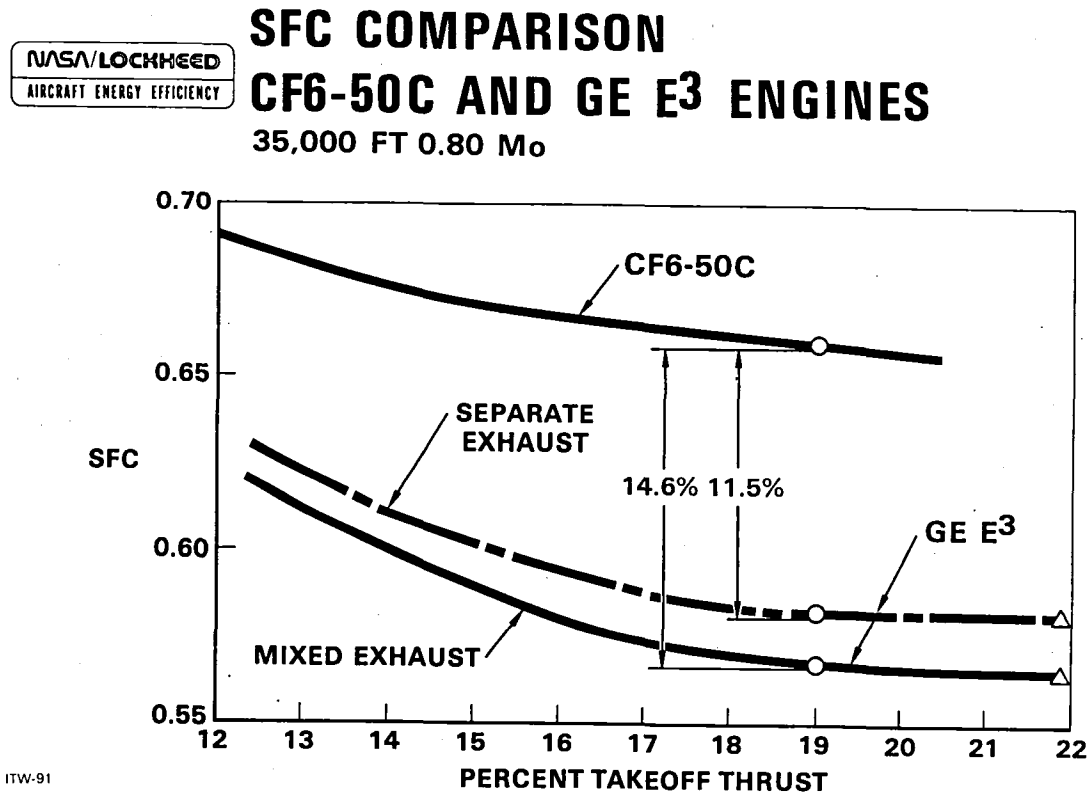
AIRCRAFT ENERGY EFFICIENCY

ALL ELECTRIC AIRCRAFT



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

ITW-63



SFC levels are shown for the E^3 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.

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AIRCRAFT ENERGY EFFICIENCY

AIRFRAME/PROPULSION INTEGRATION SUMMARY

WING	ENGINE	EXHAUST FLOW	INSTALLED NACELLE DRAG % OF AIRCRAFT DRAG	
			WITHOUT AIR/PROP* INTEGRATION	WITH AIR/PROP INTEGRATION
CONV.	CF6-50C	SEPARATE	4.3%	3.5%
CONV.	E^3	SEPARATE	4.3%	3.5%
CONV.	E^3	MIXED	7.2%	5.4%
ADV.	CF6-50C	SEPARATE	11.5%	4.3%
ADV.	E^3	SEPARATE	11.5%	4.3%
ADV.	E^3	MIXED	17.3%	6.2%

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

ITW-147

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

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

ITW-111

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.

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AIRCRAFT ENERGY EFFICIENCY

PROJECTED BENEFITS OF ADVANCED ALUMINUM ALLOYS

STRUCTURE	WEIGHT SAVING
WING	13.4%
EMPENNAGE	13.3%
STRUCTURAL WEIGHT	5.6%

ITW-148

Weight savings for the wing and empennage are shown as a percentage of the weight of that component.

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AIRCRAFT ENERGY EFFICIENCY

PROJECTED BENEFITS OF ADVANCED COMPOSITES

STRUCTURE	WEIGHT SAVING
WING	21.3%
EMPENNAGE	21.1%
STRUCTURAL WEIGHT	8.9%

ITW-149

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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

ITW-120

This chart shows projected strength, modulus, weight and cost benefits of SiC/Al metal matrix composites.

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AIRCRAFT ENERGY EFFICIENCY

PROJECTED BENEFITS OF METAL MATRIX COMPOSITES

STRUCTURE	WEIGHT SAVING
WING	17.4%
EMPENNAGE	17.2%
STRUCTURAL WEIGHT	7.2%

ITW-150

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AIRCRAFT ENERGY EFFICIENCY

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)

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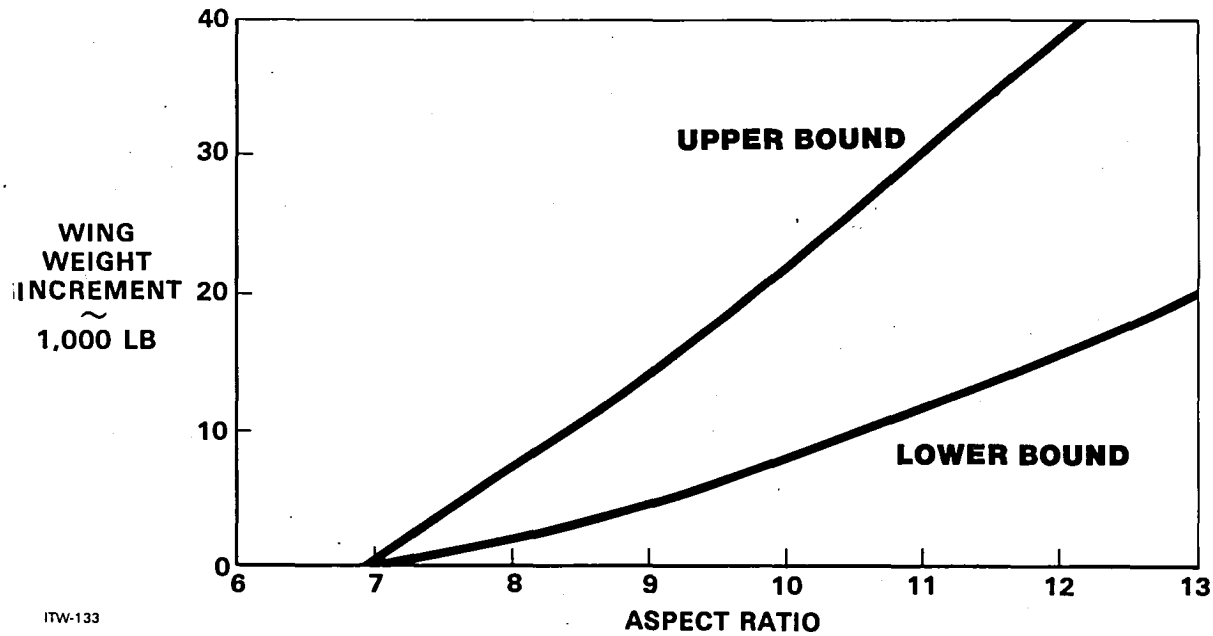
LIMITS OF WING WEIGHT EQUATIONS



The upper and lower bounds show the variation in equations used by different aircraft manufacturers relating wing weight to aspect ratio.

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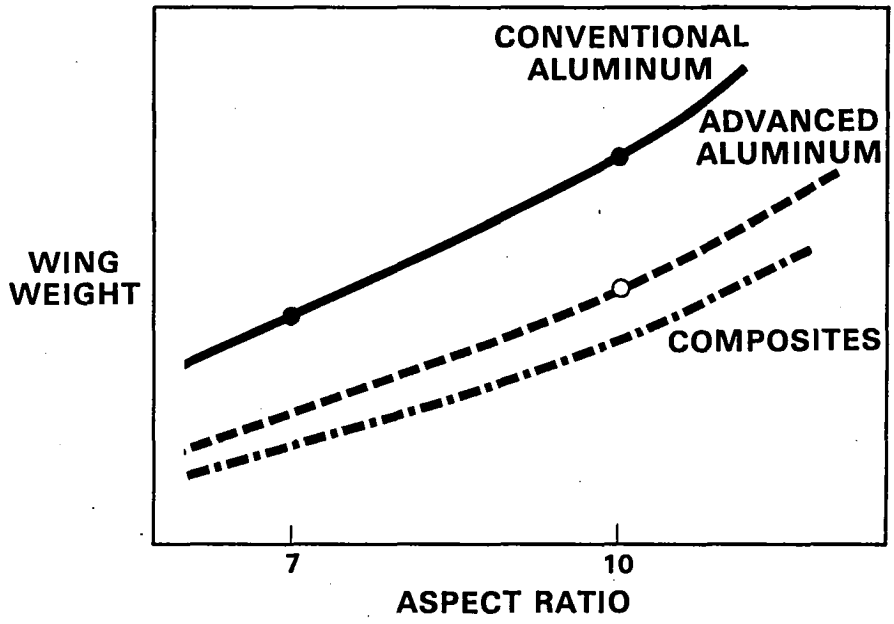
PADS CONFIGURATIONS



ITW-134

The black dots shows 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.

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AIRCRAFT ENERGY EFFICIENCY

LARGE COMPOSITE PRIMARY AIRCRAFT STRUCTURES - WING DEVELOPMENT

ADVANCED COMPOSITES FOR COMMERCIAL AIRCRAFT

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

'81 | '82 | '83 | '84 | '85 | '86 | '87

LCPAS - KEY TECHNOLOGY ($2 MIL)
- FUEL CONTAINMENT
- DAMAGE TOLERANCE
- JOINTS

5/1/81

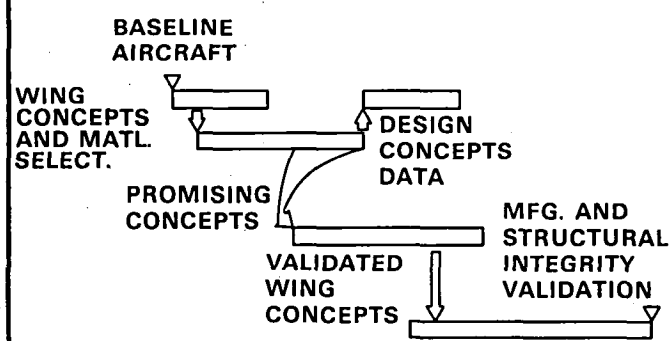
LCPAS - WING DEVELOPMENT ($38 MIL)

I PRELIMINARY DESIGN

II DESIGN CONCEPTS AND MANUFACTURING DEVELOPMENT

III DESIGN AND MANUFACTURING VERFICATION

IV FULL SCALE DEMONSTRATION



ITW-127

This shows one example of plans that are in the process of development for each technical discipline.

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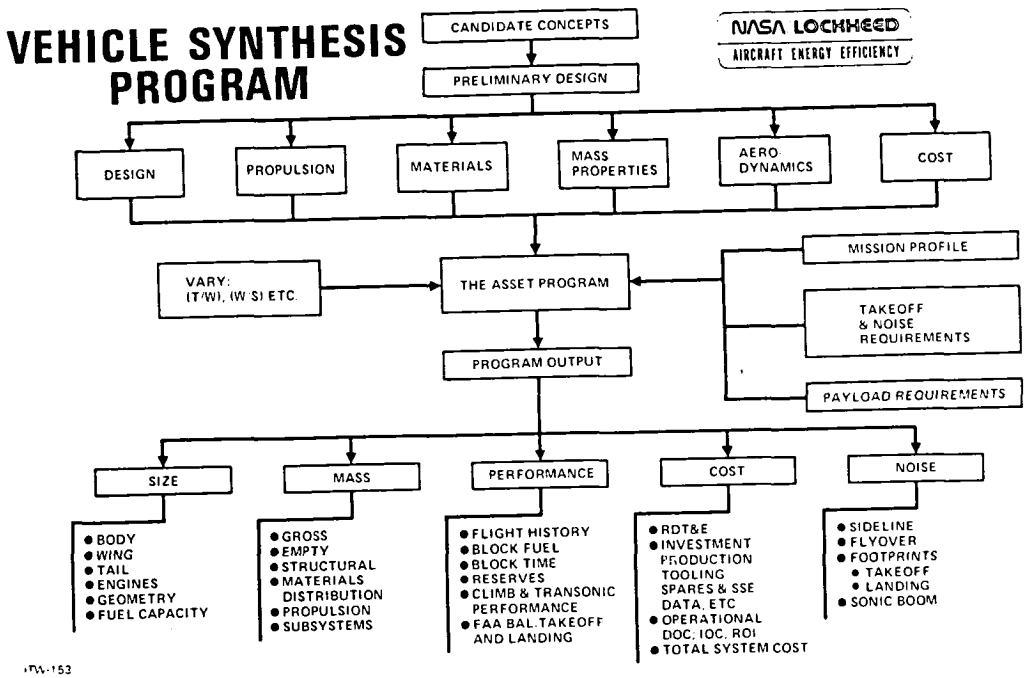
AIRCRAFT ENERGY EFFICIENCY

FUTURE PLANS

ITW-151



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.

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AIRCRAFT ENERGY EFFICIENCY

STUDY CONFIGURATION MATRIX

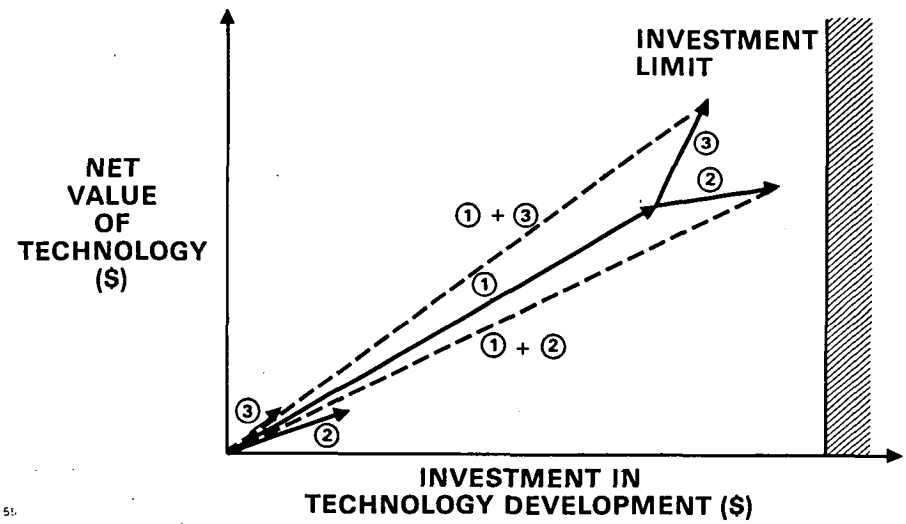
CONFIG. NO.	CONFIGURATION	AIRCRAFT DATA			ECONOMIC DATA					TECHNOLOGY COSTS			
		BLOCK FUEL	TOGW	OEW	AIRCRAFT COST	DOC	LIFE CYCLE COST	ROI	NET VALUE OF TECHNOLOGY	DEVELOP	VALIDATE	INTEGRATE	TECHNOLOGY DEVELOPMENT PRIORITY
1	BASELINE												
2	BASELINE + AIRFOIL TECHNOLOGY												
3	BASELINE + PLANFORM PARAMETERS												
4	BASELINE + HIGH LIFT TECHNOLOGY												
5	BASELINE + ACTIVE CONTROLS												
6	BASELINE + ADVANCED SYSTEMS AND CONTROLS												
7	BASELINE + ADVANCED PROPULSION TECHNOLOGY												
8	BASELINE + AIRFRAME/PROPULSION INTEGRATION												
9	BASELINE + COMPOSITES												
10	BASELINE + ADVANCED ALUMINUM ALLOYS												
11	BASELINE + TITANIUM ALLOYS												
12	BASELINE + HYBRID STRUCTURES												
13	CONFIG. 1 + 2 + 3 + 4												
14	CONFIG. 13 + 5 + 6												
15	CONFIG. 14 + 7 + 8												
16	CONFIG. 15 + 9 + 10 + 11 + 12 =												
	ADVANCED TECHNOLOGY AIRCRAFT												

ITW-154

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.

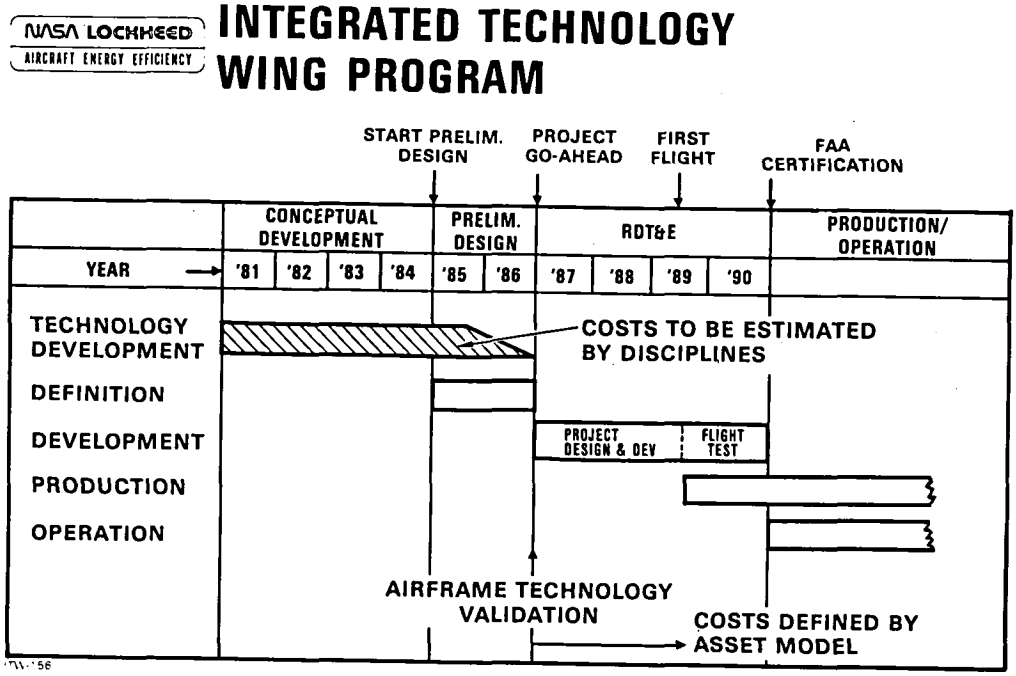
NASA LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

NET VALUE OF TECHNOLOGY VS INVESTMENT



ITW-155

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.

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LR 29801

NASA/LOCKHEED

AIRCRAFT ENERGY EFFICIENCY

AERODYNAMICS

LUIS MIRANDA/ROGER FIELD

AERODYNAMIC WING DESIGN TECHNOLOGY

INDEPENDENT RESEARCH PROGRAM

+

COLLABORATIVE PROGRAM WITH NASA-AMES

+

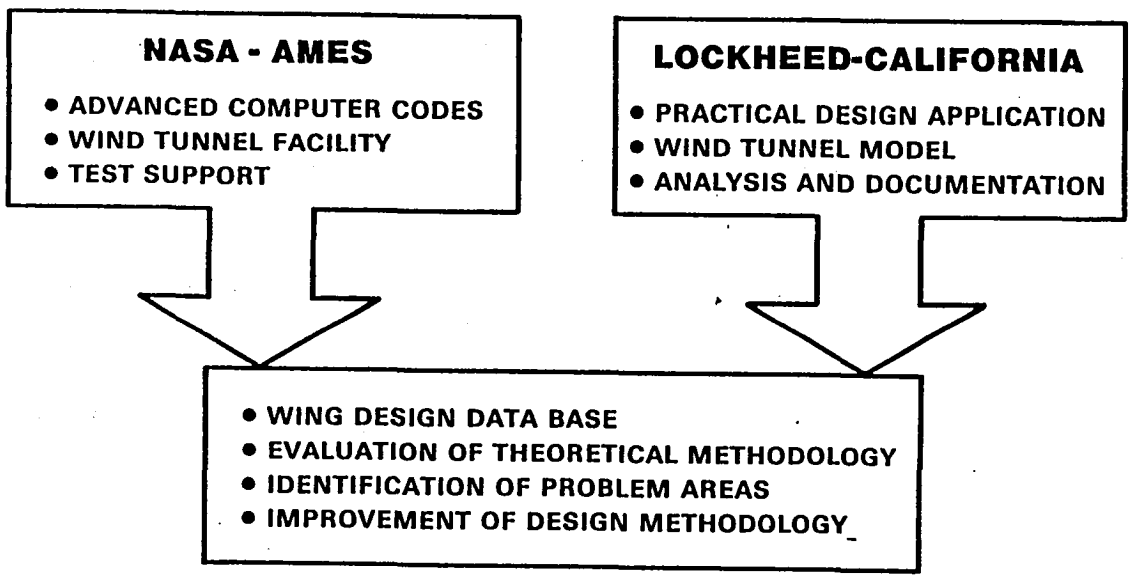
COLLABORATIVE PROGRAM WITH NASA-LANGLEY

OBJECTIVE

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

ITW-180

COLLABORATIVE WING TECHNOLOGY PROGRAM



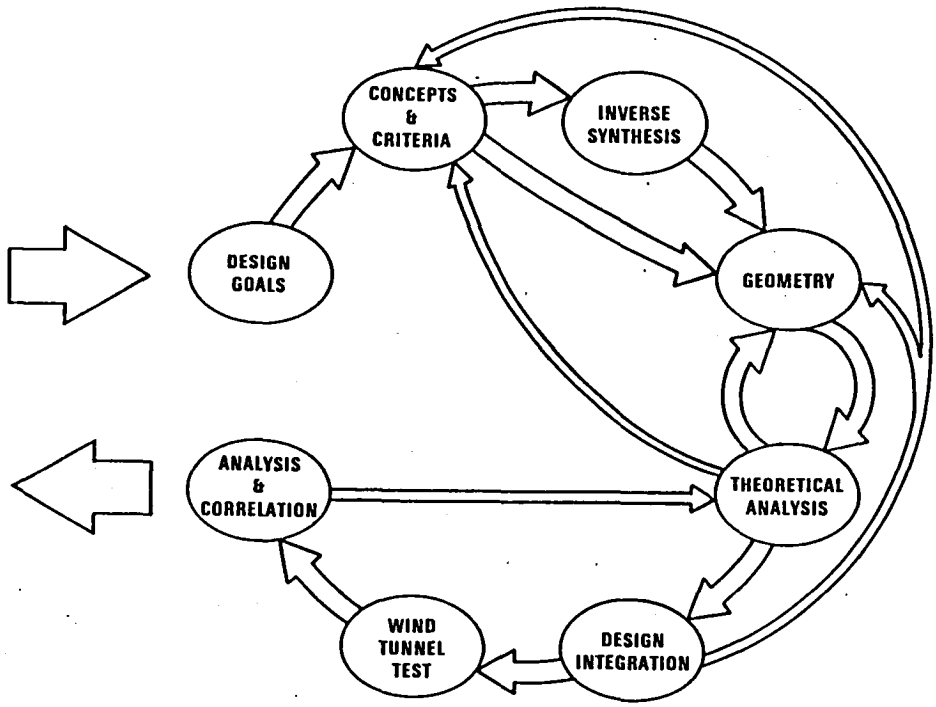
ITW-181

APPROACH

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

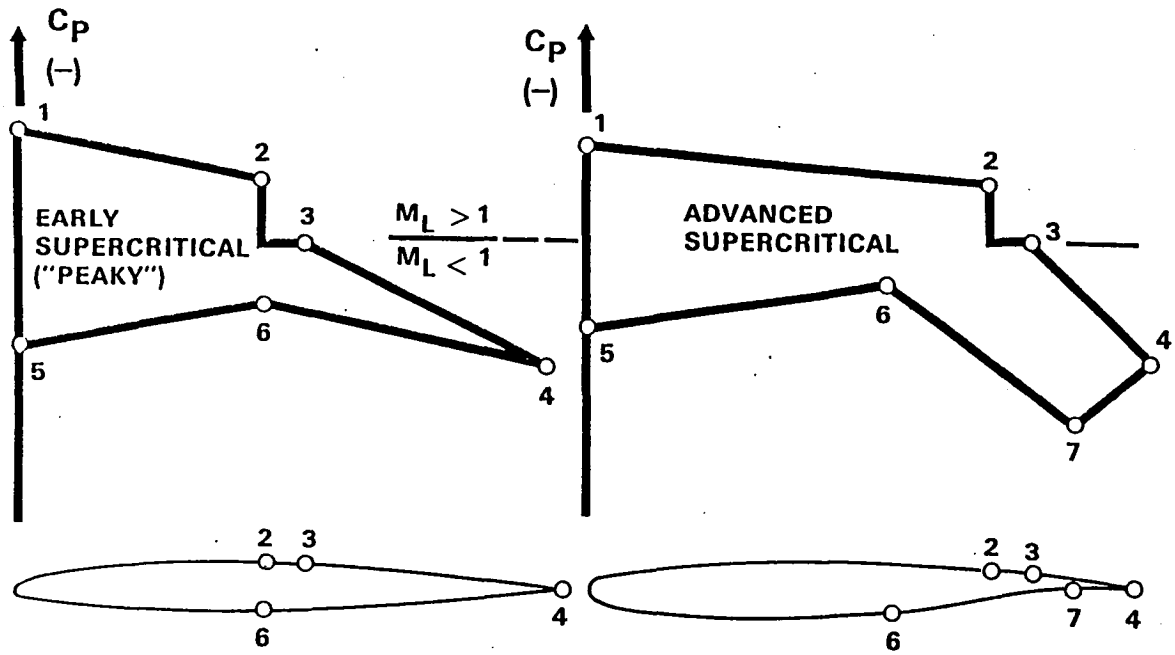
ITW-182

THE WING DESIGN PROCESS



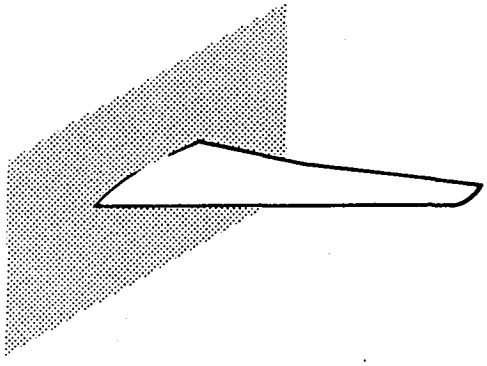
LTW-184

AIRFOIL TECHNOLOGY AND PRESSURE DISTRIBUTION CRITERIA



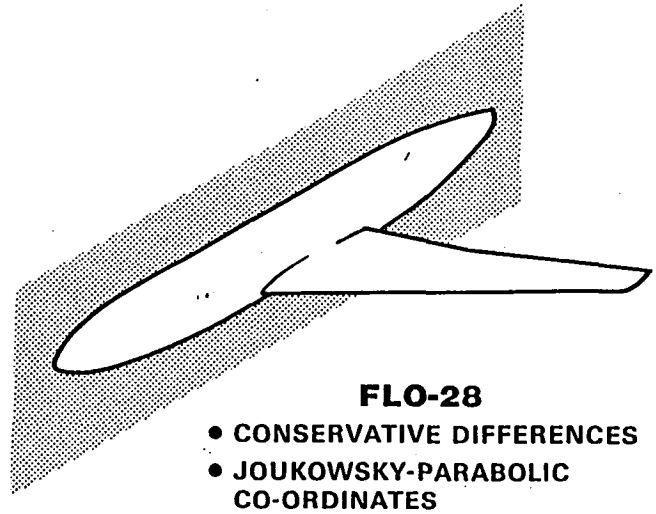
ITW-183

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

ITW-185

FLO-22 CHOSEN FOR FURTHER WORK

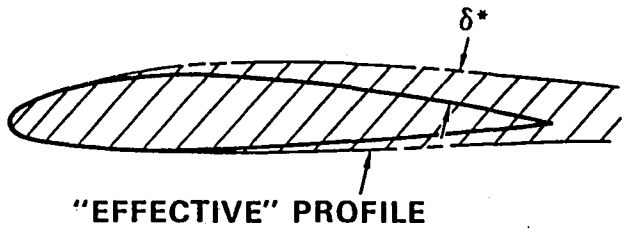
WHY?

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

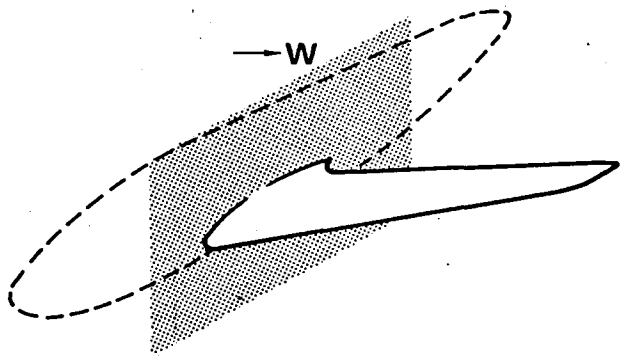
ITW-186

MODIFICATIONS TO FLO-22 (FLO-22.5)

- **VISCOUS CORRECTION**
  3-D INTEGRAL
  BOUNDARY LAYER

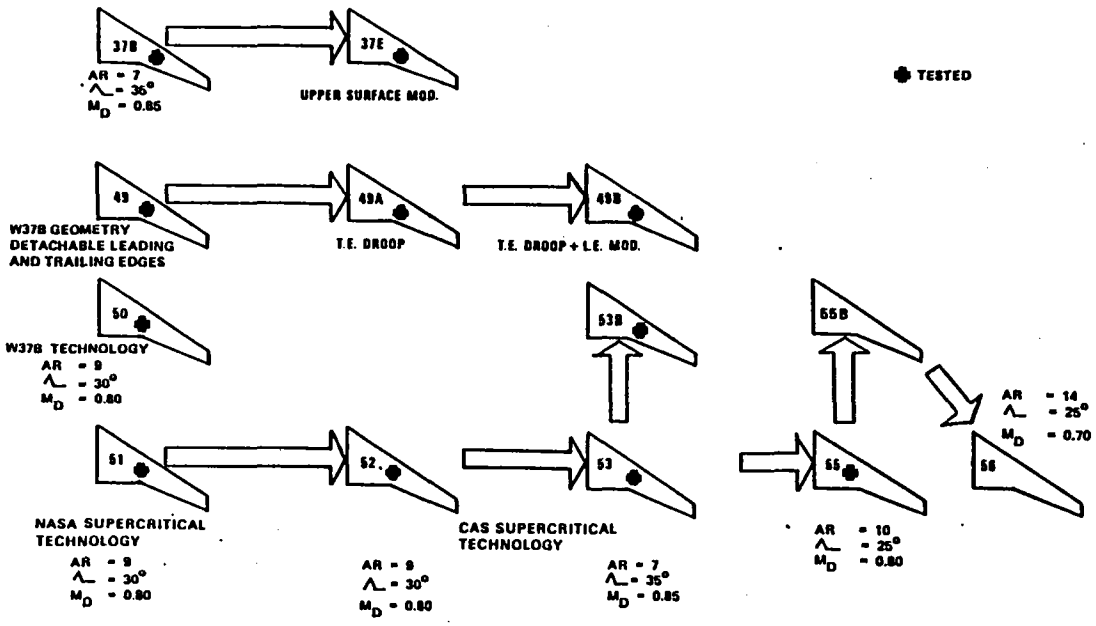


- **FUSELAGE SIMULATION**
  LINEAR THEORY
  SPANWISE FLOW IMPOSED
  AT "PLANE-OF-SYMMETRY"



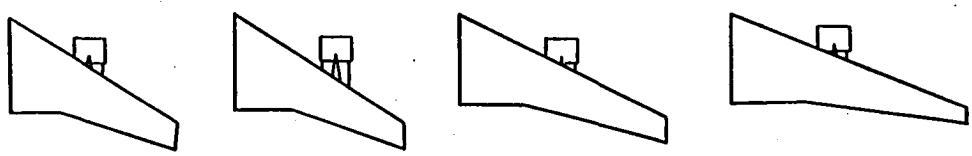
ITW-187

TRANSONIC WING TECHNOLOGY DEVELOPMENT PLAN



ITW-188

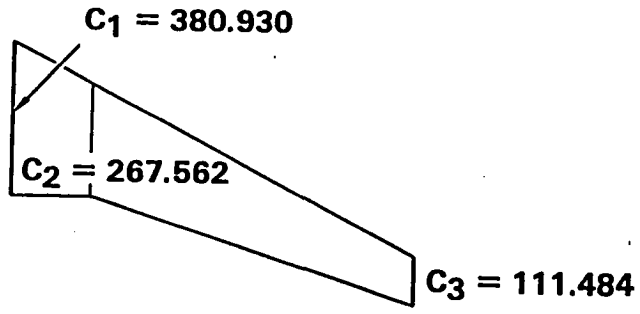
TRANSONIC WING TECHNOLOGY DEVELOPMENT



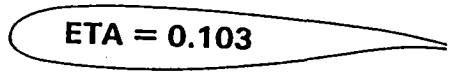
	W 49	W 53	W 55	W 56
AR	7	7	10	14
Λ	35°	35°	25°	25°
T/C (%)	10	10	12	16
M_D	0.84	0.84	0.80	0.74
C_{L_D}	0.45	0.50	0.60	0.75
$\% \Delta \frac{ML}{D}$ GOAL	0	5	14	25

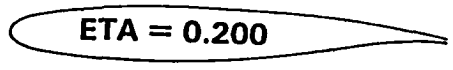
ITW-189

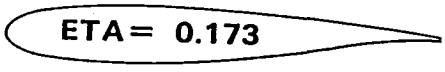
WING 55

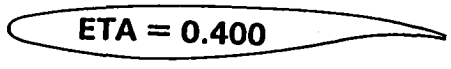


S_{REF} = 3,456 SQ FT
b = 186 FT
AR = 10.0
$\Lambda c/4 = 25^o$

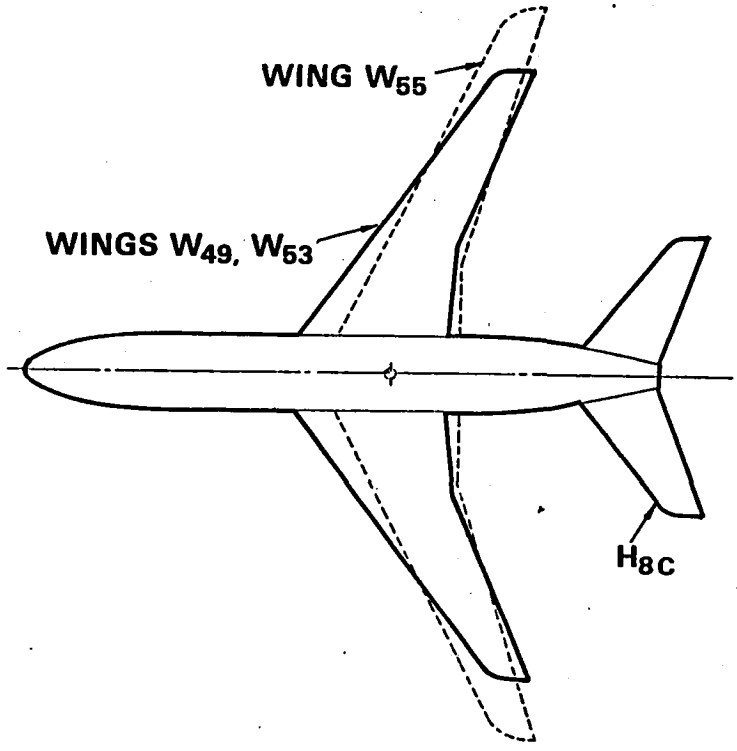








ITW-190



ITW-191

COLLABORATIVE HIGH REYNOLDS NO. TEST PROGRAM

NASA - LANGLEY

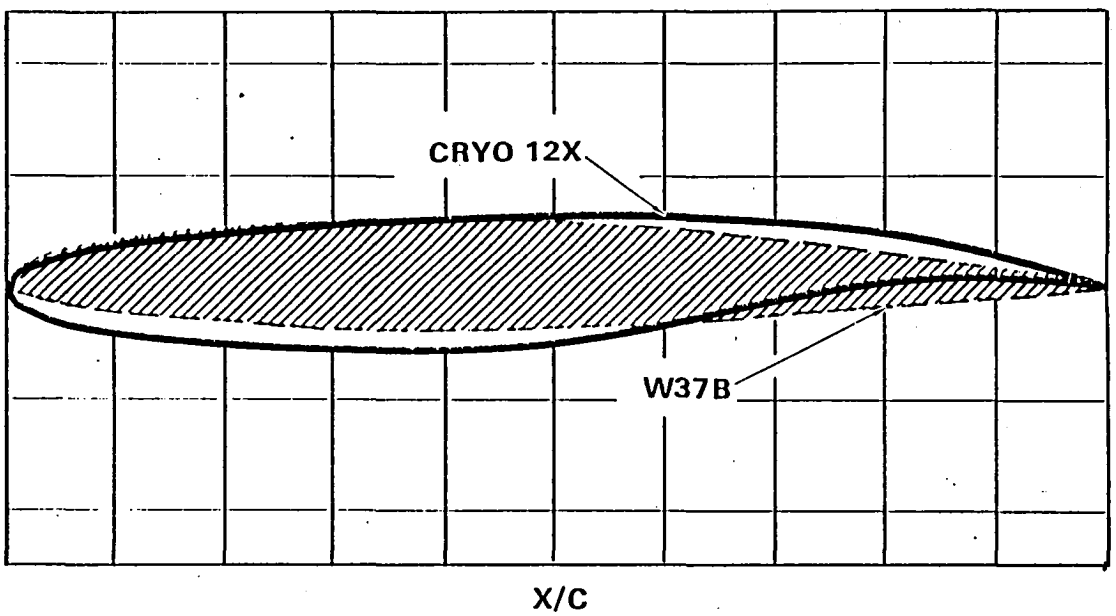
- CRYOGENIC WIND TUNNEL
- NITROGEN
- TEST SUPPORT

LOCKHEED-CALIFORNIA

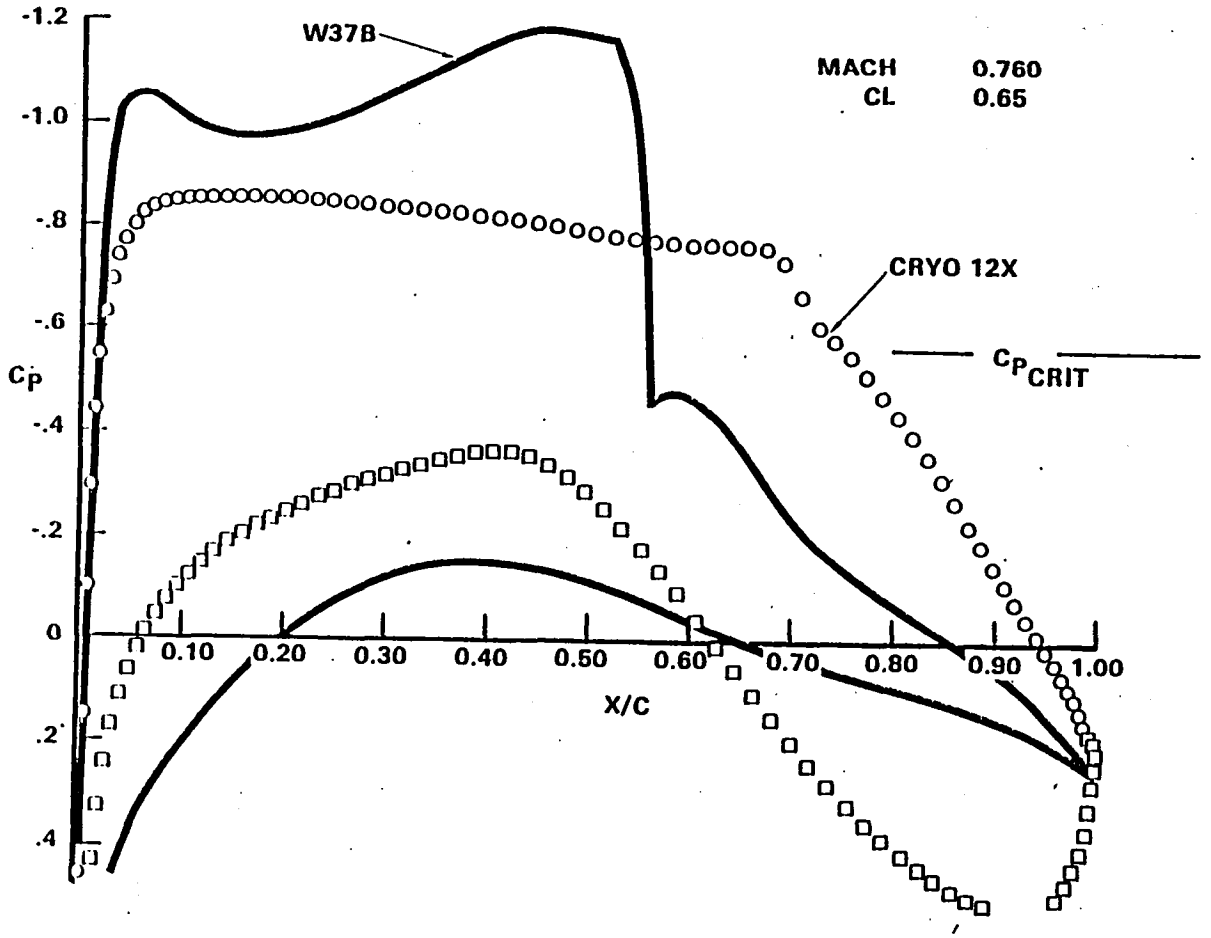
- AIRFOIL DESIGN: $C_{LD} = 0.65$; $t/c = 0.12$
- WIND TUNNEL MODELS
- ANALYSIS & DOCUMENTATION

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

ITW-192



ITW-193


W37B
MACH 0.760
CL 0.65
CRYO 12X
$C_{P_{CRIT}}$
C_P
-1.2
-1.0
-.8
-.6
-.4
-.2
0
.2
.4
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
X/C

ITW-194

PERT DRAG

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

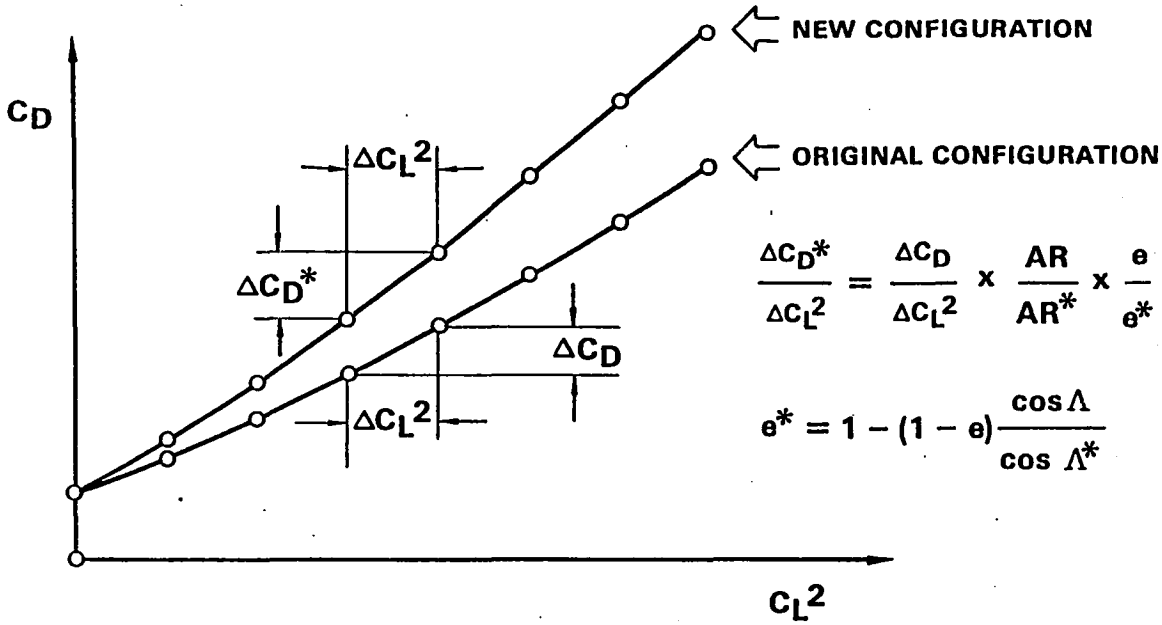
- WING AREA
- ASPECT RATIO
- SWEEP
- THICKNESS RATIO
- C.G. LOCATION
- TAIL VOLUME
- FUSELAGE LENGTH

DRAG BUILD-UP:

ITW-195

BASIC DRAG POLAR

MACH = SUBCRITICAL

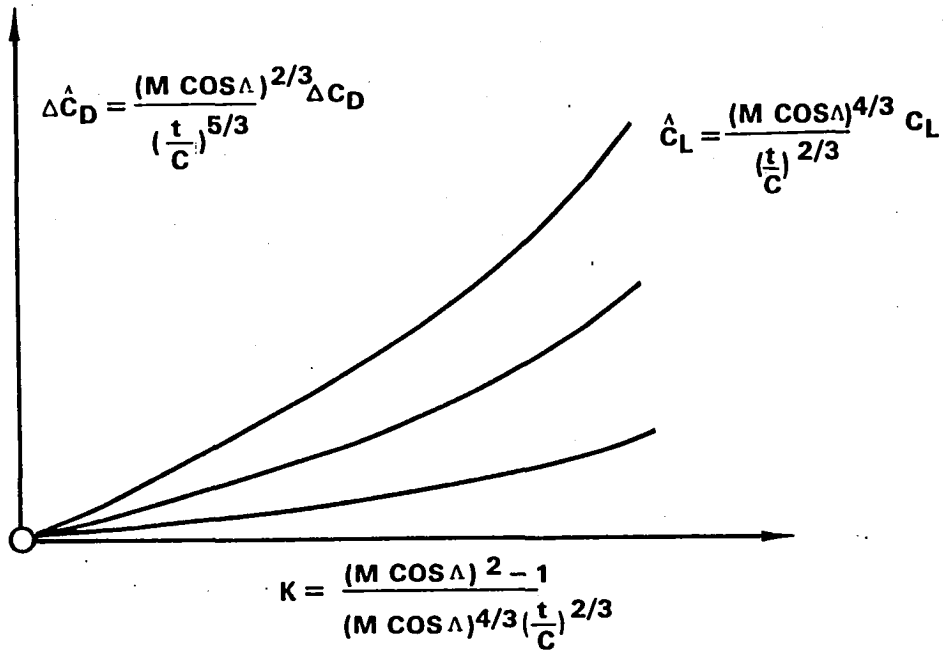


$$\frac{\Delta C_D^*}{\Delta C_L^2} = \frac{\Delta C_D}{\Delta C_L^2} \times \frac{AR}{AR^*} \times \frac{e}{e^*}$$

$$e^* = 1 - (1 - e)\frac{\cos\Lambda}{\cos\Lambda^*}$$

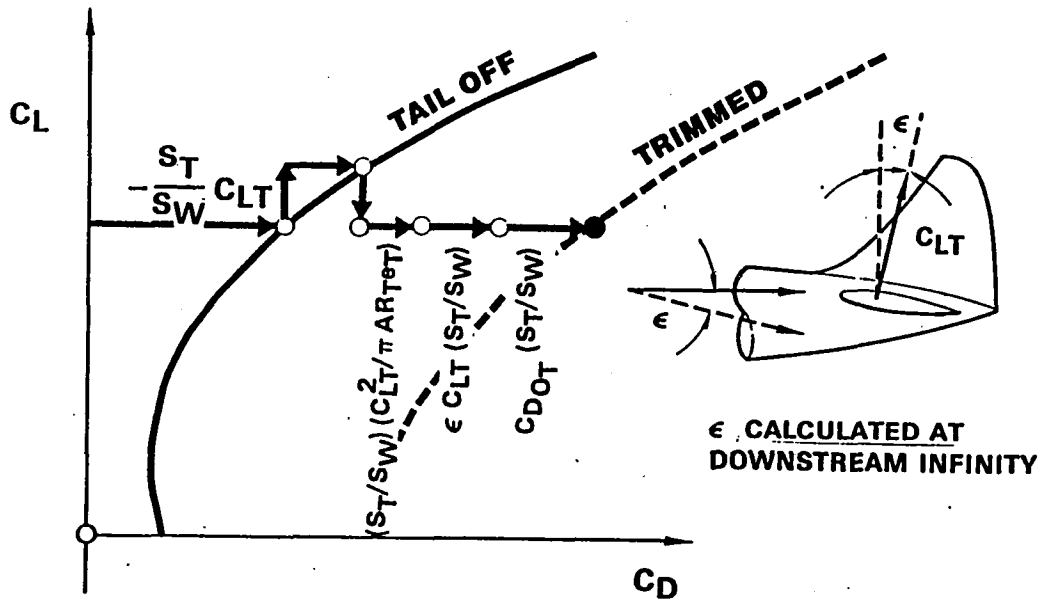
ITW-196

DRAG RISE VARIATION

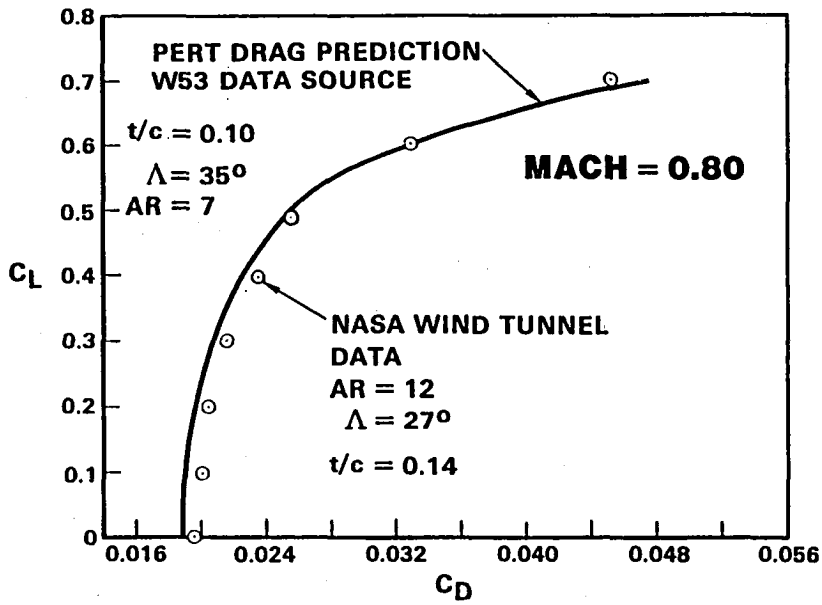


ITW-197

PERT DRAG CALCULATION OF TRIMMED DRAG

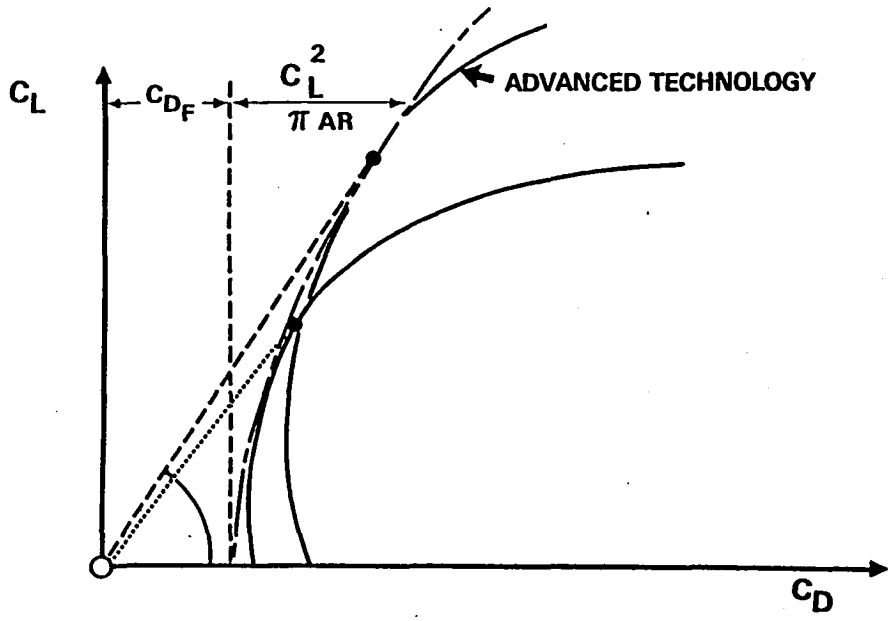


ITW-198


PERT DRAG PREDICTION
W53 DATA SOURCE
t/c = 0.10
Λ = 35°
AR = 7
MACH = 0.80
NASA WIND TUNNEL
DATA
AR = 12
Λ = 27°
t/c = 0.14
C_L
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.016
0.024
0.032
0.040
0.048
0.056
C_D

ITW-199

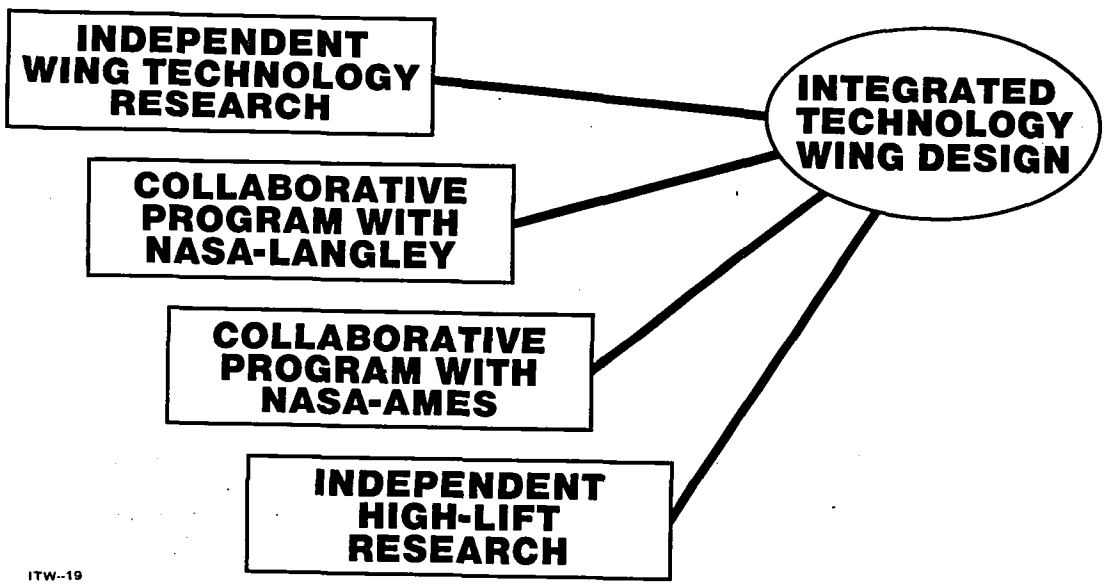
BENEFITS OF AERODYNAMIC WING TECHNOLOGY INTEGRATION



ITW-200

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

AERODYNAMIC TECHNOLOGY DEVELOPMENT

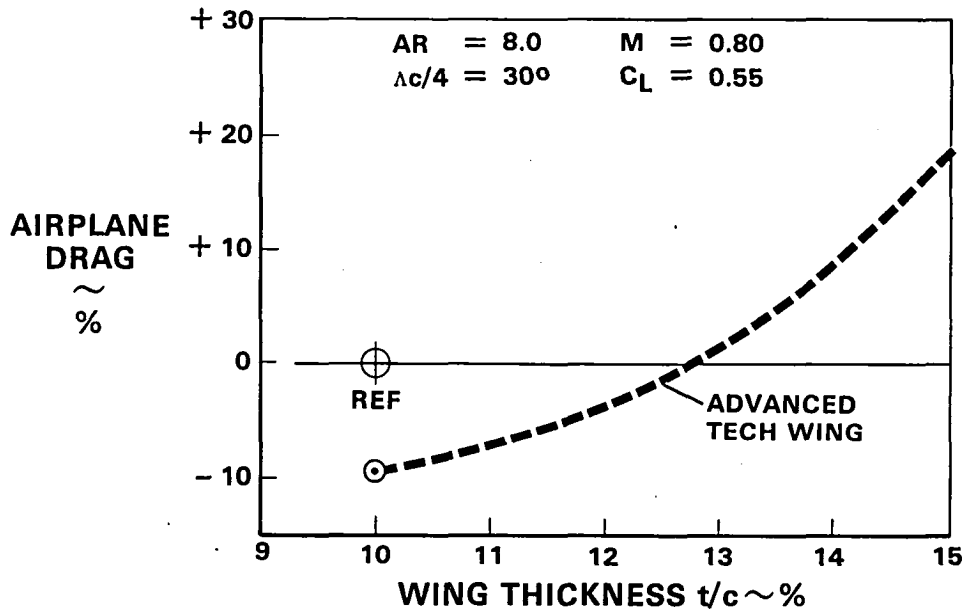


ITW-19

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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

EFFECT OF WING THICKNESS



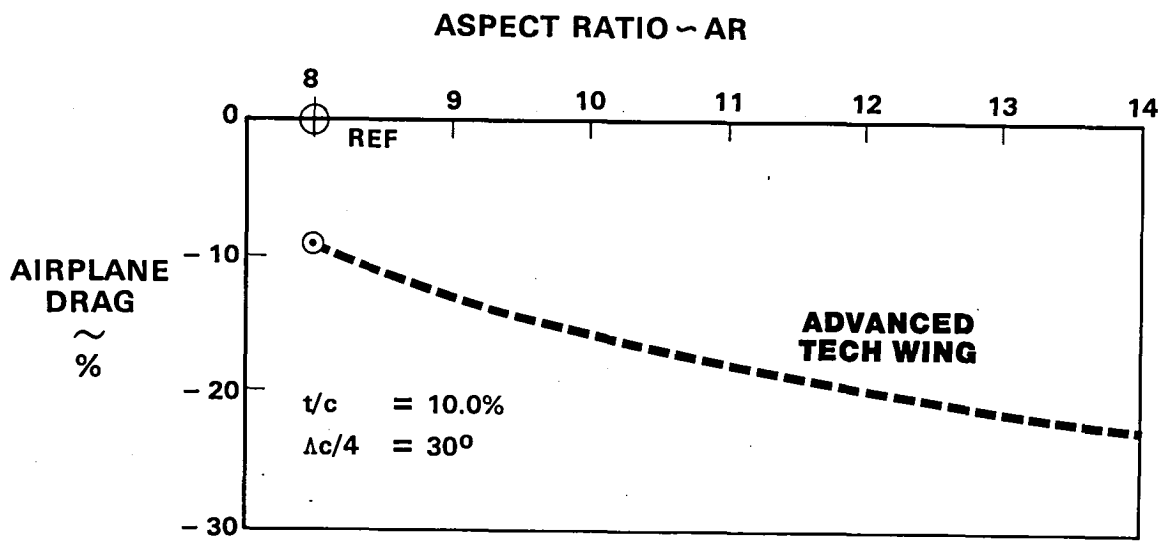
ITW-22

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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

EFFECT OF ASPECT RATIO

$M = 0.80 \bullet C_L = 0.55$

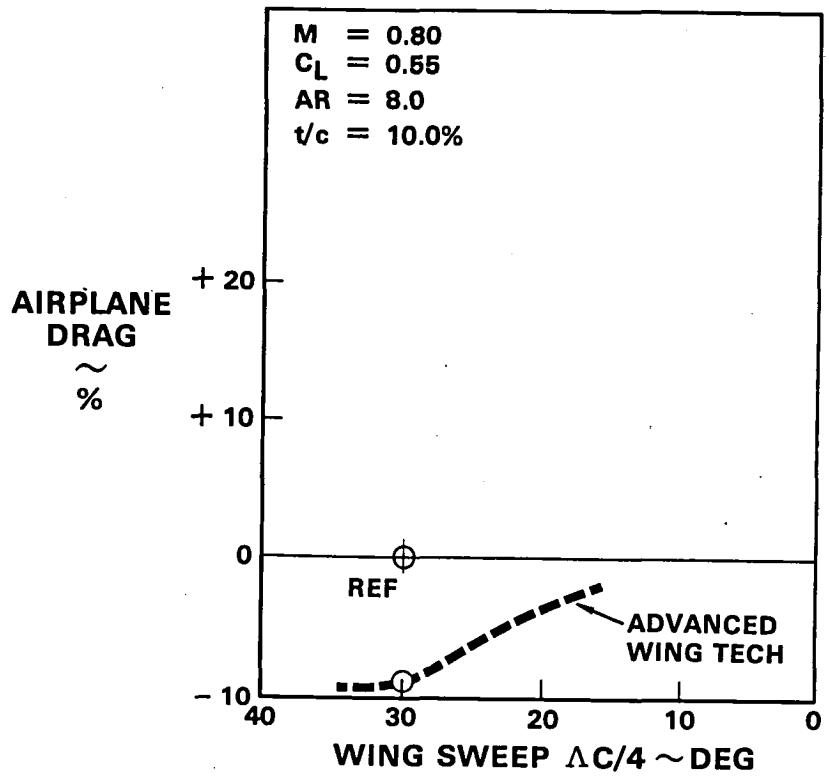


ITW-21

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".

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

EFFECT OF WING SWEEP

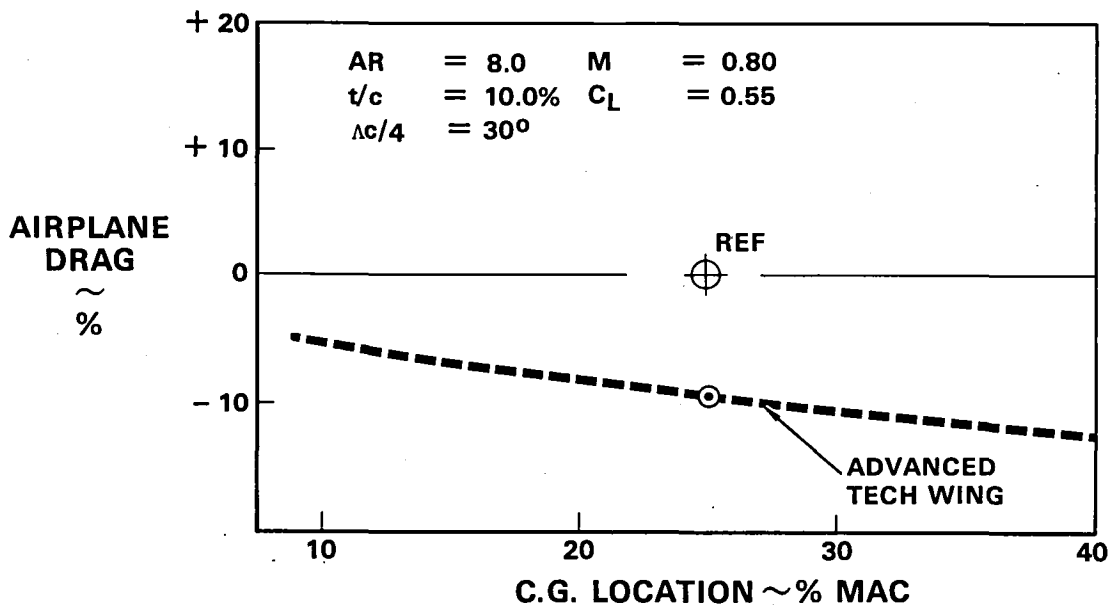


ITW-20

Advanced aerodynamic cruise technology allows for a reduction in wing sweep for the same cruise drag level as the "REF" L-1011 technology.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

EFFECT OF C.G. LOCATION



ITW-23

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".

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

HIGH LIFT SYNTHESIS

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

$$C_{D_{FLAP}} = C_{D_{CLEAN}} + \Delta C_{D_{P_{SLAT}}} + \Delta C_{D_{P_F}} + \frac{(C_{L_{CLEAN}} + \Delta C_{L_F})^2}{\pi AR} - \frac{C_{L^2_{CLEAN}}}{\pi AR}$$

- $C_{D_{CLEAN}}$, L-1011 AND S-3A FLIGHT TEST
- $\Delta C_{D_{P_{SLAT}}}$, L-1011 FLIGHT TEST
- $\Delta C_{D_{P_F}}$, L-1011 AND RAeS DATA
- $\frac{(C_{L_{CLEAN}} + \Delta C_{L_F})^2}{\pi AR}$, L-1011 AND RAeS DATA
- $\frac{C_{D^2_{CLEAN}}}{\pi AR}$, L-1011 AND RAeS DATA

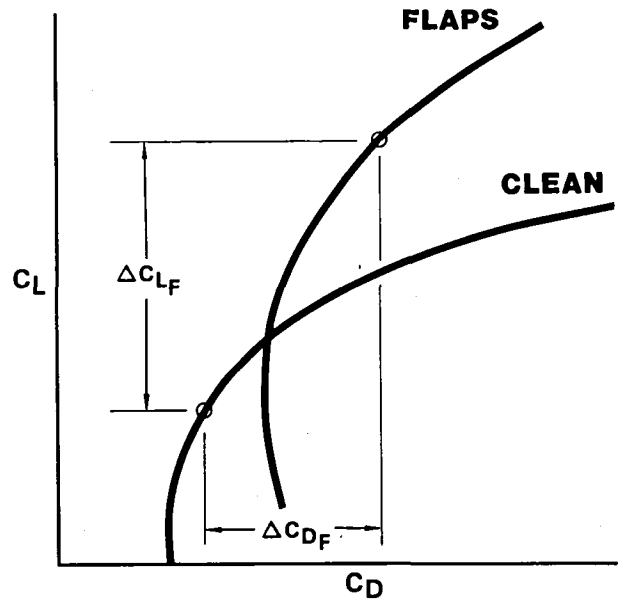
ITW-24

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.

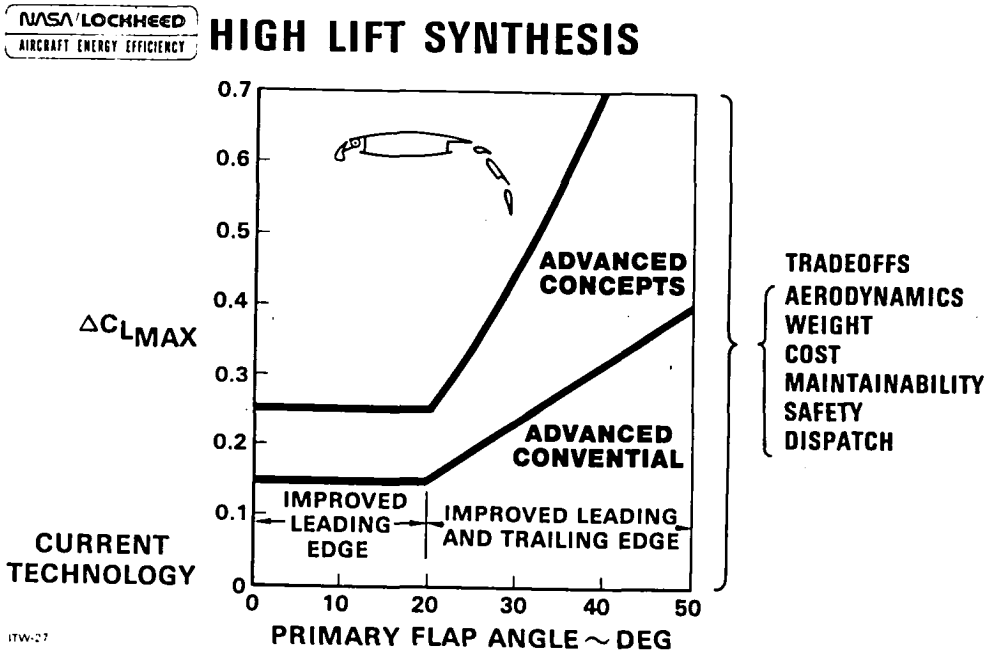
NASA LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

HIGH LIFT SYNTHESIS

CONSTANT ALPHA



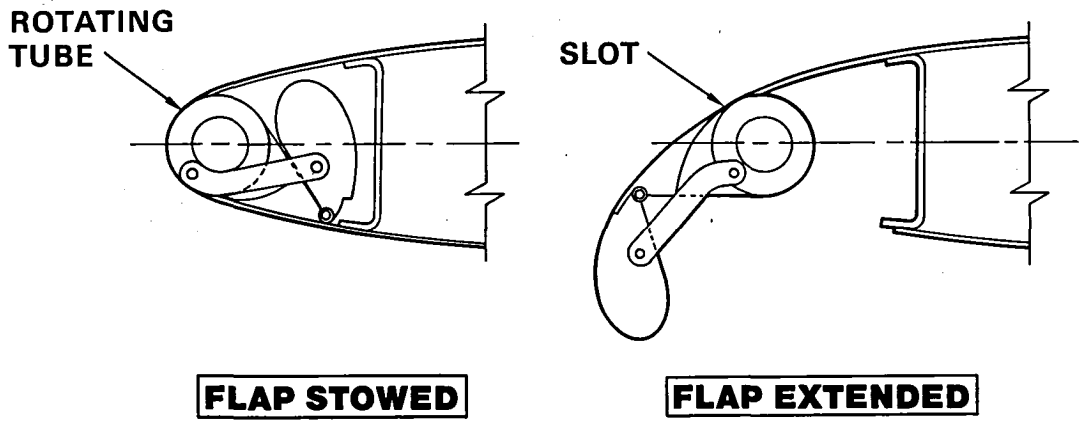
Flap and slat incremental lift and drag data are computed assuming a constant angle-of-attack for the basic clean configuration and the flapped configuration. The high-lift increments are additive to the low speed cruise polar, forming the high-lift polar.



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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

ADVANCED LEADING EDGE CONCEPT



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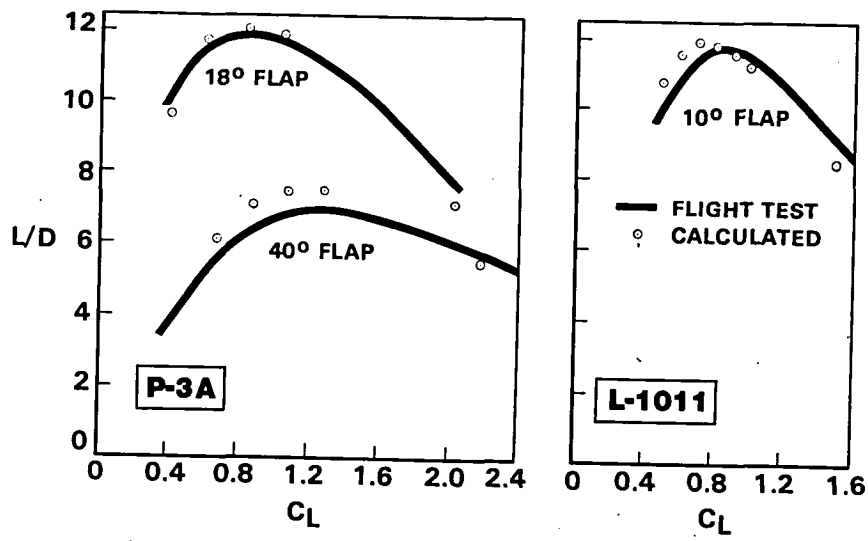
ITW-29

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.

HIGH LIFT L/D CORRELATION

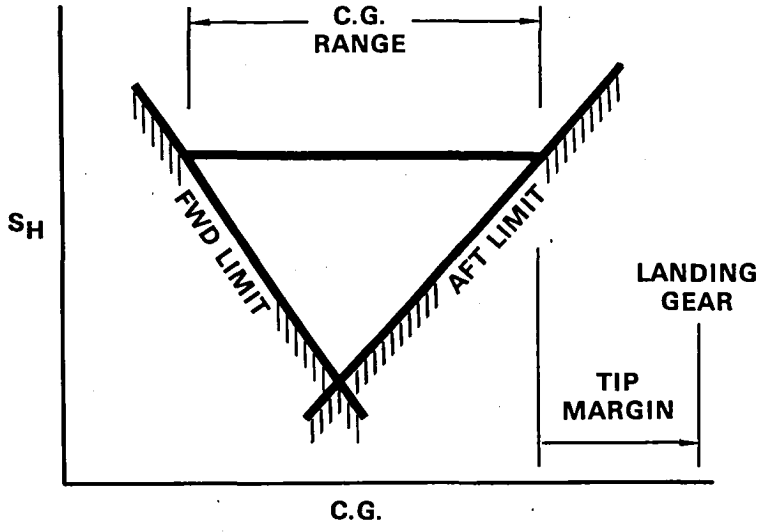


ITW-28

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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

HORIZONTAL TAIL SIZING



- PLF $C_{L_{MAX}}$
- NOSE WHEEL LIFTOFF
- POWER-ON
- STABILITY
- MANEUVER

ITW-32

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.

VERTICAL TAIL SIZING

FAA/CAA FIELD LENGTH = 7000 FEET

- GROUND MINIMUM CONTROL SPEED
- AIR MINIMUM CONTROL SPEED

STATIC DIRECTIONAL STABILITY

ITW-33

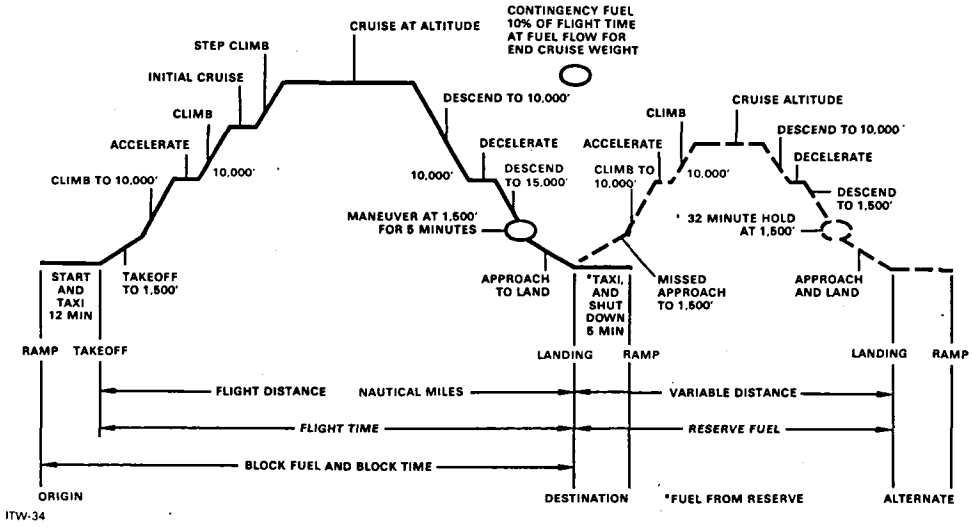
One of the primary considerations in sizing the vertical tail/rudder for multi-engined transports with wing-mounted engines is meeting the engine-out minimum control speed requirements in FAR Part 25 and BCAR:

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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

FLIGHT PROFILE



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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

CONCEPT DEVELOPMENT COSTS

DEVELOPMENT OF TECHNOLOGY	YEAR 81	82	83	84	85	86	TOTAL COSTS (PROJECT GO-AHEAD)
● TRANSONIC AIRFOIL							
ANALYSIS	415,000	455,000	710,000	880,000	710,000	540,000	$3,710,000
W/T TESTING	500,000	850,000	1,300,000	1,950,000	1,350,000	500,000	$6,450,000
● HIGH LIFT							
ANALYSIS	270,000	270,000	490,000	575,000	575,000	350,000	$2,530,000
W/T TESTING	195,000	205,000	385,000	485,000	215,000	155,000	$1,640,000
							$14,330,000

ITW-35

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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

SUMMARY OF TECHNOLOGY COSTS & BENEFITS

TECHNOLOGY APPLICATION	TECH. DEV. COST	$M(\frac{L}{D})\%$	OWE%	TECH READINESS DATE
TRANSONIC AIRFOIL PLANFORM	RESEARCH TO DATE + $10,160,000	14.0%	—	1986
HIGH LIFT PLANFORM	$ 4,170,000	—	—	1986

ITW-36

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.

LR 29801

NASA/LOCKHEED

AIRCRAFT ENERGY EFFICIENCY

ACTIVE CONTROLS/ADVANCED SYSTEMS

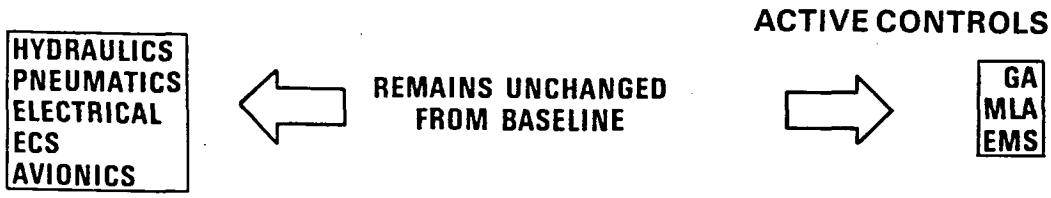
BRIAN PENROSE

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

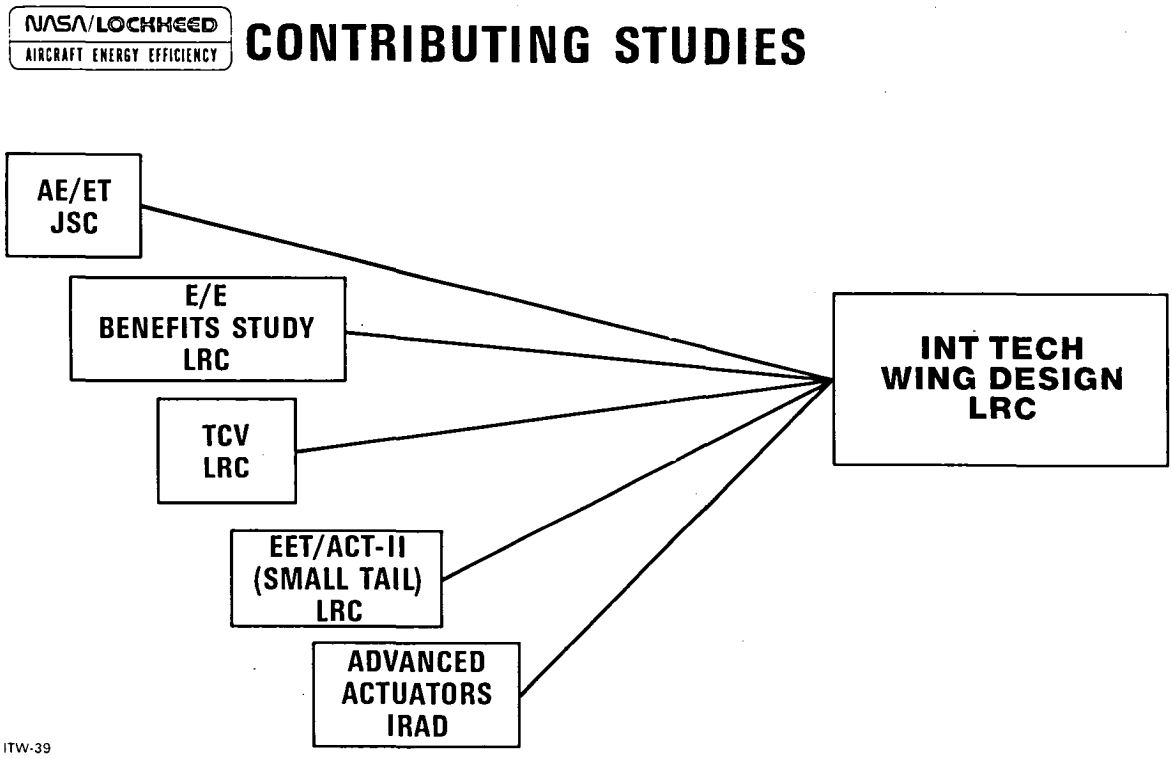
SYSTEMS DEFINITION, ACTIVE CONTROLS

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

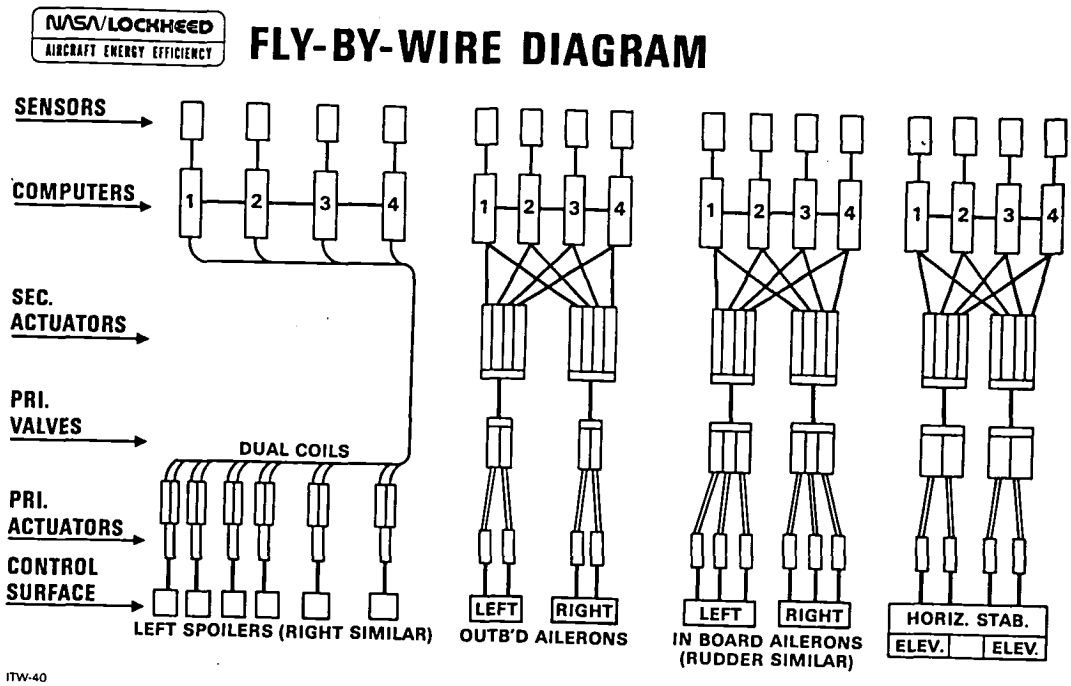
Complete as well as on-going Lockheed studies in advanced system technologies applications are being utilized toward achieving the objectives of the "Integrated Technology Wing Design" study for the configurations of 'active controls' and 'advanced systems and controls.' These contributing studies are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

"Application of Advanced Electric/Electronic Technology to Conventional Aircraft" (AE/ET), June 1980, NASA-Johnson Space Center.

"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.

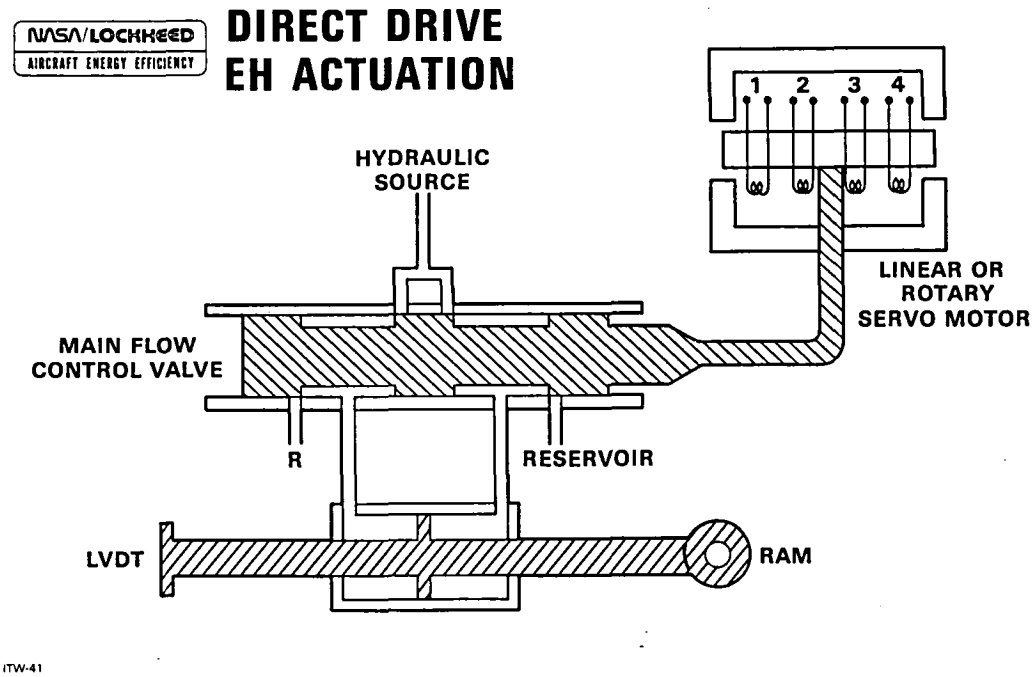
NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ACTUATOR APPLICATION MATRIX

SERVICE	DIRECT DRIVE	HINGE LINE/PWR HINGE	ELECT. ROTARY/LINEAR	DYNAVECTOR	ECCENTUATOR	STORED ENERGY	TRACTION DRIVE	IAP	DIGITAL ACTUATOR
PRIMARY FLIGHT CONTROLS	A	B	B	B	B	C	C	A	B
SLATS AND FLAPS		B	B	B	B			A	A
SPOILERS	A	B	B		B			A	A
MAIN GEAR		B	B			C	C	A	
NOSE GEAR		B	B			C	C	A	
CARGO DOOR		B	B	B	B				
INLET DOOR		B	B	B	B				
SWING WING/TAIL	A		B			C	C	A	A
THRUST REVERSER		B	B	B		C		A	
NOSE WHEEL STEERING	A		B	B				A	A
BRAKES			B					A	A
TAIL SKID			B	B		C		A	
POWERED WHEELS			B	B					B

A COMPLETE B ADVANCED C PRELIMINARY

ITW-159



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.

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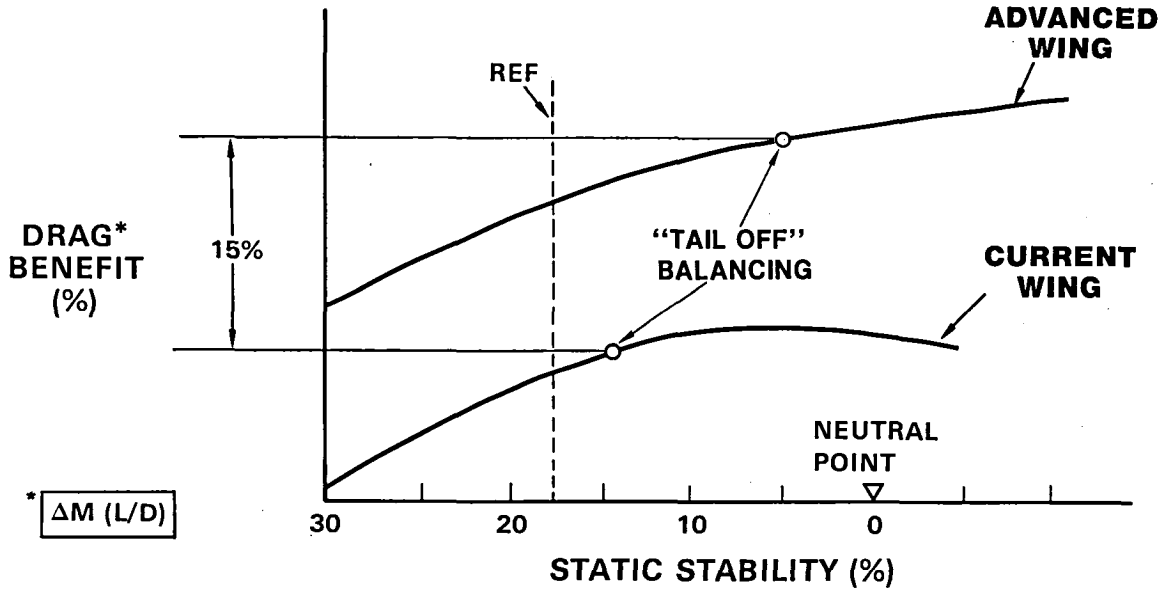
AIRCRAFT ENERGY EFFICIENCY

ADVANCED WING BENEFIT

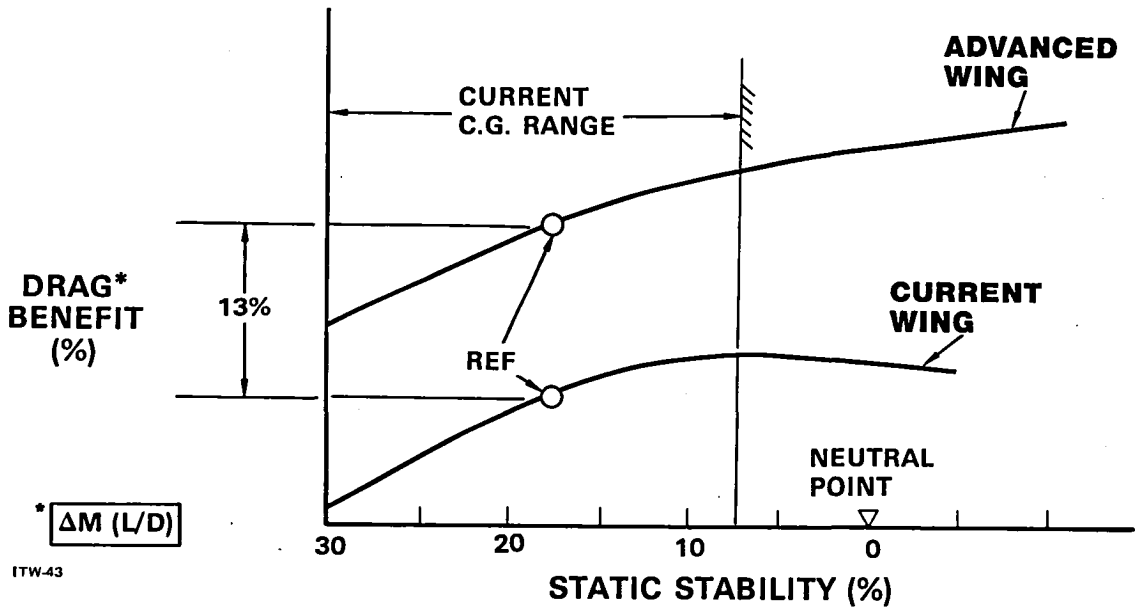


ITW-106

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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

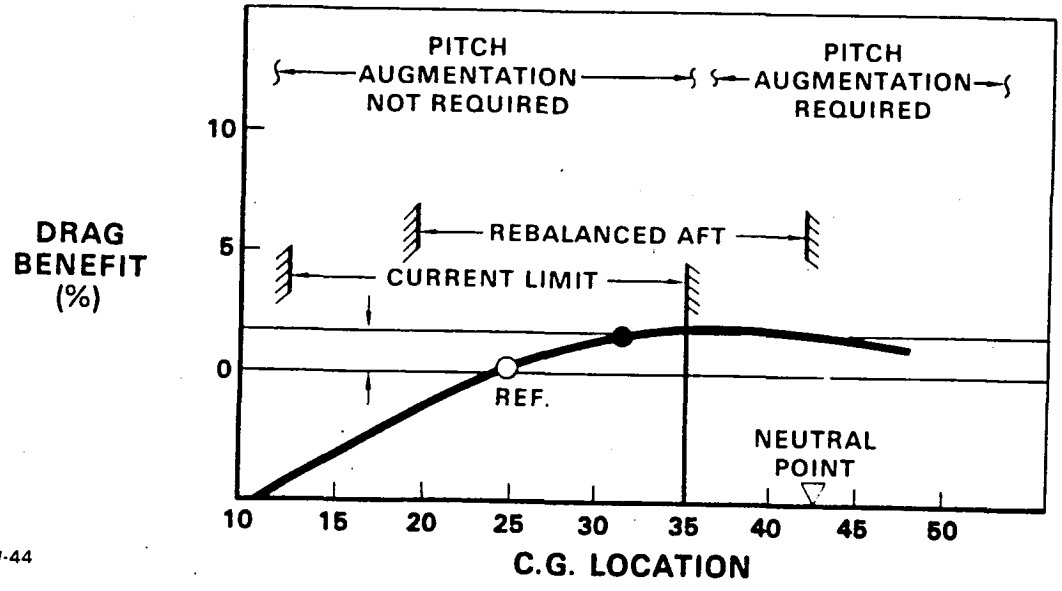
ADVANCED WING BENEFIT
CONVENTIONALLY BALANCED



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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

RELAXED STATIC STABILITY, CURRENT WING

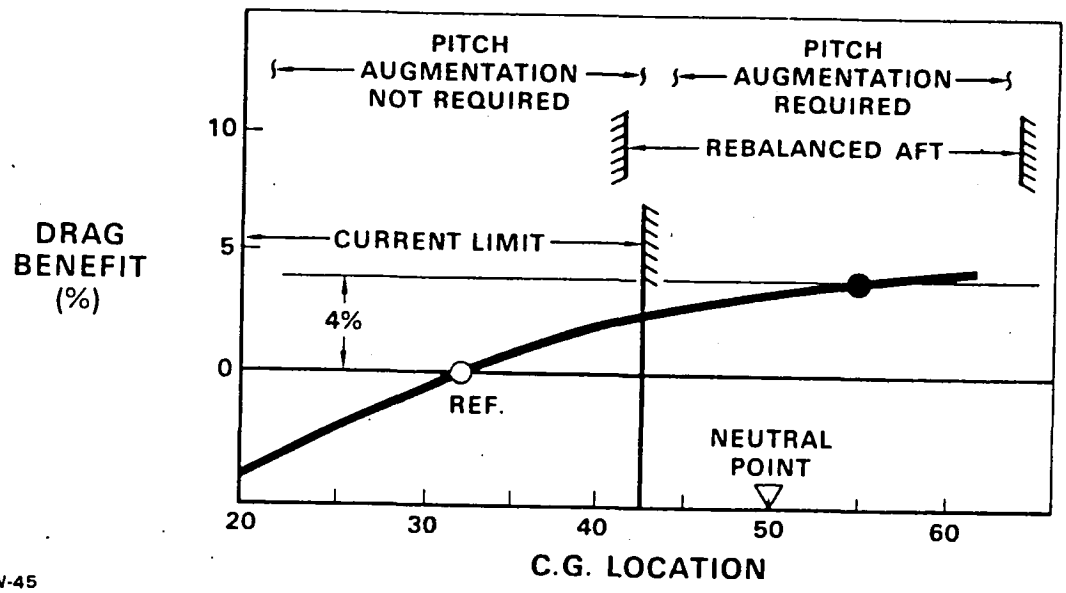


ITW-44

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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

RELAXED STATIC STABILITY, ADVANCED WING



ITW-45

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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

DRAG BENEFIT COMPARISON

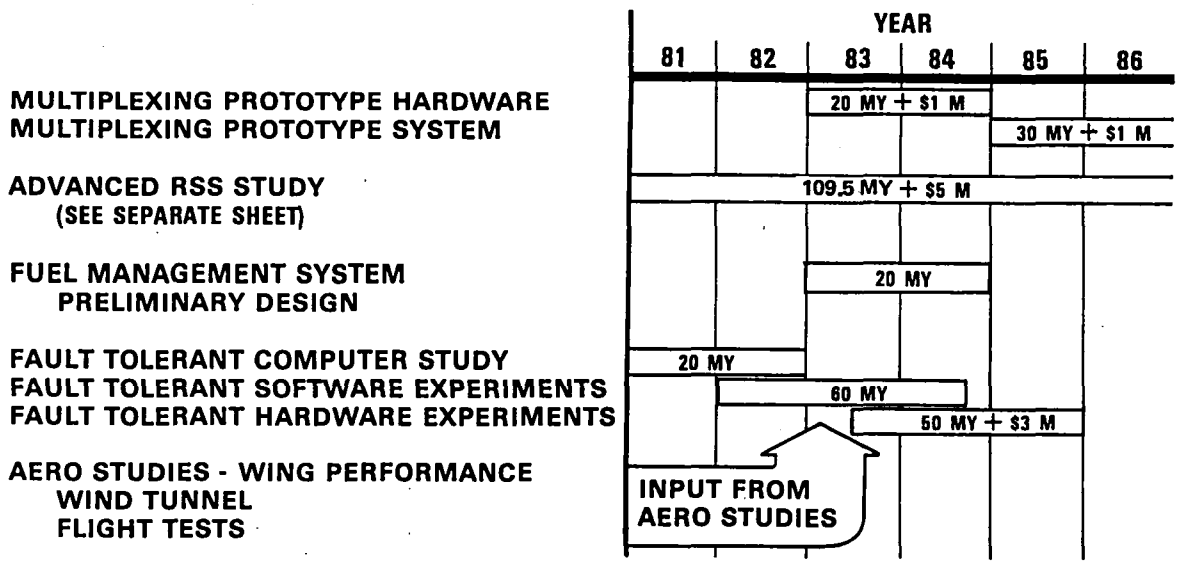
	CONVENTIONAL BALANCING	RSS & C.G. MANAGE. (ACEE)	RSS (FLY-BY-WIRE)
CURRENT WING	0	2%	N/A
ADVANCED WING	13%	15%	17%

ITW-107

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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ACTIVE CONTROLS TECHNOLOGY DEVELOPMENT



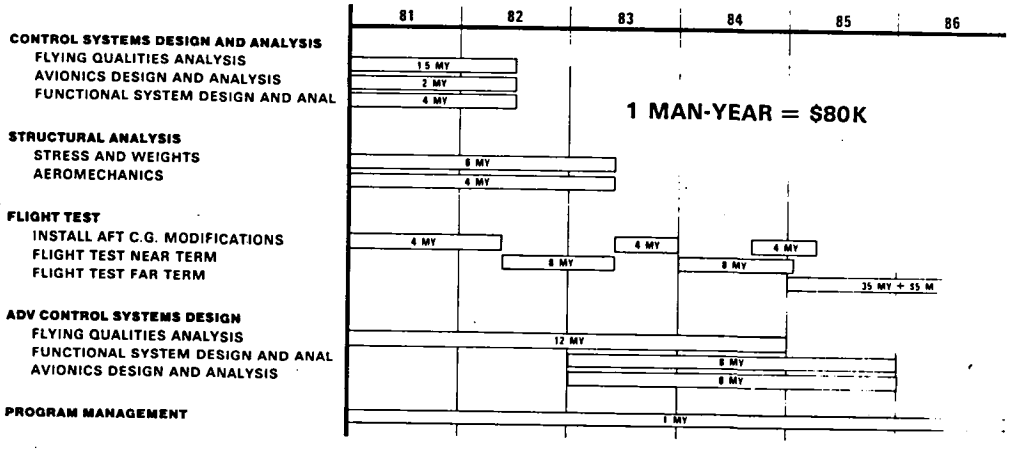
1 MAN-YEAR (MY)=$80K

ITW-46

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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ADVANCED RSS TECHNOLOGY DEVELOPMENT



ITW-47

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

ACTIVE CONTROLS SUMMARY

WEIGHT SAVINGS: 0.5% EMPTY WEIGHT

RSS PAYOFF: FUEL 4%

MAINTENANCE IMPROVEMENT

ITW-48

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

SYSTEMS DEFINITION

ADVANCED SYSTEMS AND CONTROLS TECHNOLOGIES

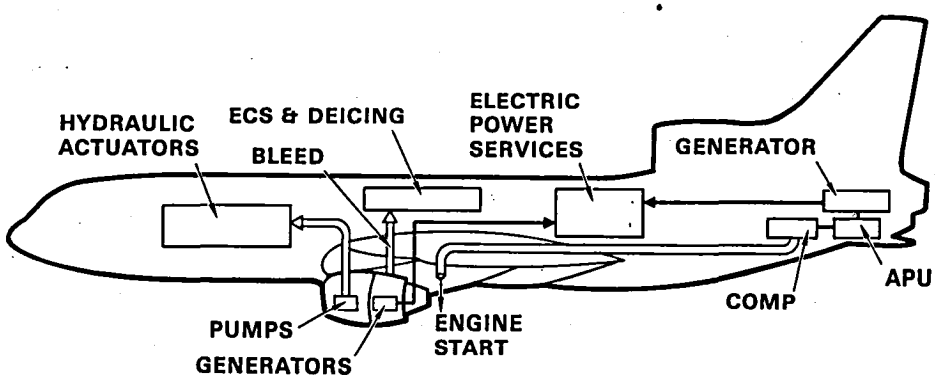
HYDRAULIC
PNEUMATIC
> POWER/DISTRIBUTION SYSTEMS REMOVED

- 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

ITW-49

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.

CONVENTIONAL SECONDARY POWER

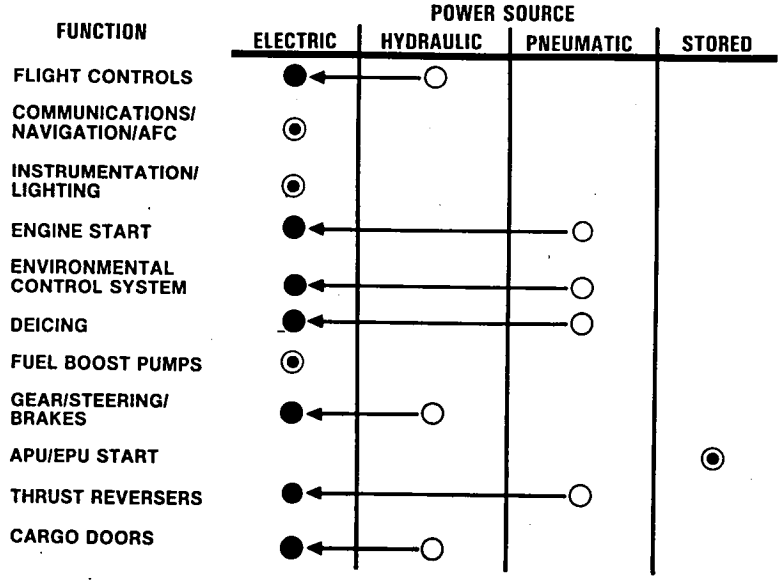


ITW-50

The figure shows the major areas within the conventional secondary power system (SPS) existing on the baseline aircraft.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

SECONDARY POWER SYSTEM: FUNCTIONS AND SERVICES



ITW-51

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

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

SECONDARY POWER

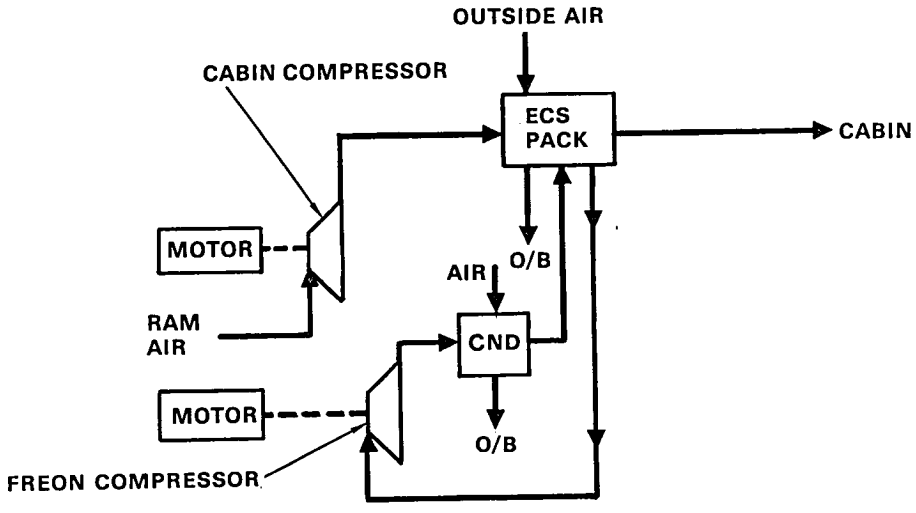
ENVIRONMENTAL CONTROL SYSTEM (ECS)	
PRESSURIZATION	
3 ECS PACKS	AT 100 KVA EACH
COOLING	AT 24 TONS
3 ECS PACKS	≃60 KVA (ON GROUND)
GALLEY	~100 KW
LIGHTING (INTERNAL/EXTERNAL)	≃10 KW
AVIONICS	≃16 KW
FLIGHT CONTROL SYSTEM (FCS)	≃60 KW
DE-ICING	
WINDSHIELDS	≃12 KW
WINGS (ELECTROTHERMAL)	≃60 KW
WINGS (ELECTRO-IMPULSE)	= 5 KW
SECONDARY POWER SYSTEM (SPS)	
3 x 250/300 KVA GENERATORS/ENGINE	

ITW-52

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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

ALL-ELECTRIC ECS



ITW-53

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:

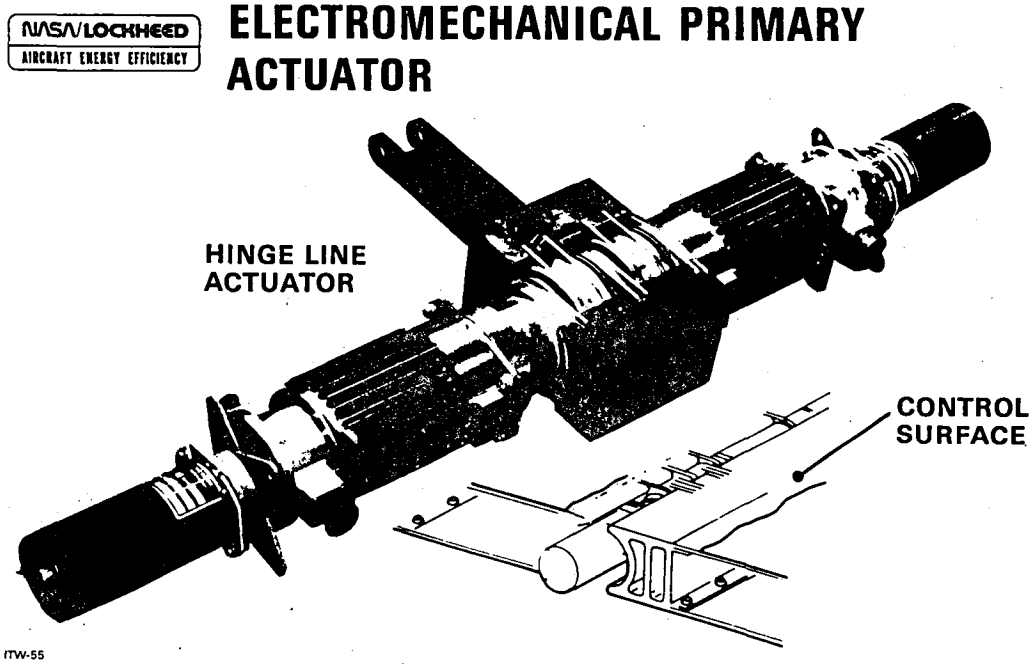
- Air compressor for fresh air pressurization
- Heat exchanger and fan for cooling fresh air with ram air
- Freon compressor for refrigeration
- Heat exchanger and fan for cooling freon with ram air
- Freon evaporator for cooling fresh air
- Electric heater

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

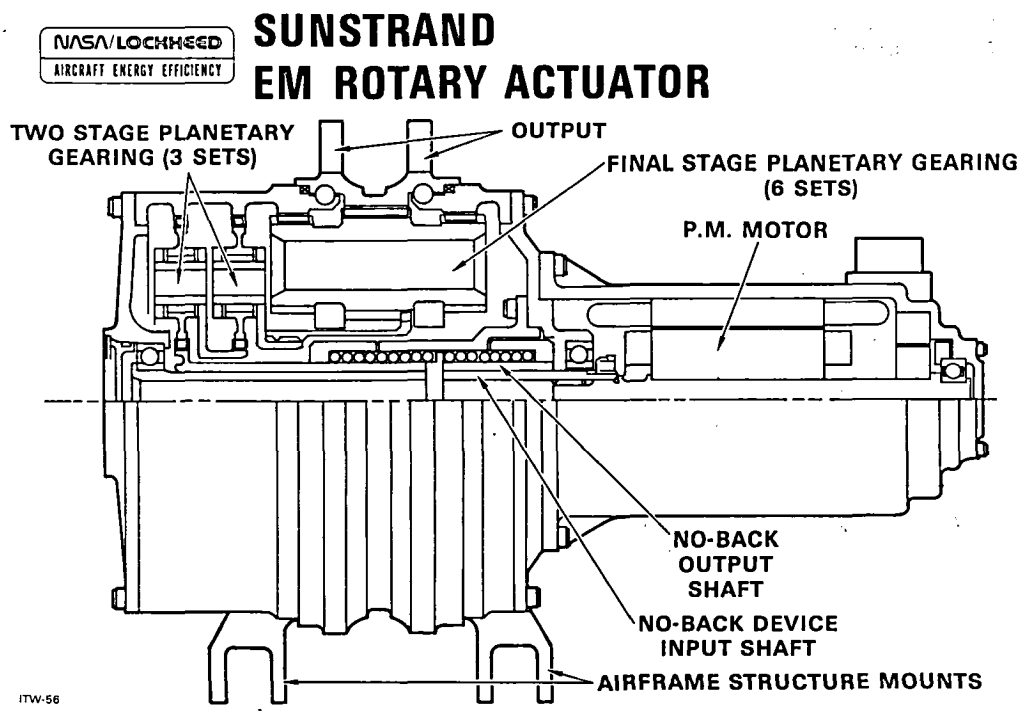
ALL-ELECTRIC ECS: OBJECTIVES

- 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

ITW-.54



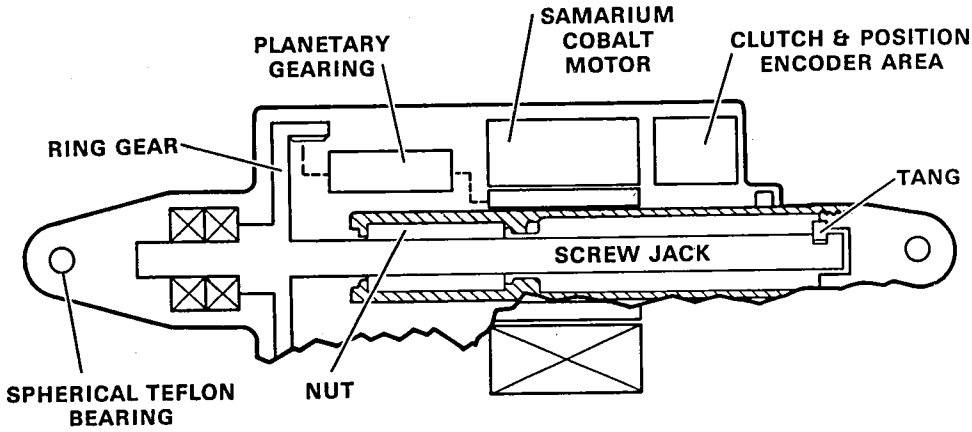
This photograph shows a hinge-line, electro-mechanical actuator that was designed and built by AiResearch. This actuator has dual redundancy in the motors and reduction gearing. "Power-hinge" type gearing at the center of the actuator outputs torque to the control surface. The samarium-cobalt motors 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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

PLESSEY LINEAR EMAS



ITW-57

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).

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

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

ITW-58

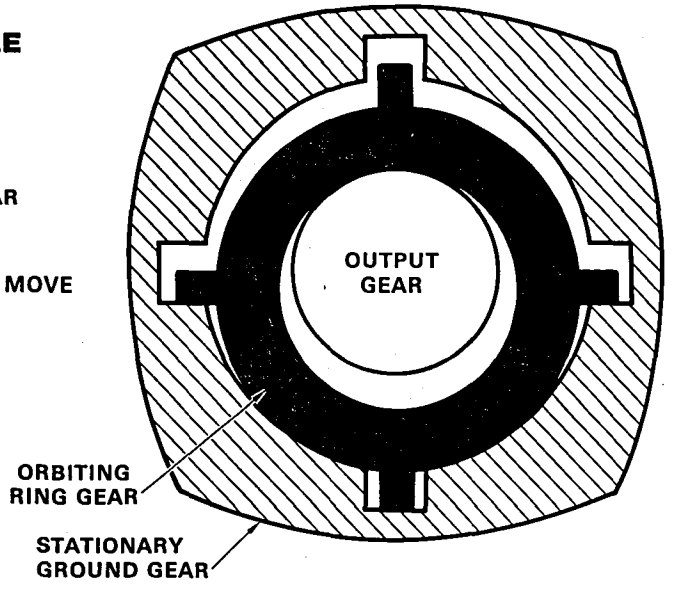
The Plessey linear actuator is currently the only EMAS, for actuation of a primary flight control surface, that has advanced to the flight test stage of its development program.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

BENDIX DYNAVECTOR ROTARY ACTUATOR

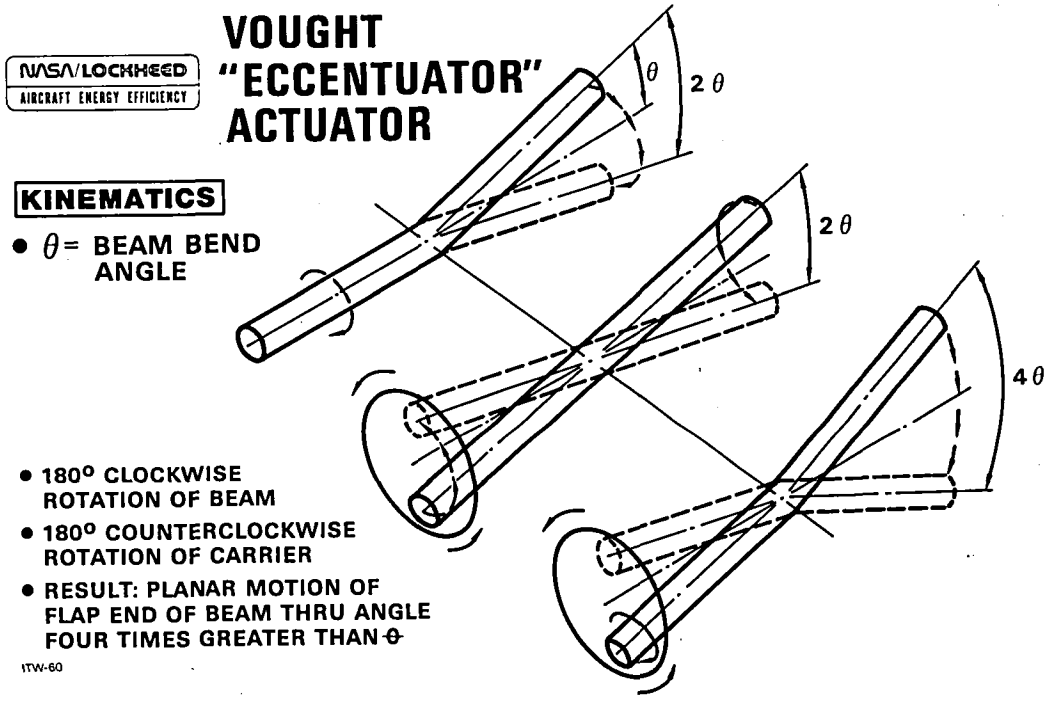
OPERATING PRINCIPLE

- RING GEAR DRIVEN BY ROTATING FORCE VECTOR
- RING GEAR ORBITS
- STATIONARY GROUND GEAR LIMITS RING GEAR ROTATION
- RING AND OUTPUT GEARS MOVE WITH EPICYCLIC MOTION
- OUTPUT GEAR HAS HIGH TORQUE ROTATION
- ONE STAGE, HIGH RATIO GEAR TRANSMISSION



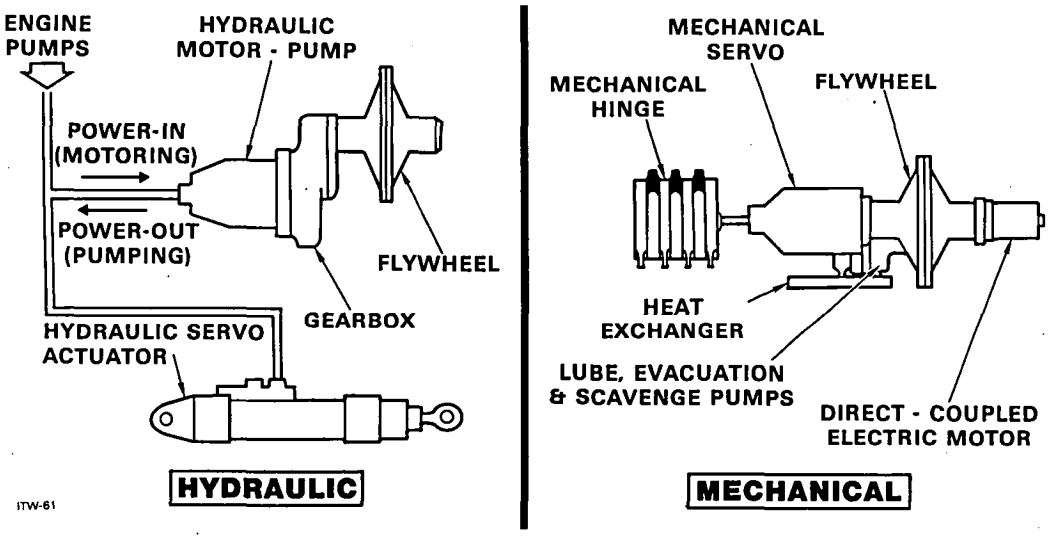
ITW-59

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 "motored" 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).

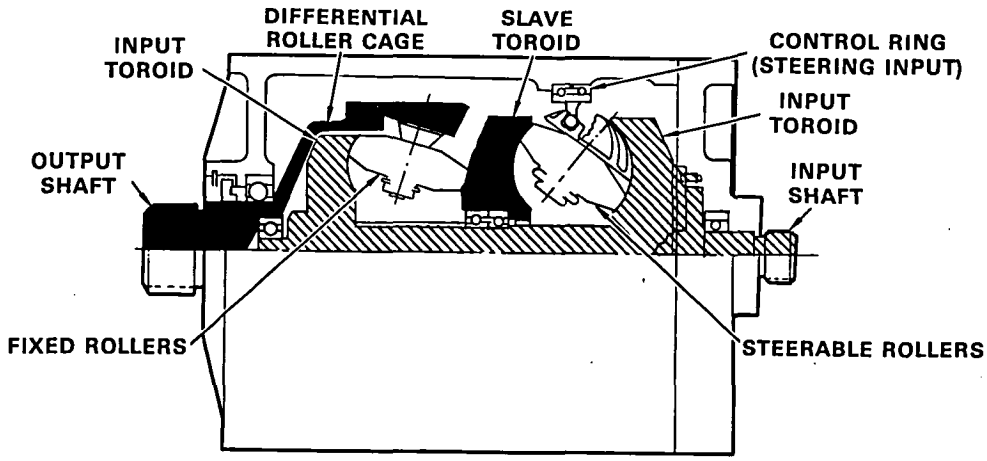
ENERGY STORAGE SUBSTATIONS



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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

TRACTION DRIVE MECHANICAL SERVO



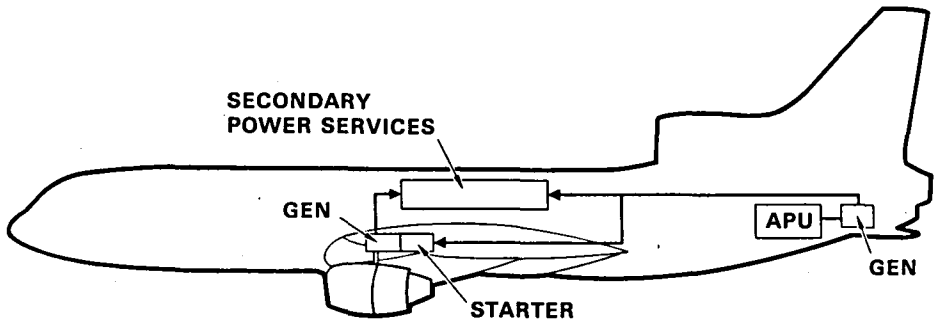
1. INPUT TOROIDS DRIVE BOTH ROLLERS
2. STEERING ROLLER DRIVES SLAVE AT REDUCED/INCREASED SPEED
3. SLAVE DRIVES (INPUTS) FIXED ROLLER
4. CAGE IS NULL WHEN INPUTS 1 & 3 TO FIXED ROLLER (RPM) ARE SAME
5. DIFFERENTIAL INPUT TO FIXED ROLLER CAUSES CAGE MOTION (OUTPUT)

ITW-62

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 counterforce 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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

ALL ELECTRIC AIRCRAFT



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

ITW-63

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

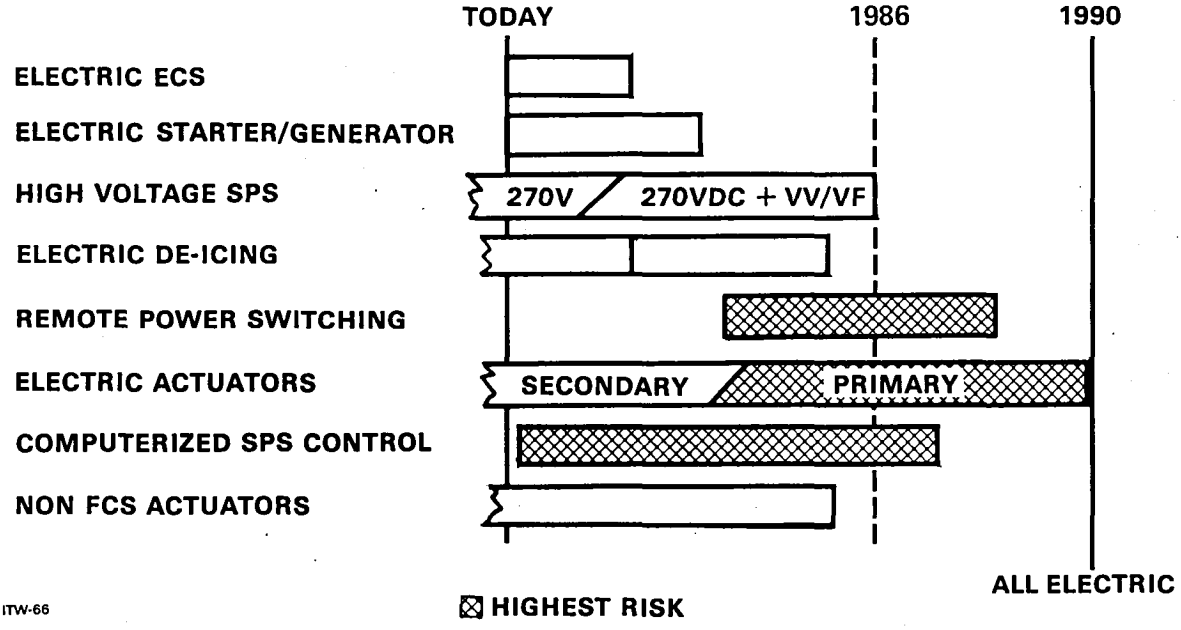
TWO MAJOR ALL-ELECTRIC PAYOFFS

		WT SAVINGS	COST SAVINGS	RISK
BLEED ELIMINATION	STARTER/GENERATOR AND ELECTRIC ECS	60%	65%	LOW
HYDRAULICS ELIMINATION	FLY-BY-WIRE, EMAS	40%	35%	HIGH

ITW-67

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ADVANCED SYSTEMS AND CONTROLS EVOLUTIONARY APPROACH



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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

DELAY REDUCTION, SAVINGS POTENTIAL

	DELAY MINUTES	% OF DOC CREW AND AIRCRAFT	% OF DOC FUEL AND WEIGHT	TOTAL
TAXI OUT (ELECTRIC WHEELS)	5	0.37	0.98	1.35
SID GEOMETRY	0	0	0	0
RNAV	4	0.29	0.47	0.77
LOITER AND HOLD	5	0.37	0.49	0.86
STAR GEOMETRY	5	0.37	0.49	0.86
TAXI IN (ELECTRIC WHEELS)	0	0	0.49	0.49
TOTAL	19 MIN			4.33%

ASSUMPTIONS:
AVERAGE U.S. DELAYS, 3000 NM CRUISE, WIDE BODY AIRCRAFT

ITW-64

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

TECHNOLOGY COSTS AND BENEFITS SUMMARY

TECHNOLOGY APPLICATION		TECH DEV COST	ΔSFC OR ΔDRAG	ΔEW	TECH READINESS DATE
RSS (INCLUDES FBW, MUX)		$34M	4%	0.45	1986
ALL-ELECTRIC	ECS	$20M	4%	1.06	1985
	EMAS	$50M		0.71	1986-90
	POWERED WHEELS	$10M			1986

ITW-68

LR 29801

NASA/LOCKHEED

AIRCRAFT ENERGY EFFICIENCY

PROPULSION/PROPULSION INTEGRATION

BOB SKARSHAUG

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

PROPULSION SYSTEM TECHNOLOGY

- ADVANCED ENGINE CONCEPTS
- PROPULSION/AIRFRAME INTEGRATION

ITW 160

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

ADVANCED ENGINE CONCEPTS

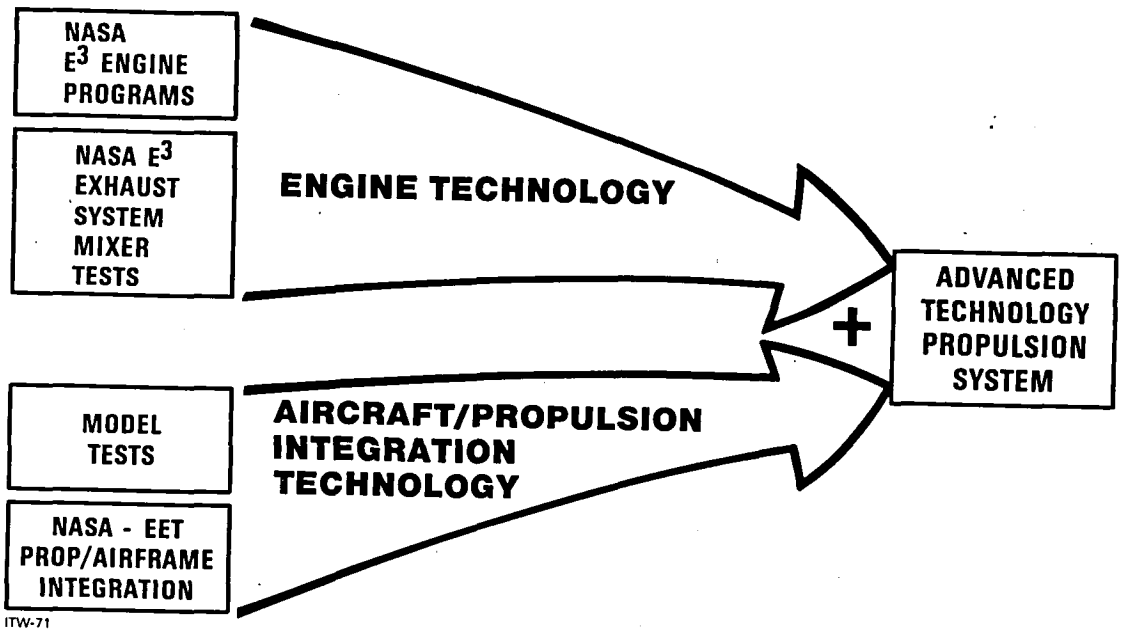
OBJECTIVES

- 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

ITW-70

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

TECHNOLOGY DATA BASE



ITW-71

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

PROPULSION SYSTEM TECHNOLOGY

APPROACH

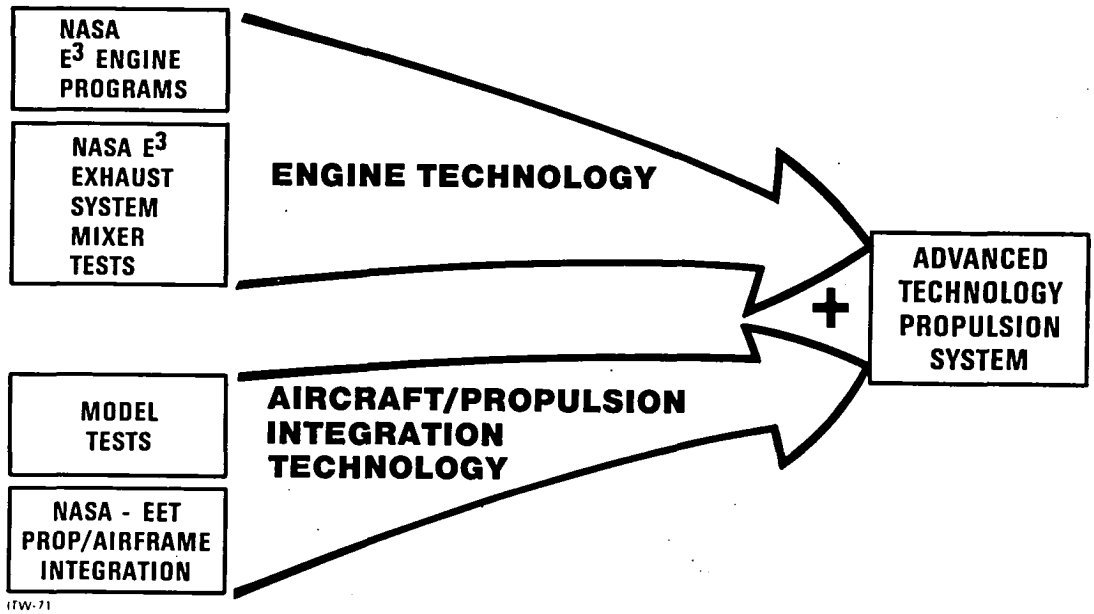
- **ADVANCED ENGINE CONCEPTS**
  - — E^3 FLIGHT PROPULSION SYSTEM
  - — SEPARATE AND MIXED FLOW EXHAUST SYSTEMS
- **PROPULSION SYSTEM/AIRCRAFT INTEGRATION**
  - — PROPULSION SYSTEMS INSTALLED ON CONVENTIONAL AND SUPERCRITICAL WINGS

ITW-172

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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

TECHNOLOGY DATA BASE



The technology data base being used in the study draws from the NASA E^3 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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

E^3 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

ITW-72

This study will use the performance and weight associated with the G.E. definition of the E^3 Flight Propulsion System (FPS). The E^3 engine program goals are provided as a reference; however, the E^3 FPS will have approximately a 14.6% improvement in cruise SFC.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

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 correlation the drag data to appropriate parameters) local contouring of the wing and/or nacelle may be necessary to eliminate the interference drag.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

PROPULSION SYSTEM TECHNOLOGY

COST/BENEFIT ASSESSMENT

ITW 162

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

COMPARISON OF E^3 FPS AND CF6-50C COMPONENT EFFICIENCIES

35,000 FT/0.8M MAX. CRUISE

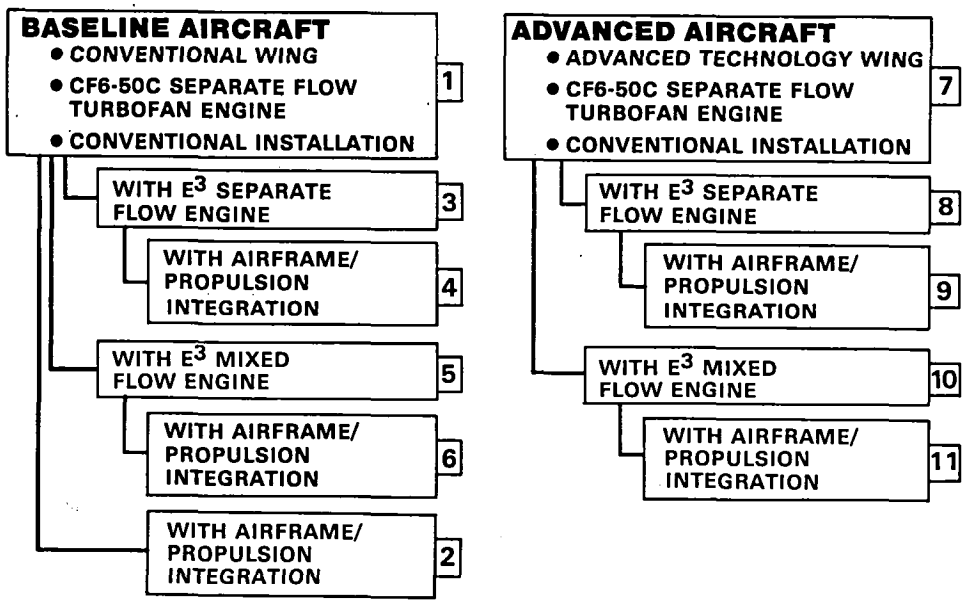
COMPONENT		E^3 Δ EFF
FAN BYPASS		+4.8 PTS
FAN HUB (BOOSTER)		+4.0 PTS
HIGH PRESSURE COMPRESSOR	— ADIABATIC	−0.3 PTS
	— POLYTROPIC	+0.4 PTS
HIGH PRESSURE TURBINE		+0.8 PTS
LOW PRESSURE TURBINE		+1.1 PTS

ITW-161

The following chart identifies the component performance improvements achieved in the E^3 FPS system relative to a CF6-50C.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

PROPULSION SYSTEM CONFIGURATION MATRIX



ITW-86

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/pylon.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

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

ITW-74

The GE CF6-50C turbofan engine was selected as the baseline propulsion system to maintain consistency with the NASA-Lewis Research Center E^3 engine studies. The CF6-50C is used in commercial service with the engine being certified in late 1973.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

BASELINE PROPULSION SYSTEM WEIGHT

CF6-50C BASELINE THRUST = 50,250 LB

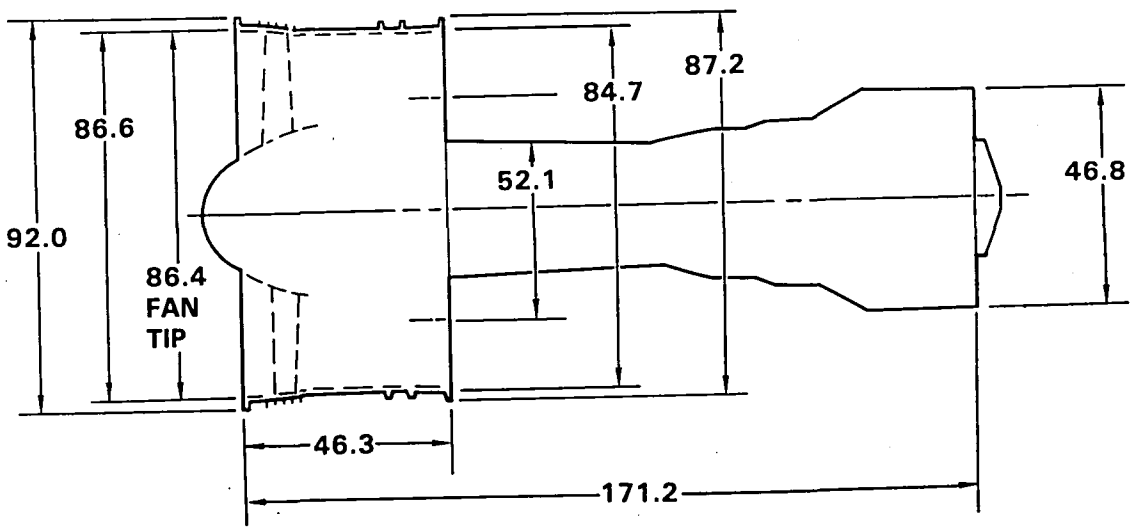
BARE ENGINE	8,700 LB
INLET	595
FAN COWL	280
FAN REVERSER	1,595
CORE COWLS	185
PRIMARY NOZZLE	300
ENGINE BUILD-UP	767
TOTAL	12,396 LB

mw-77

The CF6-50C installed propulsion weight is shown in the following chart. The propulsion system is configured similar to that used in commercial service.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

CURRENT TECHNOLOGY ENGINE (CF6-50C) ENGINE OUTLINE DIMENSIONS



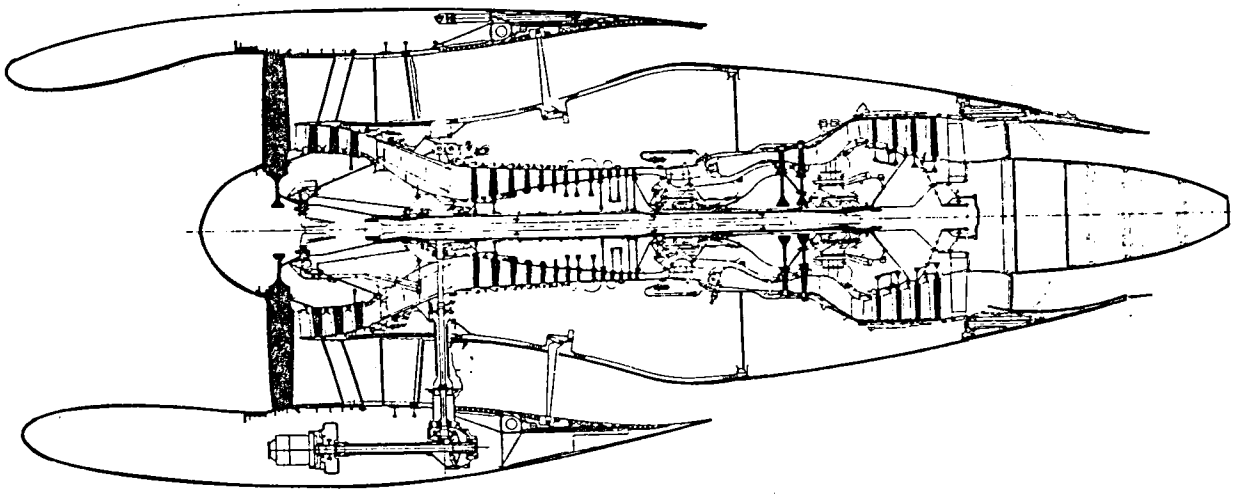
DIMENSIONS SHOWN ARE NOMINAL SIZE, F_n SLS T/O_{nom} = 50,250 LB

ITW-75

The bare engine dimensions for the CF6-50C engine for a nominal takeoff thrust size of 50250 pounds are shown in the following figure.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

INSTALLED CF6-50C FEATURES



ITW-76

A cutaway of the baseline propulsion system is shown in the following figure.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

ADVANCED PROPULSION SYSTEM

GENERAL ELECTRIC E^3 FLIGHT PROPULSION SYSTEM

- TAKEOFF THRUST _____ 46,900 LB
- TAKEOFF FLAT RATED TEMP. _____ ISA + 15°C
- BYPASS RATIO _____ 6.8
- FAN DIAMETER _____ 94.0 IN.
- ENGINE LENGTH _____ 145.3 IN.
- BARE ENGINE WEIGHT _____ 8,750 LB
- ENGINE CERTIFICATION DATE _____ 1990

ITW-78

Characteristics of the GE E^3 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°. The technology level in the engine is representative of the mid-1980's and with appropriate funding the engine could be certified by 1990.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ADVANCED TECHNOLOGY PROPULSION SYSTEM WEIGHT

E^3 REFERENCE THRUST = 46,900 LB

BARE ENGINE	8,750 LB
INLET	470
FAN REVERSER	1,270
CORE COWLS	307
PRIMARY NOZZLE	154
EXHAUST NOZZLE	306
ENGINE BUILD UP	575
	11,832 LB

ITW-83

The propulsion system weight buildup for the E^3 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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

COMPARISON OF E^3 CYCLE TO CF6-50C

	CF6-50C	E^3
• BYPASS RATIO	4.2	6.8
• FAN PRESSURE RATIO	1.76	1.65
• OVERALL PRESSURE RATIO	32	38
• TURBINE ROTOR INLET TEMP (^oF) SLS, 86^oF, TAKEOFF RATING	2445	2450
• INSTALLED CRUISE SFC 0.80, 35,000 FT, STD DAY	BASE	-14.6%
• ACTIVE CLEARANCE CONTROL		
– COMPRESSOR	NO	YES
– H.P. TURBINE	NO	YES
– L.P. TURBINE	NO	YES

ITW-81

Significant differences are noted between the E^3 FPS and the CF6-50C engine cycle. The E^3 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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

E^3 SFC IMPROVEMENT VS. CF6-50C

	% Δ SFC	
• COMPONENT ADIABATIC EFFICIENCIES	-4.1	
• MIXED FLOW EXHAUST	-3.1	
• INCREASED CYCLE PRESSURE RATIO (20%)	-1.0	
• PROPULSIVE EFFICIENCY (FPR-BPR)	-2.5	
• INCREASED TURBINE INLET TEMPERATURE (~ 170°F) (94°C)	-1.5	
• COOLING AND PARASITIC FLOWS	-1.0	
• FLOWPATH PRESSURE LOSSES	-0.1	
UNINSTALLED Δ SFC		-13.3
• REDUCED ISOLATED NACELLE DRAG	-0.6	
• INTEGRATED AIRCRAFT GENERATOR COOLING	-0.3	
INSTALLED Δ SFC IMPROVEMENTS		-14.2
• CUSTOMER BLEED AND POWER EFFECTS	+0.4	
• REGENERATIVE E^3 FUEL HEATER	-0.8	
FULLY INSTALLED (CUST. BLEED & HP)		-14.6

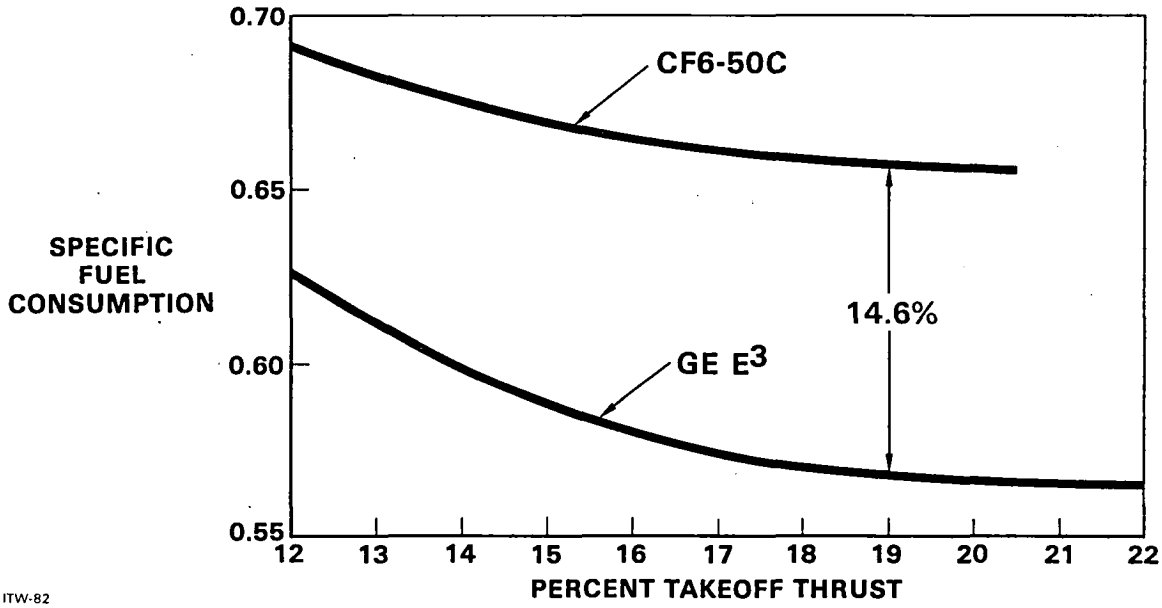
ITW-164

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 E^3 FPS relative to the CF6-50C turbofan.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

SFC COMPARISON
CF6-50C AND GE E^3 ENGINE

35,000 FT 0.80 Mo



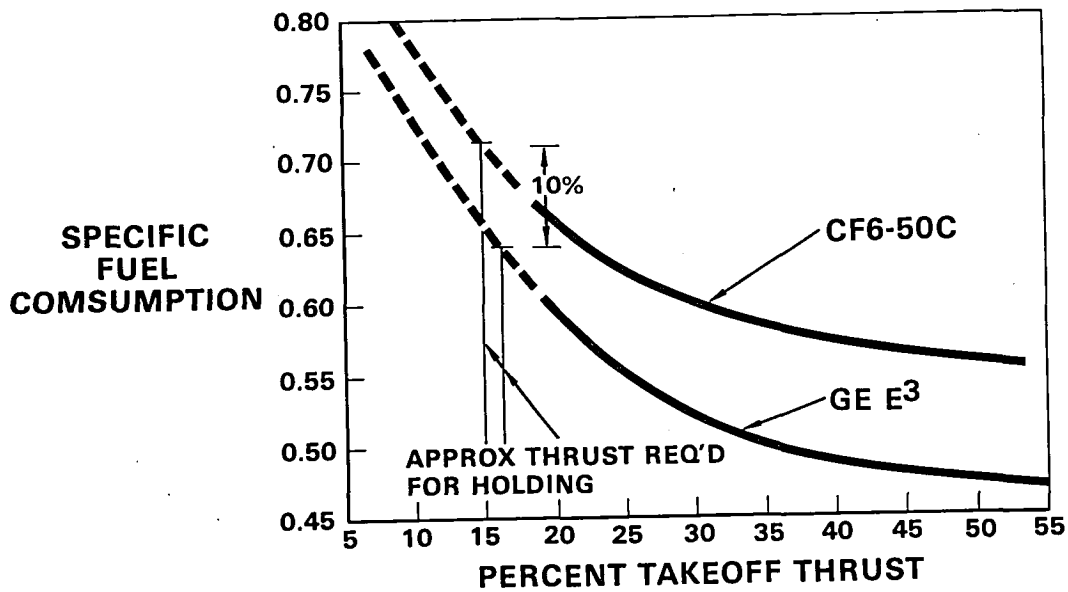
ITW-82

The following chart shows the difference in cruise SFC between the CF6-50C and the E^3 FPS. The performance level shown in the chart for the E^3 FPS includes the mixed flow exhaust system.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

SFC COMPARISON CF6-50C AND GE E3 ENGINE

SEA LEVEL 0.4 Mo

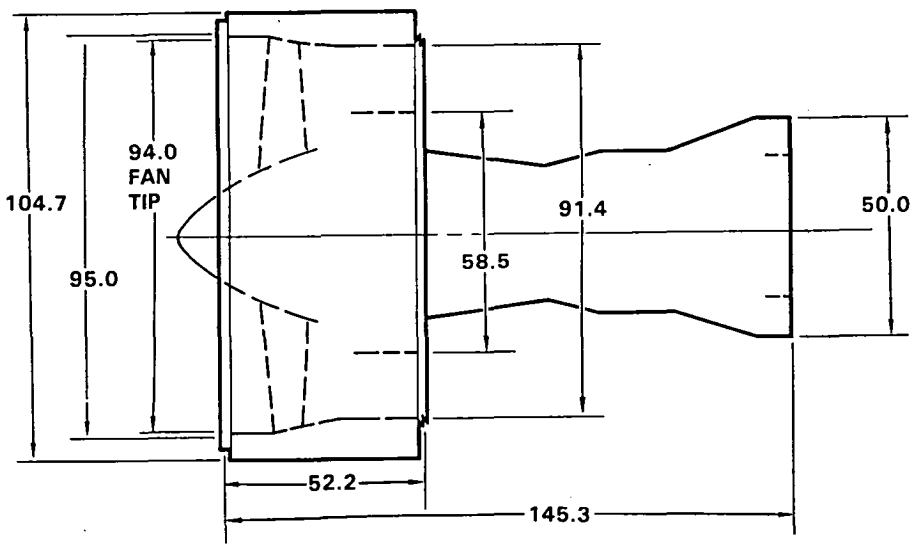


ITW-173

The following chart shows the performance improvement for the E^3 FPS for a typical holding condition.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ADVANCED TECHNOLOGY ENGINE (E^3) ENGINE OUTLINE DIMENSIONS



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

ITW-84

The following charts shows the dimensions for the E^3 FPS at a nominal takeoff thrust size of 46900 pounds.

INTEGRATED WING TECHNOLOGY STUDY

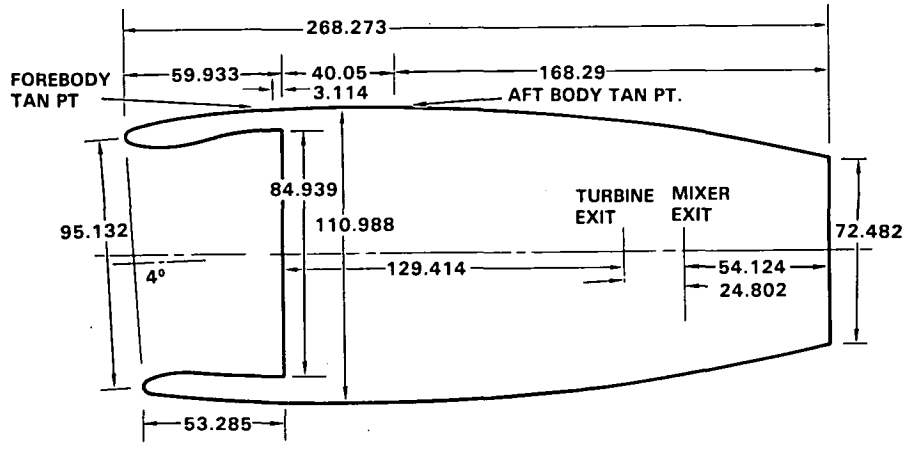
NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

BASELINE E3 MIXED FLOW NACELLE DIMENSIONS

FN_{BASE} = 46,900 LB

DIAMETER SCALING FACTOR = $\left(\frac{FN}{FN\ BASE}\right)^{0.50}$

NACELLE OVERALL LENGTH SCALING FACTOR = $\left(\frac{FN}{FN\ BASE}\right)^{0.48}$

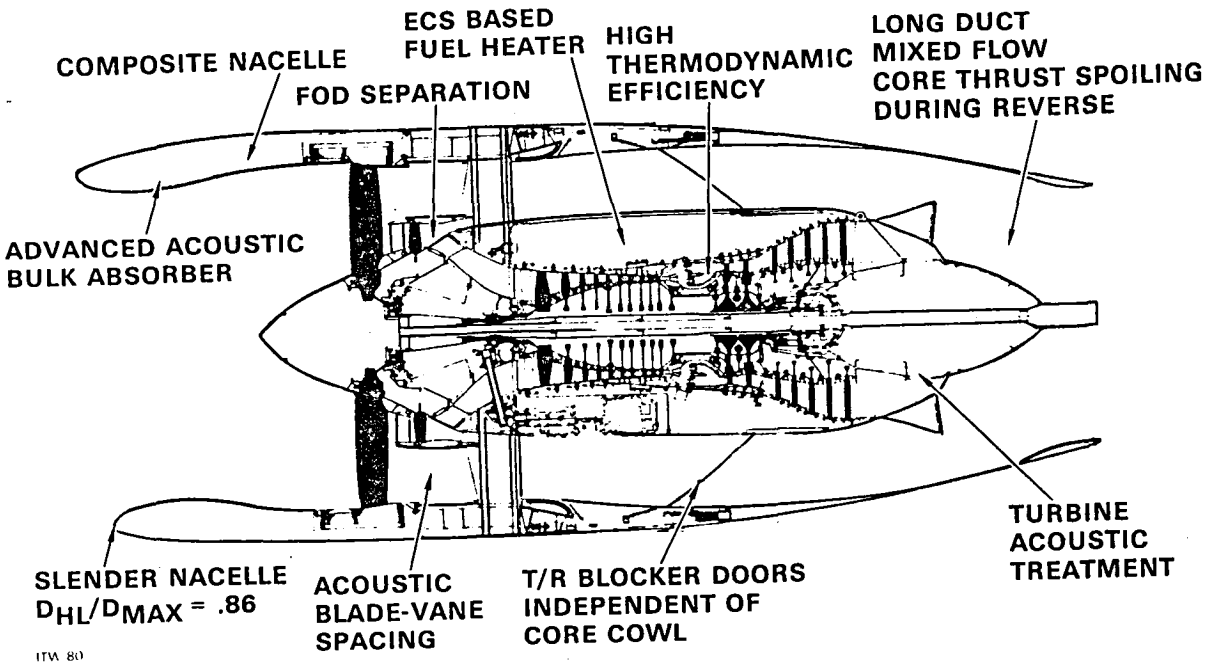


ITW-85

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° droop.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

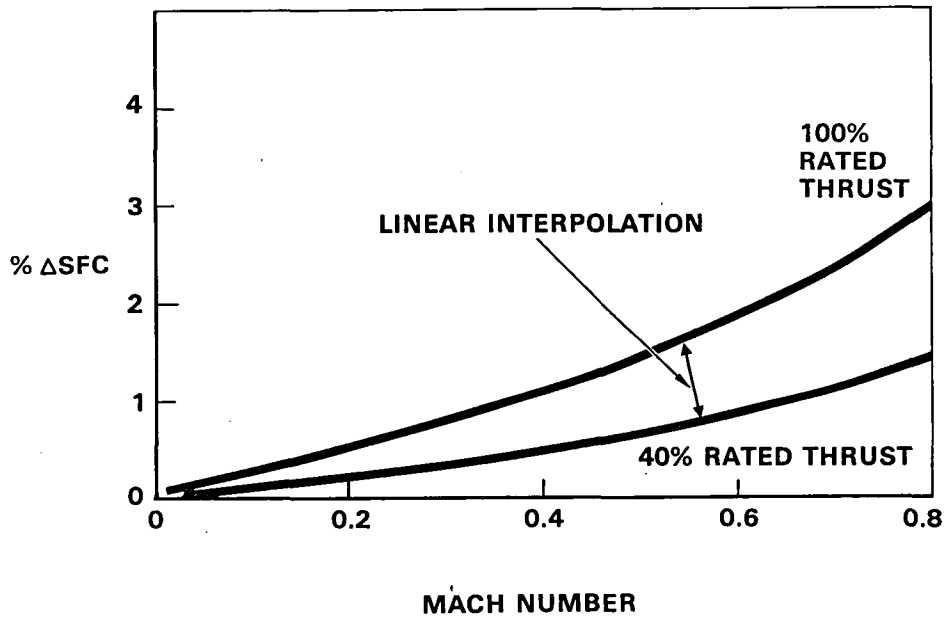
INSTALLED E^3 FPS FEATURES



ITW 80

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

E^3 SEPARATE FLOW EXHAUST % △SFC RELATIVE TO MIXED EXHAUST



ITW-90

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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

MIXED VS SEPARATE FLOW EXHAUST SYSTEM WEIGHT

REFERENCE THRUST = 46,900 LB

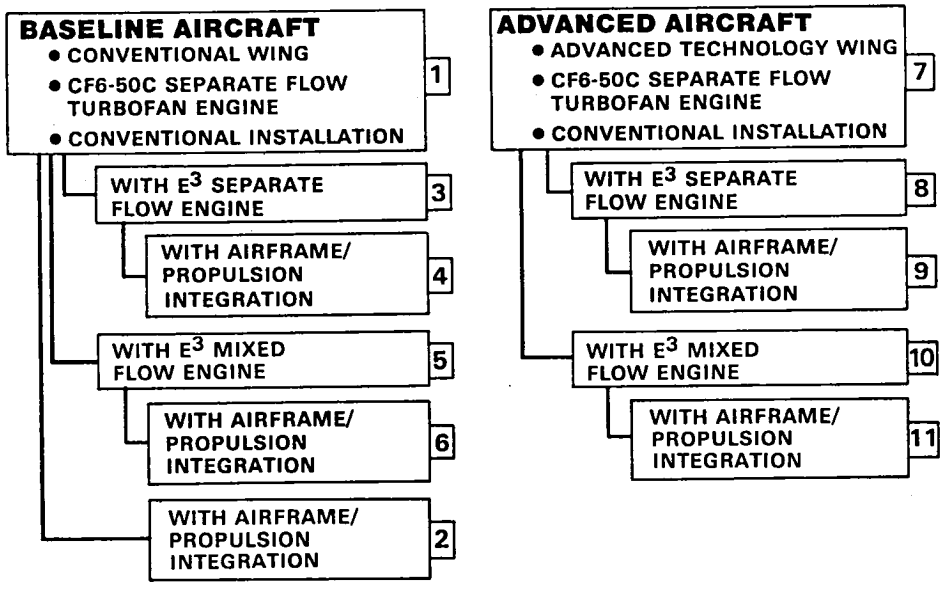
	MIXED FLOW	SEPARATE FLOW
BARE ENGINE	8,750 LB	8,750 LB
INLET	470	470
FAN REVERSER	1,270	1,532
CORE COWLS	307	216
PRIMARY NOZZLE	154	137
EXHAUST NOZZLE	306	—
ENGINE BUILD UP	575	575
TOTAL	**11,832 LB**	**11,680 LB**

ITW-92

Propulsion system weights for a mixed and separate flow exhaust system are shown in the following chart.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

PROPULSION SYSTEM CONFIGURATION MATRIX



ITW-86

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

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

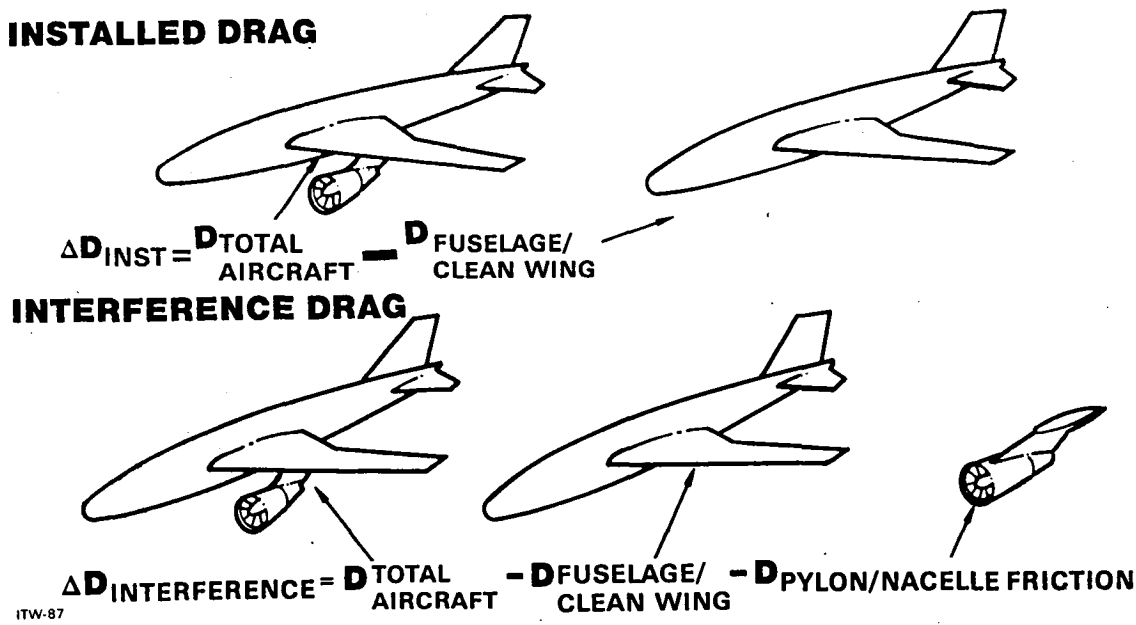
ITW-73

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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

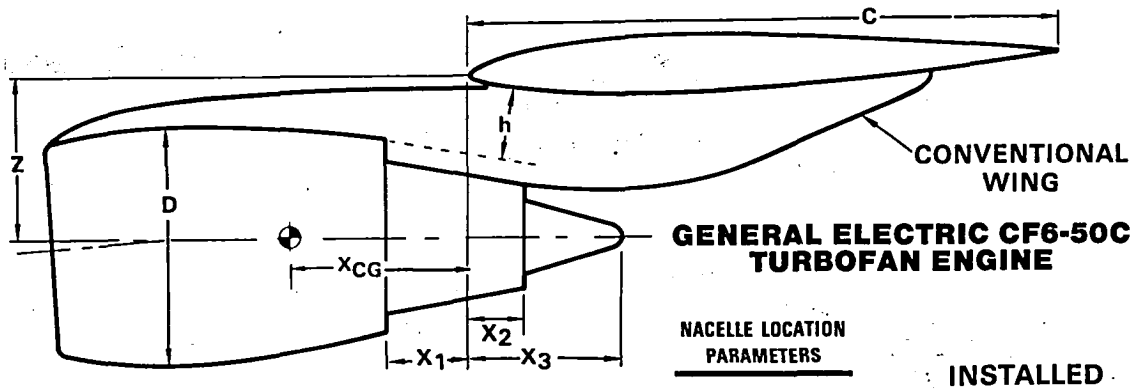
WING/PYLON/NACELLE INTERFERENCE DRAG



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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

BASELINE AIRCRAFT
(CONFIGURATION 1)



- NACELLE TYPE: COWL SEPARATE FLOW
- PYLON SHAPE: SYMMETRICAL
- PYLON CANT: 1.93° INBOARD
- NACELLE CANT: 1.93° INBOARD
- NACELLE PITCH: 2° UP
- INLET DROOP: 4°

ITW-88

NACELLE LOCATION PARAMETERS

h/X_2 = 1.167
X_2/C = 0.105
Z/D = 0.750
X_1/X_2 = 1.767
X_3/X_2 = 2.067
D/C = 0.364
X_{GG}/C = 0.290

INSTALLED DRAG

$$\frac{D_{INST}}{D_{A/C}} = 4.3\%$$

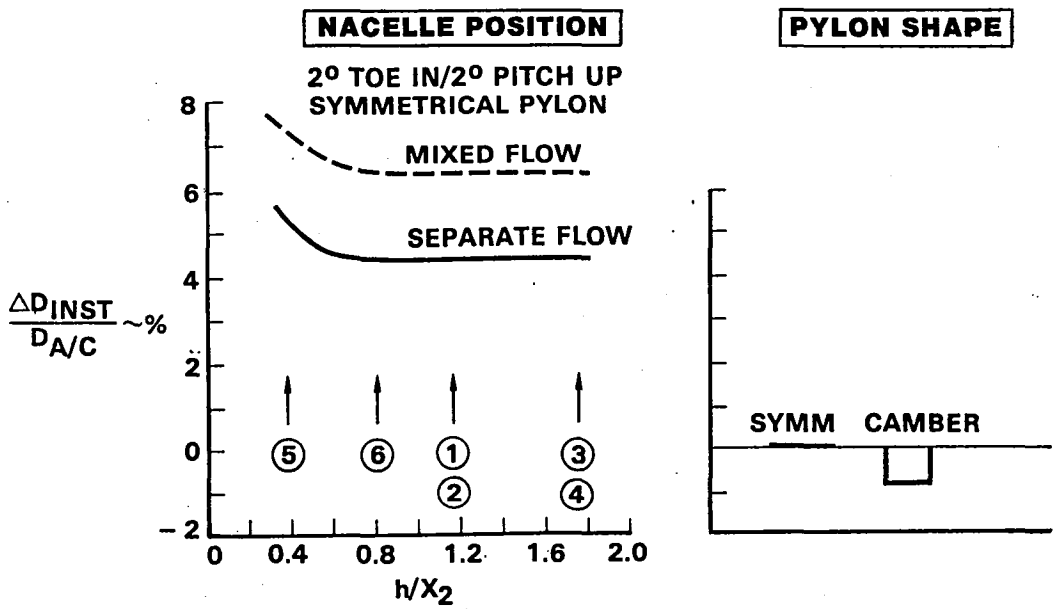
The GE CF6-50C separate flow engine/nacelle installed on the conventional aircraft is defined as a baseline configuration. The location of the nacelle relative to the wing is such that interference drag is zero and the installed nacelle drag of 4.3 percent aircraft drag is equivalent to the isolated 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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

INSTALLED NACELLE DRAG DATA FOR CONVENTIONAL AIRCRAFT

$M = 0.82 \bullet C_L = 0.35$



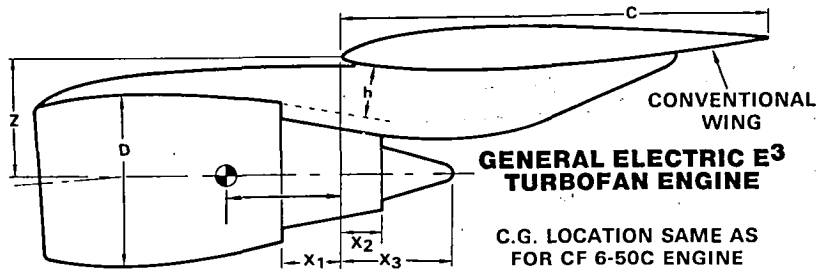
ITW-176

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 driction 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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

CONVENTIONAL AIRCRAFT WITH E^3 SEPARATE FLOW ENGINE (CONFIGURATION 3)

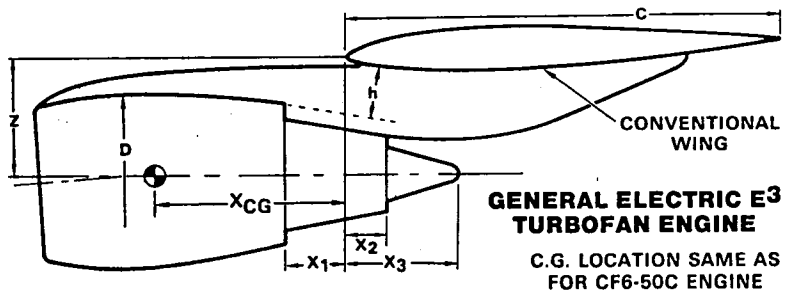


		NACELLE LOCATION PARAMETERS	INSTALLED DRAG
• NACELLE TYPE:	SEPARATE FLOW	$h/X_2 = 1.769$	
• PYLON SHAPE:	SYMMETRICAL	$X_2/C = 0.064$	
• PYLON CANT:	1.93° INBOARD	$Z/D = 0.703$	$\frac{\Delta D_{INST}}{D_{A/C}} = 4.3\%$
• NACELLE CANT:	1.93° INBOARD	$X_1/X_2 = 1.835$	
• NACELLE PITCH:	2° UP	$X_3/X_2 = 3.346$	
• INLET DROOP:	4°	$D/C = 0.388$	
		$X_{CG/C} = 0.290$	

ITW-89

Installation of the GE E^3 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 E^3 engine and subsequently scaled to the 94 inch fan diameter engine for which the performance data are based.

CONVENTIONAL AIRCRAFT WITH E^3 SEPARATE FLOW ENGINE AND AIRFRAME/PROPULSION INTEGRATION (CONFIGURATION 4)



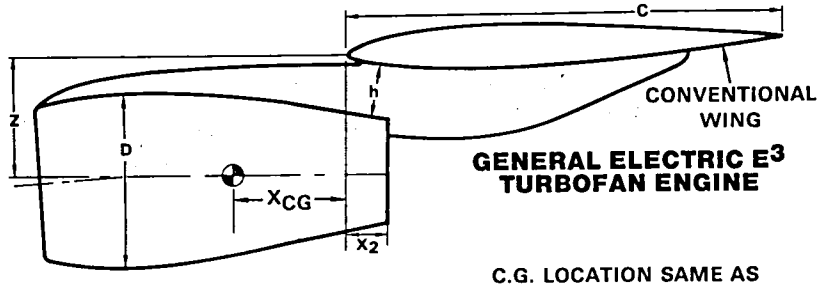
		NACELLE LOCATION PARAMETERS		INSTALLED DRAG
• NACELLE TYPE:	SEPARATE FLOW	h/X_2	= 1.769	$\frac{\Delta D_{INST}}{D_{A/C}} = 3.5\%$
• PYLON SHAPE:	CAMBERED/AREA RULE	X_2/C	= 0.064	
• PYLON CANT:	1.93° INBOARD	Z/D	= 0.703	
• NACELLE CANT:	1.93° INBOARD	X_1/X_2	= 1.835	
• NACELLE PITCH:	2° UP	X_3/X_2	= 3.346	
• INLET DROOP:	4°	D/C	= 0.388	
		X_{CG}/C	= 0.290	

ITW-175

Pylon camber/area rule for the E^3 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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

CONVENTIONAL AIRCRAFT WITH E^3 MIXED FLOW ENGINE (CONFIGURATION 5)



C.G. LOCATION SAME AS CF6-50C ENGINE

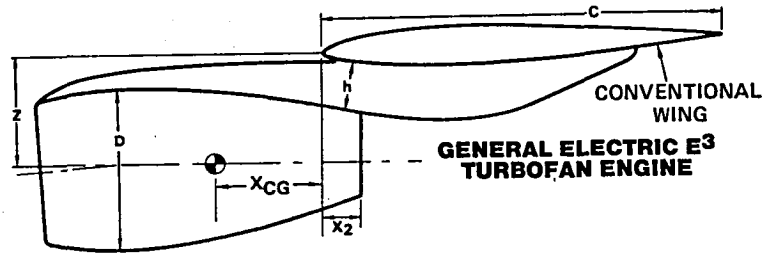
		NACELLE LOCATION PARAMETERS	INSTALLED DRAG
• NACELLE TYPE:	MIXED FLOW	$h/X^2 = 0.376$	$\frac{\Delta D_{INST}}{D_{A/C}} = 7.2\%$
• PYLON SHAPE:	SYMMETRICAL	$X^2/C = 0.236$	
• PYLON CANT:	1.93° INBOARD	$Z/D = 0.709$	
• NACELLE CANT:	1.93° INBOARD	$D/C = 0.385$	
• NACELLE PITCH:	2° UP	$X_{CG/c} = 0.290$	
• INLET DROOP:	4°		

ITW-93

Installation of the E^3 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 E^3 engine and subsequently scaled to the 94-inch fan diameter engine for which the performance data are based.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

CONVENTIONAL AIRCRAFT WITH E^3 MIXED FLOW ENGINE AND AIRFRAME/ PROPULSION INTEGRATION (CONFIGURATION 6)



- NACELLE TYPE: MIXED FLOW
- PYLON SHAPE: CAMBERED/ AREA RULE
- PYLON CANT: 1.93° INBOARD
- NACELLE CANT: 1.93° INBOARD
- NACELLE PITCH: 2° UP
- INLET DROOP: 4°

NACELLE LOCATION PARAMETERS			INSTALLED DRAG
h/X_2	=	0.800	$\frac{\Delta D_{INST}}{D_{A/C}} = 5.4\%$
X_2/C	=	0.133	
Z/D	=	0.709	
D/C	=	0.385	
X_{CG}/C	=	0.393	

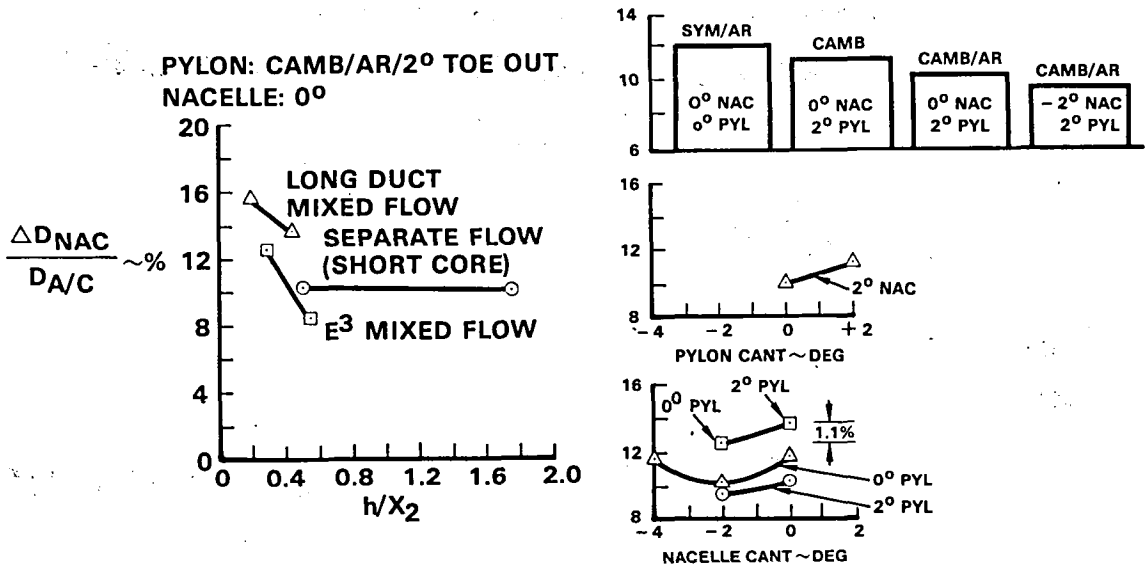
ITSV-167

Relocation of the E^3 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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

LA RC INSTALLED NACELLE DRAG TEST DATA

$M = 0.82 \bullet C_L = 0.55 \bullet C_D = 0.0350$

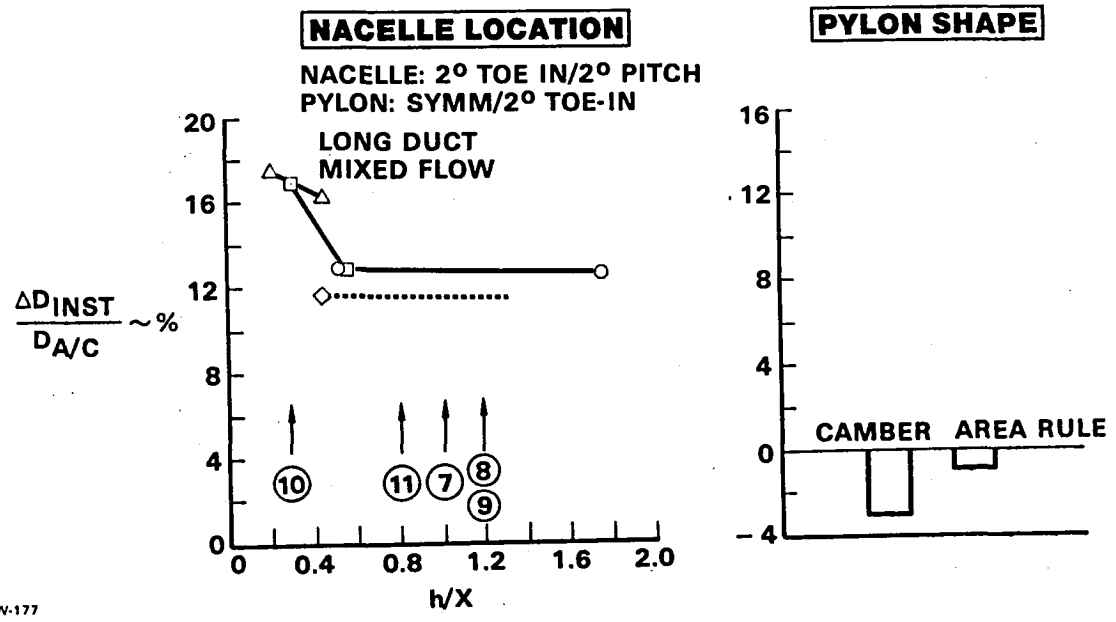


Installed nacelle drag test data from the NASA LaRC airframe/propulsion tests are presented. The effect on drag of engine/nacelle location is shown for configurations including pylon camber/area rule, zero degree nacelle cant and 2 degree pylon cant (outboard). Also shown are the incremental effects on drag resulting from pylon camber and area rule, and nacelle/pylon 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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

INSTALLED NACELLE DRAG FOR ADVANCED AIRCRAFT

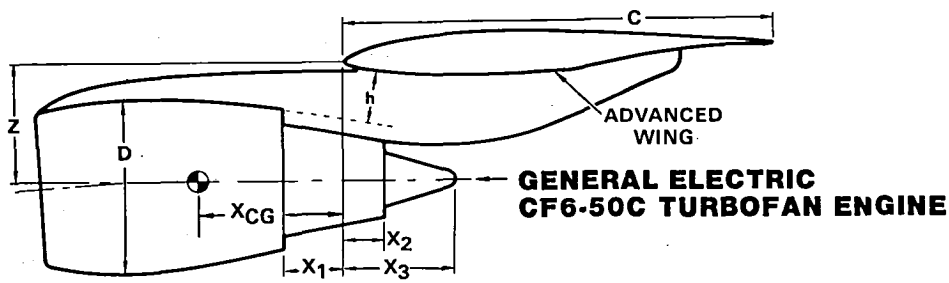
$M = 0.82$ • $C_L = 0.55$ • $C_D = 0.0350$



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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ADVANCED AIRCRAFT (CONFIGURATION 7)



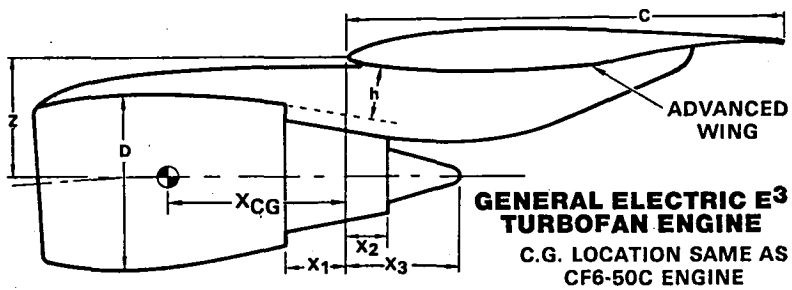
		NACELLE LOCATION PARAMETERS	INSTALLED DRAG
• NACELLE TYPE:	SEPARATE FLOW	$h/X_2 = 1.000$	
• PYLON SHAPE:	SYMMETRICAL	$X_2/C = 0.105$	
• PYLON CANT:	1.93° INBOARD	$Z/D = 0.750$	$\frac{\Delta D_{INST}}{D_{A/C}} = 11.5\%$
• NACELLE CANT:	1.93° INBOARD	$X_1/X_2 = 1.767$	
• NACELLE PITCH:	2° UP	$X_3/X_2 = 2.067$	
• INLET DROOP:	4°	$D/C = 0.364$	
		$X_{CG/C} = 0.290$	

ITW-94

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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ADVANCED AIRCRAFT WITH E3 SEPARATE FLOW ENGINE (CONFIGURATION 8)



- NACELLE TYPE: SEPARATE FLOW
- PYLON SHAPE: SYMMETRICAL
- PYLON CANT: 1.93° INBOARD
- NACELLE CANT: 1.93° INBOARD
- NACELLE PITCH: 2° UP
- INLET DROOP: 4°

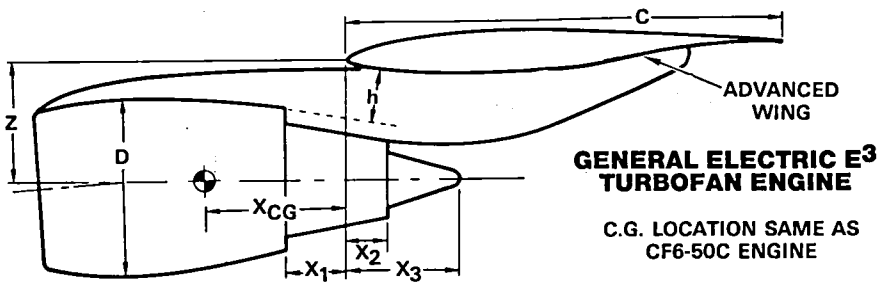
NACELLE LOCATION PARAMETERS	INSTALLED DRAG
$h/X_2 = 1.204$	$\frac{\Delta D_{INST}}{D_{A/C}} = 11.5\%$
$X_2/C = 0.064$	
$Z/D = 0.703$	
$X_1/X_2 = 1.264$	
$X_3/X_2 = 2.973$	
$D/C = 0.388$	
$X_{CG}/C = 0.290$	

ITW-95

With the GE E^3 separate flow engine installed on the advanced aircraft the installed nacelle drag increment is 11.5 percent of the aircraft drag.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ADVANCED AIRCRAFT WITH E3 SEPARATE FLOW ENGINE AND AIRFRAME/ PROPULSION INTEGRATION (CONFIGURATION 9)



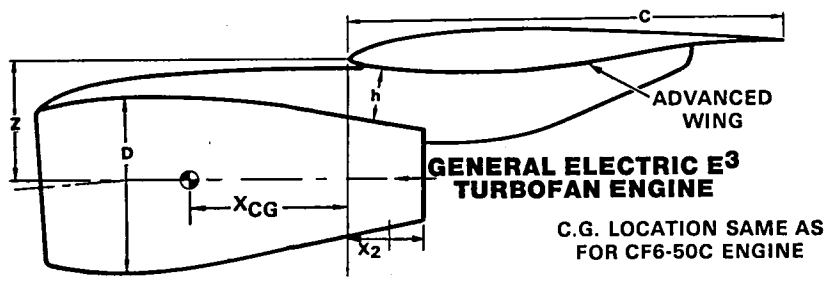
		NACELLE LOCATION PARAMETERS	INSTALLED DRAG
• NACELLE TYPE:	SEPARATE FLOW	$h/X_2 = 1.204$	$\frac{\Delta D_{INST}}{D_{A/C}} = 4.3\%$ (GOAL)
• PYLON SHAPE:	CAMBERED/ AREA RULE	$X_2/C = 0.064$ $Z/D = 0.703$	
• PYLON CANT:	1.93° INBOARD	$X_1/X_2 = 1.264$	
• NACELLE CANT:	1.93° INBOARD	$X_3/X_2 = 2.973$	
• NACELLE PITCH:	2° UP	$D/C = 0.388$	
• INLET DROOP:	4°	$X_{CG}/C = 0.290$	

ITW-96

The goal of airframe/propulsion integration program is to eliminate the interference drag of the E^3 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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ADVANCED AIRCRAFT WITH E3 MIXED FLOW ENGINE (CONFIGURATION 10)



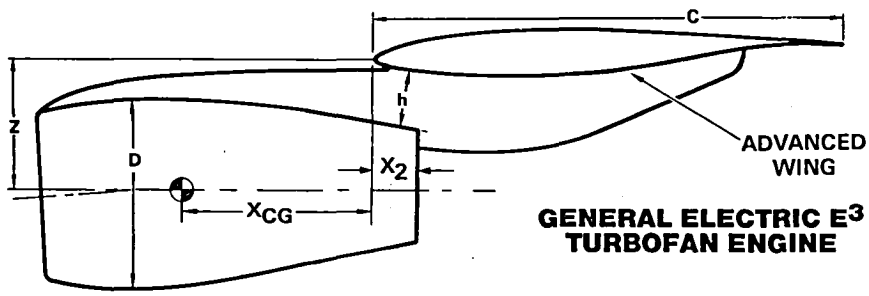
		NACELLE LOCATION PARAMETERS	INSTALLED DRAG
• NACELLE TYPE:	MIXED FLOW	$h/X_2 = 0.277$	$\frac{\Delta D_{INST}}{D_{A/C}} = 17.3\%$
• PYLON SHAPE:	SYMMETRICAL	$X_2/C = 0.236$	
• PYLON CANT:	1.93° INBOARD	$Z/D = 0.709$	
• NACELLE CANT:	1.93° INBOARD	$D/C = 0.385$	
• NACELLE PITCH:	2° UP	$X_{CG}/C = 0.290$	
• INLET DROOP:	4°		

ITW-97

For the GE E^3 mixed flow engine/nacelle installed on the advanced aircraft at the same c.g. location as that for the CF6-50C 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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

ADVANCED AIRCRAFT WITH E^3 MIXED FLOW ENGINE AND AIRFRAME/ PROPULSION INTEGRATION (CONFIGURATION 11)



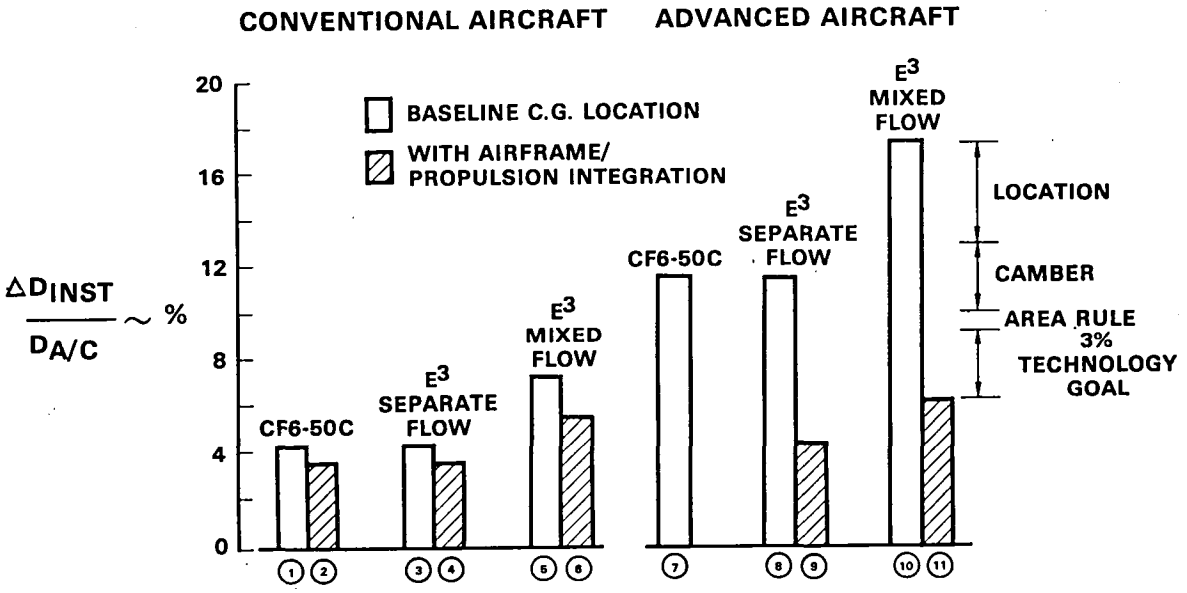
- NACELLE TYPE: MIXED FLOW
- PYLON SHAPE: CAMBERED/ AREA RULE
- PYLON CANT: 1.93° INBOARD
- NACELLE CANT: 1.93° INBOARD
- NACELLE PITCH: 2° UP
- INLET DROOP: 4°

NACELLE LOCATION PARAMETERS	INSTALLED DRAG
$h/X^2 = 0.800$ $X^2/C = 0.110$ $Z/D = 0.709$ $D/C = 0.385$ $X_{CG}/C = 0.416$	$\frac{\Delta D_{INST}}{D_{A/C}} = 6.2\%$

ITW-99

For the E^3 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/pylon/ nacelle.

INSTALLED DRAG SUMMARY



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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

PROPULSION SYSTEM TECHNOLOGY COST/BENEFIT SUMMARY

NO.	PROPULSION SYSTEM CONFIGURATION ENGINE	EXHAUST	AIRCRAFT/WING	△SFC	△DRAG	CHANGE* IN CRUISE FUEL
1	CF6-50C	SEPARATE	CONVENTIONAL	BASE	BASE	BASE
2	CF6-50C	SEPARATE	CONVENTIONAL	BASE	− 0.8%	− 0.8%
3	E^3	SEPARATE	CONVENTIONAL	− 11.5%	0.0%	−11.5%
4	E^3	SEPARATE	CONVENTIONAL	− 11.5%	− 0.8%	−12.3%
5	E^3	MIXED	CONVENTIONAL	− 14.6%	+ 2.9%	−11.7%
6	E^3	MIXED	CONVENTIONAL	−14.6%	+ 1.1%	−13.5%
7	CF6-50C	SEPARATE	ADVANCED	0	+ 7.2%	+ 7.2%
8	E^3	SEPARATE	ADVANCED	− 11.5%	+ 7.2%	− 4.3%
9	E^3	SEPARATE	ADVANCED	− 11.5%	0.0%	−11.5%
10	E^3	MIXED	ADVANCED	− 14.6%	+13.0%	− 1.6%
11	E^3	MIXED	ADVANCED	− 14.6%	+ 1.9%	−12.7%

*NOTE – DOES NOT INCLUDE ASSOCIATED WEIGHT INCREMENTS

ITW-163

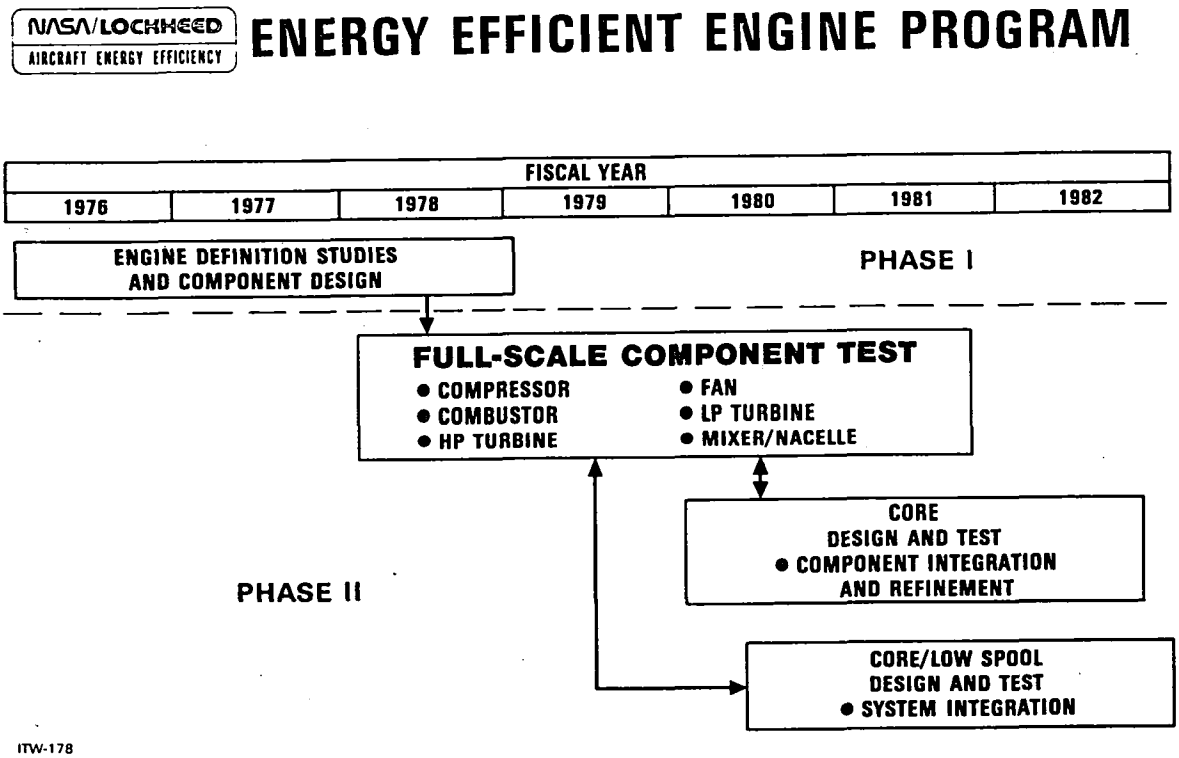
NASA/LOCKHEED

AIRCRAFT ENERGY EFFICIENCY

PROPULSION SYSTEM TECHNOLOGY

PROGRAM PLAN

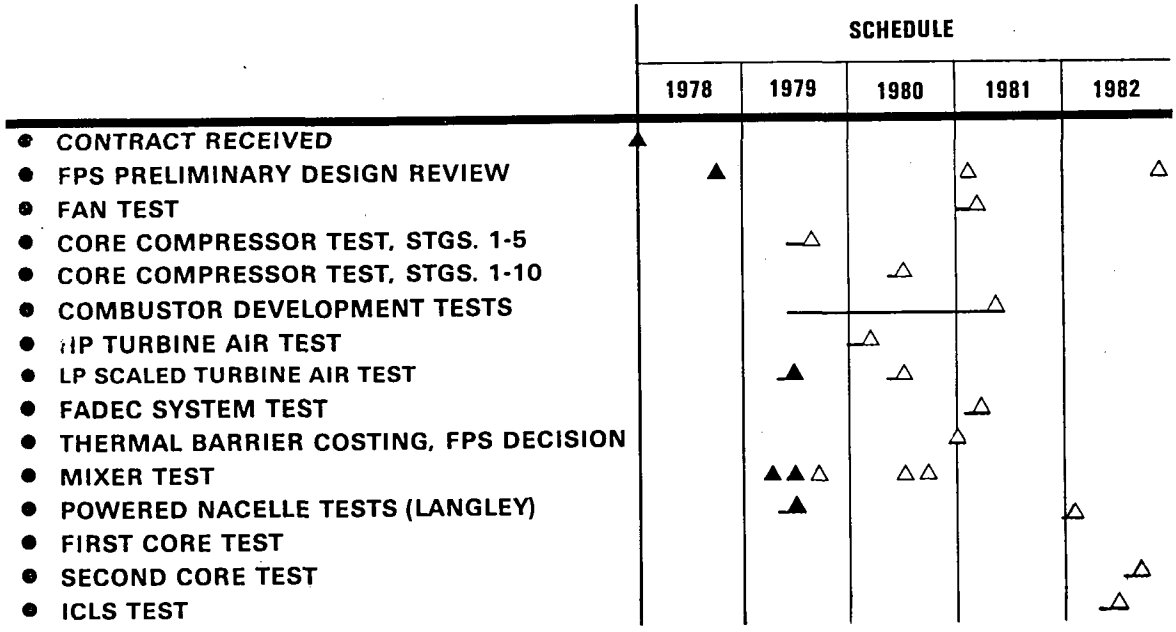
ITW-169



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.

NASA LOCKHEED AIRCRAFT ENERGY EFFICIENCY

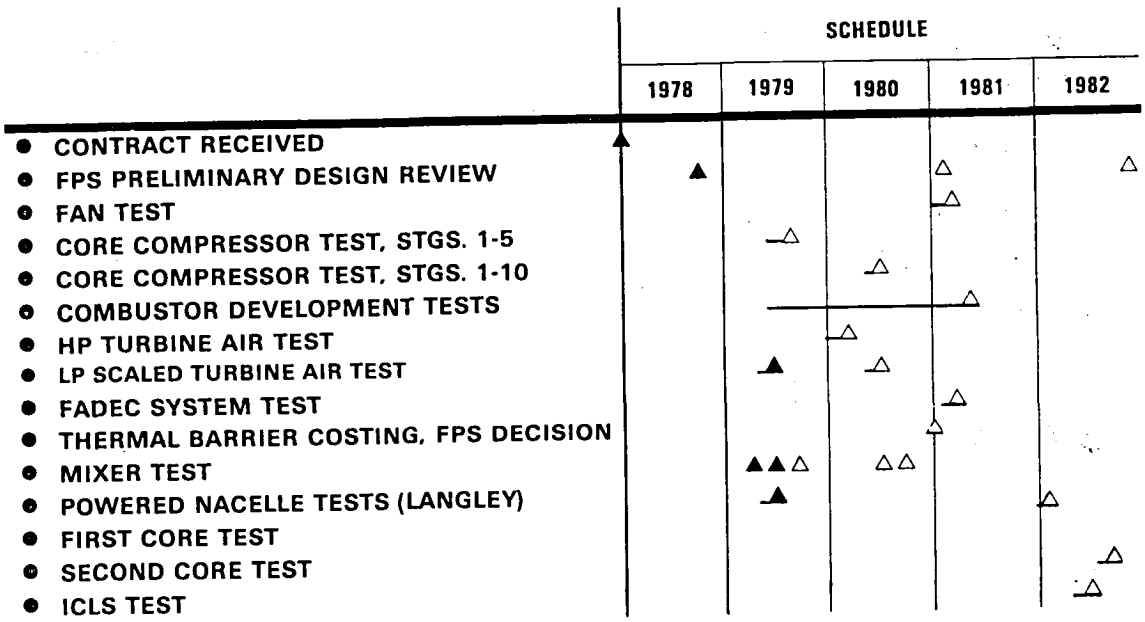
E^3 PROGRAM MILESTONES



Program milestones for the E^3 program are shown in the following chart.

NASA LOCKHEED AIRCRAFT ENERGY EFFICIENCY

E3 PROGRAM MILESTONES



ITW-101

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

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

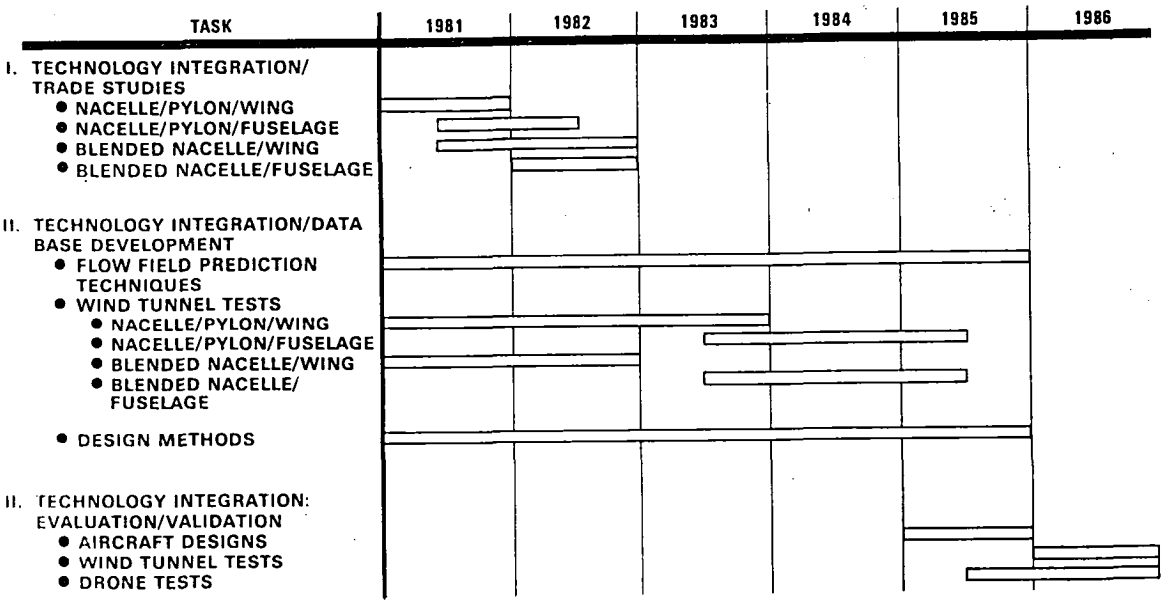
ANALYTICAL METHODS (BOPPE CODE)

- SWEEP PYLON
- REALISTIC NACELLE → 3D

ITW-179

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

OVERALL PROPULSION/AIRFRAME INTEGRATION PROGRAM SCHEDULE



ITW-102

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AIRCRAFT ENERGY EFFICIENCY

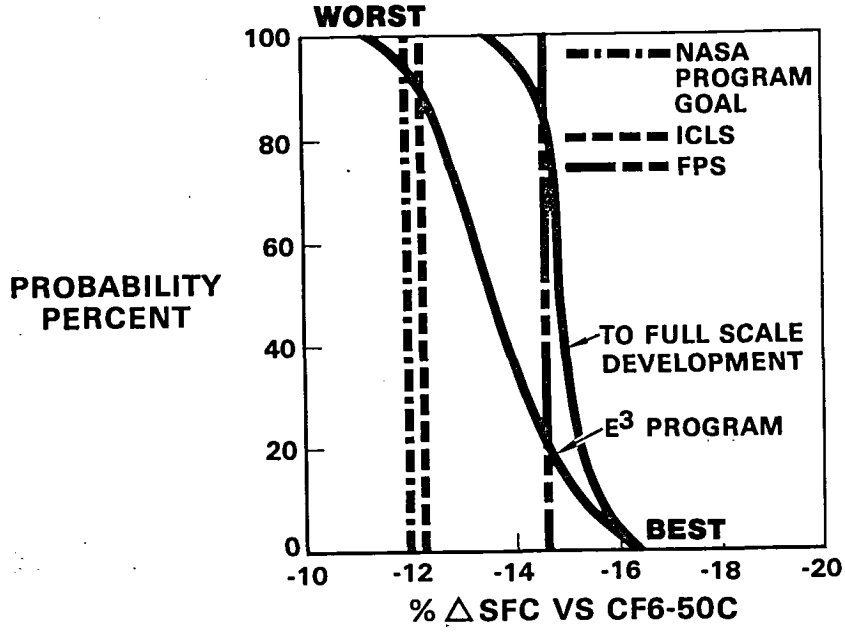
PROPULSION SYSTEM TECHNOLOGY

RISK ASSESSMENT

ITW 166

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

PROBABILITY OF ACHIEVING SFC GOALS

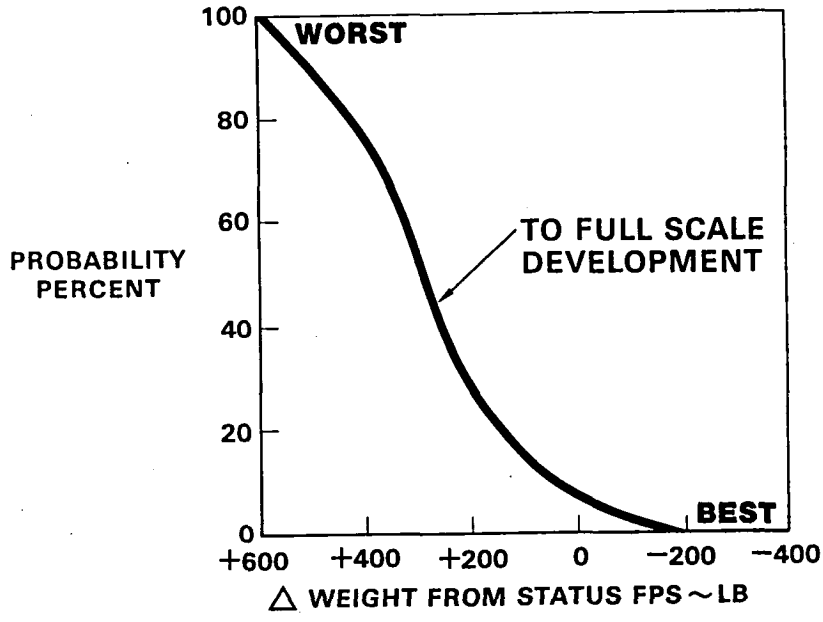


ITW-104

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.

NASA LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

PROBABILITY OF ACHIEVING FPS WEIGHT PROJECTION



ITW-103

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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

PROPULSION SYSTEM TECHNOLOGY

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

ITW-105

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AIRCRAFT ENERGY EFFICIENCY

STRUCTURES/MATERIALS

MARLON GUESS

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

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

ITW-109

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.

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AIRCRAFT ENERGY EFFICIENCY

ADVANCED ALUMINUM & METAL MATRIX COMPOSITES

ITW-110

Advanced aluminum alloys and metal matrix composite developments are covered in this section.

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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

ITW-111

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.

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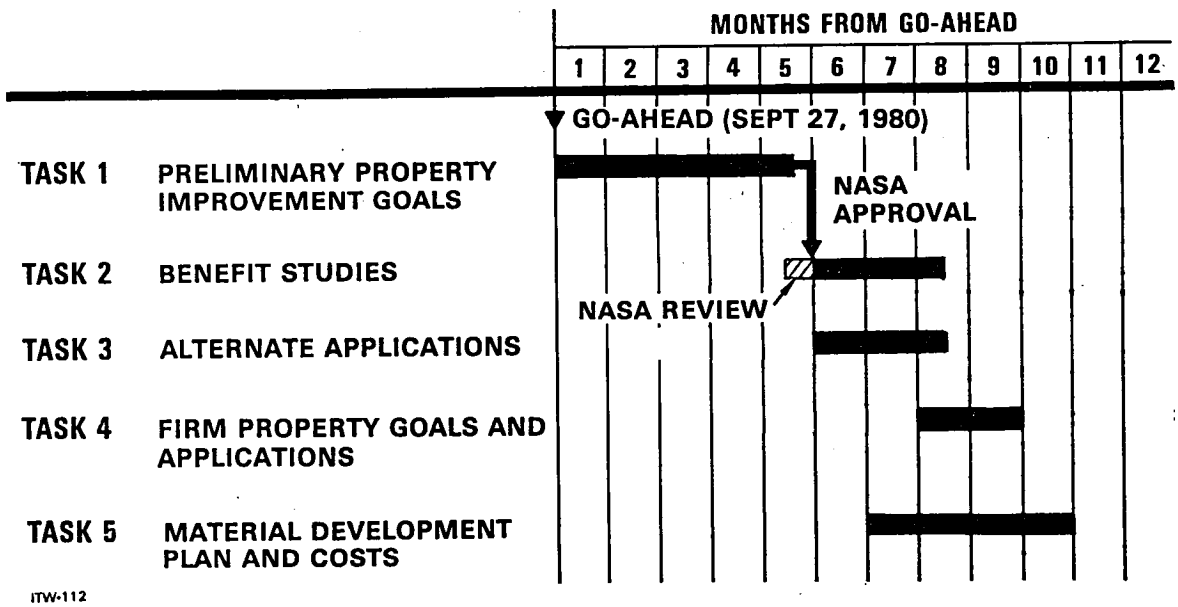
AIRCRAFT ENERGY EFFICIENCY

NAS1 - 16434 ADVANCED ALUMINUM PAYOFF STUDY



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.

NASA/LOCKHEED AIRCRAFT ENERGY EFFICIENCY

METALLURGICAL DEVELOPMENTS

- ALLOY MODIFICATIONS
- THERMAL MECHANICAL TREATMENT
- POWDER METALLURGY TECHNIQUES

ITW-113

Metallurgical developments which make possible the development of advance aluminum alloys with significant property improvements are shown above.

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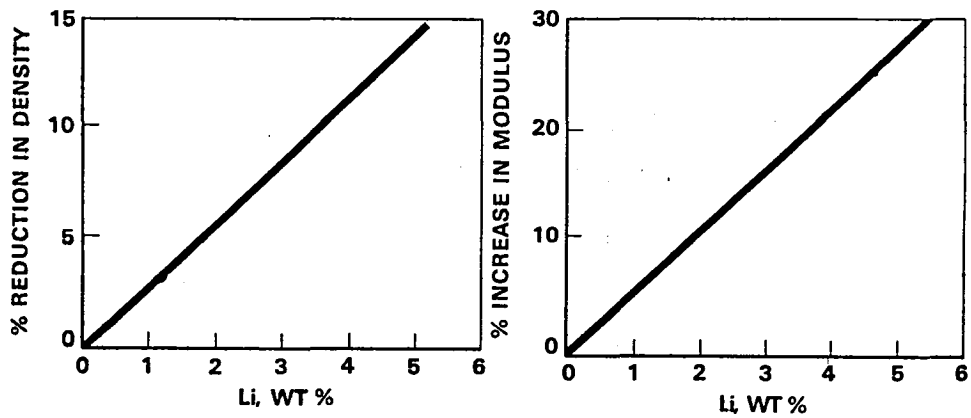
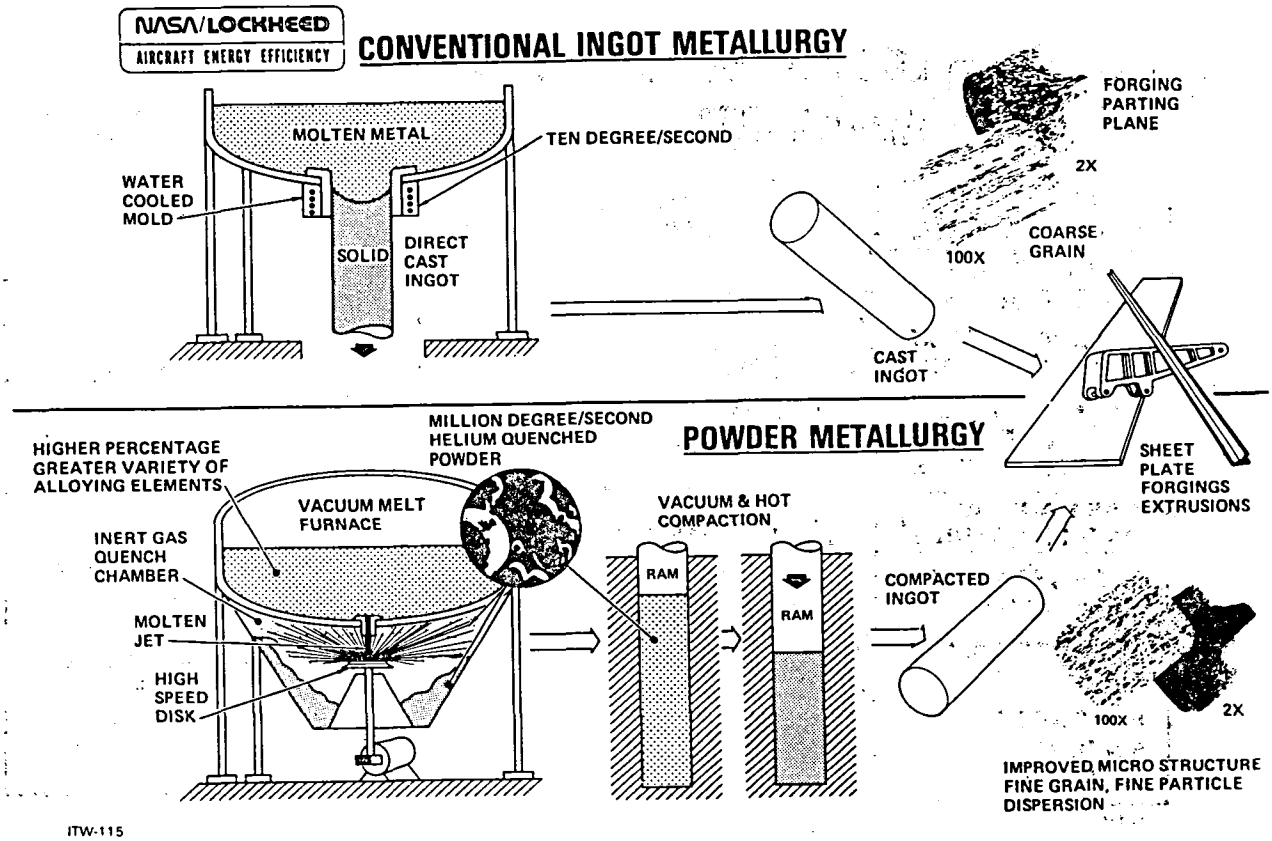
AIRCRAFT ENERGY EFFICIENCY

EFFECTS OF LITHIUM IN ALUMINUM ALLOYS



ITW-114

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.

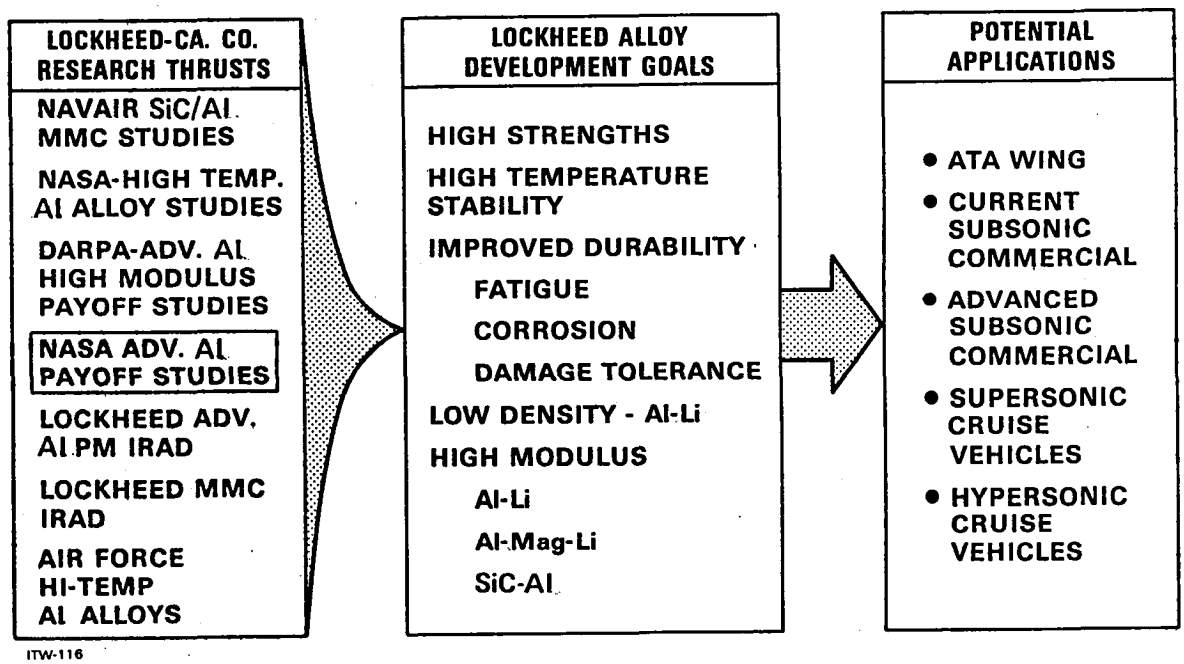


A schematic diagram of the aluminum powder metallurgy (P/M) method is shown. The sequence consists of: 1) rapid solidification (10^{6}°F/sec) of molten aluminum alloy by quenching in inert gas, one of several methods available in the industry, 2) collection and sizing of fine powders, 3) cold compaction, 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.

NASA/LOCKHEED
AIRCRAFT ENERGY EFFICIENCY

LOCKHEED-CALIFORNIA CO. ADVANCED ALUMINUM ALLOY PROGRAMS



ITW-116

This chart shows development thrusts for advanced aluminum alloys at the Lockheed-California Company, alloy development goals and potential applications.

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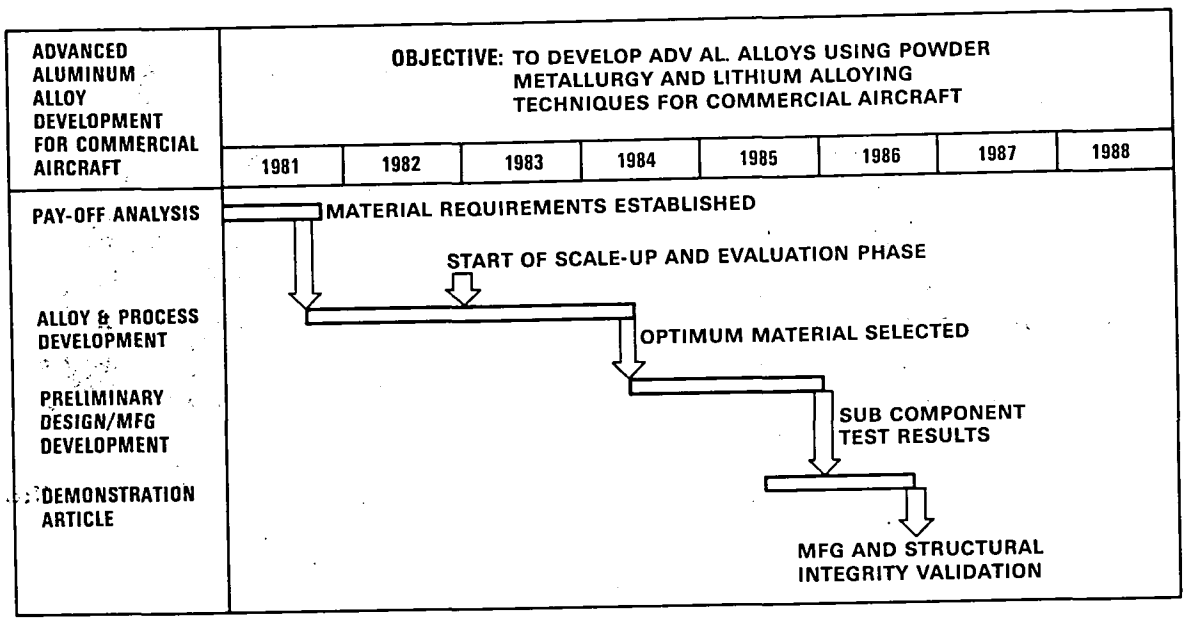
AIRCRAFT ENERGY EFFICIENCY

ADV ALUMINUM ALLOY DEVELOPMENT PLAN



ITW-117

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.

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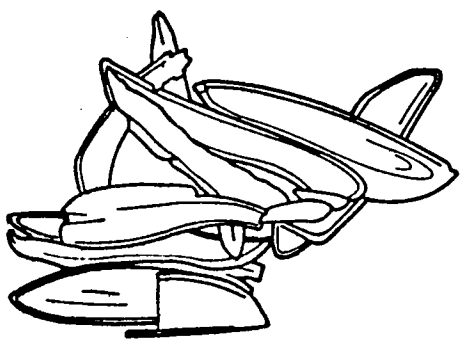
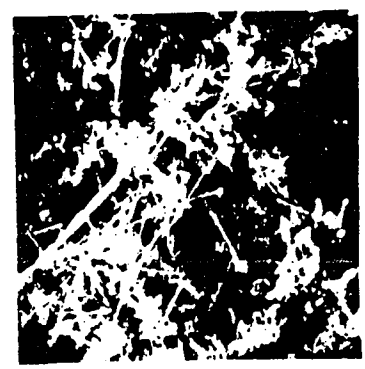
BACKGROUND: SiC/AL METAL MATRIX COMPOSITES



RICE HULLS



X1000
SILICON CARBIDE WHISKERS

WHISKER COST $5-10/LB PROJECTED

ITW-118

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.

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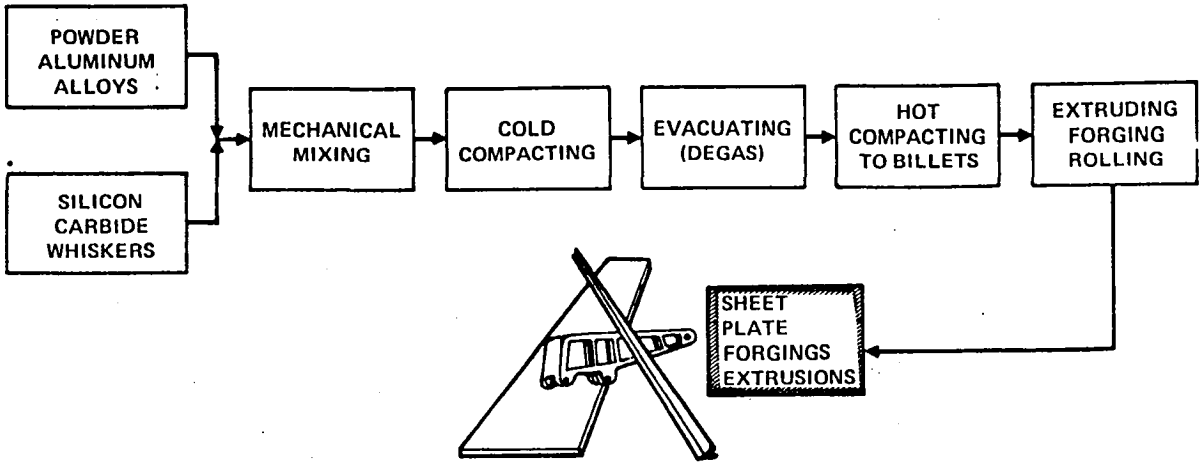
AIRCRAFT ENERGY EFFICIENCY

BACKGROUND SiC/AL METAL MATRIX COMPOSITES



ITW-119

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.

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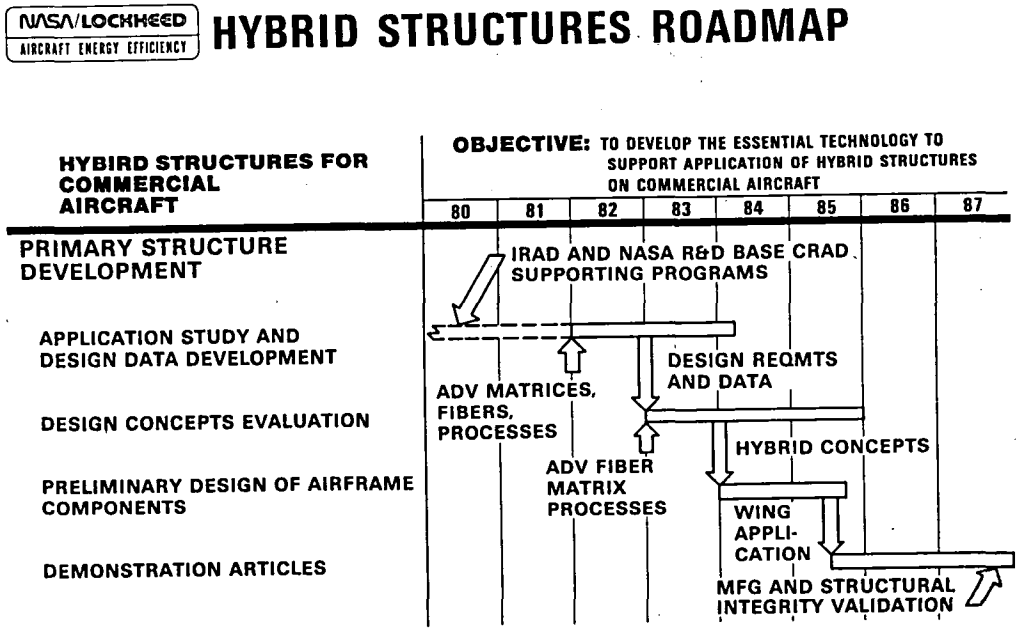
SiC/Al ADVANTAGES

- 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

ITW-120

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.

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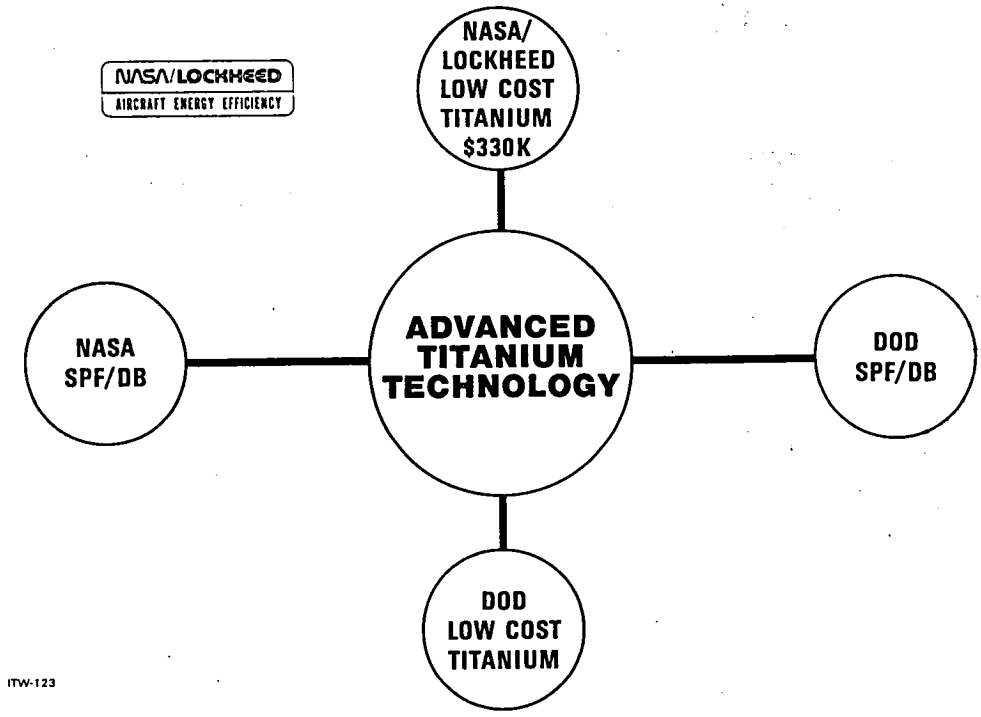
ADVANCED TITANIUM TECHNOLOGY

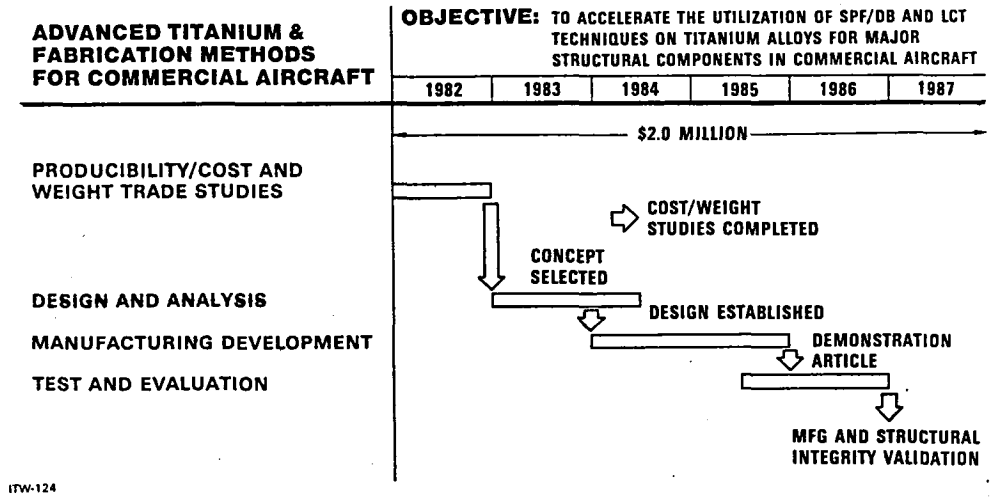
ITW-122

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



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.

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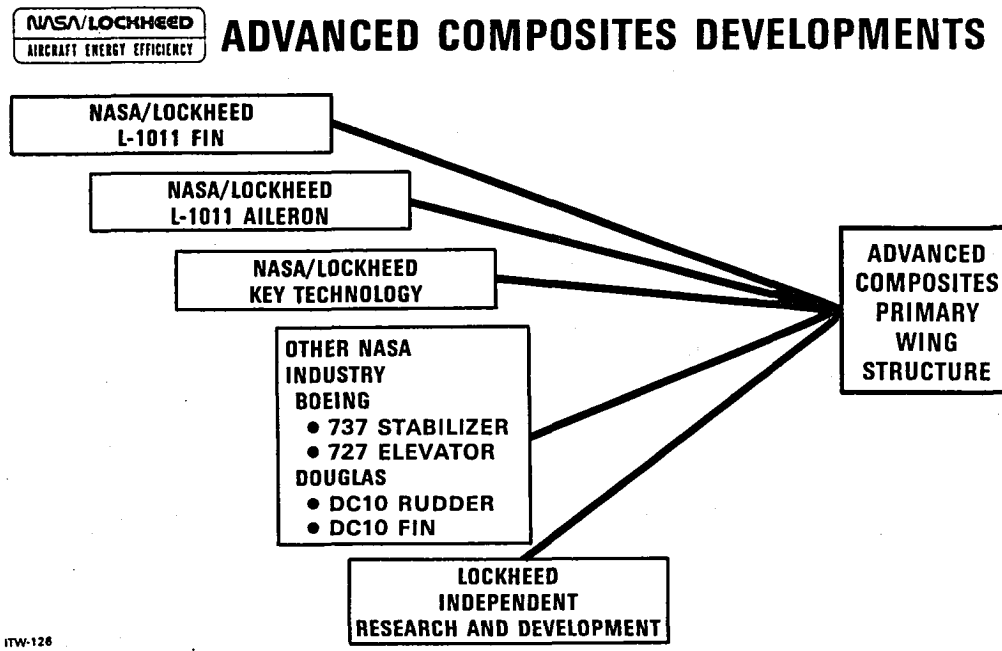
ADVANCED COMPOSITES

ITW-125

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.

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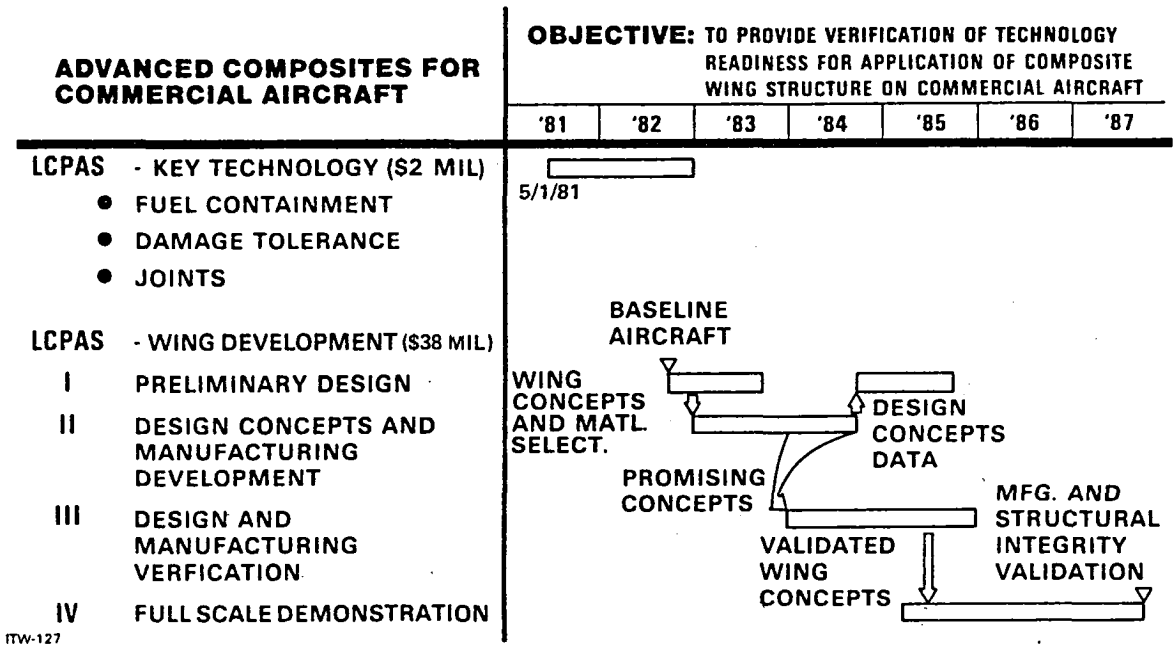
LARGE COMPOSITE PRIMARY AIRCRAFT STRUCTURES - WING DEVELOPMENT

ADVANCED COMPOSITES FOR COMMERCIAL AIRCRAFT

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



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.

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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

ITW-128

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.

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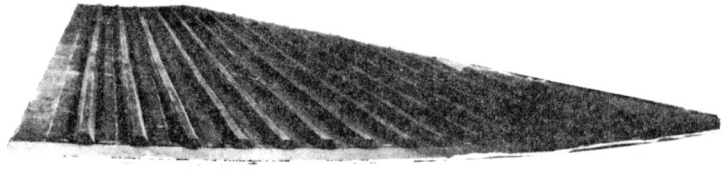
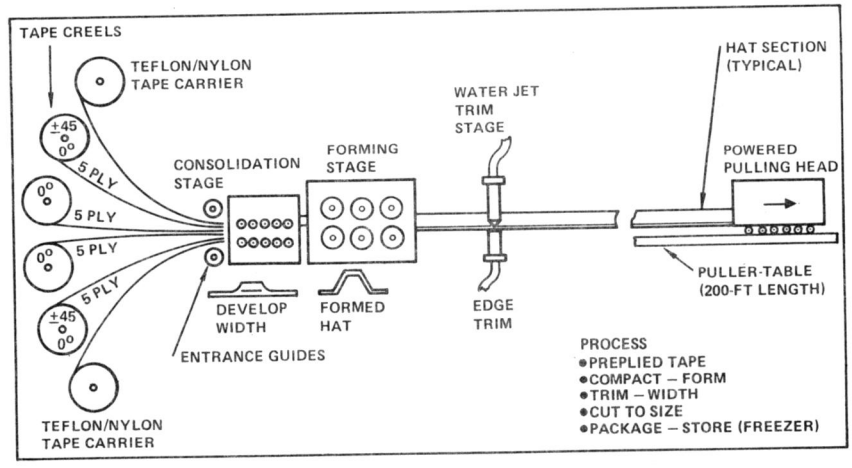
AUTOMATED-COMPOSITE STRUCTURAL SHAPES CONTINUOUS FABRICATION





ITW-129

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.

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SUMMARY OF TECHNOLOGY COSTS AND BENEFITS

TECHNOLOGY APPLICATION	TECH. DEV. COST	ΔSFC OR ΔDRAG	ΔSTRUCTURAL WEIGHT	TECH. READINESS DATE
ADVANCED ALUMINUM ALLOY	$14M*		5.6%	1986
ADVANCED COMPOSITES	$40M		8.9%	1986
METAL MATRIX (SiC/AL) COMPOSITES	$14M*		7.2%	1986
TITANIUM	$ 2M		~0	1986

*ESTIMATED COST COVERS DEVELOPMENT OF TWO ALLOYS

ITW-130

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AIRCRAFT ENERGY EFFICIENCY

PRELIMINARY AEROELASTIC DESIGN OF STRUCTURES (PADS)

NICK RADOVCICH

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