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FUEL EFFICIENCY THROUGH NEW AIRFRAME TECHNOLOGY

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INTRODUCTION

IN 1975 AND 1976, NASA DEFINED AND LAUNCHED A MAJOR HALF-BILLION-DOLLAR AERONAUTICS PROGRAM CALLED THE AIRCRAFT ENERGY EFFICIENCY (ACEE) PROGRAM. THIS PROGRAM IS DEVOTED TO DEVELOPMENT AND DEMONSTRATION OF ADVANCED TECHNOLOGIES APPLICABLE TO COMMERCIAL TRANSPORTS, WITH ABOUT HALF THE EFFORT DEVOTED TO ENGINE TECHNOLOGIES AND THE OTHER HALF TO SELECTED AIRFRAME TECHNOLOGIES.

THIS BRIEF SUMMARY REPORT OUTLINES THE FACTORS WHICH MOTIVATED THE IMPLEMENTATION OF THIS LARGE PROGRAM AND DISPLAYS ITS OVERALL CONTENT. IT THEN BRIEFLY DESCRIBES MANY OF THE SPECIFIC EFFORTS NOW COMPRISING THE THREE ACEE AIRFRAME TECHNOLOGY PROGRAMS, INDICATING PROGRESS TO DATE. IT ALSO BRIEFLY SUMMARIZES THOSE ELEMENTS OF THE AIRFRAME PROGRAMS WHICH HAVE BEEN PLANNED, BUT NOT YET IMPLEMENTED. FINALLY, IT SUMMARIZES THE CURRENT OUTLOOK FOR DERIVATION OF BENEFITS FROM THE PROGRAM.

SLIDE 2

THE UNITED STATES' CRUCIAL DEPENDENCE ON AIR TRANSPORTATION IS STRIKINGLY ILLUSTRATED BY THIS COMPARISON. AIR TRAVEL NOW ACCOUNTS FOR ABOUT 10 TIMES AS MANY PASSENGER MILES AS ITS NEAREST COMPETITOR AMONG ALTERNATE PUBLIC TRANSPORTATION MODES.

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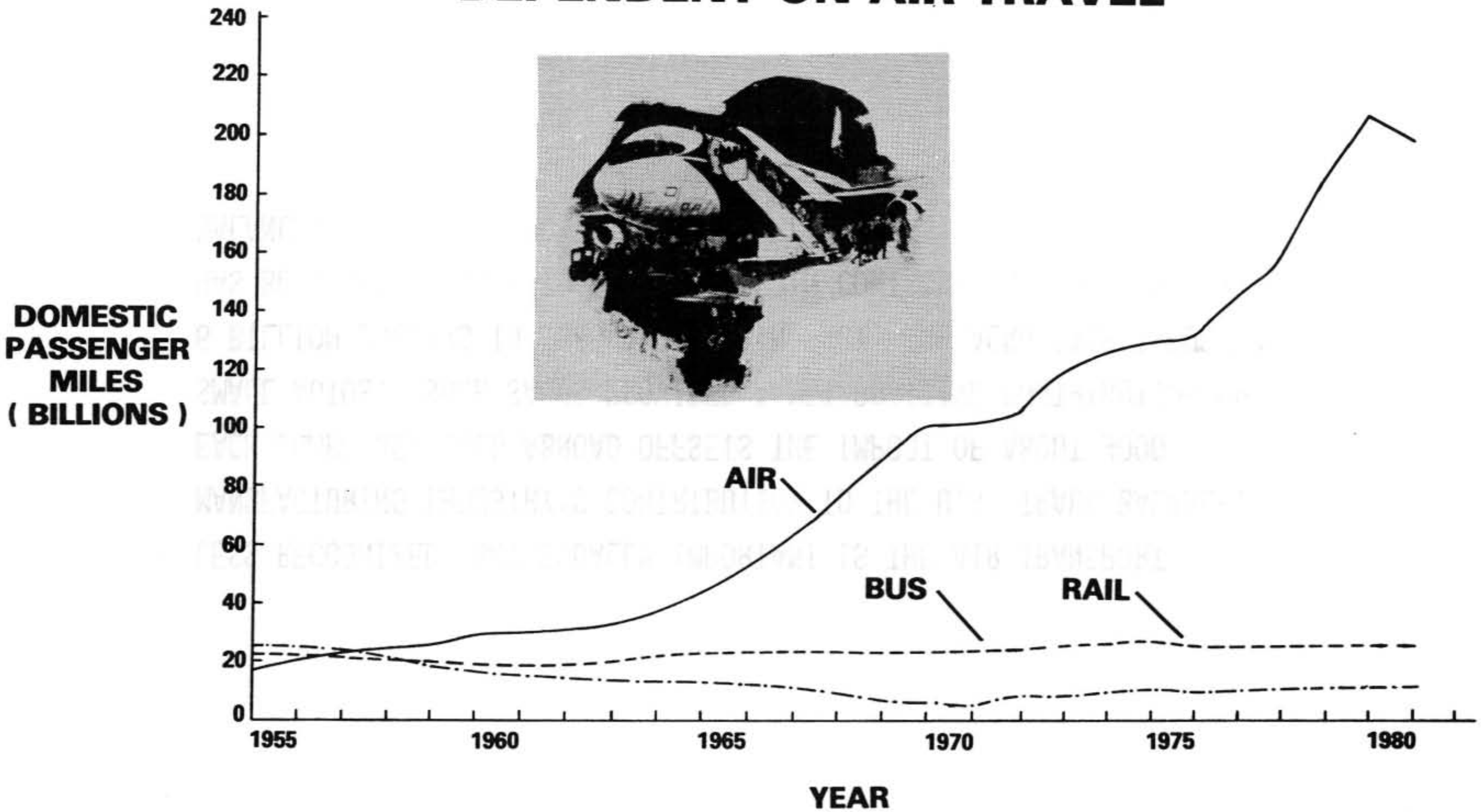
WE HAVE BECOME DEPENDENT ON AIR TRAVEL



SLIDE 3

LESS RECOGNIZED, BUT EQUALLY IMPORTANT IS THE AIR TRANSPORT MANUFACTURING INDUSTRY'S CONTRIBUTION TO THE U.S. TRADE BALANCE. EACH JUMBO JET SOLD ABROAD OFFSETS THE IMPORT OF ABOUT 9000 SMALL AUTOS. SUCH SALES PROVIDED A NET POSITIVE CONTRIBUTION OF 6 BILLION DOLLARS IN 1980 ALONE. IN FACT, THE AEROSPACE INDUSTRY HAS BEEN SECOND ONLY TO AGRICULTURE IN CONTRIBUTING POSITIVE TRADE BALANCES.

AIR TRANSPORT IMPORTANCE TO U.S. TRADE BALANCE
1980 POSITIVE BALANCE WAS 6 BILLION DOLLARS

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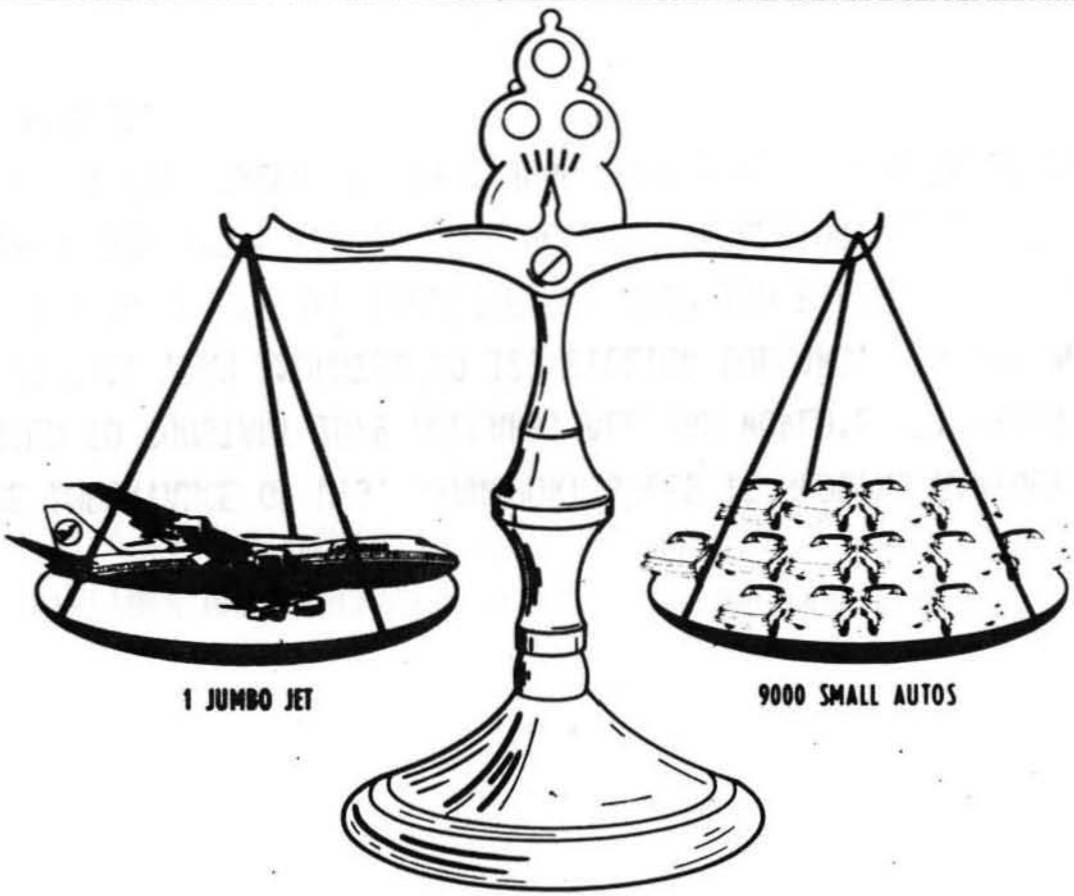
3



SLIDE 4

AND THE IMPORTANCE OF U.S. TRANSPORT SALES IS GROWING RAPIDLY. CONVERTED TO CONSTANT 1979 DOLLARS, ALL THE WORLD'S JET TRANSPORT SALES TO THAT YEAR AMOUNTED TO 120 BILLION DOLLARS. IN THE NEXT 10 YEARS ALONE SALES ARE PROJECTED AT OVER 100 BILLION DOLLARS AND SOME PROJECTIONS FOR THE BALANCE OF THE CENTURY EXCEED 220 BILLION DOLLARS. SIXTY PERCENT OF THIS HUGE MARKET WILL BE OUTSIDE THE UNITED STATES.

WORLD COMMERCIAL JET TRANSPORT DELIVERIES

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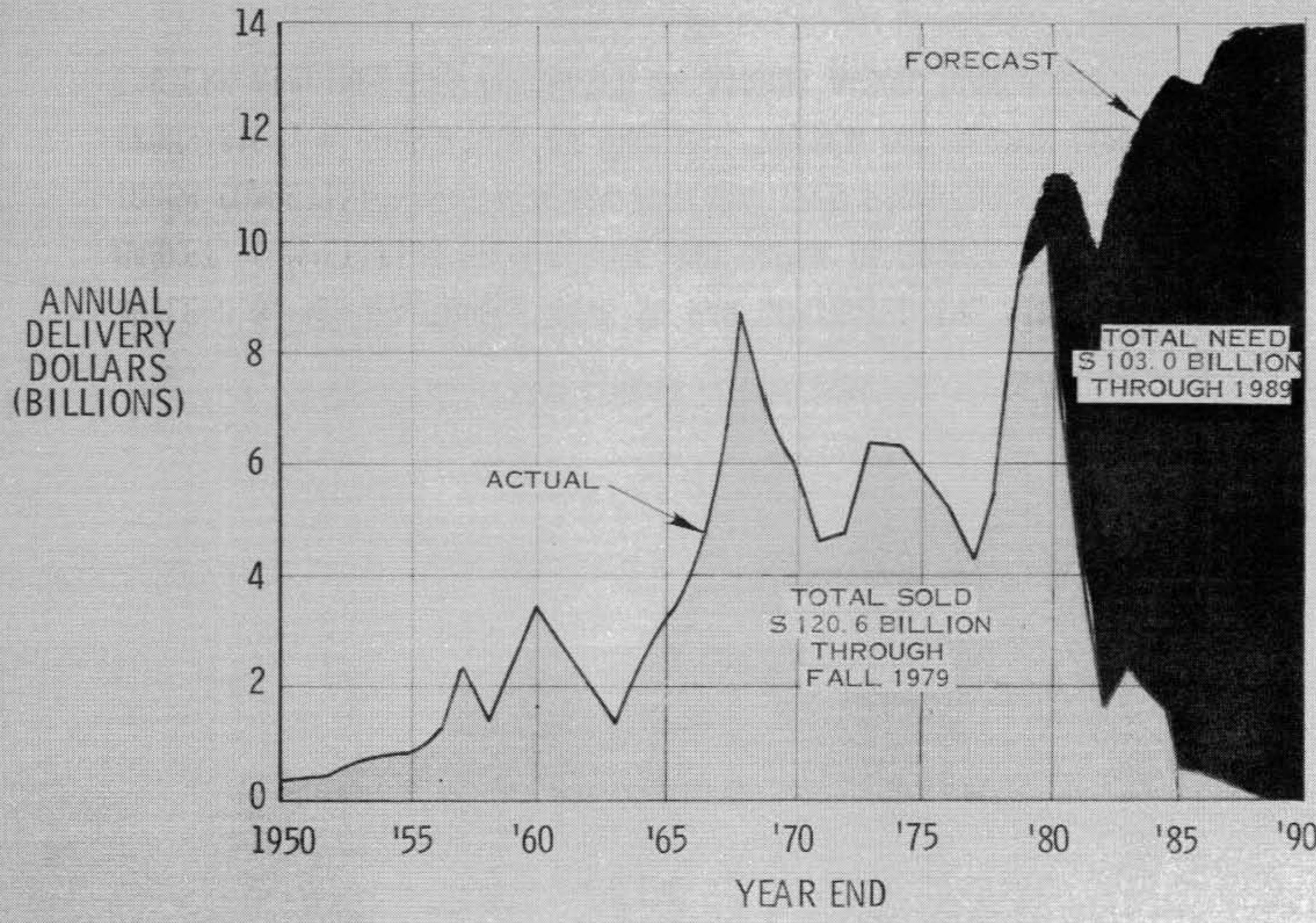
(CONSTANT 1979 DOLLARS)



NOTE: DOES NOT INCLUDE U.S.S.R. BUILT

SLIDE 5

WHILE U.S. MANUFACTURERS HAVE SO FAR DOMINATED THE AIR TRANSPORT MARKET, COMPETITION FROM EUROPE AND JAPAN IS GROWING. IN FACT, TOUGH COMPETITION HAS ALREADY MATERIALIZED FROM EUROPEAN AIRBUS INDUSTRIES, A CONSORTIUM OF ENGLISH, FRENCH AND GERMAN COMPANIES. EASTERN AIRLINES HAS PURCHASED 34 AIRBUS A-300 TRANSPORTS.


DAILY PRESS, Newport News, Va., Wednesday, December 14, 1977
European-Built Airbus Cracks U.S. Market
EASTERN
B1B9A1
6/80
5

SLIDE 6

AND, IN THE LAST FEW YEARS AIRBUS INDUSTRIES HAS, ON THE AVERAGE, CAPTURED SOME 20 PERCENT OF THE WORLD MARKET AND MOVED FIRMLY AHEAD OF DOUGLAS AND LOCKHEED TO BECOME THE SECOND LARGEST TRANSPORT MANUFACTURER IN THE WORLD. THESE GAINS REFLECT ENLIGHTENED AND SUBSTANTIAL HELP FROM THE EUROPEAN GOVERNMENTS INVOLVED.

SHARE OF THE WORLD JET TRANSPORT MARKET

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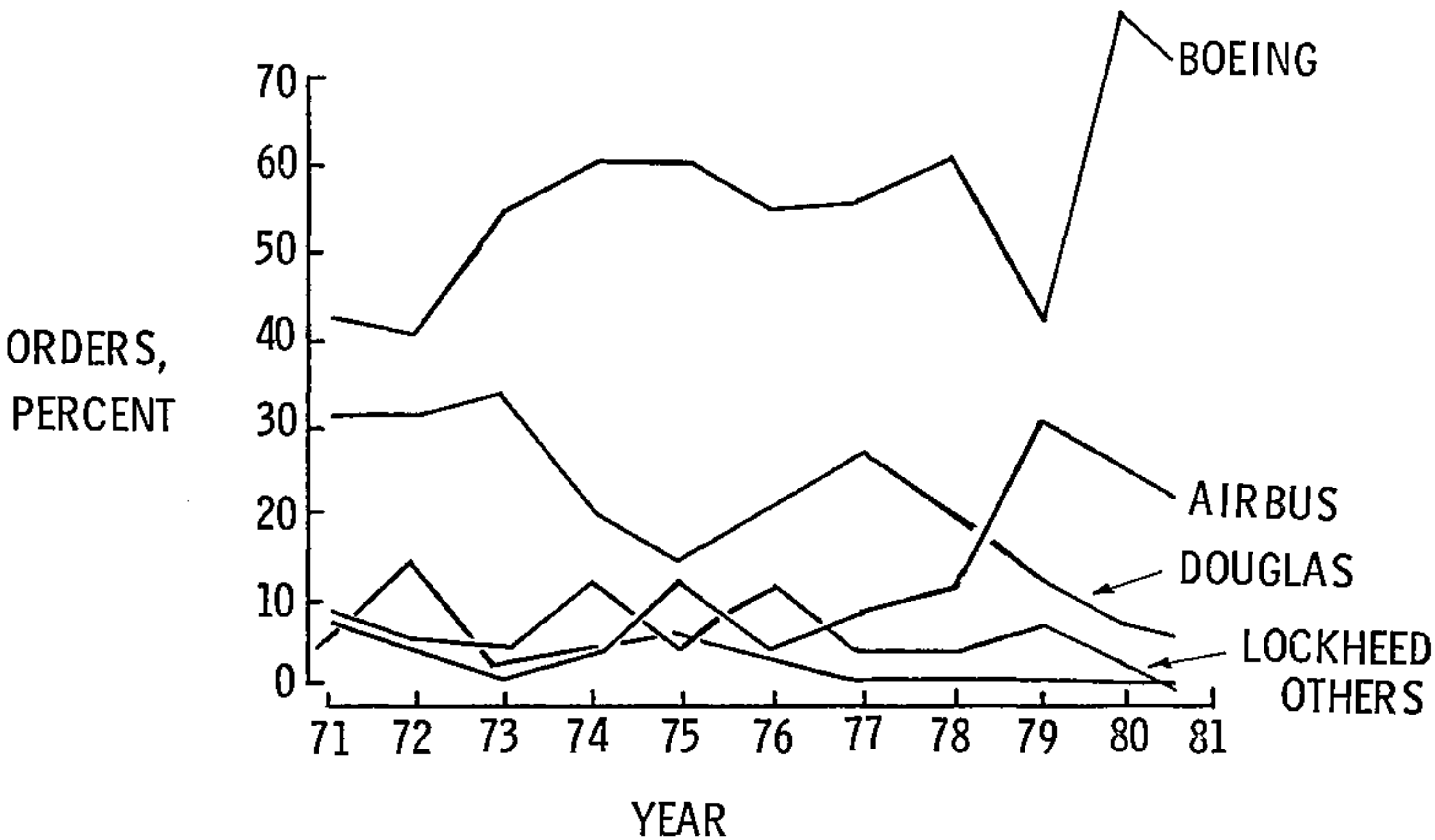
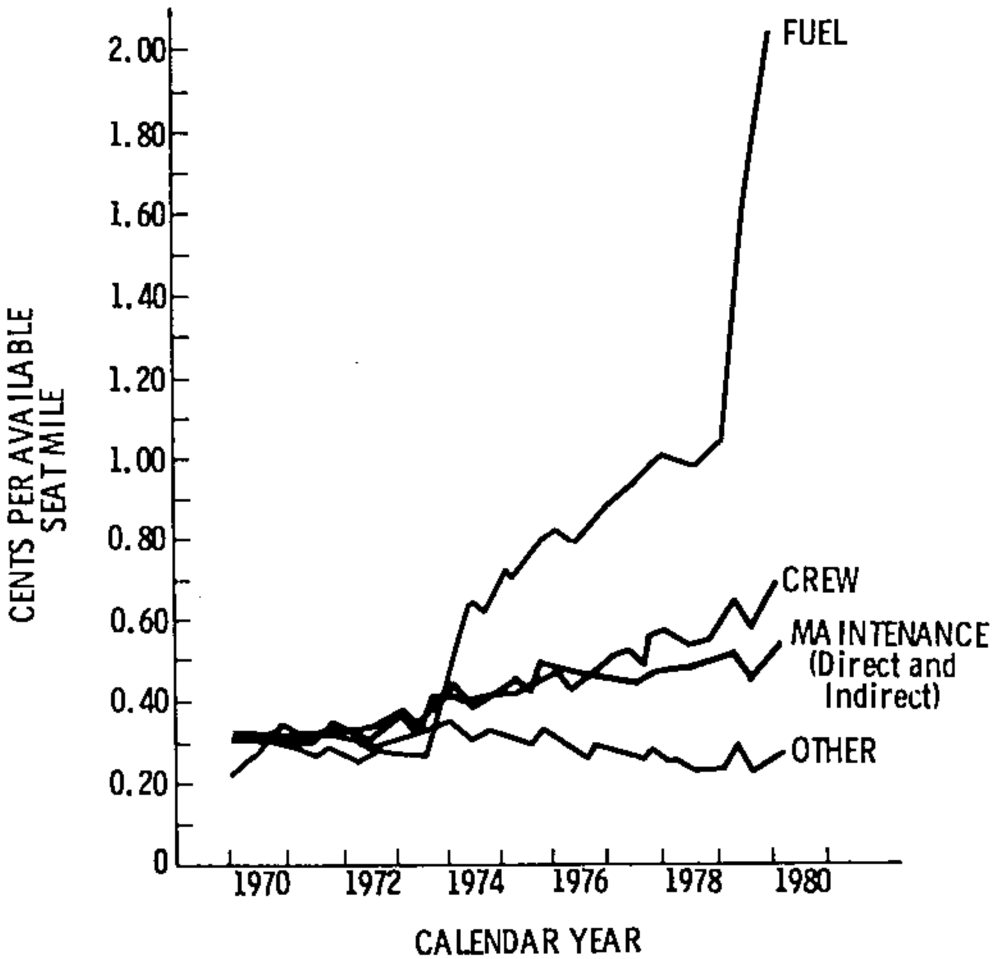


SLIDE 7

SUPERIMPOSED ON THIS MARKET SITUATION HAVE BEEN THE RECENT SHARP INCREASES IN THE COST OF JET AVIATION FUEL. THE IMPACT OF FUEL ON AIRLINE DIRECT OPERATING COSTS IS NOW GREATER THAN THE REMAINING COST ELEMENTS COMBINED.

THUS, MINIMIZING FUEL CONSUMPTION HAS BECOME CRITICALLY IMPORTANT TO THE AIRLINES' FINANCIAL HEALTH AND ABILITY TO OFFER QUALITY AIR TRANSPORTATION AT REASONABLE COST. AND, CLEARLY, THE KEY DESIGN GOAL FOR NEW AND IMPROVED AIRCRAFT, THAT CAN EFFECTIVELY COMPLETE FOR THE EXPECTED LARGE TRANSPORT MARKET OF THE NEXT TWO DECADES, IS <u>FUEL EFFICIENCY</u>!

ELEMENTS OF AIRLINE DIRECT OPERATING COST



SLIDE 8

RECOGNIZING THE NEW IMPORTANCE OF FUEL EFFICIENCY, AND IN RESPONSE TO A DIRECT REQUEST FROM THE SENATE OF THE UNITED STATES NASA MOUNTED AN EFFORT IN 1975 TO DEFINE TECHNOLOGY ADVANCES FOR FUEL CONSERVATION. A YEAR-LONG PLANNING ACTIVITY, WITH ADVICE FROM THE INDUSTRY AND REVIEW BY THE SENATE COMMITTEE ON AERONAUTICAL AND SPACE SCIENCES, LED TO FORMULATION OF THE AIRCRAFT ENERGY EFFICIENCY PROGRAM WITH THE SPECIFIC OBJECTIVE OF PRESERVING OUR AIR TRANSPORT INDUSTRY'S COMPETITIVE ADVANTAGE IN WORLD MARKETS THROUGH TECHNOLOGY FOR FUEL EFFICIENCY.

BIA
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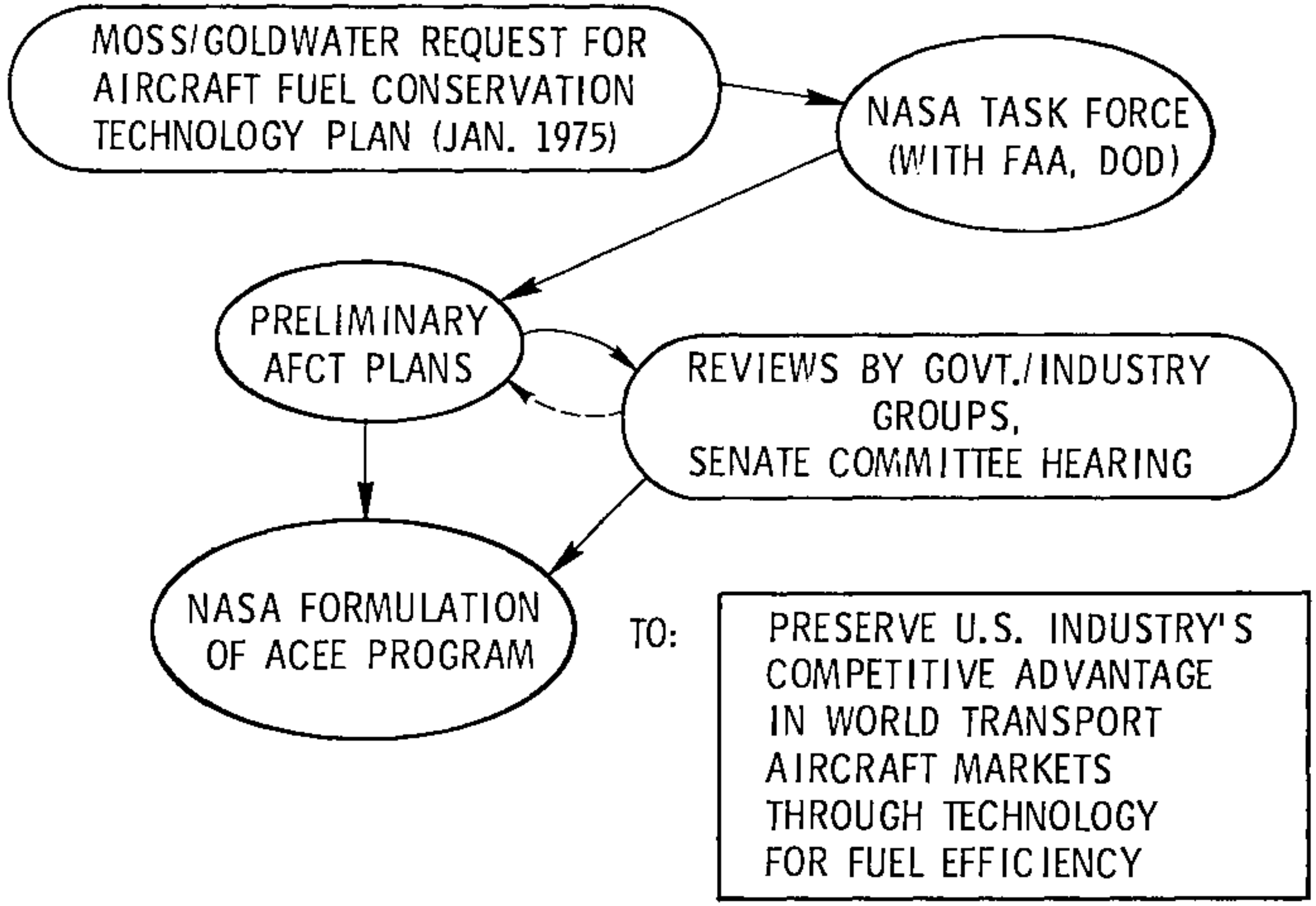
EVOLUTION OF THE AIRCRAFT ENERGY EFFICIENCY (ACEE) PROGRAM



SIX DIFFERENT TECHNOLOGY AREAS WERE IDENTIFIED WITH SUBSTANTIAL POTENTIAL FOR REDUCING TRANSPORT FUEL CONSUMPTION AND WITH AN ESTIMATED COMBINED POTENTIAL FOR 50 PERCENT REDUCTION. EACH PERCENT REDUCTION IN FUEL CONSUMPTION IS ABOUT 70,000 GALLONS OF FUEL PER WIDE-BODY AIRCRAFT PER YEAR. ALL SIX TECHNOLOGY DEVELOPMENT ACTIVITIES HAVE BEEN IMPLEMENTED IN THE ACEE PROGRAM.

POTENTIAL OF TECHNOLOGIES FOR REDUCED FUEL CONSUMPTION

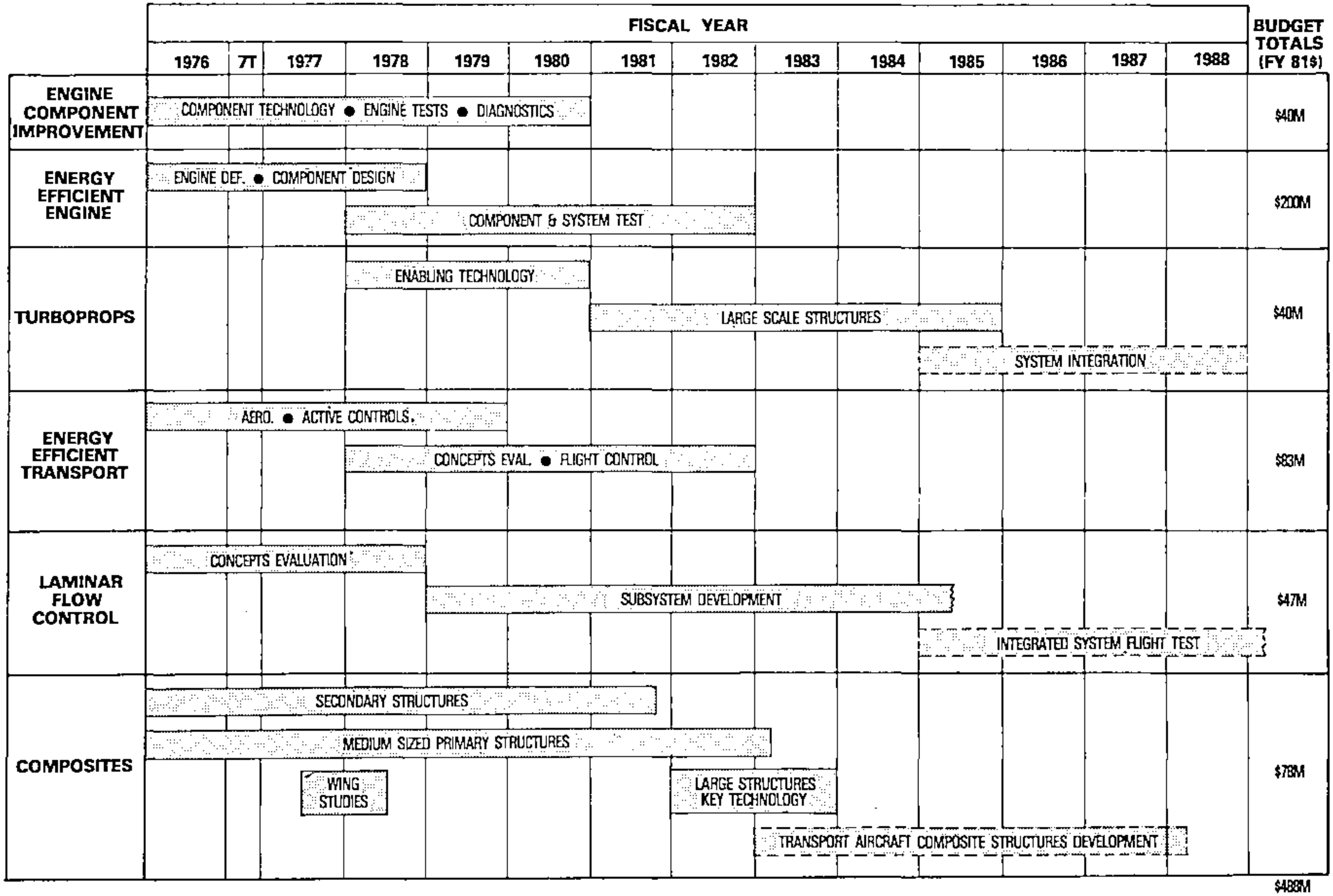
° ENGINE COMPONENT IMPROVEMENT	5%
° ADVANCED "ENERGY EFFICIENT ENGINE"	10%
° ADVANCED TURBOPROPS	15-20%
° COMPOSITE STRUCTURES	10-15%
° AERODYNAMICS AND ACTIVE CONTROLS	10-20%
° LAMINAR FLOW CONTROL	20-40%
° COMBINED POTENTIAL	50%

SLIDE 10

THE TIMING OF THE VARIOUS ELEMENTS OF THE ACEE PROGRAM IS SUMMARIZED HERE. THREE EFFORTS, ENGINE COMPONENT IMPROVEMENT, ENERGY EFFICIENT ENGINE DEVELOPMENT, AND ENERGY EFFICIENT TRANSPORT TECHNOLOGY (ADVANCED AERODYNAMICS AND ACTIVE CONTROLS), ARE NEARING COMPLETION. THE REMAINING EFFORTS, ADVANCED TURBO PROPS, COMPOSITE STRUCTURES, AND LAMINAR FLOW CONTROL HAVE FUTURE PHASES (SHOWN DASHED) FOR WHICH FUNDING COMMITMENTS HAVE NOT YET BEEN MADE. THESE FUTURE PHASES COULD CONTINUE THROUGH THE 1980'S.

FUNDING FOR THE COMMITTED EFFORTS (SOLID LINES) IS SHOWN AT THE RIGHT IN 1981 DOLLARS. THE TOTAL (488 MILLION DOLLARS) IS EXPECTED TO GROW WITH THE ADDITION OF FUTURE PHASES AND WITH ESCALATION.

AIRCRAFT ENERGY EFFICIENCY PROGRAM



SLIDE 11

PROGRAM MANAGEMENT RESPONSIBILITY FOR THE ACEE PROGRAM RESIDES IN NASA'S OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY IN THE TRANSPORT AIRCRAFT BRANCH* OF THE AERONAUTICAL SYSTEMS DIVISION. RESPONSIBILITY FOR MANAGING THE IMPLEMENTATION OF THE ENGINE ELEMENTS OF THE PROGRAM HAS BEEN DELEGATED TO THE ENERGY CONSERVATIVE ENGINES OFFICE OF THE LEWIS RESEARCH CENTER, AND RESPONSIBILITY FOR MANAGING THE IMPLEMENTATION OF THE AIRFRAME ELEMENTS IS ASSIGNED TO THE AIRCRAFT ENERGY EFFICIENCY PROJECT OFFICE OF THE LANGLEY RESEARCH CENTER.

THIS SUMMARY WILL BRIEFLY ADDRESS THE CONTENT AND STATUS OF THE ENGINE EFFORTS AND THEN WILL PROVIDE A MORE COMPREHENSIVE DESCRIPTION OF THE THREE AIRFRAME EFFORTS.

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* EXCEPT THAT ENERGY EFFICIENT ENGINE PROGRAM MANAGEMENT IS ASSIGNED TO THE PROPULSION BRANCH OF THE RESEARCH AND TECHNOLOGY DIVISION.

ACEE PROGRAM MANAGEMENT

LEWIS RESEARCH CENTER	OFFICE OF AERONAUTICS & SPACE TECHNOLOGY	LANGLEY RESEARCH CENTER
J. F. McCARTHY	J. L. KERREBROCK	D.P. HEARTH
AERONAUTICS DIRECTORATE	AERONAUTICAL SYSTEMS DIVISION	PROJECTS DIRECTORATE
M. A. BEHEIM	W. S. AIKEN (ACTING)	H.T. WRIGHT
ENERGY CONSERVATIVE ENGINES OFFICE	TRANSPORT AIRCRAFT BRANCH	ACEE PROJECT OFFICE
D.C. NORED	R. L. WINBLADE	R. L. JAMES, JR.

LEWIS RESEARCH CENTER – ENERGY CONSERVATIVE ENGINES OFFICE:

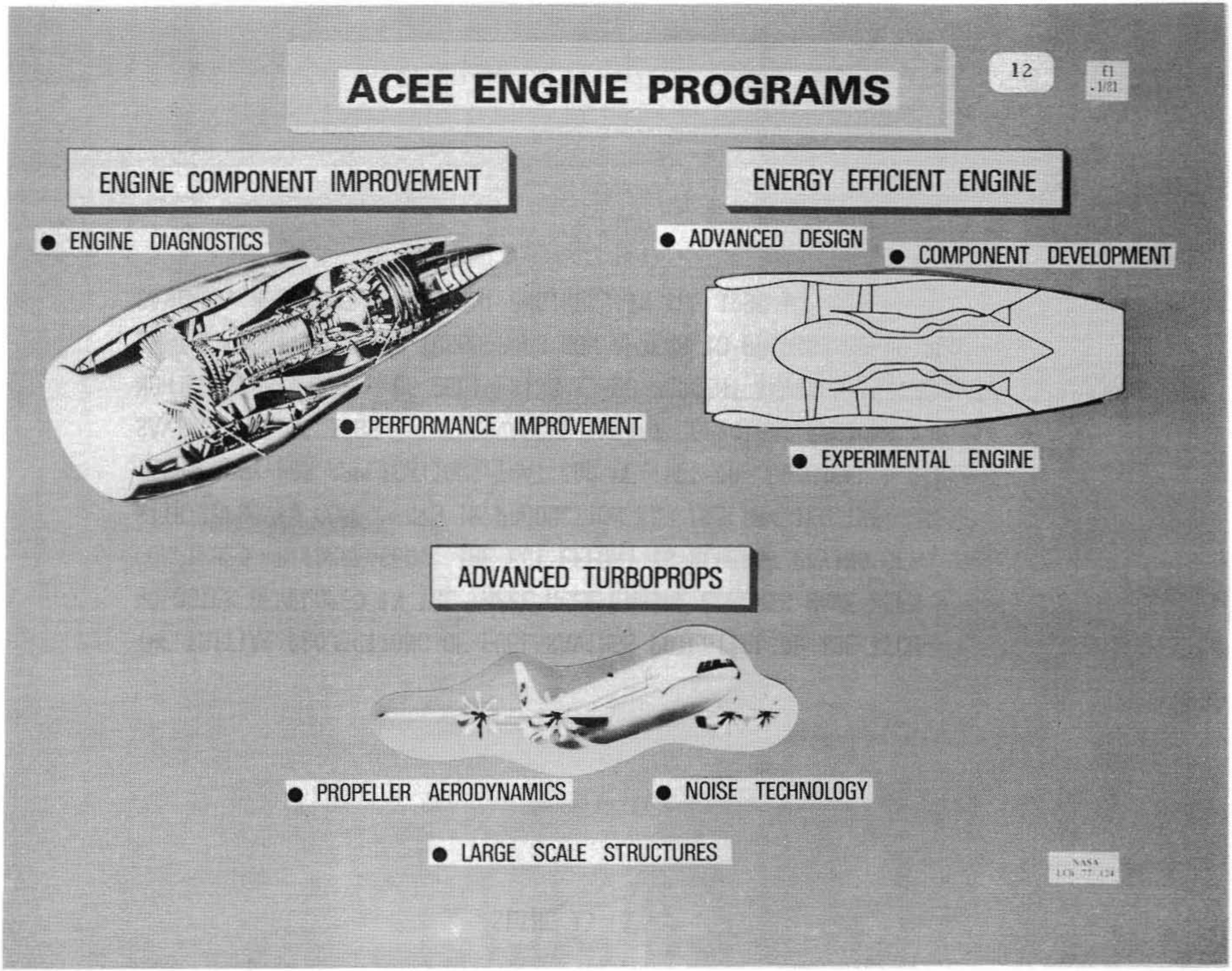
- ENGINE COMPONENT IMPROVEMENT
- ENERGY EFFICIENT ENGINE
- TURBOPROPS

LANGLEY RESEARCH CENTER – ACEE PROJECT OFFICE:

- COMPOSITE PRIMARY STRUCTURES
- ENERGY EFFICIENT TRANSPORT TECH.
- LAMINAR FLOW CONTROL

SLIDE 12

ENGINE COMPONENT IMPROVEMENT INCLUDES SPECIFIC EFFORTS TO DIAGNOSE THE CAUSES OF PERFORMANCE DETERIORATION IN CURRENT ENGINE DESIGNS AND TO DEVELOP COMPONENT CHANGES FOR IMPROVED PERFORMANCE. THE ENERGY EFFICIENT ENGINE EFFORT WILL CARRY TWO ADVANCED, MORE EFFICIENT DESIGNS THROUGH THE COMPONENT DEVELOPMENT AND EXPERIMENTAL ENGINE GROUND TEST STAGES. THE ADVANCED TURBOPROP EFFORT IS AIMED AT EXTENDING THE OPERATION OF TURBOPROPS, WHICH ARE MORE EFFICIENT THAN JETS, TO THE HIGHER SPEED RANGE OF TODAY'S JET TRANSPORTS. THE FIRST TWO PHASES OF THIS EFFORT ARE FOCUSED ON DEVELOPING AND VERIFYING EFFICIENT SHAPES AND STRUCTURES FOR THE PROPELLORS AND ON SOLVING THE SPECIAL NOISE PROBLEMS PRESENTED BY PROPS WHOSE TIPS ARE MOVING AT SUPERSONIC SPEEDS. ALL THESE EFFORTS ARE BEING CARRIED OUT BY THE U.S. COMMERCIAL AIRCRAFT ENGINE INDUSTRY IN (USUALLY COST-SHARED) CONTRACTS WITH NASA.


ACEE ENGINE PROGRAMS
12
ENGINE COMPONENT IMPROVEMENT
● ENGINE DIAGNOSTICS
● PERFORMANCE IMPROVEMENT
ENERGY EFFICIENT ENGINE
● ADVANCED DESIGN
● COMPONENT DEVELOPMENT
● EXPERIMENTAL ENGINE
ADVANCED TURBOPROPS
● PROPELLER AERODYNAMICS
● NOISE TECHNOLOGY
● LARGE SCALE STRUCTURES
NASA

SLIDE 13

THE INITIAL PROJECTIONS OF FUEL SAVINGS POTENTIAL OF THE TECHNOLOGIES DEVELOPED IN THE THREE ACEE ENGINE EFFORTS HAVE BEEN CONFIRMED OR INCREASED. THE ECI EFFORT IS ALREADY PAYING OFF WITH IMPROVED COMPONENTS IN PRODUCTION AND HAS READIED THE TECHNOLOGY FOR APPLICATIONS THAT CAN DELIVER THE PROMISED 5 PERCENT SAVINGS BEFORE 1985. THE ADVANCED ENERGY EFFICIENT ENGINES ARE NOW SEEN AS CAPABLE OF DELIVERING 15-20 PERCENT SAVINGS IN THE LATE 1980's. AND ADVANCED TURBOPROPS NOW APPEAR TO PROMISE 30-40 PERCENT SAVINGS, RELATIVE TO CURRENT ENGINES, IN THE 1990's.

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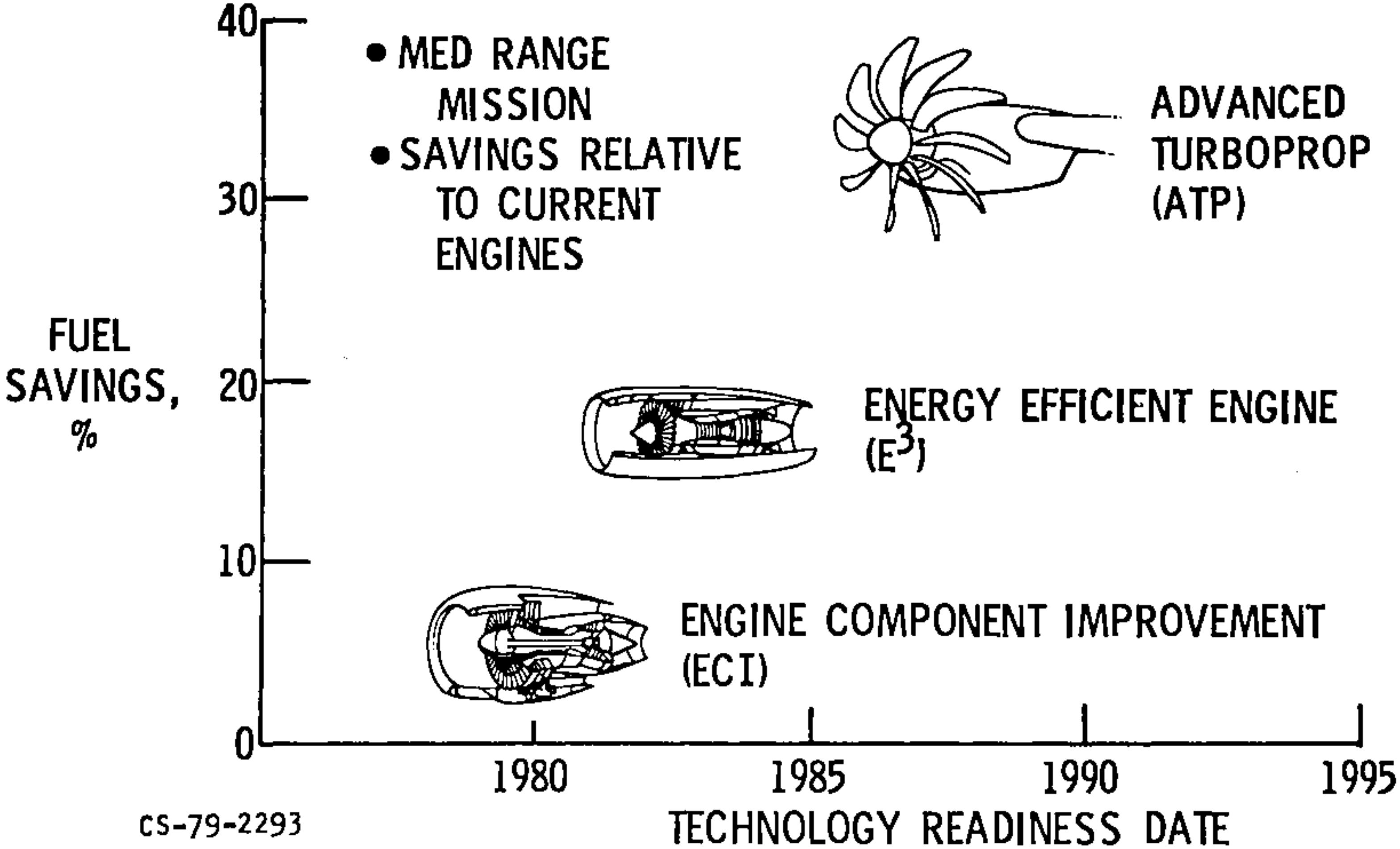
ACEE PROPULSION PROJECTS

PROJECTED FUEL SAVINGS & TECHNOLOGY READINESS DATES



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SLIDE 14

DESCRIPTION OF THE AIRFRAME ELEMENTS OF THE ACEE PROGRAM WILL BEGIN WITH THE COMPOSITE PRIMARY AIRCRAFT STRUCTURES (CPAS) PROJECT.

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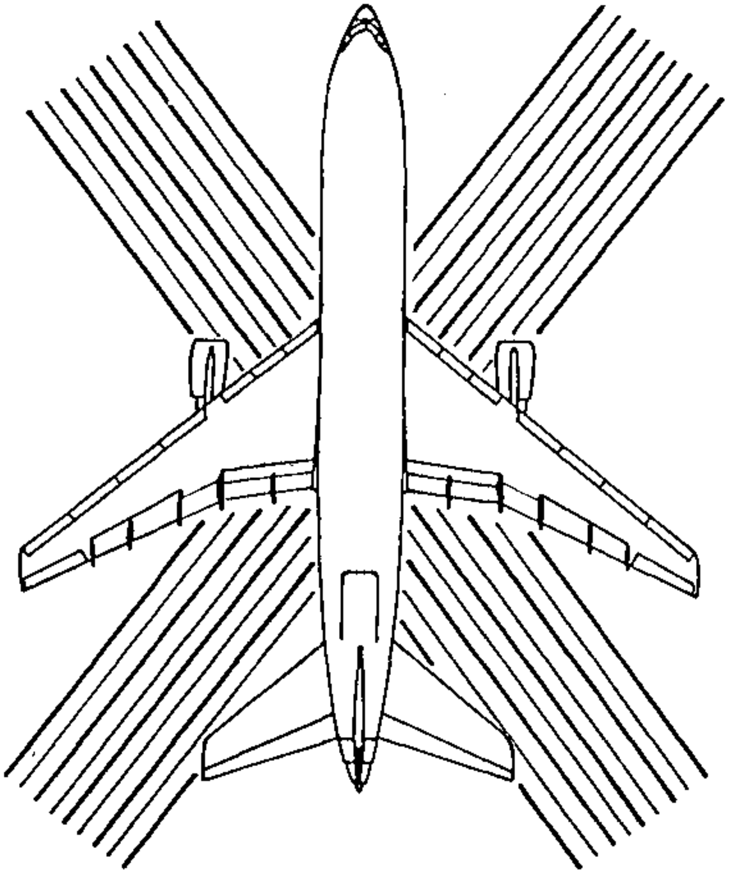
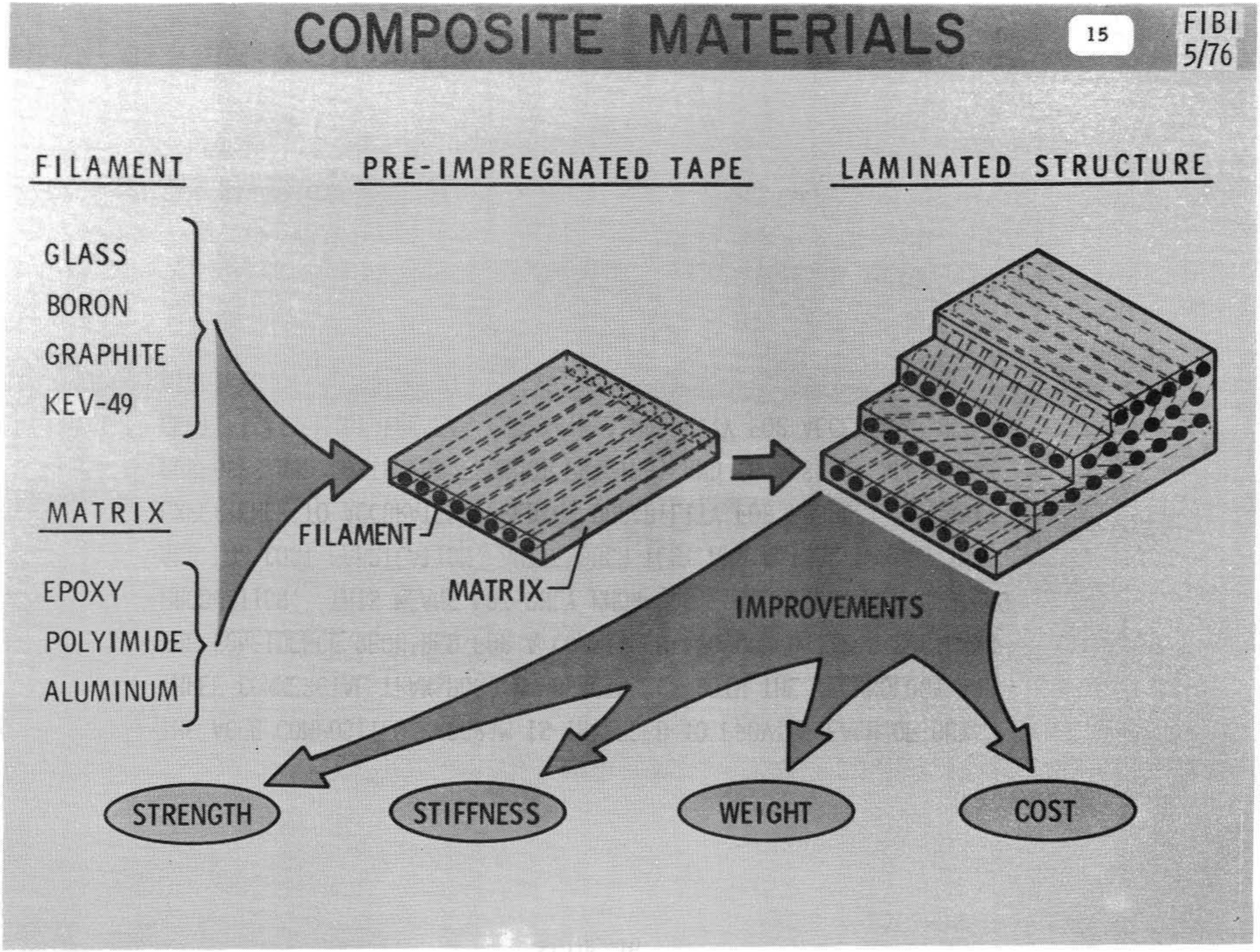
5/80



COMPOSITE PRIMARY AIRCRAFT STRUCTURES

SLIDE 15

THE WORD "COMPOSITE" IS USED TO DENOTE STRUCTURES MADE BY EMBEDDING FILAMENTS OF ONE MATERIAL IN A SHEET OF ANOTHER MATERIAL (CALLED THE "MATRIX") TO FORM A "PLY" OF PARALLEL FIBERS (TAPE) OR WOVEN CLOTH. PLIES ARE THEN LAID UP AT DIFFERENT ANGLES AND CURED UNDER HEAT AND PRESSURE TO FORM STRUCTURES WITH GREATER STRENGTH AND STIFFNESS OR LESS WEIGHT THAN CONVENTIONAL METAL STRUCTURES. REDUCED COST IS ALSO FEASIBLE AND DESIRABLE IN APPLICATION OF SUCH MATERIALS TO COMMERCIAL AIRPLANE STRUCTURES. COMMON FIBERGLASS WITH GLASS FILAMENTS IN EPOXY IS AN EXAMPLE OF A COMPOSITE MATERIAL. OF PRIMARY INTEREST IN COMMERCIAL TRANSPORT STRUCTURES ARE VARIOUS GRAPHITE FILAMENTS AND SEVERAL DIFFERENT EPOXY MATRIX MATERIALS.


COMPOSITE MATERIALS
15
FIBI
5/76
FILAMENT
PRE-IMPREGNATED TAPE
LAMINATED STRUCTURE
GLASS
BORON
GRAPHITE
KEV-49
MATRIX
EPOXY
POLYIMIDE
ALUMINUM
FILAMENT
MATRIX
IMPROVEMENTS
STRENGTH
STIFFNESS
WEIGHT
COST

SLIDE 16

THE ACEE COMPOSITES PROGRAM IS INTENDED TO PROVIDE EACH OF OUR THREE COMMERCIAL TRANSPORT MANUFACTURERS BOTH THE TECHNOLOGY AND THE CONFIDENCE REQUIRED FOR A COMMITMENT TO COMPOSITE STRUCTURES PRODUCTION. THIS MEANS NOT ONLY KNOW-HOW FOR PREDICTABLE DESIGNS AND LOW COST FABRICATION, BUT ENOUGH TEST AND ACTUAL MANUFACTURING EXPERIENCE TO ACCURATELY PREDICT DURABILITY FOR PRODUCT WARRANTY PURPOSES AND COSTS FOR PRODUCT PRICING, AND TO ASSURE SAFETY FOR CERTIFICATION BY THE FAA AND MAINTAINABILITY FOR ACCEPTANCE BY THE AIRLINES.

A C E E COMPOSITE PROGRAM

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OBJECTIVE

PROVIDE THE **TECHNOLOGY** AND **CONFIDENCE** SO THAT COMMERCIAL TRANSPORT MANUFACTURERS CAN COMMIT TO PRODUCTION OF COMPOSITES IN THEIR FUTURE AIRCRAFT:

SECONDARY STRUCTURE - 1980 TO 1985

PRIMARY STRUCTURE - 1985 - 1990

TECHNOLOGY

- DESIGN CRITERIA, METHODS AND DATA
- QUALIFIED DESIGN CONCEPTS
- COST COMPETITIVE MANUFACTURING PROCESSES

CONFIDENCE

- DURABILITY/WARRANTY
- QUANTITY COST VERIFICATION
- FAA CERTIFICATION
- AIRLINE ACCEPTANCE

SLIDE 17

TOWARD THIS END, THE MANUFACTURERS ARE DEVELOPING COMPOSITE VERSIONS OF STRUCTURAL COMPONENTS ON EXISTING AIRCRAFT WITH NASA PAYING 90 PERCENT OF THE COST. DEVELOPMENT INVOLVES TESTING OF VARIOUS MATERIAL OPTIONS BEFORE SELECTING ONE AND THEN EXTENSIVE TESTING TO DEVELOP AN ADEQUATE DATA BASE OF MATERIAL STRENGTH AND STIFFNESS PROPERTIES. DESIGN OPTIONS ARE NARROWED TO ONE THROUGH ANALYSIS AND A VARIED SPECTRUM OF DEVELOPMENT TESTS ON SMALL AND LARGE SUBCOMPONENTS. IN PARALLEL WITH THIS, A SUITABLE PRODUCTION PROCESS INCLUDING ECONOMICAL PLY PREPARATION AND CURE AT HIGH TEMPERATURE AND PRESSURE IS EVOLVED, TOOLS ARE DESIGNED AND FABRICATED, AND FULL SCALE COMPONENTS THEN MANUFACTURED FOR GROUND QUALIFICATION TESTS, FLIGHT TESTS, AND AIRLINE SERVICE. THE VARIOUS TESTS INCLUDE MANY THAT ARE REQUIRED BY FAA FOR FLIGHT CERTIFICATION, WHICH MUST PRECEDE AIRLINE SERVICE. INSPECTION AND REPAIR METHODS TO INSURE ADEQUATE MAINTENANCE IN SERVICE ARE ALSO DEVELOPED.

COMPONENT DEVELOPMENT TOWARD A PRODUCTION COMMITMENT

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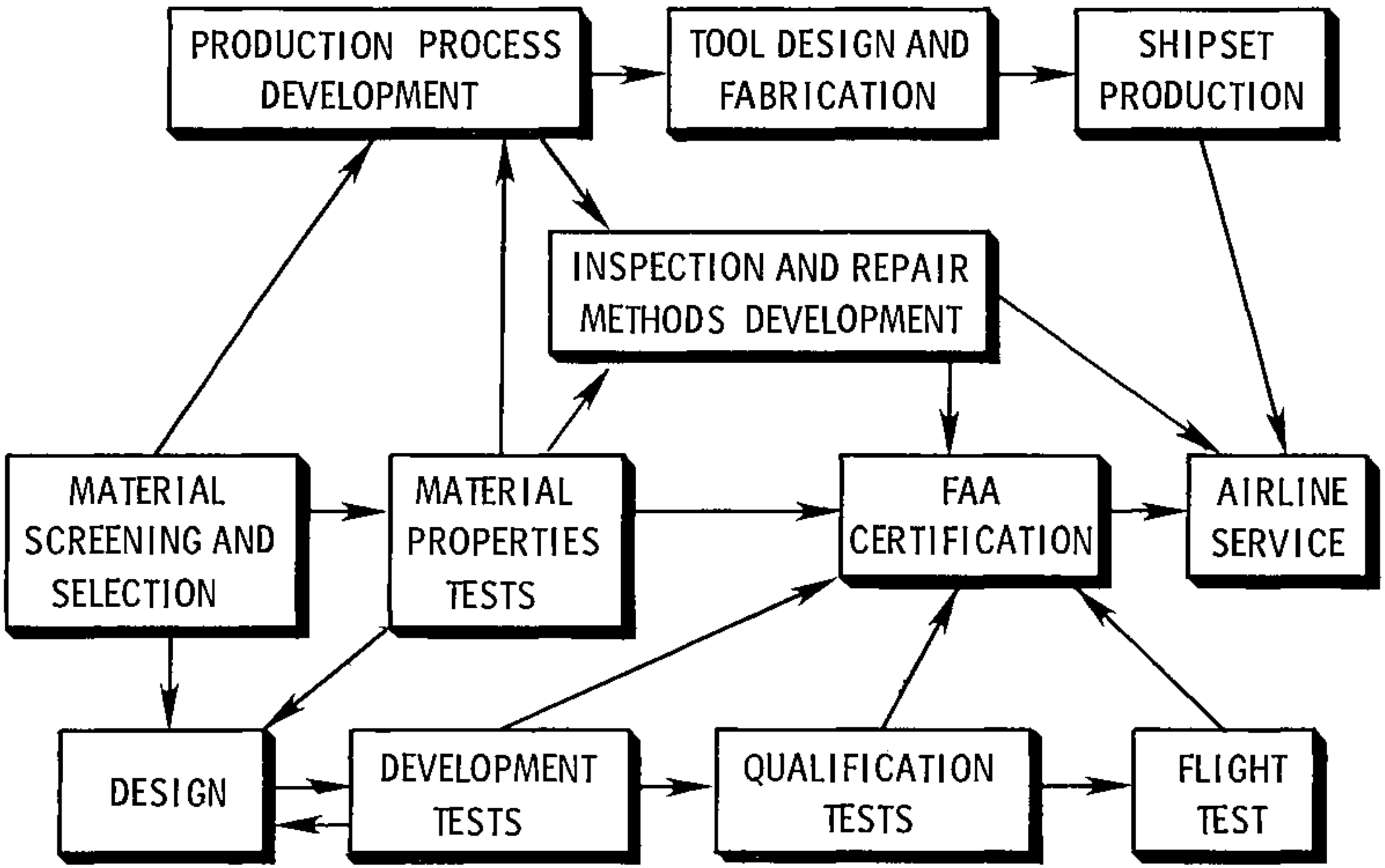
1/80



SLIDE 18

COMPOSITE COMPONENTS DEVELOPED IN THIS WAY INCLUDE THE ELEVATORS ON THE BOEING 727, THE INBOARD AILERONS OF THE LOCKHEED L-1011, AND THE UPPER AFT RUDDER OF THE DOUGLAS DC-10. SUCH STRUCTURES ARE CALLED "SECONDARY" STRUCTURES BECAUSE THEY DO NOT CARRY PRIMARY FLIGHT LOADS AND ARE NOT CRITICAL TO FLIGHT SAFETY.

ACEE

COMPOSITE SECONDARY STRUCTURES

BOEING 727 COMPOSITE ELEVATOR

DOUGLAS DC-10 COMPOSITE RUDDER

LOCKHEED L-1011 COMPOSITE AILERON

NASA
LCh-78-92

THE ACEE COMPOSITE SECONDARY STRUCTURES EFFORTS ARE ESSENTIALLY COMPLETE. FOR EXAMPLE, TWENTY COMPOSITE UPPER AFT RUDDERS, WITH 26 PERCENT WEIGHT SAVINGS, HAVE BEEN MANUFACTURED, CERTIFICATED BY THE FAA, AND COMMITTED TO FLIGHT SERVICE ON OPERATIONAL DC-10's. TWELVE COMPOSITE RUDDERS ARE ALREADY IN SERVICE AND ONE HAS ACCUMULATED OVER 20,000 FLIGHT HOURS. THE ONLY INCIDENT IN ALL THIS FLIGHT EXPERIENCE WAS MINOR DAMAGE FROM A LIGHTENING STRIKE THAT DID NOT REQUIRE REPAIR UNTIL THE AIRCRAFT WAS REPAINTED SOME TWO YEARS AFTER THE INCIDENT.

THE COVERS, SPARS, AND RIBS ARE CURED AND BONDED TOGETHER INTO THE ASSEMBLED RUDDER IN A SINGLE CURE CYCLE THAT WILL BEGIN TO YIELD MANUFACTURING COST SAVINGS, RELATIVE TO THE ALUMINUM RUDDER, IF MORE THAN 75 COMPOSITE RUDDERS ARE PRODUCED. A PRODUCTION DECISION IS PENDING.

19

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1/81

DC-10 COMPOSITE RUDDER
LIGHTNING DAMAGE

SLIDE 20

FIVE SHIPSETS OF COMPOSITE INBOARD AILERONS FOR THE LOCKHEED L-1011 HAVE BEEN MANUFACTURED, GROUND AND FLIGHT TESTED, AND CERTIFICATED BY FAA PREPARATORY TO PLANNED FLIGHT SERVICE ON COMMERCIAL AIRCRAFT. SINCE WEIGHT SAVINGS ARE 24 PERCENT AND THE REDUCED NUMBER OF RIBS AND FASTENERS PROVIDES A POTENTIAL FOR ULTIMATE COST SAVINGS, A PRODUCTION DECISION IS POSSIBLE.

L-1011 COMPOSITE GROUND TEST AILERON

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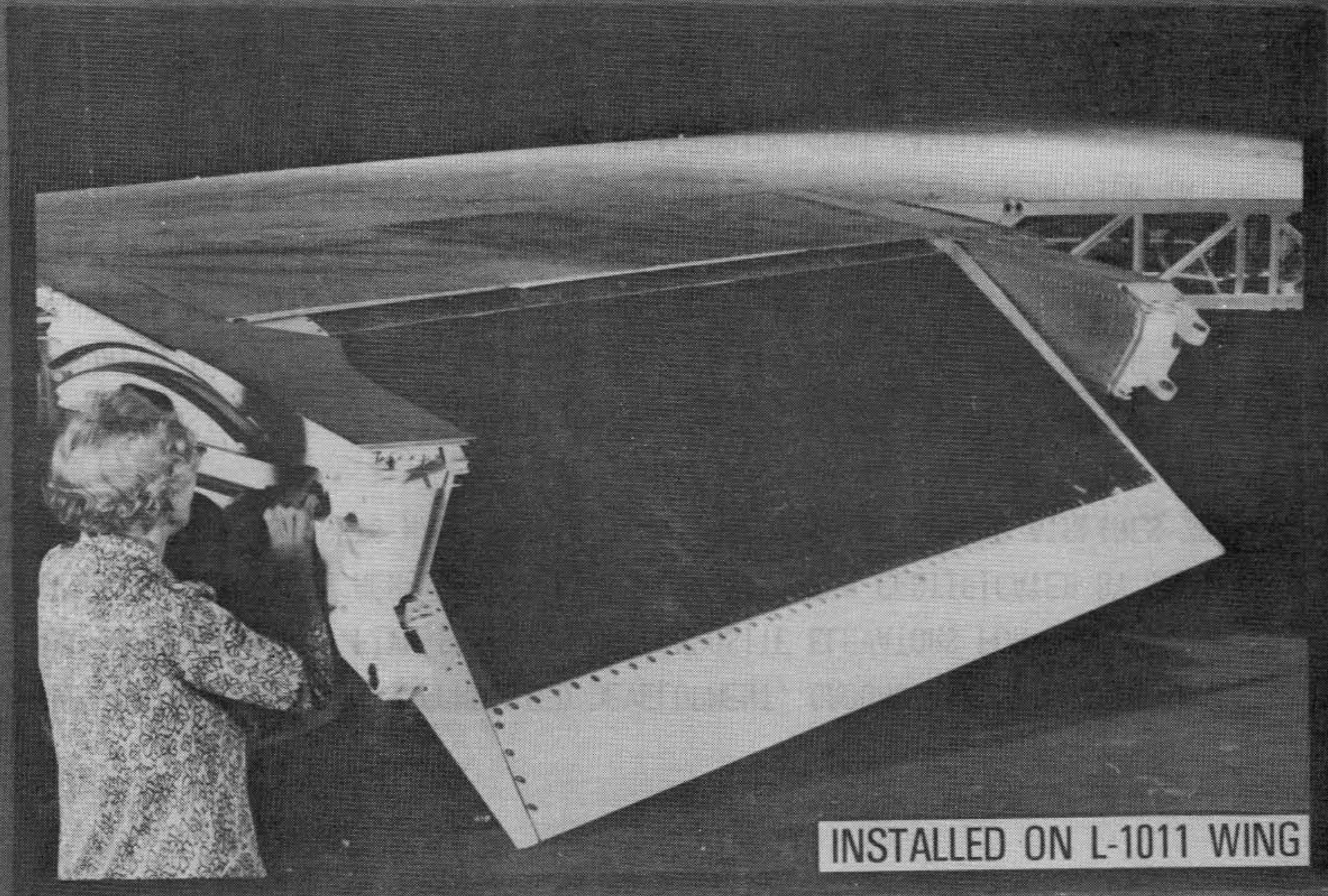

SLIDE 21

THE BOEING COMPANY HAS COMPLETED DEVELOPMENT, GROUND AND FLIGHT TESTING, AND MANUFACTURE OF FIVE SHIPSETS OF COMPOSITE ELEVATORS FOR THE 727. FOUR SHIPSETS ARE SHOWN HERE. THIS STRUCTURE HAS BEEN CERTIFICATED BY THE FAA AND ALL FIVE SHIPSETS HAVE BEEN PUT INTO SERVICE ON UNITED AIRLINES 727's.

THE COMPOSITE ELEVATOR'S CONSTRUCTION EMPLOYS LIGHT WEIGHT HONEYCOMB SANDWICH IN THE COVERS AND IN THE WEBS OF THE FEW RIBS. THE COVER SANDWICH CONSISTS OF ONLY ONE PLY OF CLOTH AND ONE PLY OF TAPE ON EACH SIDE OF A NOMEX HONEYCOMB CORE. THIS CONSTRUCTION IS NOT ONLY 25 PERCENT LIGHTER THAN THE METAL ELEVATOR BUT PERMITS A 41 PERCENT REDUCTION IN THE NUMBER OF PARTS AND A POTENTIAL MANUFACTURING COST SAVING.

727 GRAPHITE-EPOXY ELEVATORS

21

F4A12A
11/79

SLIDE 22

BOEING HAS COMMITTED ALL THE CONTROL SURFACES OF BOTH THE NEW 767 AIRCRAFT (SHOWN HERE) AND THE NEW 757 AIRCRAFT TO GRAPHITE/EPOXY WITH CONSTRUCTION SIMILAR TO THE 727 ELEVATORS. FIXED SECONDARY STRUCTURE AT THE WING ROOT AND TRAILING EDGE AND TAIL SURFACE TRAILING EDGES PLUS COWLINGS, DOORS, ETC., HAS ALSO BEEN COMMITTED TO SIMILAR COMPOSITE CONSTRUCTION WHERE SOME GRAPHITE PLIES ARE REPLACED WITH KEVLAR. TOTAL WEIGHT SAVED ON THE 767 IS ABOUT 845 LBS, CORRESPONDING TO ABOUT 2 PERCENT FUEL SAVING. THIS AMOUNTS TO 100,000 GALLONS PER YEAR PER AIRCRAFT. WHEN IN FULL PRODUCTION OF THESE TWO AIRCRAFT, BOEING WILL UTILIZE 87,000 POUNDS OF GRAPHITE/EPOXY PREPREG EACH MONTH.

COMPOSITE STRUCTURE ON B-767

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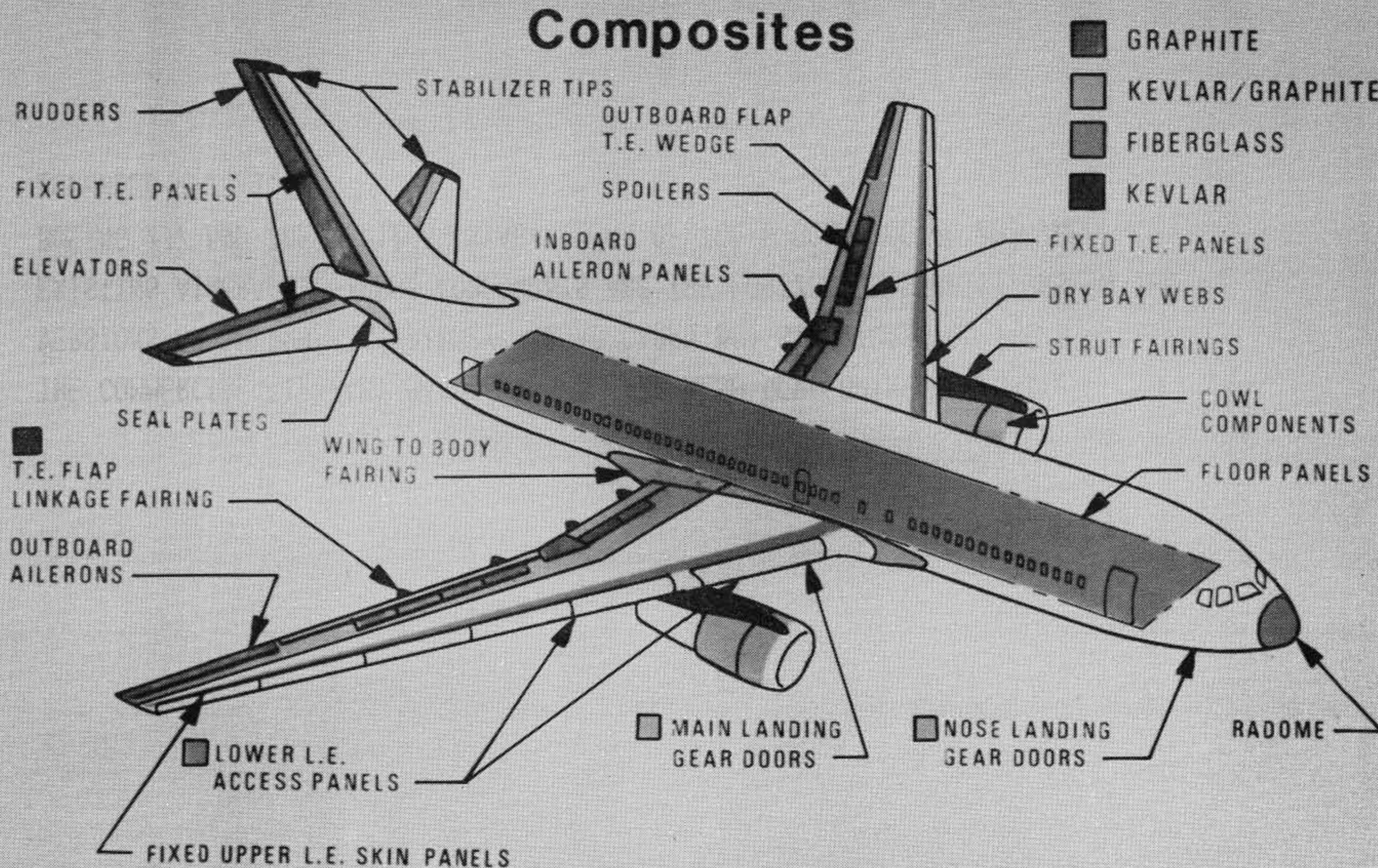

SLIDE 23

THE COMMERCIAL AIRCRAFT MANUFACTURERS ARE ALSO DEVELOPING COMPOSITE VERSIONS OF EMPENNAGE "PRIMARY" (LOAD CARRYING) STRUCTURES ON THEIR EXISTING AIRCRAFT. THESE COMPONENTS ARE THE HORIZONTAL STABILIZERS ON THE BOEING 737 AND THE VERTICAL STABILIZERS OF THE DOUGLAS DC-10 AND THE LOCKHEED L-1011.

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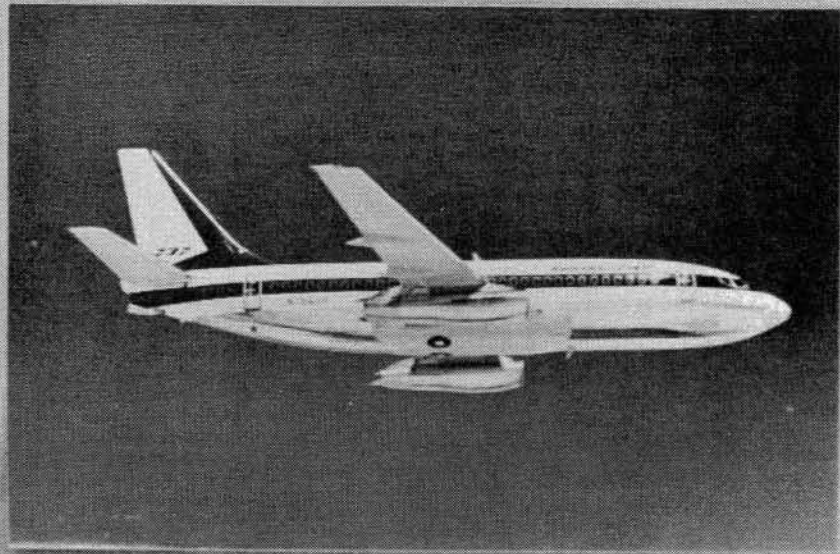
COMPOSITE MEDIUM PRIMARY STRUCTURES



BOEING 737 COMPOSITE HORIZONTAL STABILIZER

DOUGLAS DC-10 COMPOSITE VERTICAL STABILIZER

LOCKHEED L-1011 COMPOSITE VERTICAL FIN

NASA
L-78-91

SLIDE 24

THE I-STIFFENED, SOLID LAMINATE SKINS, THE SOLID LAMINATE SPARS, AND THE HONEYCOMB RIBS OF THE 737 STABILIZERS ARE SEPARATELY LAID UP ON RIGID TOOLING, VACUUM BAGGED, AND AUTOCLAVE CURED IN A PRESCRIBED CYCLE OF APPLIED PRESSURES AND TEMPERATURES UP TO 350° F. THE SEPARATE COMPONENTS ARE THEN DRILLED AND ASSEMBLED WITH MECHANICAL FASTENERS.

COMPOSITE 737 STABILIZER ASSEMBLY METHODS

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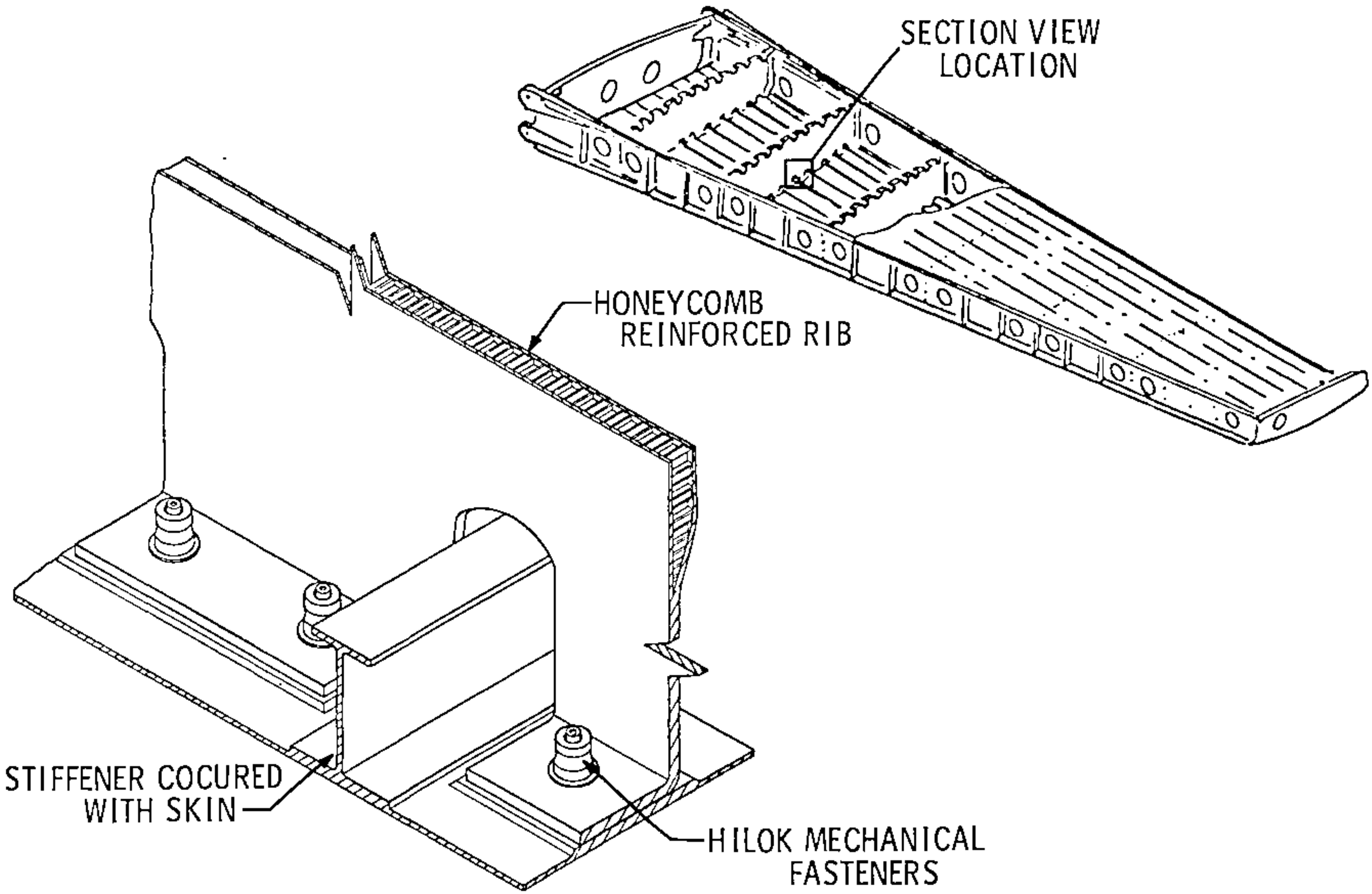
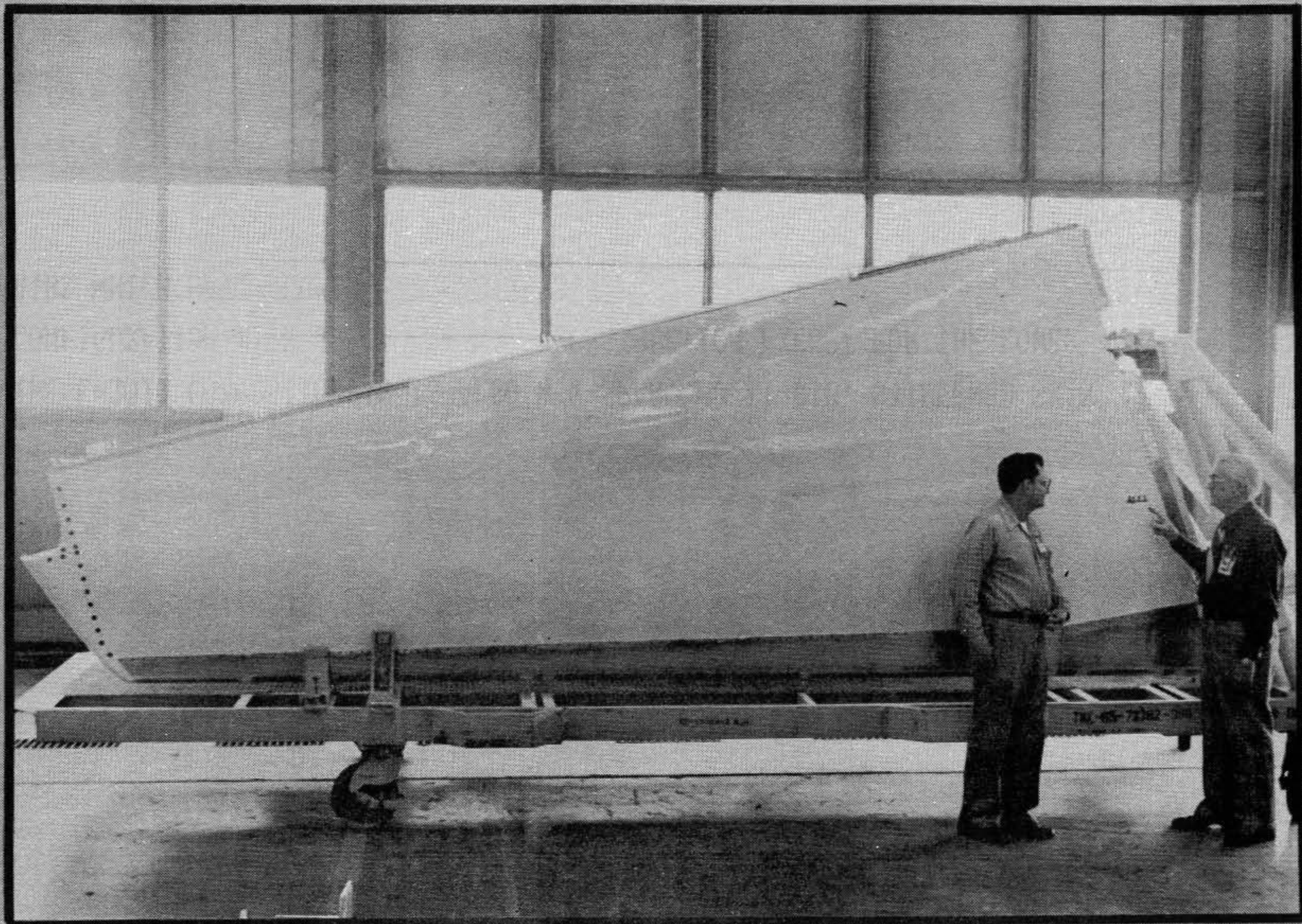


GROUND TESTING OF AN ASSEMBLED 737 COMPOSITE STABILIZER UNIT IS COMPLETE AND THE FIRST SHIPSET COMPLETED FLIGHT TESTING IN SEPTEMBER 1980. THIS MARKED THE FIRST FLIGHT OF COMPOSITE PRIMARY STRUCTURE ON A COMMERCIAL TRANSPORT AIRCRAFT. PRODUCTION OF FIVE SHIPSETS FOR MANUFACTURING COST EXPERIENCE AND POSSIBLE FLIGHT SERVICE IS ALSO COMPLETE AND FAA CERTIFICATION IS EXPECTED IN MARCH 1982. WEIGHT SAVINGS OVER THE ALUMINUM STABILIZERS IS 22 PERCENT.

737 ADVANCED COMPOSITE HORIZONTAL STABILIZER

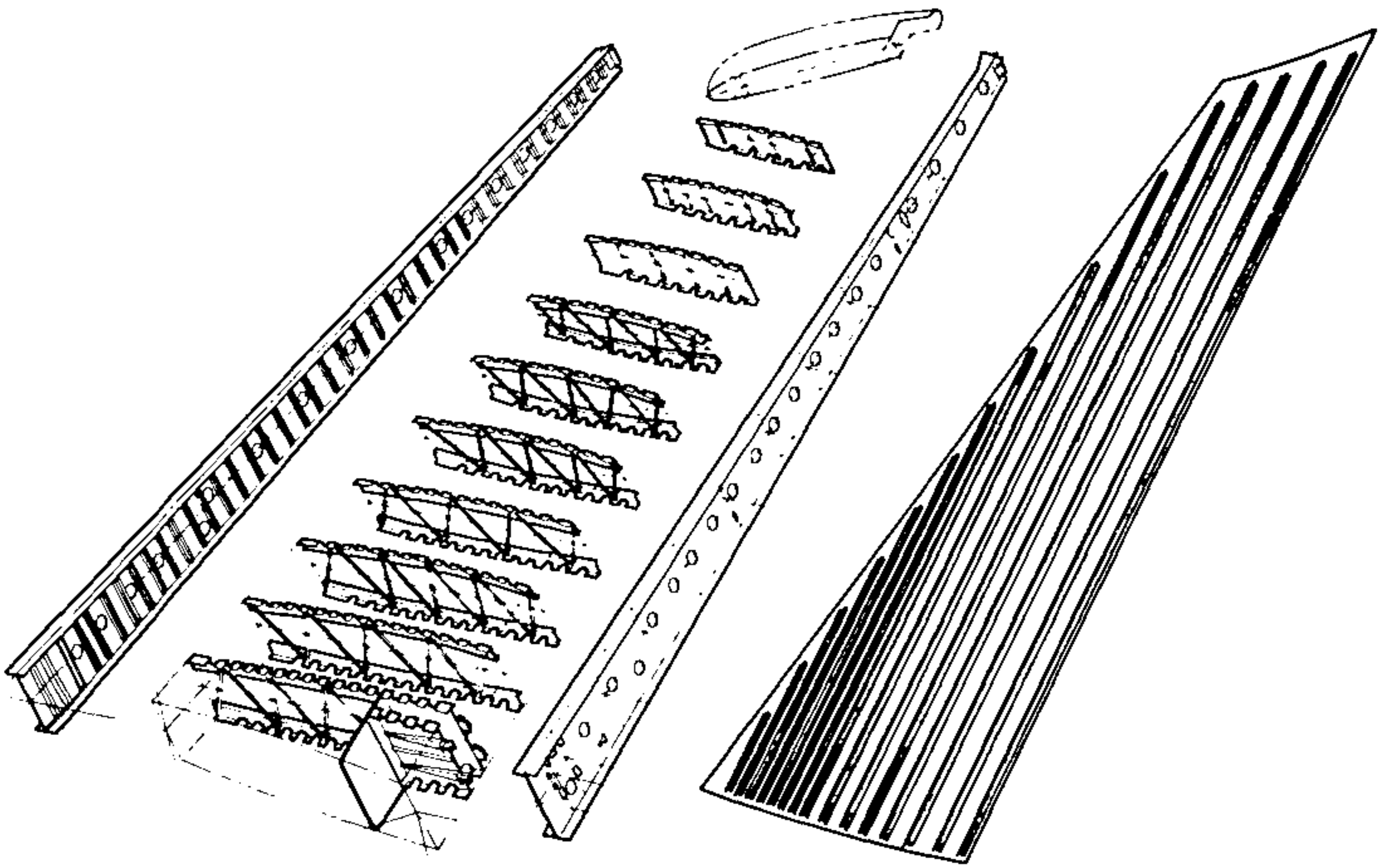
R/H UNIT OF FLIGHT TEST SHIPSET



SLIDE 26

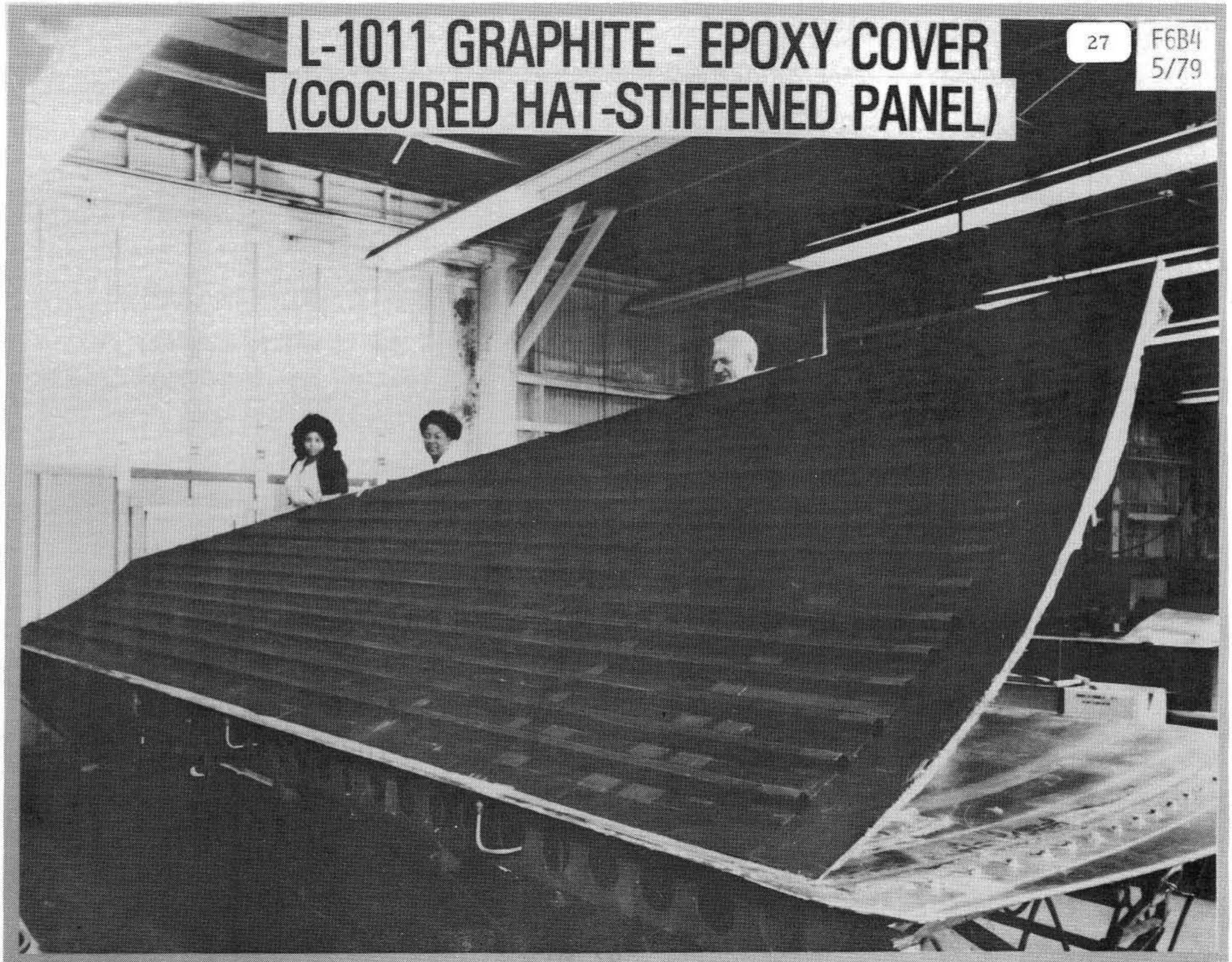
THE L-1011 COMPOSITE FIN IS ALSO A 2-SPAR, MULTI-RIB, STIFFENED SKIN CONFIGURATION WITH SOLID LAMINATE CONSTRUCTION EXCEPT FOR THE LOWER RIBS WHICH HAVE ALUMINUM TRUSS WEBS.

L-1011 FIN STRUCTURAL CONFIGURATION



SLIDE 27

THE L-1011 FIN COVERS ARE 25 FEET LONG BY 9 FEET WIDE AT THE ROOT AND HAVE HAT-SECTION STIFFENERS THAT REQUIRE INTERNAL AND EXTERNAL MANDRELS FOR SIMULTANEOUS PRESSURE APPLICATION. THIS IS ONE OF THE LARGEST, MOST COMPLEX COMPOSITE STRUCTURES YET PRODUCED IN A SINGLE CURE CYCLE.

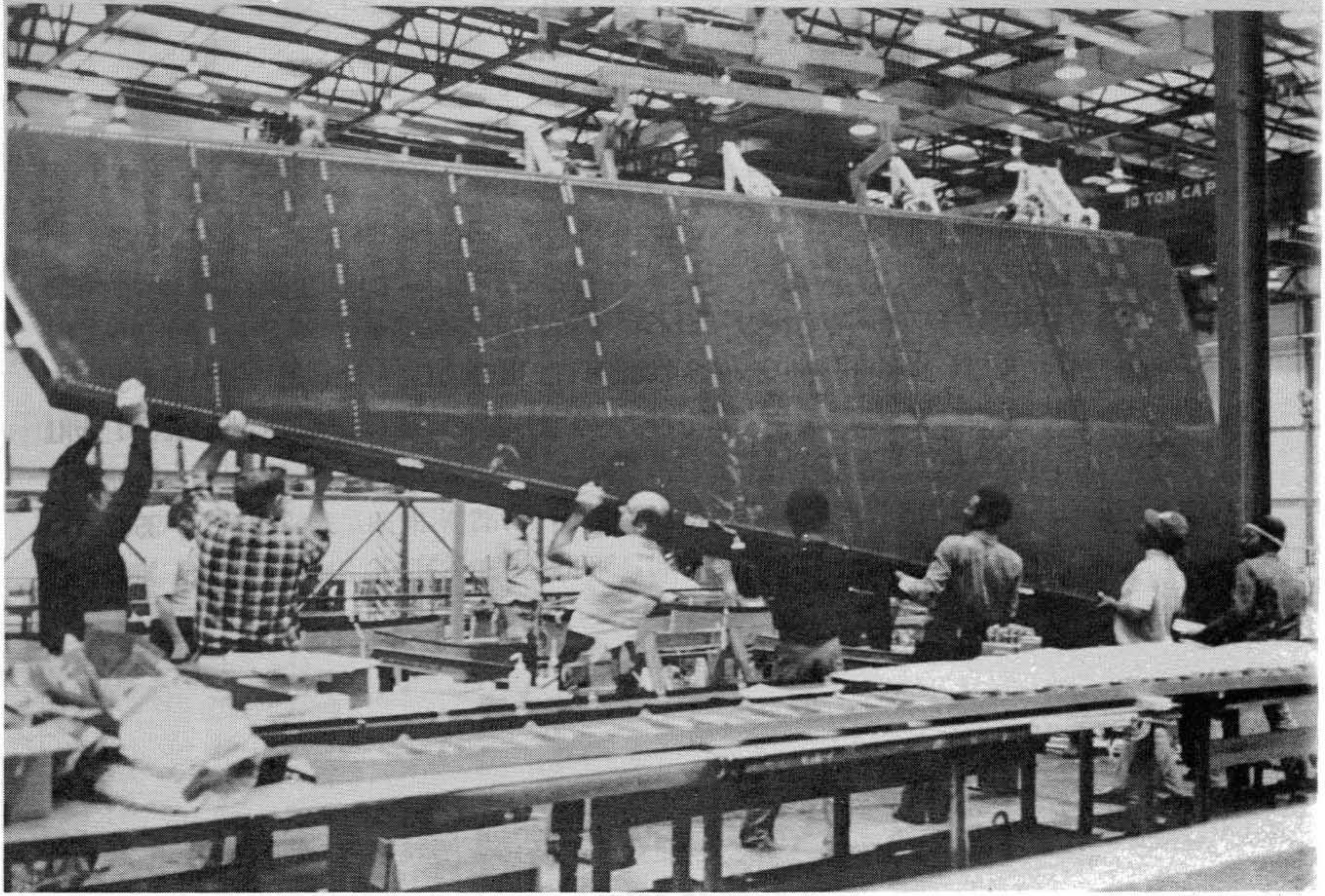

L-1011 GRAPHITE - EPOXY COVER
(COCURED HAT-STIFFENED PANEL)
27
F6B4
5/79

SLIDE 28

TWO COMPLETE L-1011 COMPOSITE FINS HAVE BEEN ASSEMBLED AND ONE OF THESE FAILED JUST BELOW DESIGN ULTIMATE LOAD IN STATIC GROUND TEST REVEALING A MINOR DESIGN FLAW. THE OTHER IS BEING STRENGTHENED AND WILL BE TESTED TO QUALIFY THE MODIFIED DESIGN. SAVINGS OF 28 PERCENT HAVE BEEN CONFIRMED. FLIGHT TESTING OF THE L-1011 COMPOSITE FIN IS NOT PLANNED.

L-1011 ADVANCED COMPOSITE VERTICAL FIN

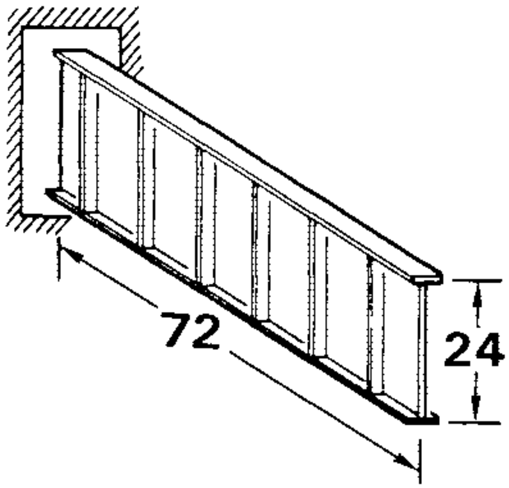
F6B18
5/80



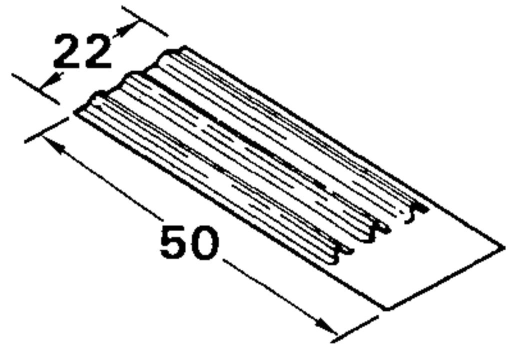
SLIDE 29

INSTEAD, AN EXTENSIVE SERIES OF "PRODUCTION READINESS VERIFICATION TESTS" OF LARGE SEGMENTS OF THE FIN SPARS AND COVERS WAS UNDERTAKEN. STATIC STRENGTH TESTS OF TEN SPAR AND TEN COVER SPECIMENS HAVE ALREADY CONFIRMED THAT LARGE SCALE COMPOSITE STRUCTURES, FABRICATED WITH PRODUCTION METHODS, ARE AS RELIABLE IN THEIR STRENGTH PERFORMANCE AS CONVENTIONAL METAL STRUCTURES. TWELVE MORE SPAR AND TWELVE MORE COVER SPECIMENS WERE ALSO MANUFACTURED FOR DURABILITY TESTS.

PRODUCTION READINESS VERIFICATION TESTS



(A) SPAR SEGMENT

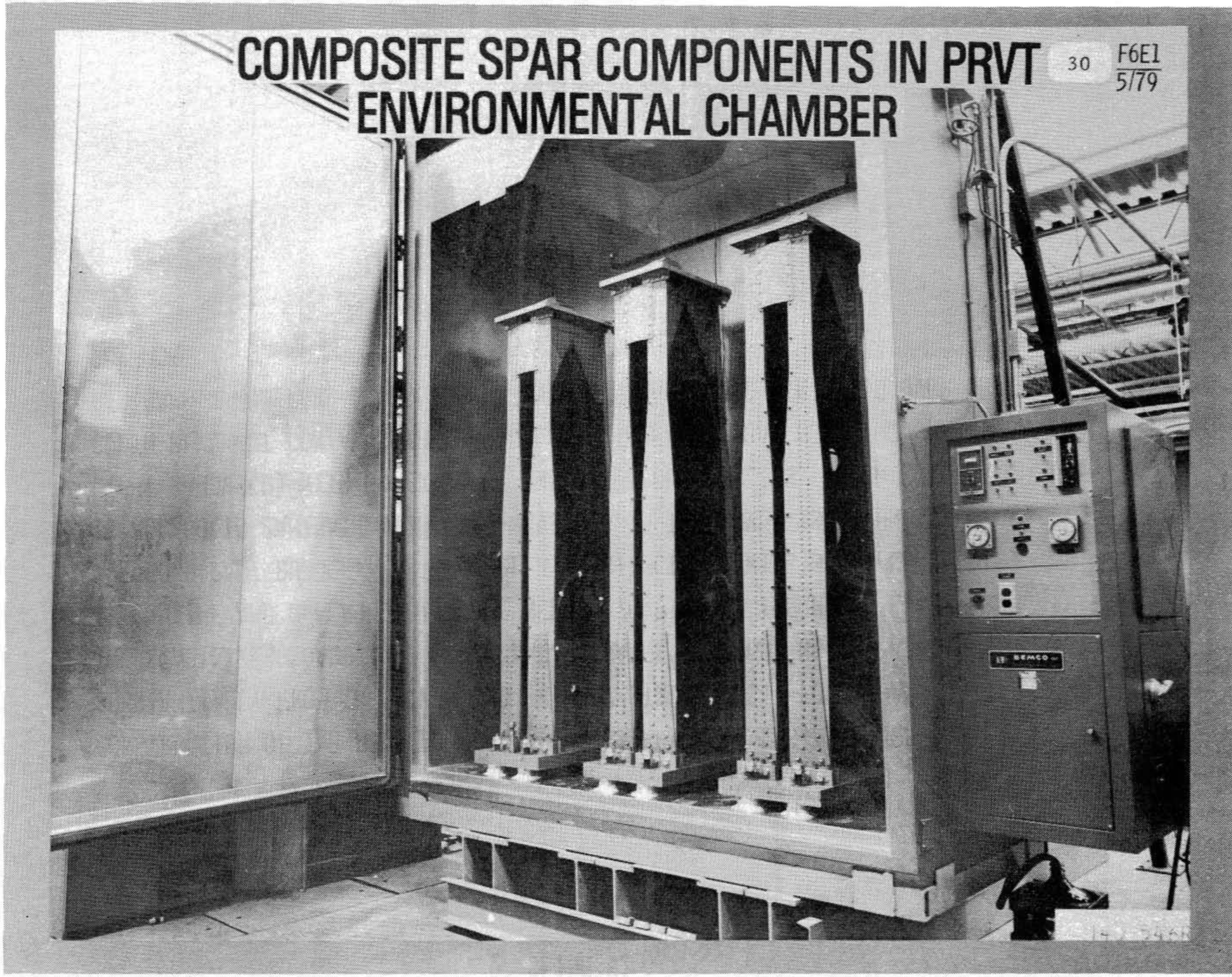


(B) COVER SEGMENT

12	DURABILITY SPECIMENS	12
10	STATIC STRENGTH SPECIMENS	10
22		22

SLIDE 30

THE DURABILITY SPECIMENS ARE NOW UNDERGOING CYCLIC EXPOSURE TO HIGH AND LOW TEMPERATURES, HIGH HUMIDITY, AND MECHANICAL LOADS THAT WILL SIMULATE A TWENTY-YEAR LIFE TIME OF SERVICE IN FOUR YEARS OF TESTING. THE PHOTO SHOWS ONE OF TWO SPAR CHAMBERS WITHIN WHICH SIX SPAR SEGMENTS ARE UNDERGOING SIMULATED FLIGHT ENVIRONMENTS. TWO MORE CHAMBERS ARE ALSO OPERATING WITH SIX COVER SEGMENTS EACH. THIS TESTING WILL BE COMPLETED IN LATE 1983 AND WILL ADD SUBSTANTIALLY TO THE KNOWLEDGE AND CONFIDENCE WITH WHICH COMPOSITE APPLICATIONS TO PRIMARY STRUCTURE CAN BE MADE. TWO EACH OF THE SPARS AND COVERS ARE BEING TESTED AT HIGHER-THAN-DESIGN STRAIN LEVELS IN AN EFFORT TO DELINEATE WORKING STRAIN LIMITS FOR PRODUCTION QUALITY STRUCTURES FABRICATED WITH TODAY'S EPOXY MATERIALS.

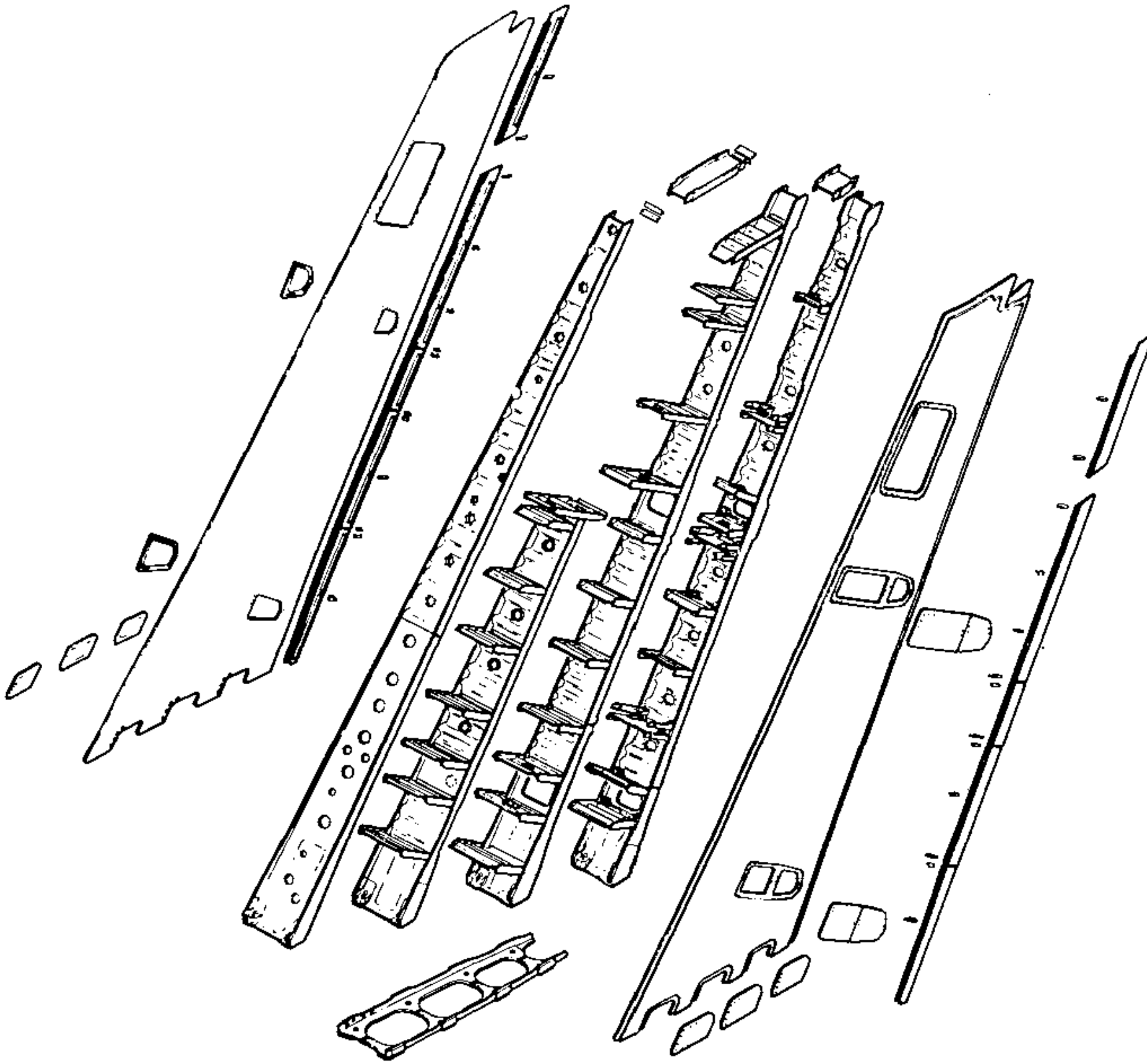

COMPOSITE SPAR COMPONENTS IN PRVT
ENVIRONMENTAL CHAMBER
30
F6E1
5/79

SLIDE 31

CONSTRUCTION OF THE DOUGLAS DC-10 COMPOSITE VERTICAL STABILIZER DIFFERS SUBSTANTIALLY FROM THE OTHER TWO PRIMARY STRUCTURES. FOUR SPARS CARRY THE STABILIZER LOADS INTO FOUR "BANJO FRAMES" SUPPORTING THE AIRCRAFT'S AFT ENGINE AND NUMEROUS RIBS ARE NEEDED TO PICK UP THE HINGE LOADS FROM THE FOUR-PART RUDDER. THIS COMPLEX SUBSTRUCTURE, WITH MULTIPLE JOINTS, IS ALL SOLID LAMINATE WITH SINE-WAVE WEBS. THE COVER IS AN UNUSUALLY LIGHT SANDWICH, WITH NOMEX CORE, TWO OUTER CLOTH PLIES, AND ONE INNER CLOTH PLY, BUT CONTAINS THE SOLID LAMINATE PLIES THAT FORM THE SPAR AND RIB CAPS. NUMEROUS ACCESS DOORS AND ANTENNAE ARE DISTRIBUTED OVER THE SURFACE.

DC-10 COMPOSITE VERTICAL STABILIZER

31 F8A1B
9/80



SLIDE 32

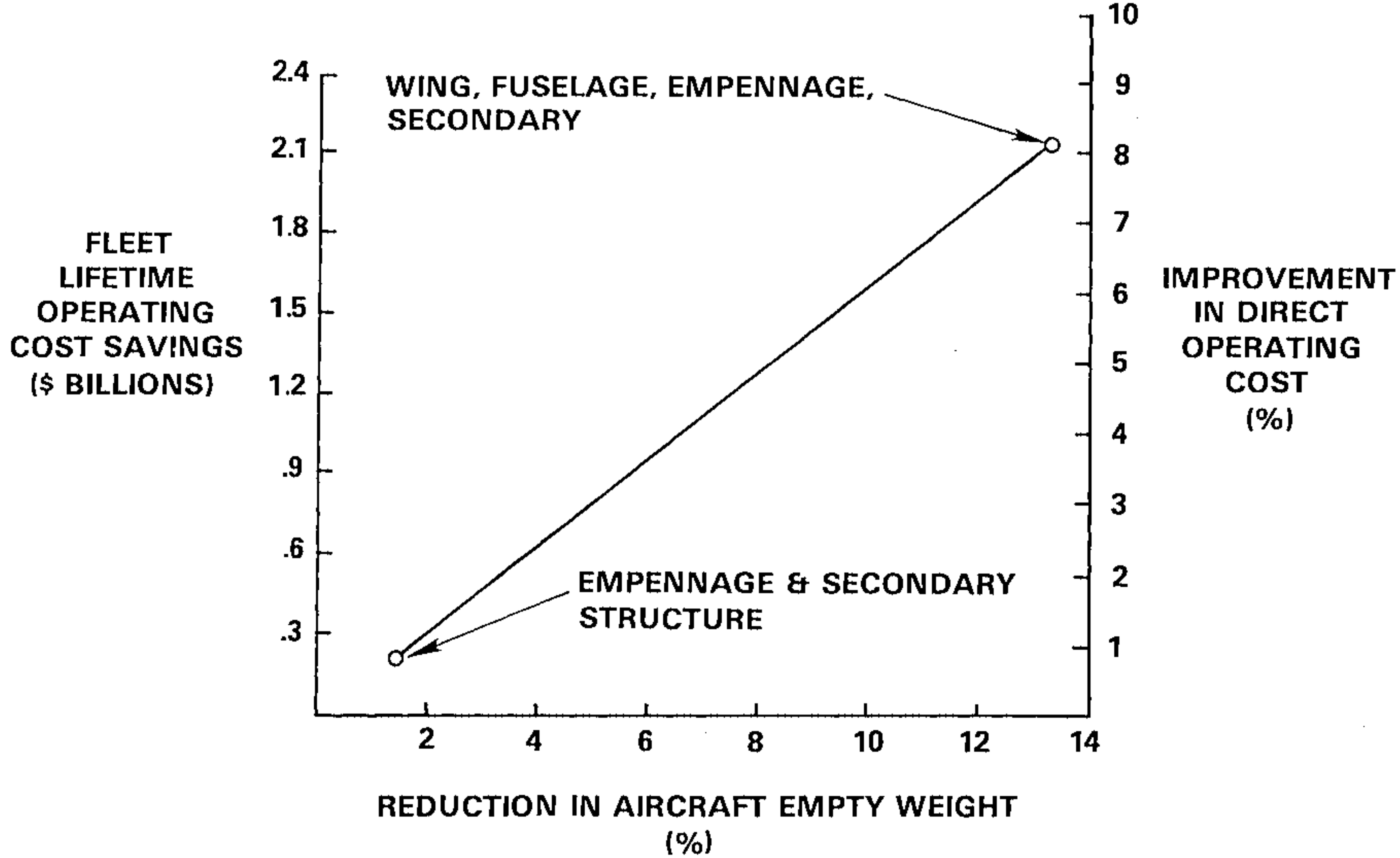
ALL SUBCOMPONENTS (COVERS, SPARS, AND RIBS) OF THREE FULL SCALE VERTICAL STABILIZERS HAVE BEEN SUCCESSFULLY FABRICATED AND ONE HAS BEEN ASSEMBLED. WEIGHT SAVING IS 23 PERCENT. THE FIRST STABILIZER WILL BE GROUND TESTED AND 2 WILL BE INTRODUCED INTO AIRLINE FLIGHT SERVICE AFTER CERTIFICATION BY THE FAA.


32
F8F2
10/81
DC-10
ADVANCED COMPOSITE
VERTICAL STABILIZER
N68048

WHILE SUCH APPLICATIONS OF ADVANCED COMPOSITES TO CONTROL SURFACE AND EMPENNAGE PRIMARY STRUCTURE CAN PROVIDE SUBSTANTIAL SAVINGS (UP TO 1 PERCENT REDUCTION IN DIRECT OPERATING COSTS), EXTENSION OF THIS TECHNOLOGY TO THE LARGER WING AND FUSELAGE STRUCTURES WILL PRODUCE TOTAL BENEFITS EIGHT TIMES AS GREAT, WITH ABOUT HALF CONTRIBUTED BY EACH. THESE RESULTS ARE BASED ON AN ECONOMIC ANALYSIS OF A 200 AIRPLANE FLEET, ASSUMING 25 PERCENT STRUCTURAL WEIGHT SAVINGS AND 80-CENTS-PER-GALLON FUEL.

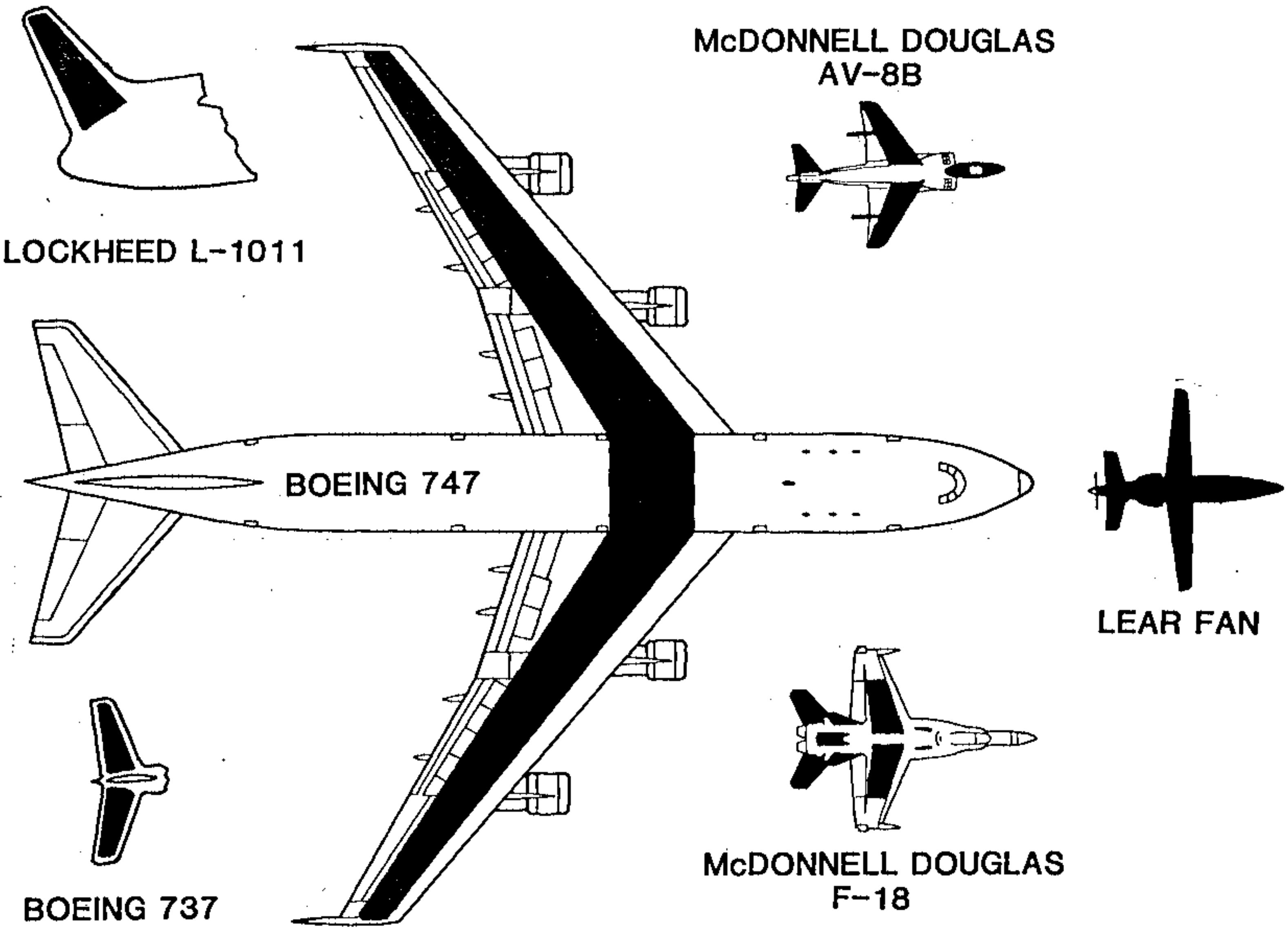
F12A1
1/81

CPAS
BENEFITS OF LARGE PRIMARY STRUCTURES
(1979 $ - 80¢/GAL. FUEL)



AND, INDEED, A MAJOR EXTENSION OF THE TECHNOLOGY IS REQUIRED. WHILE THERE ARE MILITARY APPLICATIONS AND ONE GENERAL AVIATION APPLICATION OF COMPOSITES TO WING AND FUSELAGE STRUCTURES, THE SCALE OF THESE STRUCTURES IS NO GREATER THAN THAT OF THE ACEE COMPOSITE EMPENNAGE COMPONENTS. TRANSPORT WINGS, ON THE OTHER HAND, INVOLVE UNPRECEDENTED PHYSICAL DIMENSIONS AND PARAMETER RANGES FOR COMPOSITES. FOR THIS AND OTHER REASONS, CERTAIN "KEY TECHNOLOGY" ISSUES MUST BE RESOLVED PRIOR TO SUCH COMPOSITE APPLICATIONS.

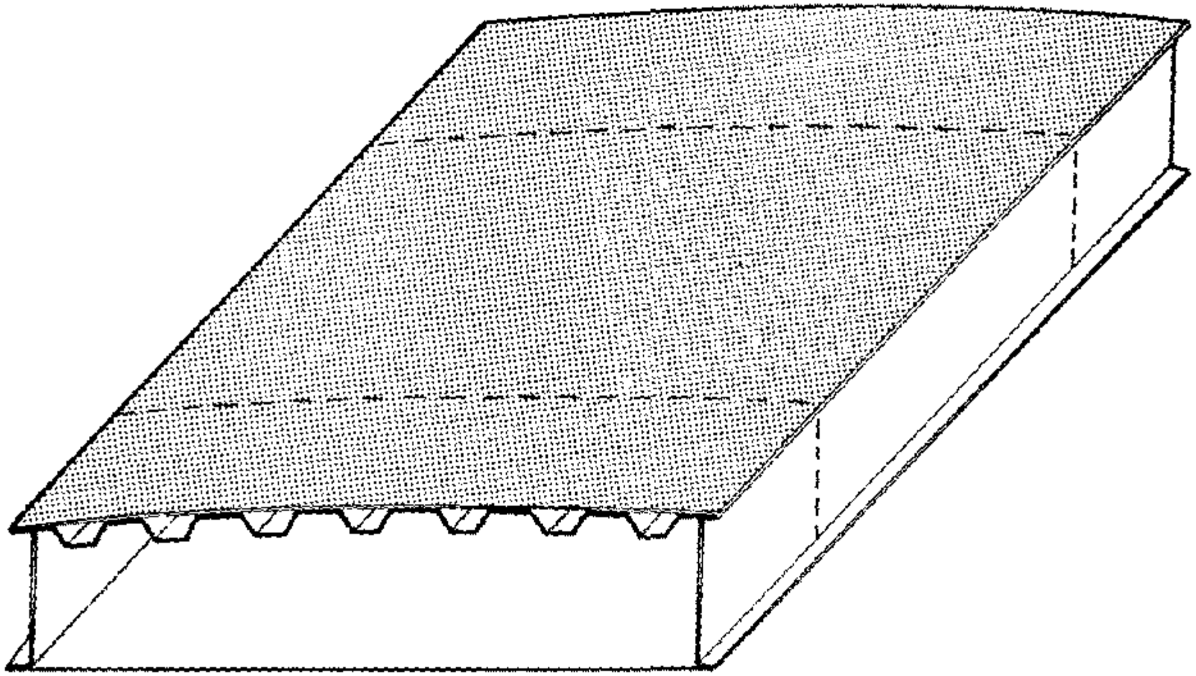
TRANSPORT AIRCRAFT COMPOSITE WING STRUCTURES



NASA HAS ALREADY INITIATED TWO-YEAR CONTRACTS WITH THE COMMERCIAL AIRFRAME MANUFACTURERS TO ADDRESS THE MOST CRITICAL OF THESE "KEY TECHNOLOGY" ISSUES. ALL THREE CONTRACTORS WILL DEFINE BASELINE ADVANCED WINGS AT THE CONCEPTUAL DESIGN LEVEL. ONE CONTRACTOR WILL THEN ADDRESS DAMAGE TOLERANCE WITH MANY DEVELOPMENT TESTS OF TYPICAL STRENGTH-CRITICAL THICK SECTIONS TO DETERMINE ACCEPTABLE STRAIN LEVELS, ETC.

A SECOND CONTRACTOR WILL FOCUS ON FUEL CONTAINMENT AND RELATED ISSUES, INCLUDING LIGHTNING PROTECTION. THE SKETCH AND WORDS DEPICT THE POSSIBLE NATURE OF MAJOR DEMONSTRATION TEST SPECIMENS AND LOADINGS THAT COULD EVALUATE PROPOSED DESIGNS FOR RESOLUTION OF THESE TECHNOLOGY ISSUES.

KEY TECHNOLOGY DEMONSTRATION ARTICLES



DAMAGE TOLERANCE

- ONE COVER, SPARS AND RIBS FUNCTIONALLY SIMULATED
- SIMULATED DAMAGE
- SPECTRUM FATIGUE LOADING PLUS RESIDUAL STRENGTH

FUEL CONTAINMENT

- ONE COVER AND REAR SPAR FUNCTIONALLY SIMULATED
- HIGH G-LOADING (DECELERATION)
- SPECTRUM FATIGUE LOADING INCLUDING FUEL PRESSURIZATION

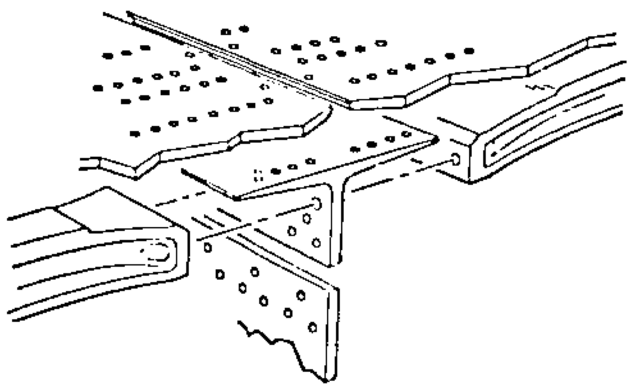
SLIDE 36

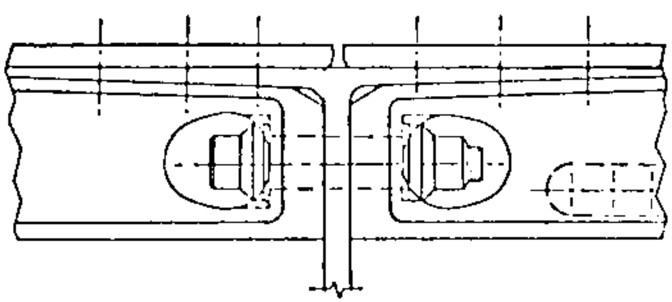
THE THIRD "KEY TECHNOLOGY" CONTRACTOR WILL FOCUS ON DESIGN AND EVALUATION OF CRITICAL COMPLEX JOINTS IN COMPOSITE WING STRUCTURE. WHILE DURABILITY UNDER FATIGUE LOADING IS SEEN TO BE AN ISSUE IN ALL THREE KEY TECHNOLOGY AREAS, THE THREE CONTRACTOR EFFORTS ADDRESS SEPARATE AND DISTINCT KEY TECHNOLOGY DEVELOPMENT TASKS.

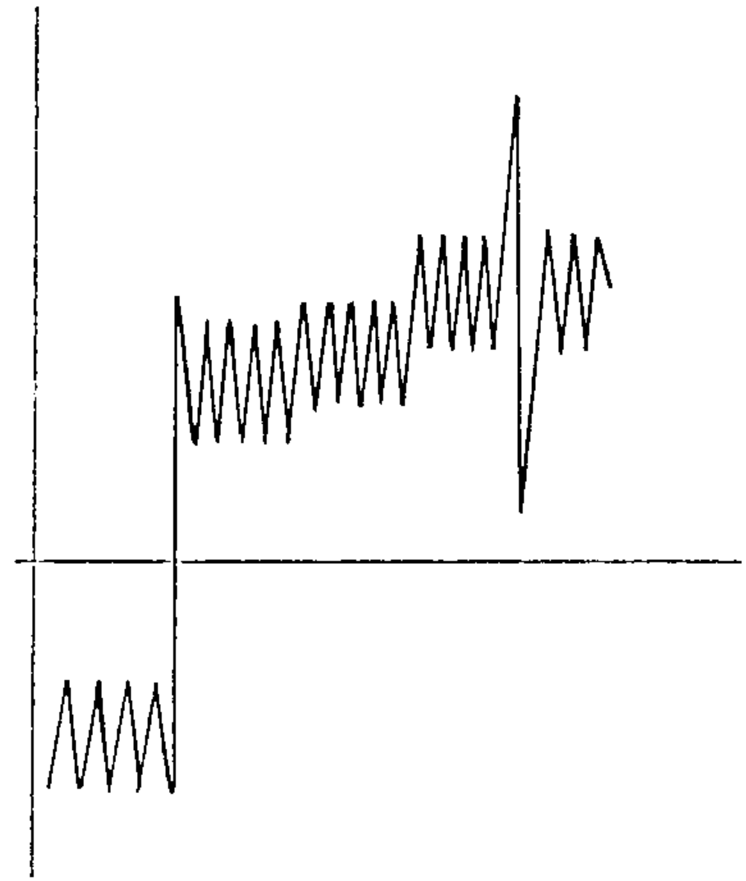
SPECIAL EFFORTS ARE BEING MADE TO PROMOTE INFORMATION EXCHANGE AMONG THE THREE CONTRACTORS TO OBVIATE THE NEED FOR ADDITIONAL REDUNDANT EFFORTS.

KEY TECHNOLOGY DEMONSTRATION

CRITICAL JOINTS







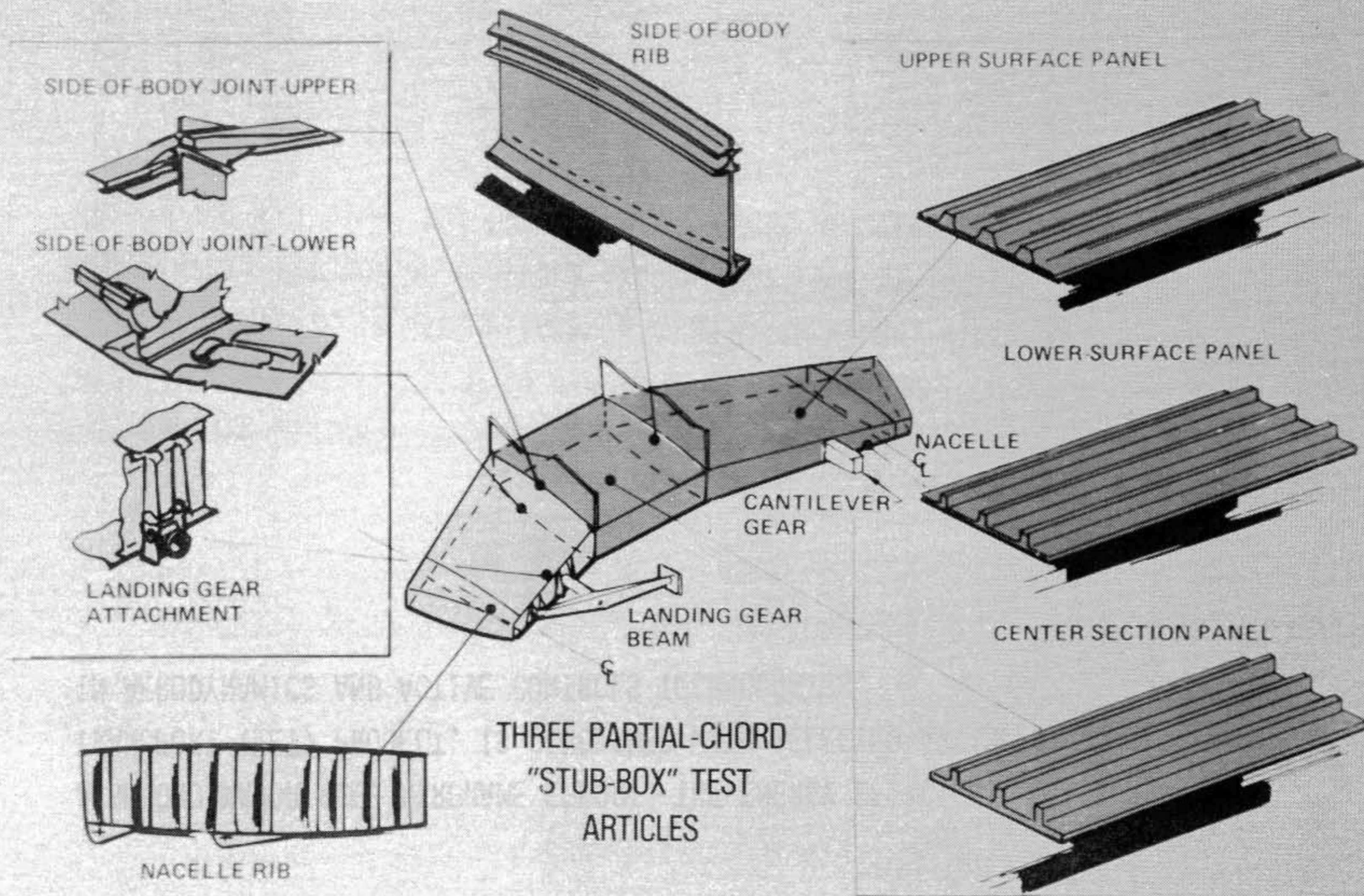
SPECTRUM FATIGUE LOADING

SLIDE 37

A TRANSPORT AIRCRAFT COMPOSITE STRUCTURES (TACS) PROGRAM IS PROPOSED TO FOLLOW THE "KEY TECHNOLOGY" EFFORTS. THIS PROGRAM WILL EMBODY EXTENSIVE COUPON AND SUBCOMPONENT TESTING BY EACH AIRFRAME MANUFACTURER LEADING TO TESTS OF MAJOR PARTIAL-CHORD WING STUB-BOX SPECIMENS FOR DESIGN AND MANUFACTURING PROCESS EVALUATION. THE THREE CONTRACTORS WILL AGAIN EMPHASIZE ASSIGNED, DIFFERENT DESIGN ISSUES AND APPROACHES AND SHARE THEIR INFORMATION AND WILL COOPERATE WITH EACH OTHER AND NASA IN THE FINAL STUB-BOX TEST PROGRAM. THIS TACS PROGRAM IS THOUGHT TO BE THE MINIMUM EFFORT THAT COULD PREPARE THE INDUSTRY TO PROCEED WITH DEVELOPMENT OF COMPOSITE WINGS ON NEW OR REWINGED TRANSPORTS FOR INITIAL OPERATION ABOUT 1990.

TRANSPORT AIRCRAFT COMPOSITE STRUCTURES

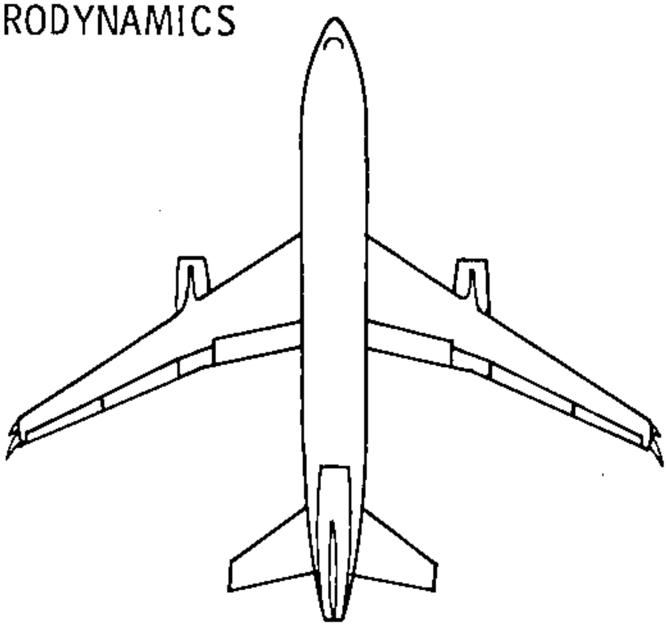
DEVELOPMENT TEST PLAN



SLIDE 38

A SECOND MAJOR ACEE AIRFRAME EFFORT, THE ENERGY EFFICIENT TRANSPORT (EET) PROJECT, IS CONCERNED WITH SELECTED ADVANCES IN AERODYNAMICS AND ACTIVE CONTROLS TECHNOLOGIES.

AERODYNAMICS



ACTIVE
CONTROLS

ENERGY EFFICIENT TRANSPORT TECHNOLOGY

THE EET PROJECT AIMS, NOT ONLY AT <u>DEVELOPMENT</u> OF SELECTED AERODYNAMICS AND ACTIVE CONTROLS INNOVATIONS, BUT AT THEIR EARLY APPLICATION IN DERIVATIVES OF CURRENT TRANSPORT AIRCRAFT OR THEIR LATER APPLICATION TO NEW OR RE-WINGED AIRCRAFT OF THE 1985-90 TIME PERIOD.

ENERGY EFFICIENT TRANSPORT (EET)

A4B
12/76

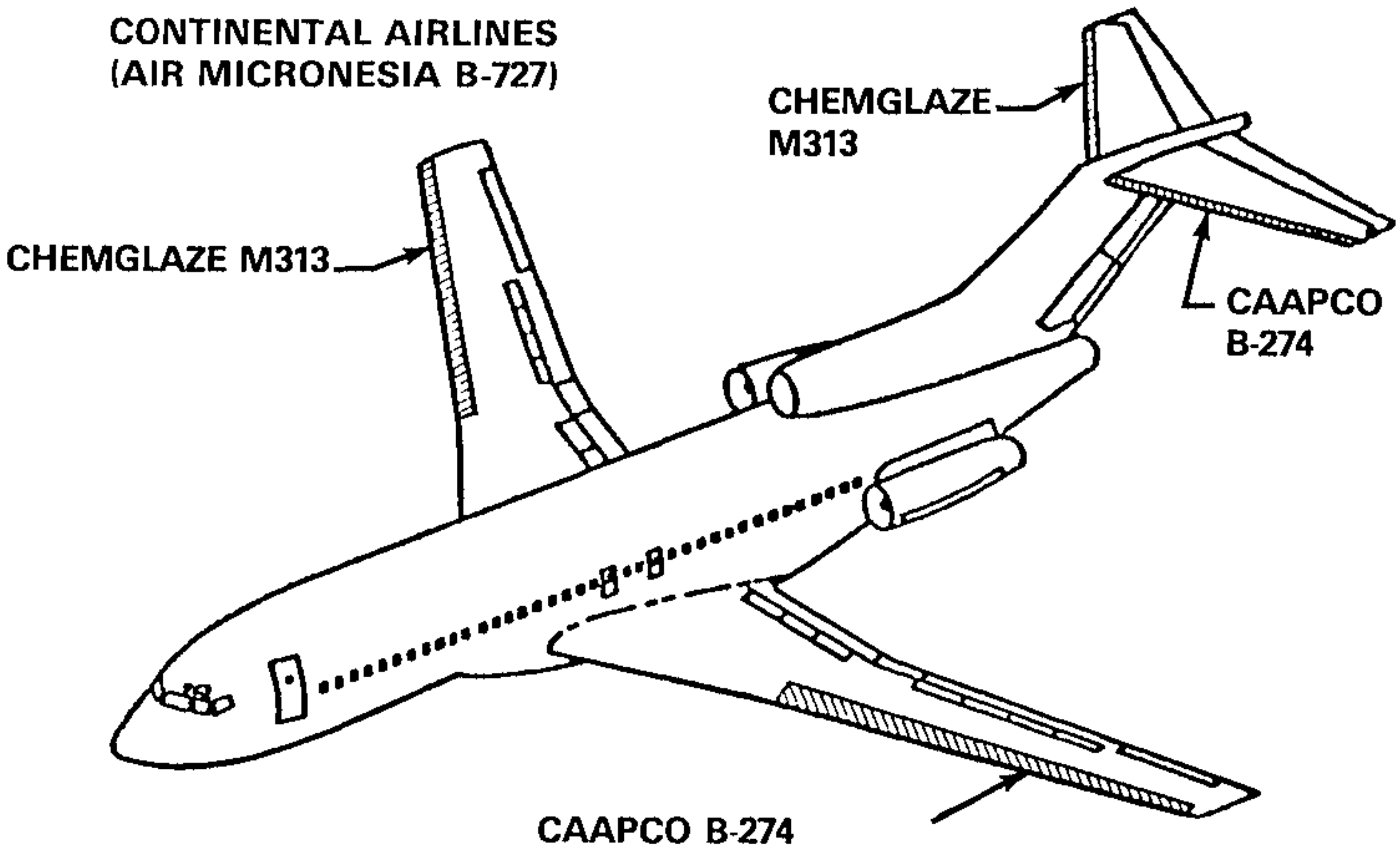
OBJECTIVE

DEVELOP ADVANCED AERODYNAMICS AND ACTIVE CONTROLS TECHNOLOGIES AND EXPEDITE EARLY INDUSTRY APPLICATION INTO DERIVATIVE AND FUTURE PRODUCTION COMMERCIAL TRANSPORT AIRCRAFT.

AN EXAMPLE OF EET TECHNOLOGY WITH EARLY APPLICATION POTENTIAL IS PLASTIC COATINGS FOR SMOOTHER WING AND TAIL SURFACES. THE DURABILITY OF A LARGE NUMBER OF CANDIDATE PLASTIC COATING MATERIALS WAS EVALUATED IN GROUND TESTS AND TWO MATERIALS (CHEMGLAZE M313 AND CAAPCO B-274) WERE FLOWN FOR OVER ONE YEAR ON WING AND HORIZONTAL TAIL LEADING EDGES OF A AIR MICRONESIA B-727 IN THE SOUTH PACIFIC WHERE CORAL DUST AND HEAVY RAINFALL PROVIDE A SEVERE EROSION ENVIRONMENT. THE PLASTIC MATERIALS PROVED MORE DURABLE THAN THE AIRCRAFT'S ALUMINUM ALLOY AND A WORTHWHILE MAINTENANCE-COST-SAVING BENEFIT WAS RECOGNIZED. FURTHER FLIGHT SERVICE IN THE UNITED STATES HAS FOLLOWED, GROUND TESTS OF LIGHTNING AND ICING PERFORMANCE HAVE SHOWED NO ADVERSE EFFECTS OF THE PLASTIC COATINGS, AND GROUND TESTS TO EVALUATE THEIR BENEFICIAL OR DETRIMENTAL EFFECTS ON CORROSION ARE UNDERWAY.

AIRCRAFT SURFACE COATINGS

FLIGHT SERVICE EVALUATION

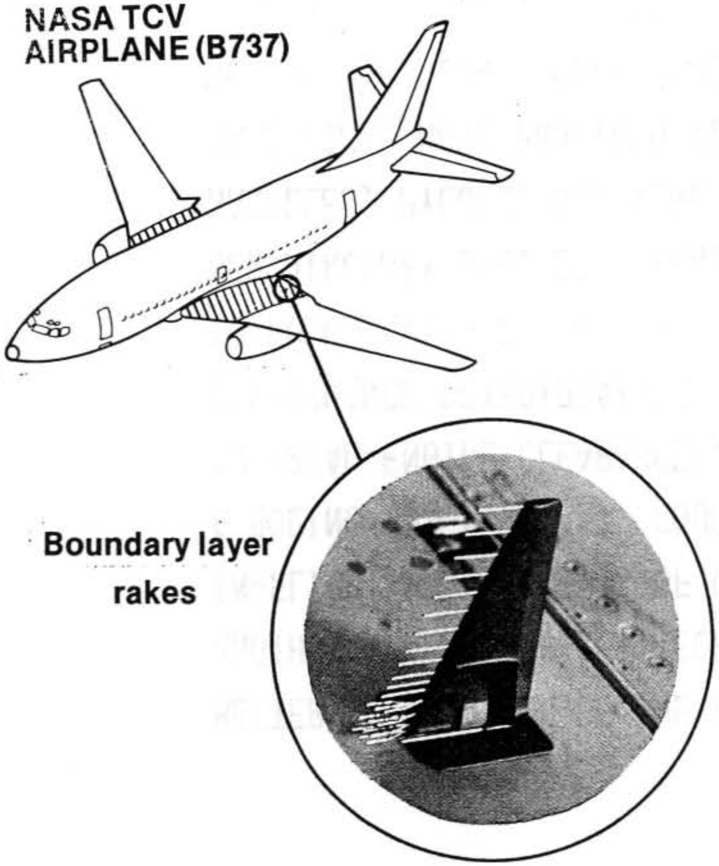


SLIDE 41

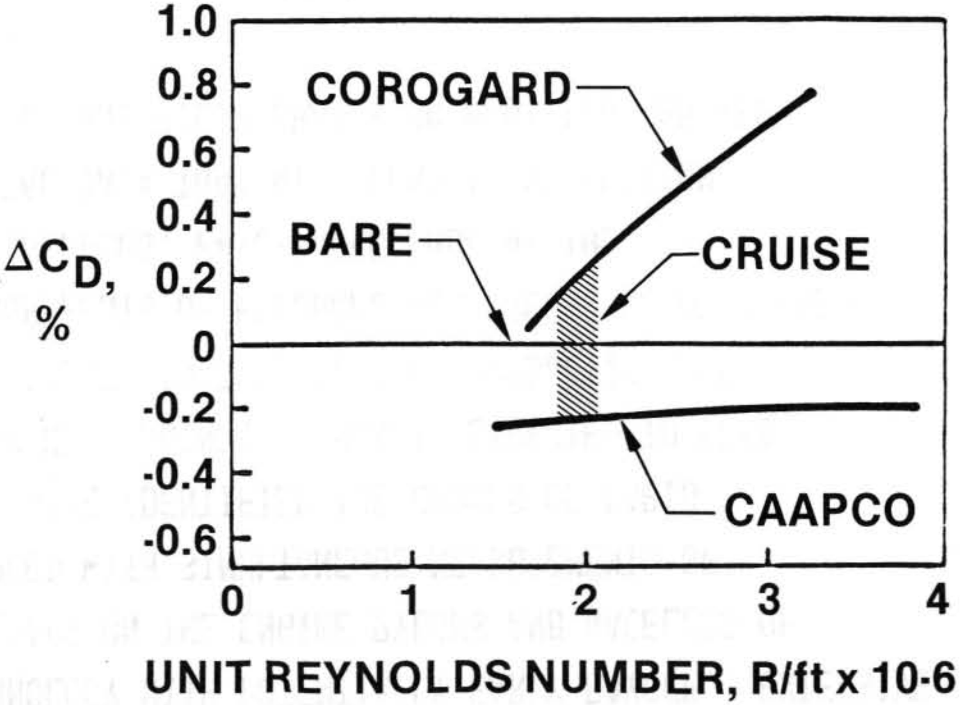
FINALLY, THE DRAG-SAVING POTENTIAL OF THE CAAPCO PLASTIC COATING WAS EVALUATED IN PIGGY-BACK FLIGHT TESTS ON THE BOEING 737 USED IN NASA'S TERMINAL CONTROLLED VEHICLE (TCV) PROJECT. DIRECT COMPARISON WAS MADE OF THE CONDITION OF THE BOUNDARY LAYER FLOW OVER THE COATED AREA ON ONE WING AND OVER A CORRESPONDING BARE METAL SURFACE ON THE OTHER. ALSO EVALUATED WAS A PAINT, CALLED "COROGARD," WHICH IS WIDELY USED FOR CORROSION PROTECTION. THE TOTAL AIRPLANE DRAG DIFFERENCES, ASSUMING COVERAGE OF BOTH SURFACES OF WINGS AND TAIL, WERE INFERRED FROM THE BOUNDARY LAYER MEASUREMENTS. AT CRUISE CONDITIONS, THE CAAPCO PLASTIC COATING WOULD REDUCE TOTAL DRAG 0.2 PERCENT WHEREAS COROGARD ON WING AND TAIL SURFACES APPARENTLY INCREASES TOTAL AIRPLANE DRAG A LIKE AMOUNT. THUS, IF THE PLASTIC COATINGS PROVE ACCEPTABLE IN THE ONGOING CORROSION TESTS, THEY MAY PROVIDE A LOW-COST AVENUE TO ABOUT 0.4 PERCENT FUEL SAVINGS ON COROGARD-PROTECTED AIRCRAFT. ON A WIDE-BODY TRANSPORT, THIS WOULD BE ABOUT 30,000 GALLONS EACH YEAR.

EFFECT OF SURFACE COATINGS ON DRAG

FLIGHT MEASUREMENTS



TOTAL AIRPLANE DRAG (INFERRED)



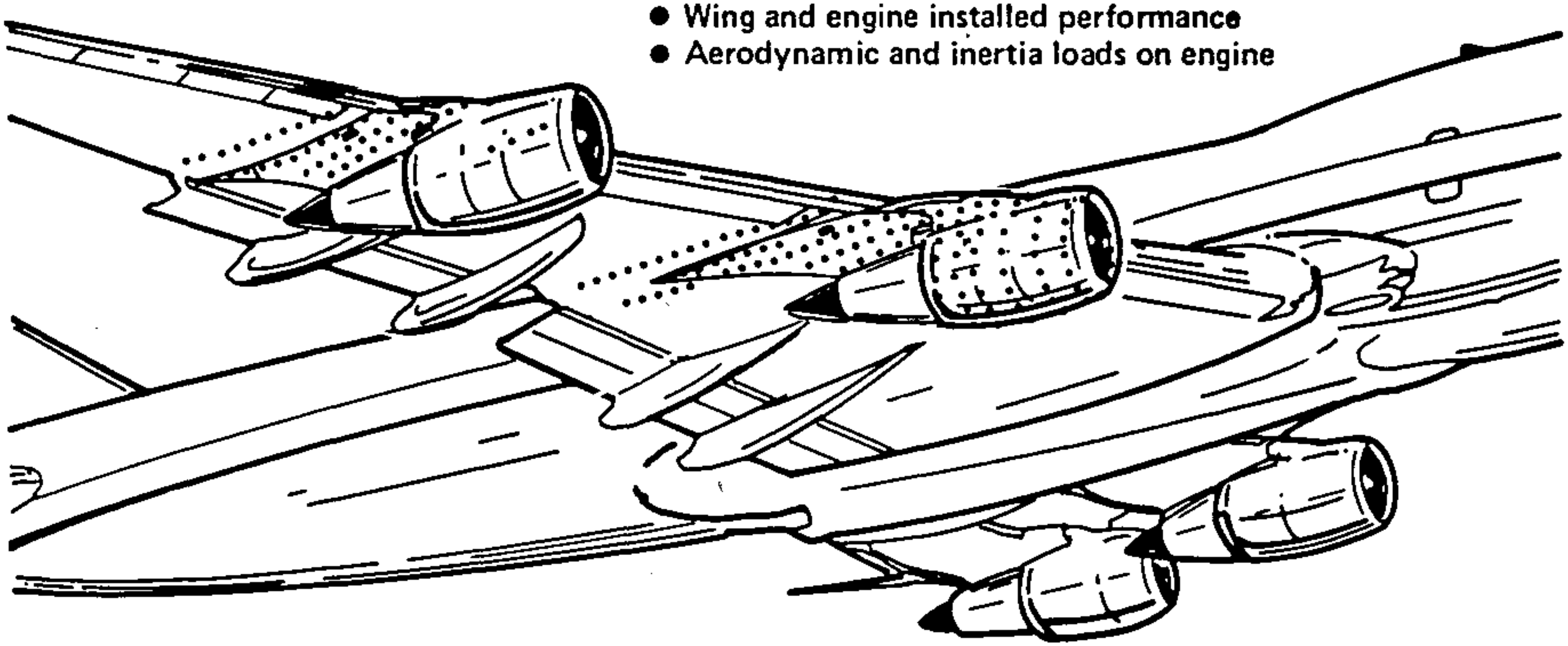
SLIDE 42

BETTER INTEGRATION OF THE PROPULSION SYSTEM WITH THE AIRFRAME IS ANOTHER EXAMPLE OF EET TECHNOLOGY WITH POTENTIALLY EARLY PAYOFF. EXTENSIVE IN-FLIGHT MEASUREMENTS OF LOADS ON THE ENGINE PYLONS AND NACELLES OF A BOEING 747 AIRCRAFT, COUPLED WITH SIMULTANEOUS MEASUREMENTS OF INTERNAL ENGINE CLEARANCES, HAVE IDENTIFIED THE CAUSES OF RAPID PERFORMANCE DETERIORATION IN NEW ENGINES. THIS IS EXPECTED TO LEAD TO FUEL SAVING DESIGN IMPROVEMENTS IN BOTH CURRENT PRODUCTION AND NEW AIRCRAFT ENGINES. MEASUREMENTS OF EXTERNAL AIR PRESSURES OVER THE NACELLES, PYLONS, AND WING SURFACES, WHICH WERE MADE AT THE SAME TIME, HAVE PROVIDED VITAL DATA THAT WILL LEAD TO DEFINITION OF IMPROVED LOWER-DRAG NACELLE AND PYLON SHAPES ON MODIFIED AND NEW AIRCRAFT OF THE NEAR FUTURE.

Nacelle Aerodynamic and Inertia Loads (NAIL)

OBJECTIVES: IN-FLIGHT MEASURED DATA BASE

- Wing and engine installed performance
- Aerodynamic and inertia loads on engine



JOINT PROGRAM

- NASA-Lewis and P&WA
- NASA-Langley and BCAC

INSTRUMENTATION

- 693 pressure measurements
- 30 accelerometers
- 12 blade clearance measurements
- 7 rate gyros

SLIDE 43

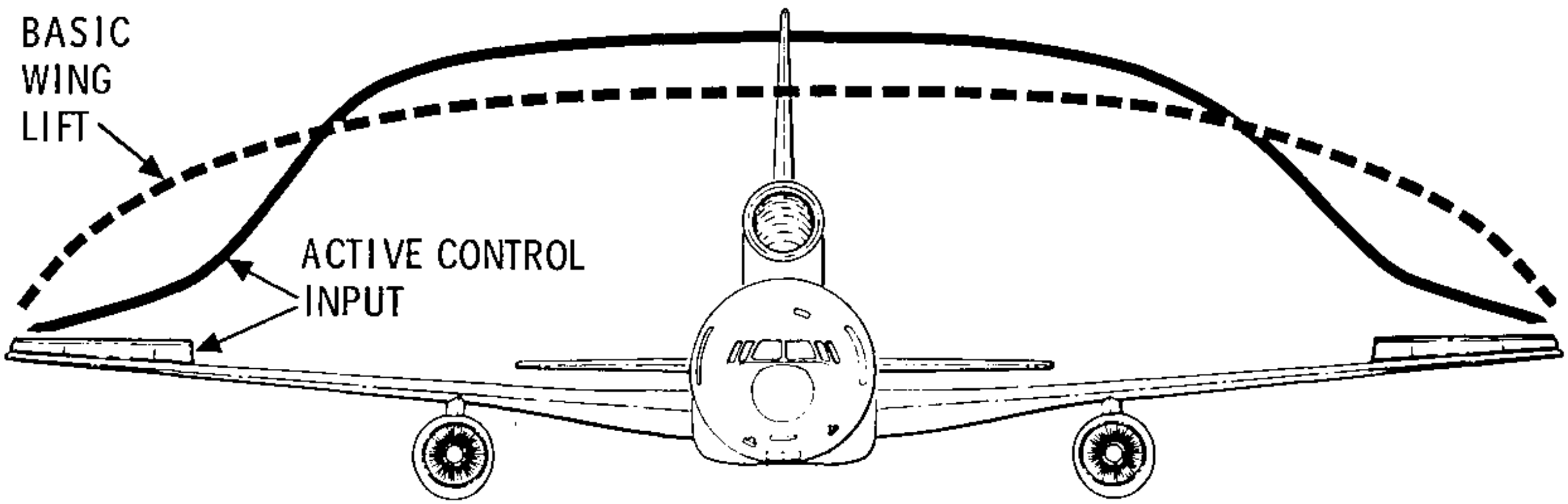
ANOTHER AERODYNAMIC INNOVATION, WITH POTENTIAL FOR PROVIDING NEAR-TERM FUEL SAVINGS, IS ADDITION OF "WINGLETS" TO THE WING TIPS OF SOME EXISTING AIRCRAFT. WINGLETS ARE CAREFULLY DESIGNED TO TAKE ADVANTAGE OF THE WING-TIP VORTEX (THE FLOW AROUND THE WING TIP FROM THE BOTTOM SURFACE TO THE TOP SURFACE OF THE WING) TO PROVIDE A FORWARD COMPONENT OF AERODYNAMIC FORCE THAT WILL AUGMENT THE ENGINE THRUST AND SAVE FUEL. FLIGHT TESTS HAVE CONFIRMED ABOUT 3 PERCENT FUEL SAVING POTENTIAL FOR WINGLETS ON A DC-10 TRANSPORT. FURTHER DEVELOPMENT AND EVALUATION TOWARD THEIR EARLY APPLICATION ON NEW DC-10's AND THEIR RETROFIT ON OPERATIONAL DC-10's IS LIKELY.

FLIGHT TEST OF DC-10 WITH WINGLETS

NEAR-TERM FUEL-SAVING CHANGES IN WING GEOMETRY, SUCH AS WINGLETS OR TIP EXTENSIONS, CAN BE MADE POSSIBLE OR MORE PRODUCTIVE BY ADDITION OF "ACTIVE CONTROL" OF WING LOADS. ACTIVE CONTROLS ARE AIRCRAFT CONTROL SURFACES THAT ARE OPERATED BY FAST-ACTING ACTUATORS LINKED, THROUGH A COMPUTER, TO STRESS OR MOTION SENSORS. THE COMPUTER IS PROGRAMMED WITH A SUITABLE "CONTROL LAW" TO INTERPRET SIGNALS FROM THE SENSORS AND PROPERLY INSTRUCT THE ACTUATORS TO RAPIDLY DEFLECT THE CONTROL SURFACES SO THAT EXCESS DYNAMIC LOADS, FROM MANEUVERS OR GUSTS, ARE COUNTERACTED. THE FIGURE ILLUSTRATES SUCH DEFLECTION OF THE OUTBOARD AILERONS OF A LOCKHEED L-1011 WHICH, WITHOUT CHANGING THE TOTAL LIFT FORCE ON THE WING, MODIFIES ITS SPANWISE DISTRIBUTION IN SUCH A WAY THAT WING BENDING STRESSES ARE REDUCED. ADDITION OF SUCH CONTROLS, THEN, COULD PERMIT THE REMOVAL OF STRUCTURAL WEIGHT FROM THE WING OR, ALTERNATIVELY, ALLOW THE SPAN TO BE INCREASED WITHOUT STRUCTURAL WEIGHT ADDITIONS.

L-1011 ACTIVE MANEUVER LOAD CONTROL

H7A2
1/80

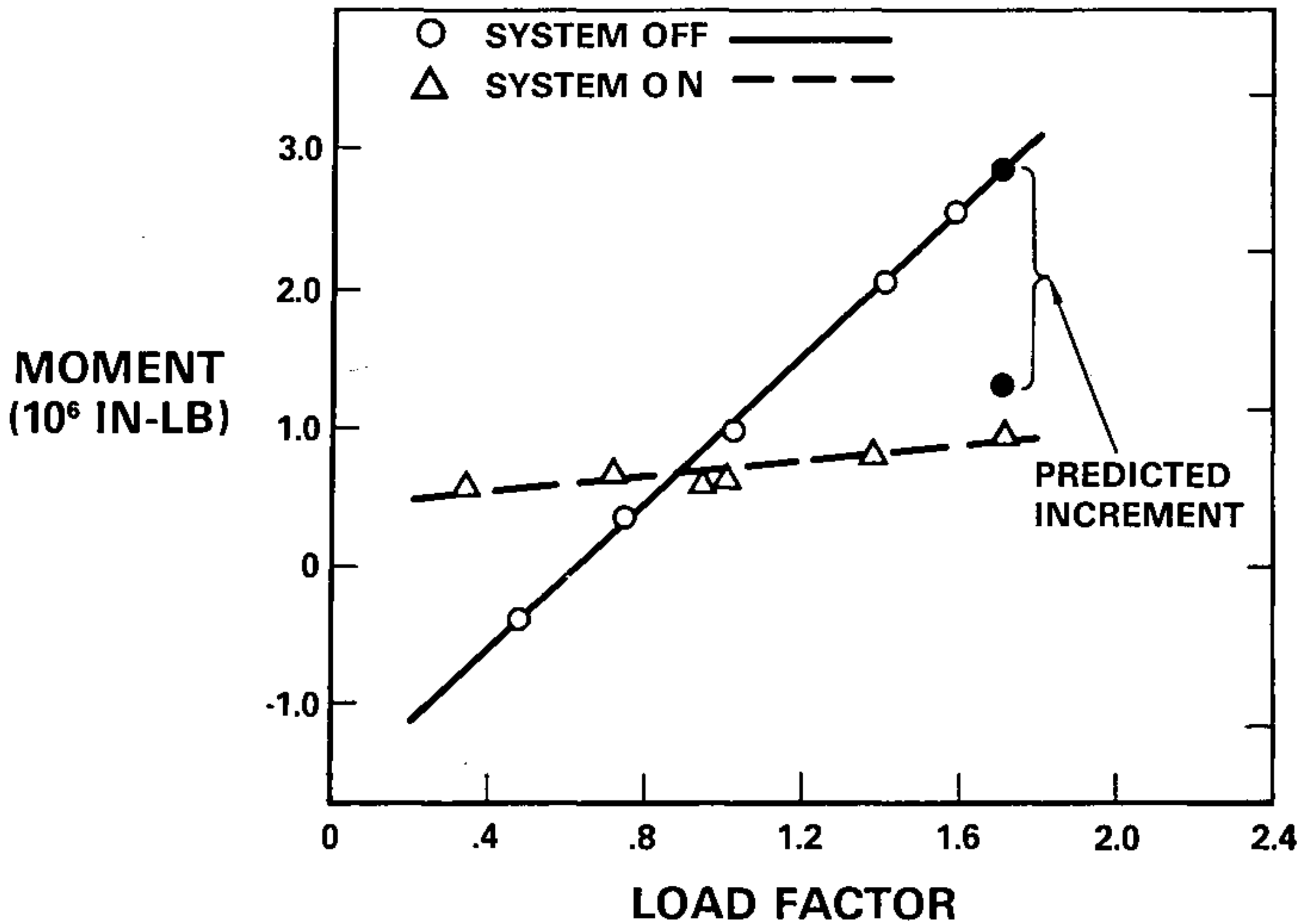


SLIDE 45

WITH THE LATTER GOAL IN MIND, LOCKHEED FLIGHT-TESTED SUCH AN ACTIVE CONTROL SYSTEM TOGETHER WITH EXTENDED WING TIPS UNDER A COST-SHARED EET CONTRACT WITH NASA. THE PLOT SHOWS THE VARIATION OF WING BENDING MOMENT AT THE 71 PERCENT SPAN LOCATION WITH THE AIRCRAFT ACCELERATION (CALLED "LOAD FACTOR") PRODUCED BY THE MANEUVER. WITH THE ACTIVE CONTROL SYSTEM OFF (SOLID CURVE), THE BENDING MOMENT AND STRESS INCREASE RAPIDLY WITH LOAD FACTOR. WITH THE ACTIVE SYSTEM OPERATING (DASHED CURVE), THE INCREASE WITH LOAD FACTOR IS VERY SLIGHT AND A LARGE STRESS REDUCTION IS EVIDENT AT HIGH LOADS. AN IMPORTANT RESULT OF THE FLIGHT TESTS WAS THE CLOSE AGREEMENT OF THIS MEASURED STRESS REDUCTION WITH THE ANALYTICALLY PREDICTED REDUCTION.

EET

MANEUVER LOAD CONTROL
WING BENDING MOMENT AT 71% SPAN



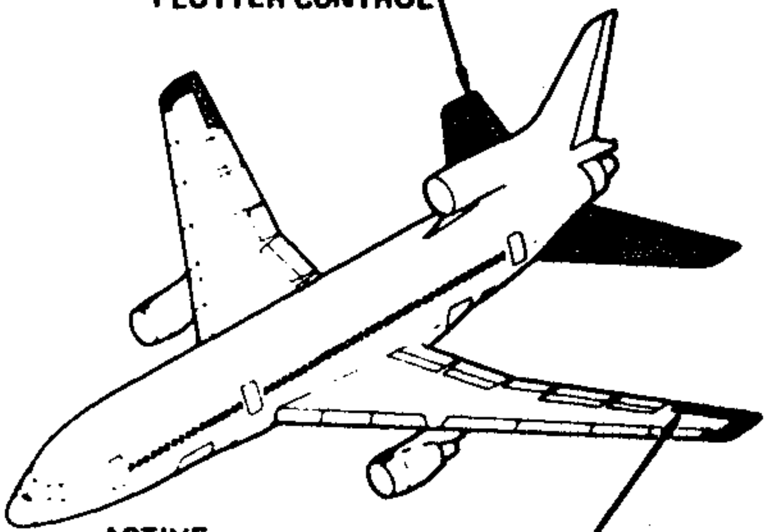
SLIDE 46

WITH THE CONFIDENCE DERIVED FROM THE EET FLIGHT TEST, LOCKHEED DESIGNED A SIMPLER "PRODUCTION" SYSTEM WHICH WAS OFFERED FOR SALE ON THE L-1011-500 AIRCRAFT ALONG WITH 4.5-FOOT WING-TIP EXTENSIONS GUARANTEED TO PRODUCE 3 PERCENT FUEL SAVINGS.

L-1011 ACTIVE WING LOAD ALLEVIATION SYSTEM

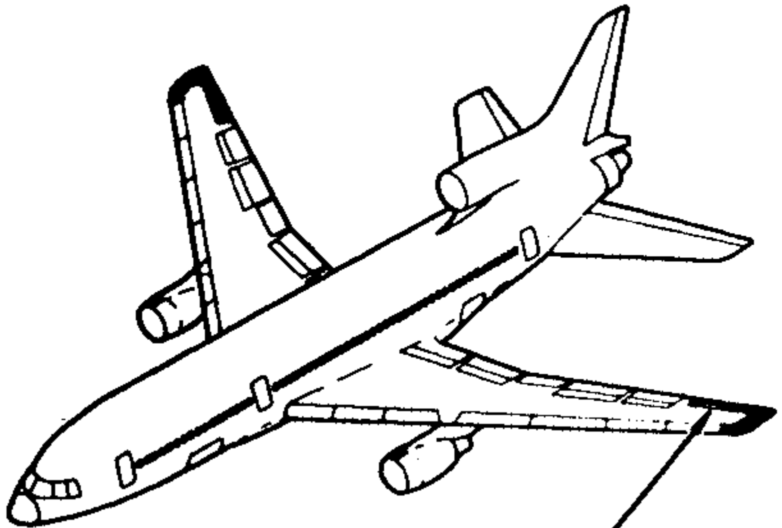
DEVELOPMENT CONFIGURATION

21 SENSORS



PRODUCTION CONFIGURATION

12 SENSORS



SLIDE 47

THE L-1011-500, WITH THESE CHANGES WAS CERTIFICATED BY THE FEDERAL AVIATION ADMINISTRATION AND ENTERED SERVICE WITH PAN AMERICAN AIRWAYS IN MAY 1980. ITS PERFORMANCE TO DATE HAS BEEN BETTER THAN EXPECTED WITH FUEL SAVINGS, ATTRIBUTED TO THE EXTENDED TIPS AND ACTIVE CONTROL SYSTEM, EXCEEDING 300,000 GALLONS PER YEAR PER AIRCRAFT.

ROLL-OUT OF L-1011-500 WITH EXTENDED TIPS AND ACTIVE CONTROLS

47

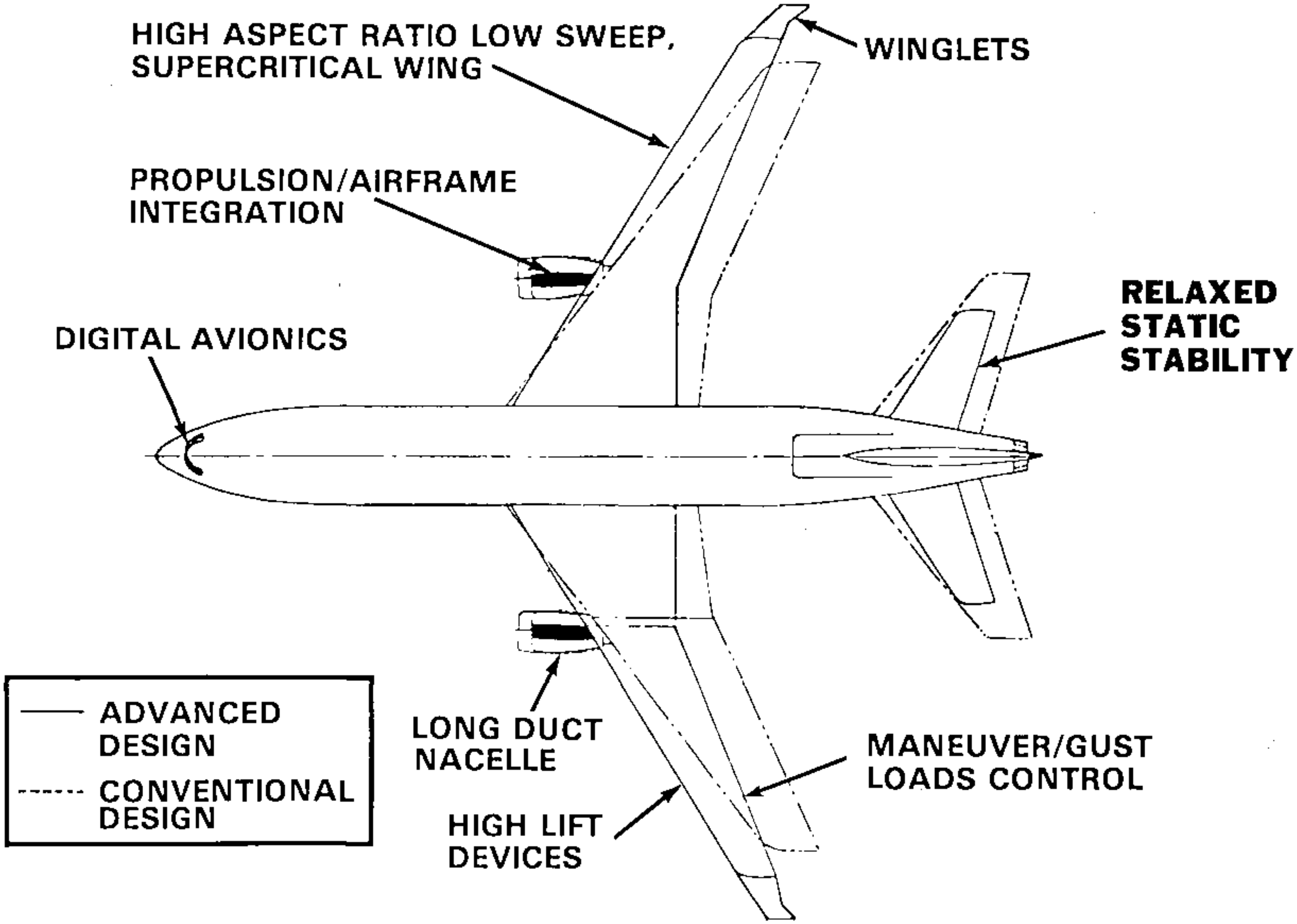
H7A7
1/80

WHILE IMPROVED FUEL EFFICIENCY IN NEAR-TERM DERIVATIVES OF CURRENT AIRCRAFT IS EXTREMELY IMPORTANT, NEW OR REWINGED AIRCRAFT INTRODUCED AFTER 1985 WILL COMPRISE THE LION'S SHARE OF THE EXPECTED 200 BILLION DOLLAR MARKET FORESEEN IN THE NEXT TWO DECADES. MUCH OF THE ACEE/EET EFFORT IS, THUS, FOCUSED ON ADVANCED TECHNOLOGY APPLICABLE TO SUCH FARTHER TERM AIRCRAFT. PARTICULARLY IMPORTANT FOR THE NEW AIRCRAFT OF THE FUTURE IS DEVELOPMENT OF ADVANCED SUPERCRITICAL WINGS WHOSE GREATER LENGTH AND LOWER SWEEP CAN PROVIDE AS MUCH AS 20 PERCENT REDUCTION IN DRAG AND, HENCE, FUEL CONSUMPTION. NEW, COMPATIBLE NACELLE AND PYLON GEOMETRIES, AND NEW HIGH LIFT DEVICES MUST ACCOMPANY THE NEW WING CONFIGURATIONS. AND AN EARLY EET STUDY HAS SHOWN A POTENTIAL BENEFIT OF WINGLETS COUPLED WITH ADVANCED SUPERCRITICAL WINGS.

IN ADDITION TO ACTIVE WING LOAD ALLEVIATION, AIRCRAFT INTRODUCED LATER IN THIS DECADE AND BEYOND CAN BE EXPECTED TO EMPLOY INCREASING DEGREES OF ACTIVE STABILITY AUGMENTATION TOWARD DECREASED TAIL SIZE OR ALTERNATIVE BENEFITS; DEVELOPMENT OF SUCH ACTIVE CONTROL SYSTEMS, TOGETHER WITH COMPATIBLE ADVANCES IN DIGITAL AVIONICS, IS THUS A SIGNIFICANT PART OF THE ACEE/EET PROJECT EFFORT.

EET

ADVANCED TECHNOLOGY FEATURES

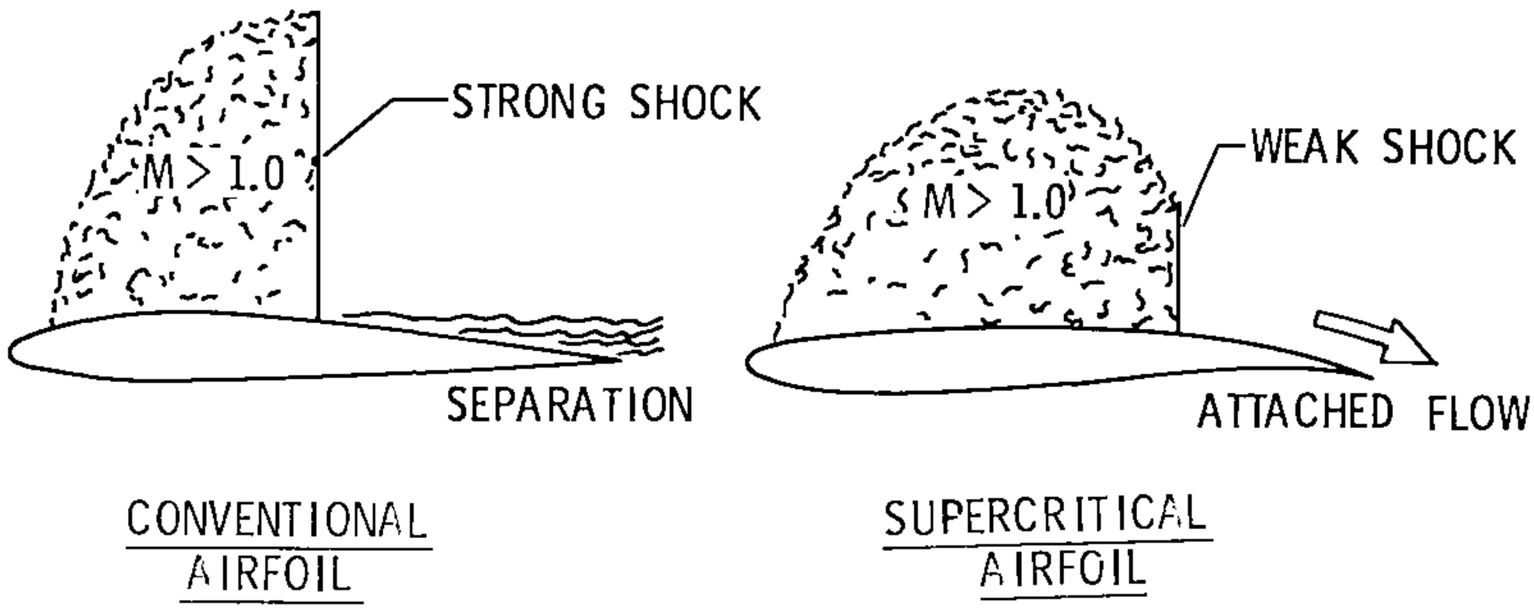


SLIDE 49

IN AIRCRAFT FLYING AT JET TRANSPORT SPEEDS, A REGION OF SUPERSONIC FLOW DEVELOPS OVER THE UPPER SURFACE OF THE WINGS AS SHOWN IN BOTH SKETCHES. ON CURRENT TRANSPORTS WITH CONVENTIONAL AIRFOILS, THIS REGION ENDS IN A STRONG SHOCK WHICH INCREASES TURBULENCE AND LIMITS THE AMOUNT OF LIFT THAT CAN BE ACHIEVED WITHOUT SUBSTANTIAL DRAG. THE "SUPERCRITICAL" AIRFOILS OF NEW TRANSPORTS WILL HAVE FLATTER UPPER SURFACES CAREFULLY SHAPED TO LIMIT THE STRENGTH OF THIS TERMINAL SHOCK AND MAINTAIN STABLE FLOW EVEN WITH LESS SWEEP AND THICKER CROSS-SECTIONS; THE LATTER, IN TURN, ALLOWS THE CONSTRUCTION OF LONGER, MORE FUEL EFFICIENT WINGS WITHOUT UNDUE STRUCTURAL PENALTY.

SUPERCRITICAL FLOW PHENOMENA

H2B3
1/80

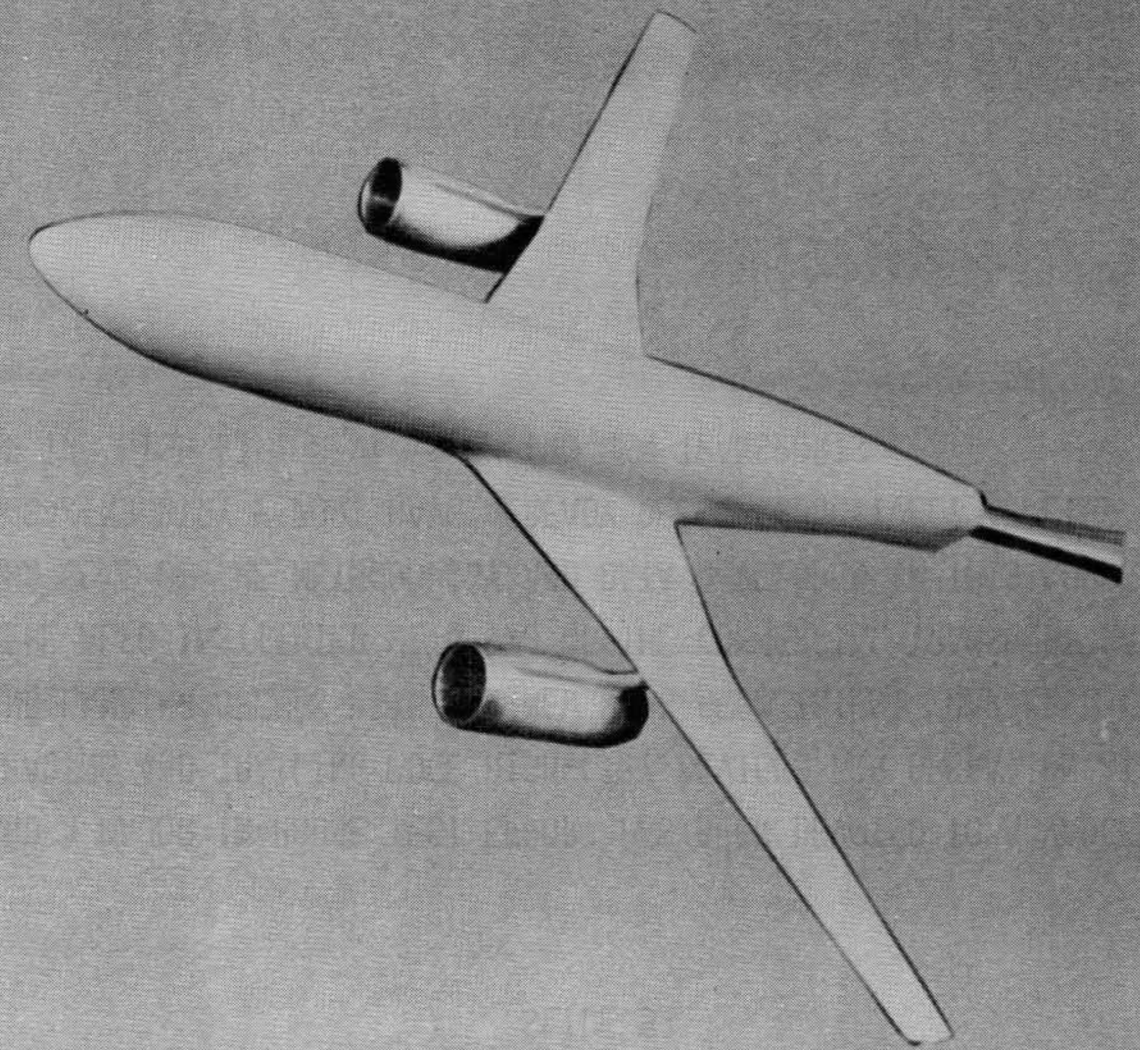


AS PART OF THE ACEE/EET PROJECT, NASA HAS CONDUCTED EXTENSIVE WIND TUNNEL TESTS TO ROUND OUT A COMPREHENSIVE DATA BASE AND DEVELOPED ANALYTICAL METHODS FOR DESIGN OF ADVANCED, LOW-DRAG SUPERCRITICAL WINGS. SOME OF THIS TESTING HAS EXPLORED THEIR COMPATIBILITY WITH PROPOSED ADVANCED LONG-DUCT ENGINE NACELLE CONFIGURATIONS.

NASA EET OAST

NASA HIGH ASPECT RATIO WING MODEL

LANGLEY 8-FT TRANSONIC PRESSURE TUNNEL



NASA HQ RF79 3277(3)
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SLIDE 51

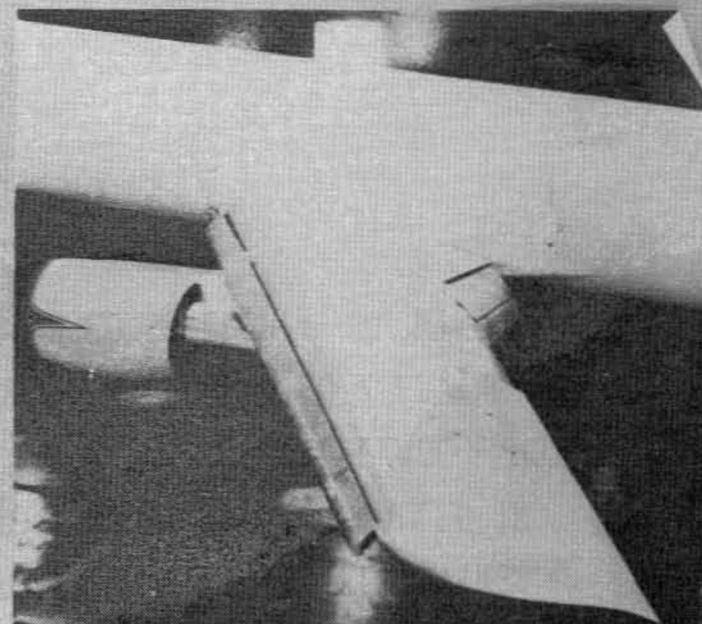
AND A MAJOR IN-HOUSE TEST EFFORT HAS BEEN DEVOTED TO ADVANCED LEADING AND TRAILING EDGE HIGH-LIFT DEVICES FOR OPERATION AT TAKE-OFF AND LANDING SPEEDS WITH THE NEW WING GEOMETRIES. PARALLEL CONTRACT TASKS WERE ALSO INSTITUTED WITH TWO OF THE COMMERCIAL TRANSPORT MANUFACTURERS AND SOME OF THE METHODOLOGY AND DATA DEVELOPED IN THIS COOPERATIVE NASA/INDUSTRY EFFORT HAVE ALREADY BEEN PRODUCTIVELY APPLIED TO DESIGN OF THE HIGH LIFT DEVICES ON TWO NEW TRANSPORTS.

ENERGY EFFICIENT TRANSPORT

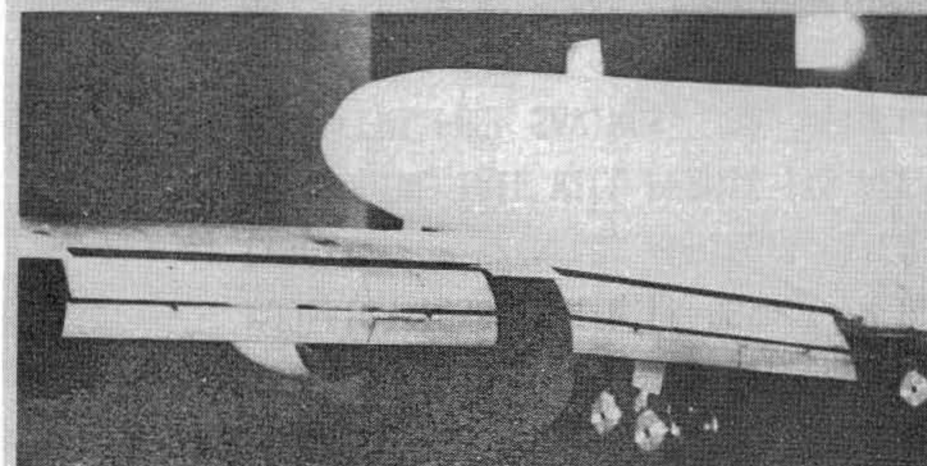
H2E1
1/80
51

LOW SPEED AERODYNAMICS

BASELINE HIGH LIFT MODEL
AR = 12; t/c = 14/12/10%
$\Lambda c/4 = 27^\circ$; $C_{L_{DESIGN}} = 0.7$



LEADING EDGE SLAT – 50°



PARTIAL SPAN TWO-SEGMENTED FLAPS
30° VANE – 60° AFT FLAP

NASA
LCh–78–106

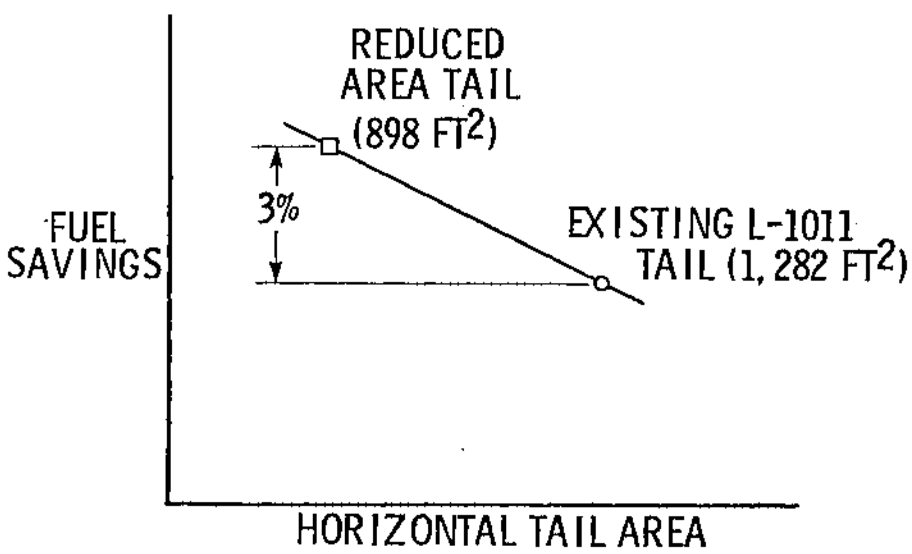
SLIDE 52

ACTIVE CONTROLS FOR STABILITY AUGMENTATION PERMIT CERTAIN AIRCRAFT MODIFICATIONS THAT WILL RESULT IN FUEL SAVING BENEFITS. ON THE LOCKHEED L-1011, FOR EXAMPLE, ADDING A PITCH ACTIVE CONTROL SYSTEM (PACS) TO THE HORIZONTAL TAIL WILL PERMIT ITS AREA TO BE REDUCED 30 PERCENT AND PRODUCE 3 PERCENT FUEL SAVINGS. OR, WITHOUT REDUCING THE TAIL SIZE, THE CENTER OF GRAVITY DURING CRUISE CAN BE MOVED AFT FOR 2 PERCENT FUEL SAVINGS ON THE CURRENT AIRCRAFT BY PUMPING FUEL TO A SMALL TANK INSTALLED IN THE VERTICAL TAIL ABOVE THE ENGINE OR BY INCREASING THE FUSELAGE LENGTH BEHIND THE WING. THESE MEASURES WILL PRODUCE 4 PERCENT FUEL SAVING IF THE AIRCRAFT HAS BEEN REWINGED WITH AN ADVANCED SUPERCRITICAL WING.

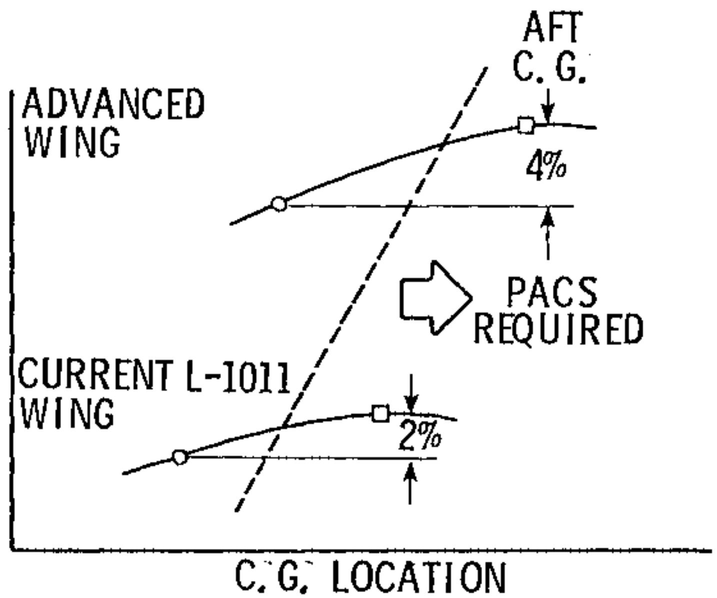
L-1011 MODIFICATIONS & FUEL SAVINGS PERMITTED BY PITCH ACTIVE CONTROL SYSTEM (PACS)

52

REDUCED AREA TAIL



AFT C.G. LOCATIONS

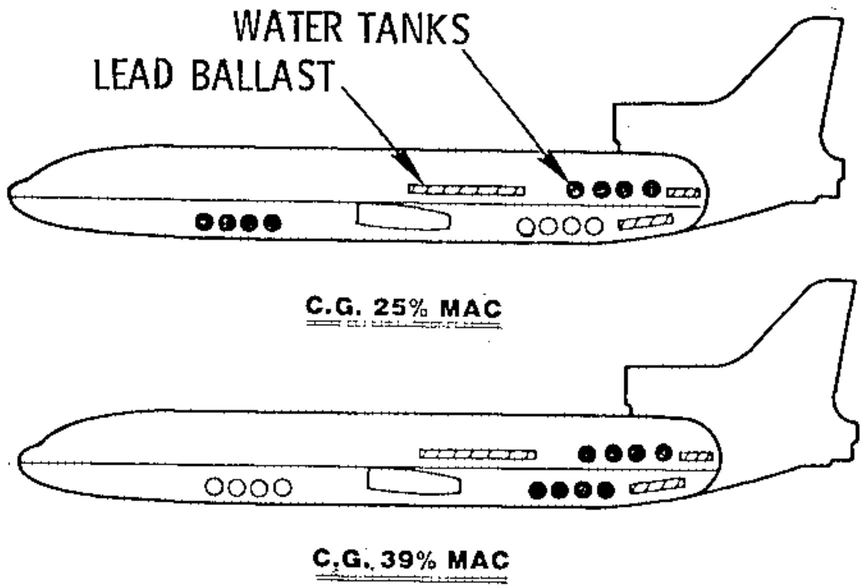


SLIDE 53

TO PREPARE FOR THE ADDITION OF SUCH SYSTEMS TO FUTURE PRODUCTION L-1011's, LOCKHEED WILL CONDUCT WIND TUNNEL TESTS OF A SMALL TAIL DESIGN AND WILL CONDUCT FLIGHT TESTS OF NEAR-TERM AND ADVANCED PITCH ACTIVE CONTROL SYSTEMS (PACS) UNDER A COST-SHARED ACEE/EET CONTRACT. THE FLIGHT TESTS OF THE NEAR-TERM PACS WILL BE CONDUCTED AT CENTER OF GRAVITY (C.G.) LOCATIONS AS FAR AFT AS 39 PERCENT OF THE MEAN AERODYNAMIC CHORD (MAC) OF THE WING, ACHIEVED BY ADDING LEAD AND WATER BALLAST. THE LATTER INCLUDES PROVISIONS FOR PUMPING WATER BALLAST FROM FORWARD TO AFT TANKS TO VARY THE C.G. LOCATION FROM ITS NORMAL 25 PERCENT MAC POSITION. FOR LATER TESTS OF AN ADVANCED PACS WITH THE C.G. AT 43 PERCENT MAC, THE AFT-BALLASTED CONDITION WILL BE AUGMENTED BY LIMITING THE FUEL SUPPLY TO THE OUT-BOARD WING TANKS. THE 43 PERCENT MAC POSITION OF THE CENTER OF GRAVITY IS AFT OF THE NEUTRAL STABILITY POINT WHERE THE AIRCRAFT IS UNSTABLE WITHOUT AUGMENTATION, BUT STILL CONTROLLABLE BY THE PILOT SHOULD THE ACTIVE SYSTEM BE LOST. THUS, THESE TESTS SPAN THE FULL RANGE FROM POTENTIAL EARLY 1980's APPLICATIONS OF A PACS TO STRETCHED L-1011's TO POTENTIAL LATE 1980's APPLICATIONS OF PACS TO REWINGED AIRCRAFT.

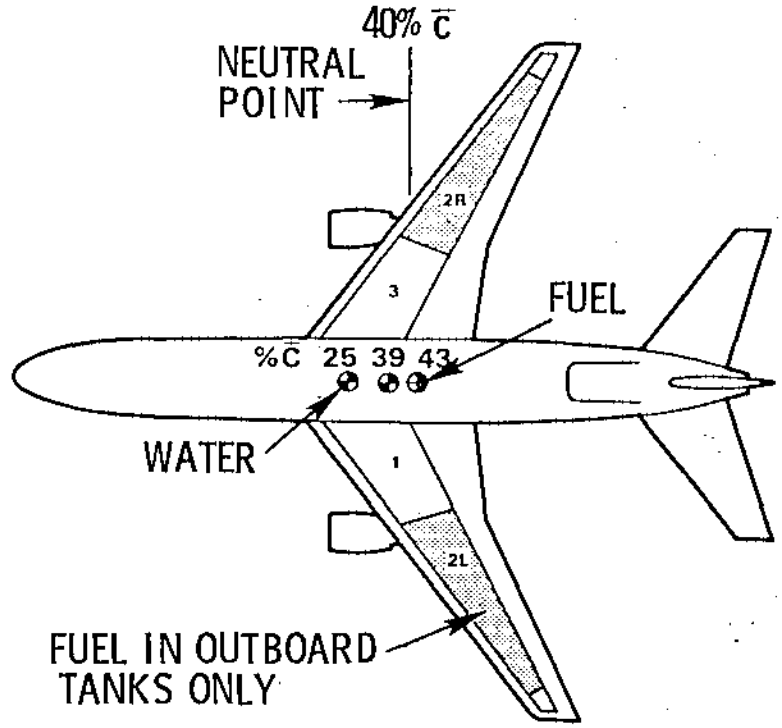
L-1011 C.G.-MANAGEMENT PROVISIONS FOR FLIGHT TEST OF ACTIVE STABILITY AUGMENTATION SYSTEMS

BALLAST DISTRIBUTION



NEAR TERM SYSTEM

FUEL MANAGEMENT



ADVANCED SYSTEM

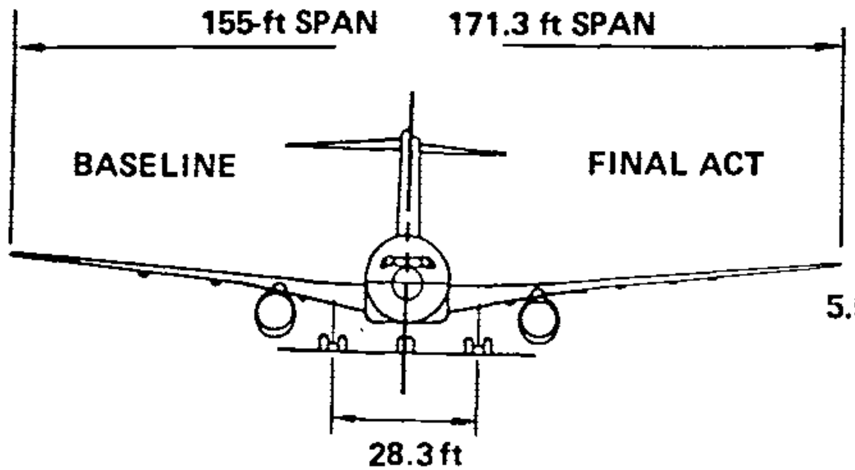
BUT THE EET PROGRAM LOOKS ALSO AT POTENTIALLY MORE AGRESSIVE APPLICATIONS OF ACTIVE CONTROL SYSTEMS TO NEW AIRCRAFT LATE IN THE DECADE. FOR EXAMPLE, A COST-SHARED CONTRACT WITH BOEING HAS INCLUDED COMPREHENSIVE DEFINITION AND EVALUATION OF AN ADVANCED NEW AIRCRAFT DESIGN WHERE A NUMBER OF ACTIVE CONTROL FUNCTIONS HAVE BEEN CONSIDERED AS AN INTEGRAL PART OF THE DESIGN PROCESS. IN PARTICULAR, PITCH STABILITY AUGMENTATION IN THIS DESIGN IS RELIED ON TO THE EXTENT THAT COMPLETE LOSS OF THE PACS WOULD CAUSE LOSS OF THE AIRCRAFT. THUS, THE POSTULATED PACS MUST BE DESIGNED TO BE AS RELIABLE AS THE AIRCRAFT STRUCTURE ITSELF; THE IMPOSED REQUIREMENT IS DESIGN, SO THAT THE AVERAGE TIME TO LOSS OF THE FUNCTION IS 10,000 YEARS. THE OTHER ACTIVE CONTROL FUNCTIONS ARE INCORPORATED WITH THE LESS AGRESSIVE RELIABILITY GOAL OF 10 YEARS AVERAGE TIME TO LOSS OF THE FUNCTION.

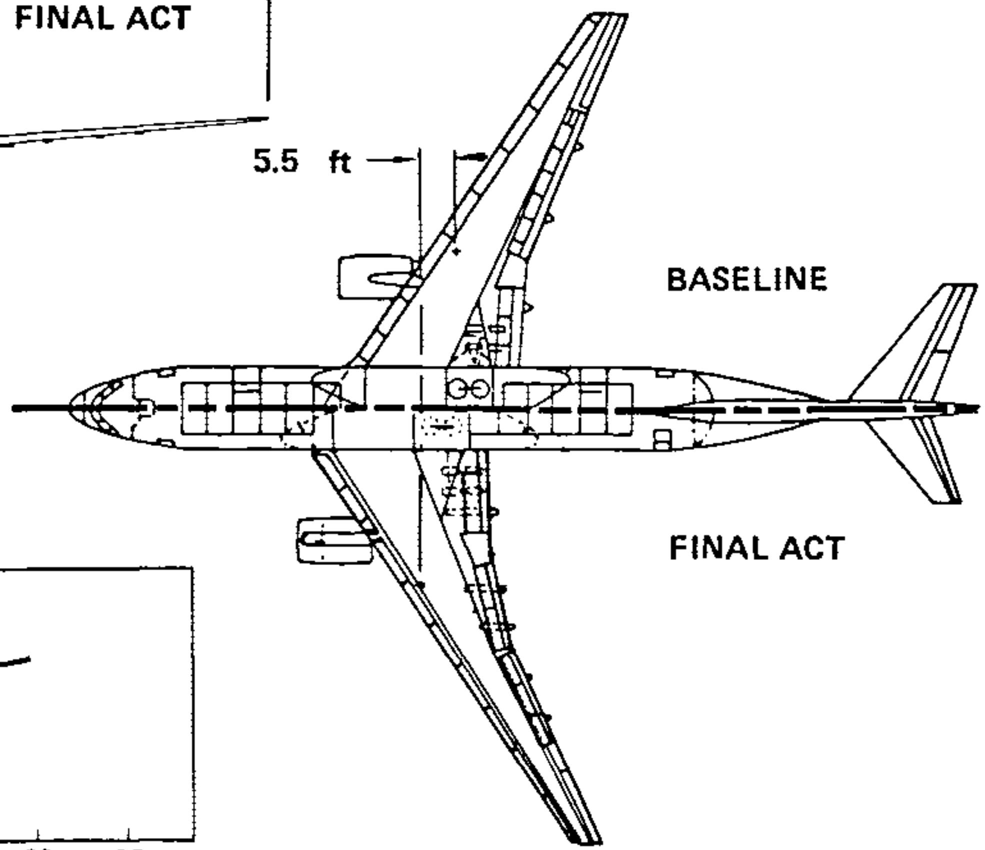
BOEING INTEGRATED-APPLICATION-OF-ACTIVE-CONTROLS STUDY

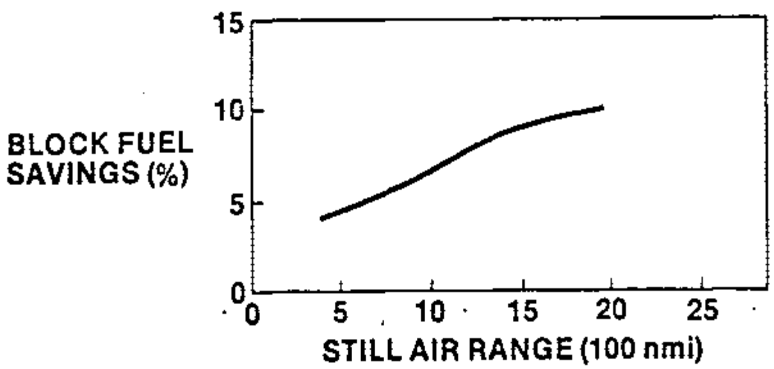
ACTIVE CONTROL FUNCTIONS	EFFECT OF LOSS OF FUNCTION	REQUIRED RELIABILITY (AV. TIME/TO LOSS OF FUNCTION)
° PITCH STABILITY AUGMENTATION	AIRCRAFT LOSS	10000 YEARS
° LATERAL STABILITY AUGMENTATION ° ANGLE-OF-ATTACK LIMITING ° WING MANUEVER LOAD CONTROL ° WING GUST LOAD ALLEVIATION ° FLUTTER MODE CONTROL	REDUCTION OF SPEED, ALTITUDE AND RANGE CAPABILITY	10 YEARS

THE BOEING ACTIVE CONTROLS TECHNOLOGY (ACT) AIRCRAFT WAS DESIGNED FOR THE SAME MISSION AND, EXCEPT FOR THE ADDED ACT, THE SAME ADVANCED TECHNOLOGY LEVEL AS AN EXISTING 200-PASSENGER, 2000-NAUTICAL MILE CONVENTIONAL BASELINE AIRCRAFT DESIGN. ADDITION OF THE ACTIVE CONTROL FUNCTIONS LED TO A WING WITH"ASPECT RATIO" (LENGTH TO WIDTH RATIO) INCREASED FROM 8.7 TO 12 POSITIONED 5.5 FEET FURTHER FORWARD ON THE FUSELAGE. THE HORIZONTAL TAIL SIZE DECREASED DRAMATICALLY. AS SHOWN BY THE INSET PLOT, THE RESULTING SAVINGS IN "BLOCK FUEL" (TOTAL FUEL CONSUMED BETWEEN AIRPORT GATES) VARIED FROM 5 PERCENT AT 500-NAUTICAL-MILE RANGE TO 10 PERCENT AT THE 2000-NAUTICAL-MILE DESIGN RANGE. THE LATTER SAVING AMOUNTS TO 500,000 GALLONS PER YEAR FOR EACH OF THESE 200-PASSENGER AIRCRAFT. THE ECONOMIC SIGNIFICANCE OF THESE CHANGES WAS EVALUATED AT THE 500-NAUTICAL-MILE RANGE WHERE MOST AIRCRAFT FUEL IS CONSUMED. IT WAS FOUND THAT DIRECT OPERATING COSTS WERE DECREASED BY 2 PERCENT, ENOUGH TO PAY BACK THE ADDITIONAL $600,000 COST OF THE ACT AIRCRAFT IN LESS THAN 2 YEARS.

Conventional Baseline and Final ACT Configuration Comparison







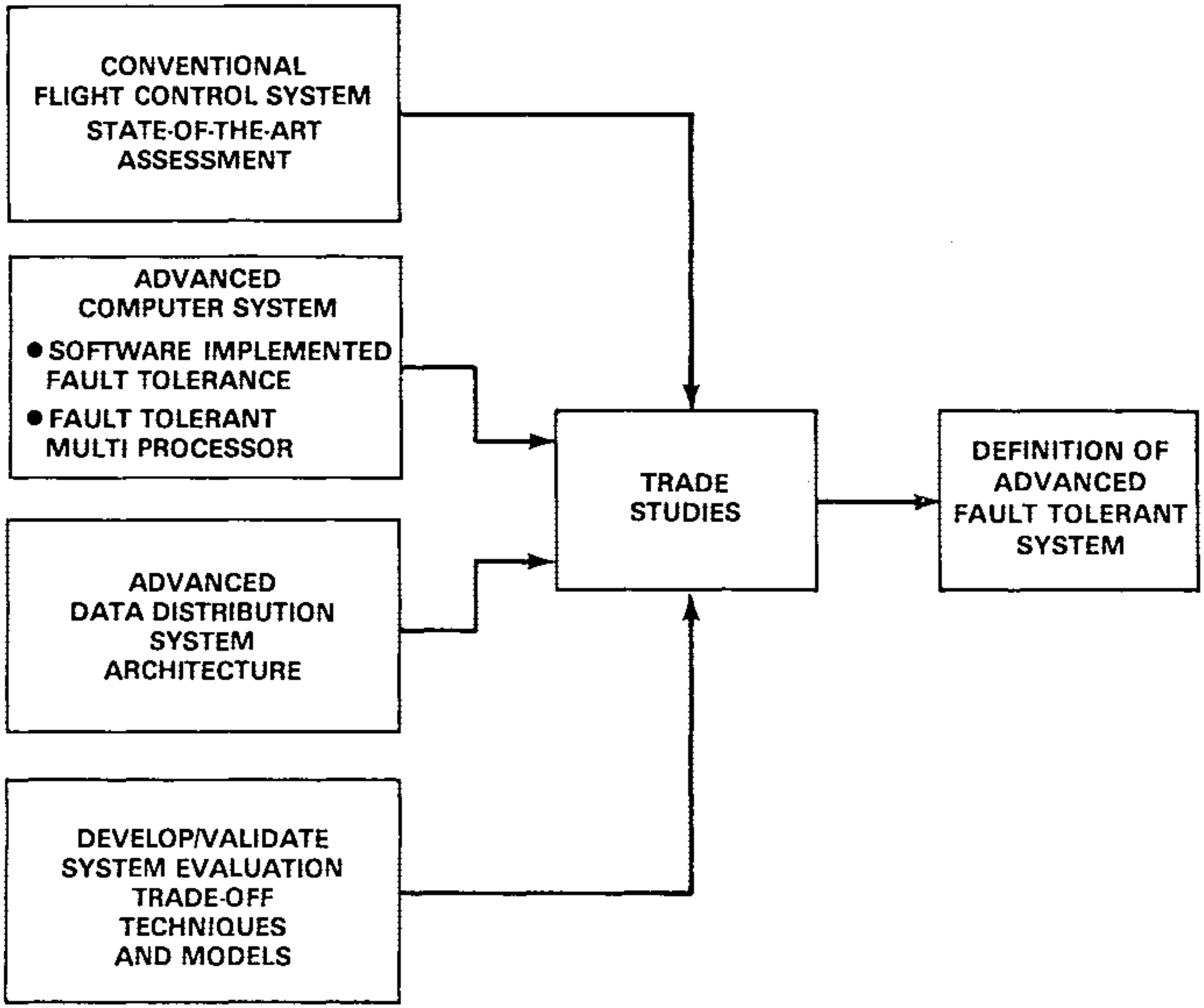
SLIDE 56

THE BOEING EFFORT WILL CONTINUE, WITH PARTIAL NASA HELP, TO DEVELOP AND TEST A REDUNDANT ACTIVE CONTROL SYSTEM ARCHITECTURE THAT CAN MEET THE REQUIRED STRINGENT RELIABILITY GOALS. IN THE MEANTIME A PARALLEL EFFORT TOWARD THE SAME END HAS BEEN UNDERWAY AT NASA'S LANGLEY RESEARCH CENTER FOR SOME TIME. THIS HAS INCLUDED A SURVEY OF THE RELIABILITY OF STATE-OF-THE-ART FLIGHT CONTROL SYSTEMS, DEVELOPMENT OF TWO ADVANCED "FAULT-TOLERANT" COMPUTER SYSTEMS TO THE POINT WHERE LAB TESTS OF PROTOTYPES ARE UNDERWAY, DEFINITION OF ADVANCED DATA DISTRIBUTION SYSTEM ARCHITECTURES, AND DEVELOPMENT OF VIABLE METHODS FOR TIMELY ASSESSMENT OF THE ATTAINED RELIABILITY LEVEL IN SUCH ADVANCED FAULT TOLERANT SYSTEMS THAT ARE DESIGNED TO SURVIVE MANY HUMAN LIFETIMES OF SERVICE WITHOUT SYSTEM FAILURE.

EET

RELIABLE, MAINTAINABLE FLIGHT CONTROLS

H3E
1/80



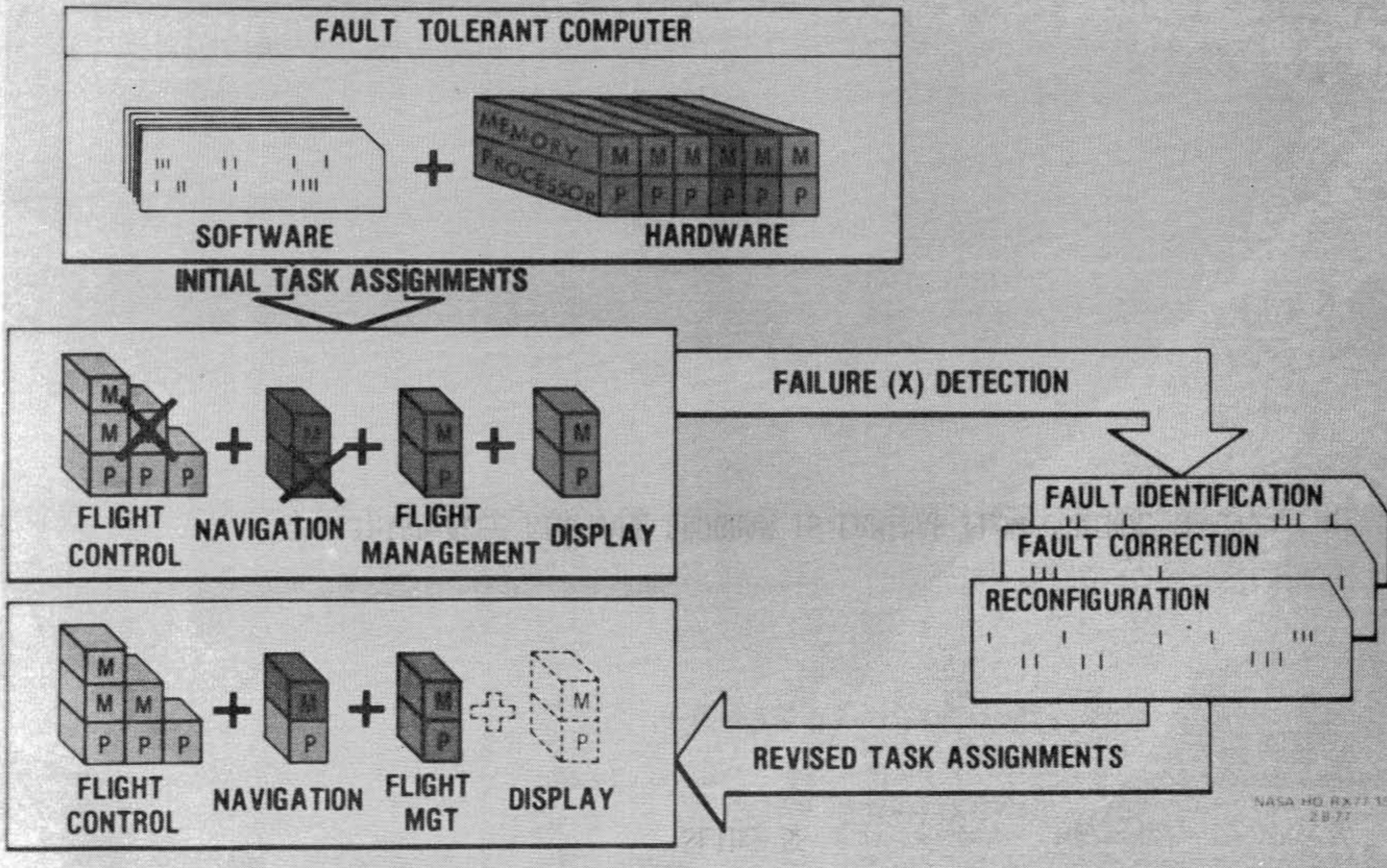
SLIDE 57

BOTH THE ADVANCED FAULT-TOLERANT COMPUTER SYSTEMS UNDERGOING TESTS PERFORM THEIR VARIOUS FLIGHT CONTROL FUNCTIONS WITH DIFFERENT ASSEMBLIES OF THE SAME PROCESSOR (P) AND MEMORY (M) MODULES. THE SYSTEMS ARE PROGRAMMED TO IDENTIFY MODULES THAT ARE MALFUNCTIONING AND TO RECONFIGURE THEMSELVES TO ISOLATE THE FAULTY MODULES, REPLACING THEM WITH SPARES OR WITH HEALTHY MODULES THAT HAVE BEEN PERFORMING LESS CRITICAL FUNCTIONS. IN THIS WAY, THEY CAN TOLERATE LOCAL FAULTS WHILE ACHIEVING THE NEEDED EXTREME TOTAL-SYSTEM-RELIABILITY THAT WILL PERMIT FUTURE TRANSPORTS TO SAFELY RELY ON ACTIVE CONTROLS FOR CRUCIAL FLIGHT STABILITY OR LOAD-RELIEF-FUNCTIONS.

H3F1
1/80

ENERGY EFFICIENT TRANSPORT PROGRAM

ADVANCED COMPUTER SYSTEM



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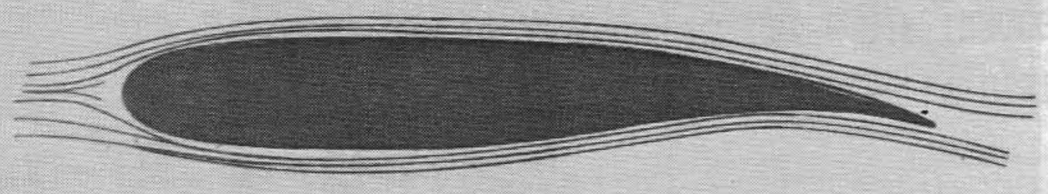
SLIDE 58

THE THIRD ACEE AIRFRAME PROGRAM IS LAMINAR FLOW CONTROL (LFC).



LAMINAR FLOW CONTROL

SLIDE 59

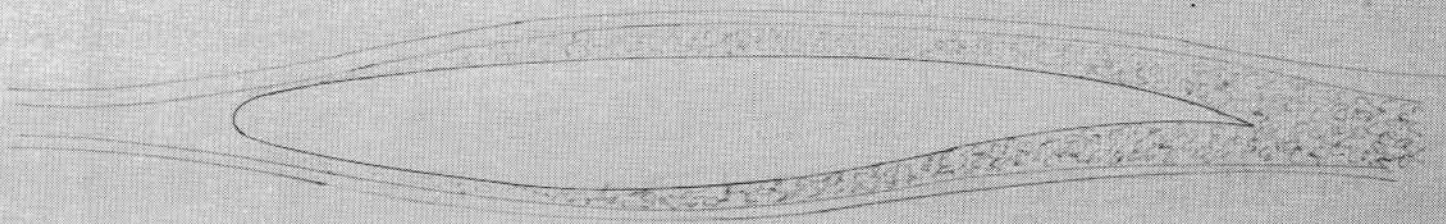
LAMINAR FLOW CONTROL IS CONCERNED WITH THE RELATIVELY THIN "BOUNDARY LAYER" OF AIR ADJACENT TO THE WING AND TAIL SURFACES OF THE AIRCRAFT. AT THE LEADING EDGES, THIS BOUNDARY LAYER STARTS OUT THIN AND "LAMINAR," WITH THE AIR VELOCITY RELATIVE TO THE SURFACE VARYING SMOOTHLY FROM ZERO AT THE SURFACE TO STREAM VELOCITY ONLY A SHORT DISTANCE OUTWARD. HOWEVER, DISTURBANCES WITHIN THE BOUNDARY LAYER QUICKLY CONVERT IT TO A VORTEX-INFESTED "TURBULENT" LAYER THAT EXERTS A HIGH FRICTION (OR "VISCOUS") DRAG FORCE ON THE AIRCRAFT SURFACE. THIS VISCOUS DRAG IS A PRIMARY CONTRIBUTOR TO AIRCRAFT FUEL CONSUMPTION.

IT HAS LONG BEEN KNOWN THAT CAREFULLY DISTRIBUTED AND CONTROLLED SUCTION OF SMALL AMOUNTS OF BOUNDARY-LAYER AIR THROUGH THE SURFACE CAN KEEP BOUNDARY LAYER DISTURBANCES SMALL AND ALLOW THE BOUNDARY LAYER TO REMAIN IN ITS LAMINAR STATE WITH LOCAL VISCOUS-DRAG FORCES A SMALL FRACTION OF TURBULENT VALUES,EVEN WITH CONSERVATIVE ACCOUNT OF SUCTION AREA LIMITS, SUCTION LOSSES, ETC., FUEL SAVINGS OVER THE MOST ADVANCED FUTURE TURBULENT-FLOW TRANSPORTS WILL EXCEED 20 PERCENT.

WHAT IS LAMINAR FLOW CONTROL ?

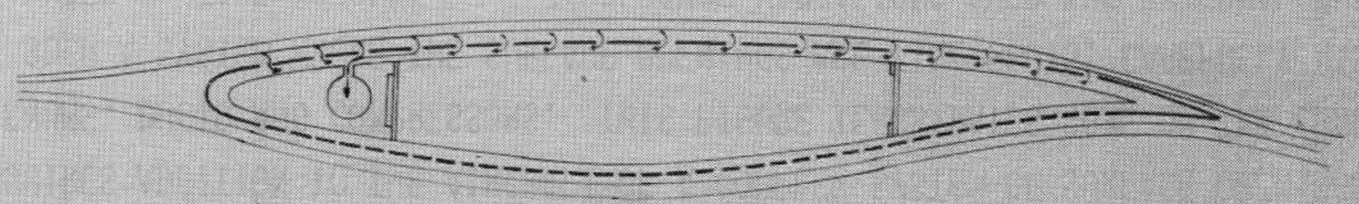
G2A
5/80

- NORMAL SURFACE LAYER



THICK AND TURBULENT WITH HIGH DRAG

- SUCTION - STABILIZED SURFACE LAYER

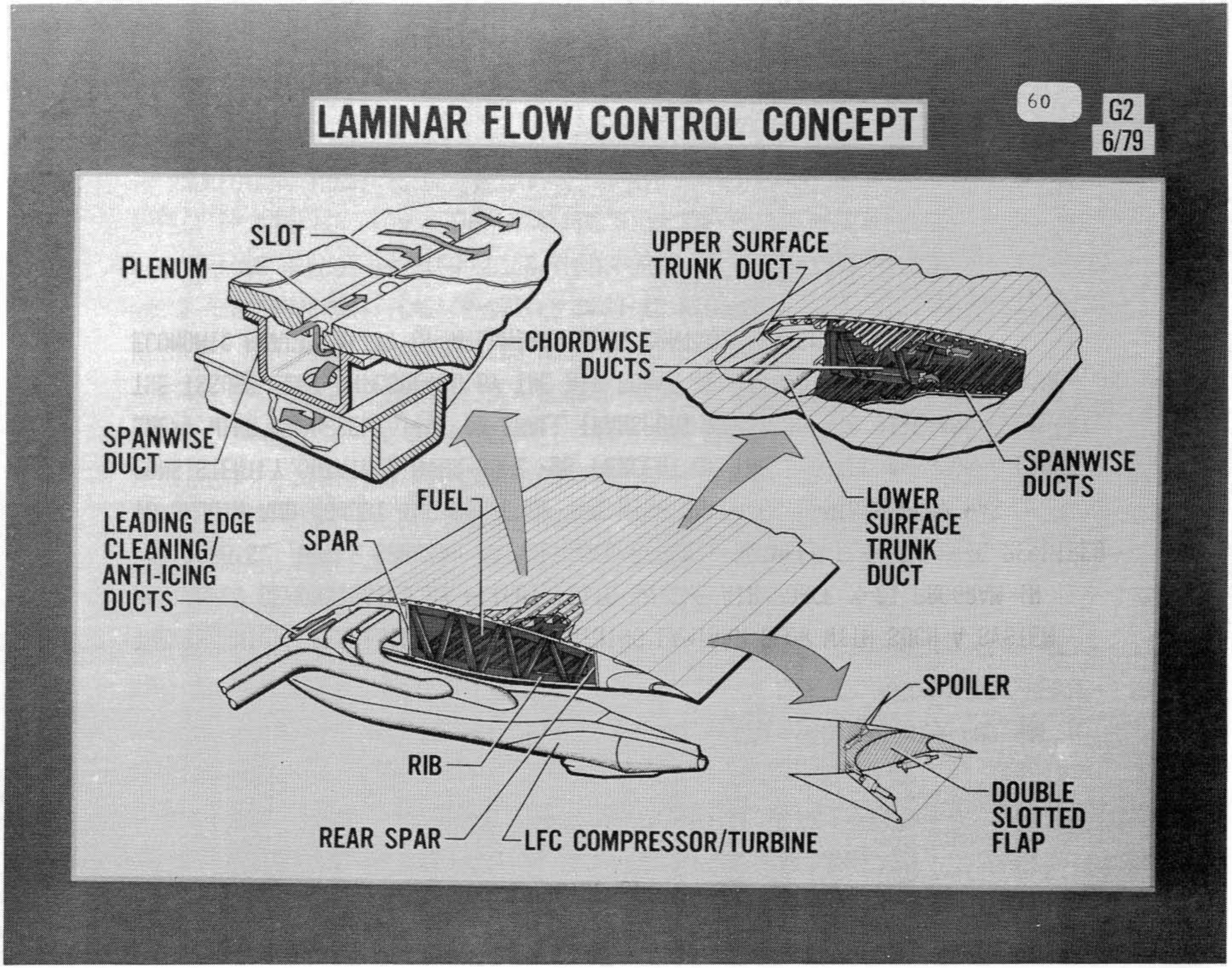


THIN AND LAMINAR WITH LOW DRAG

- BENEFIT: MINIMUM 20% FUEL SAVING OVER FUTURE TURBULENT TRANSPORTS

SLIDE 60

ACHIEVING THE NEEDED SUCTION OF BOUNDARY LAYER AIR THROUGH THE SURFACE REQUIRES ADDITION TO THE AIRCRAFT OF A COMPLEX SYSTEM OF SURFACE OPENINGS, PLENUMS, DUCTS AND COMPRESSORS. THIS FIGURE ILLUSTRATES SOME OF THE CHARACTERISTICS OF SUCH A SYSTEM WHERE THE SURFACE OPENINGS ARE FINE SLOTS, CAREFULLY DISTRIBUTED TO TAKE ACCOUNT OF THE PRESSURE VARIATIONS OVER THE EXTERNAL SURFACE IN FLIGHT. ACHIEVING THE NECESSARY CAREFUL VARIATIONS IN SUCTION LEVELS OVER THE SURFACE IS ACCOMPLISHED WITH PROPERLY SIZED AND SPACED "METERING HOLES" IN THE PLENUMS AND DUCTS THAT COLLECT THE SUCTION AIR, CHANNEL IT SPANWISE AND CHORDWISE JUST UNDER THE SURFACE TO LARGE "TRUNK DUCTS" OUTSIDE THE MAIN WING-BOX STRUCTURE, AND THENCE TO THE COMPRESSORS.


LAMINAR FLOW CONTROL CONCEPT
60
G2
6/79
SLOT
PLENUM
CHORDWISE
DUCTS
SPANWISE
DUCT
UPPER SURFACE
TRUNK DUCT
SPANWISE
DUCTS
LOWER
SURFACE
TRUNK
DUCT
FUEL
LEADING EDGE
CLEANING/
ANTI-ICING
DUCTS
SPAR
SPOILER
RIB
DOUBLE
SLOTTED
FLAP
REAR SPAR
LFC COMPRESSOR/TURBINE

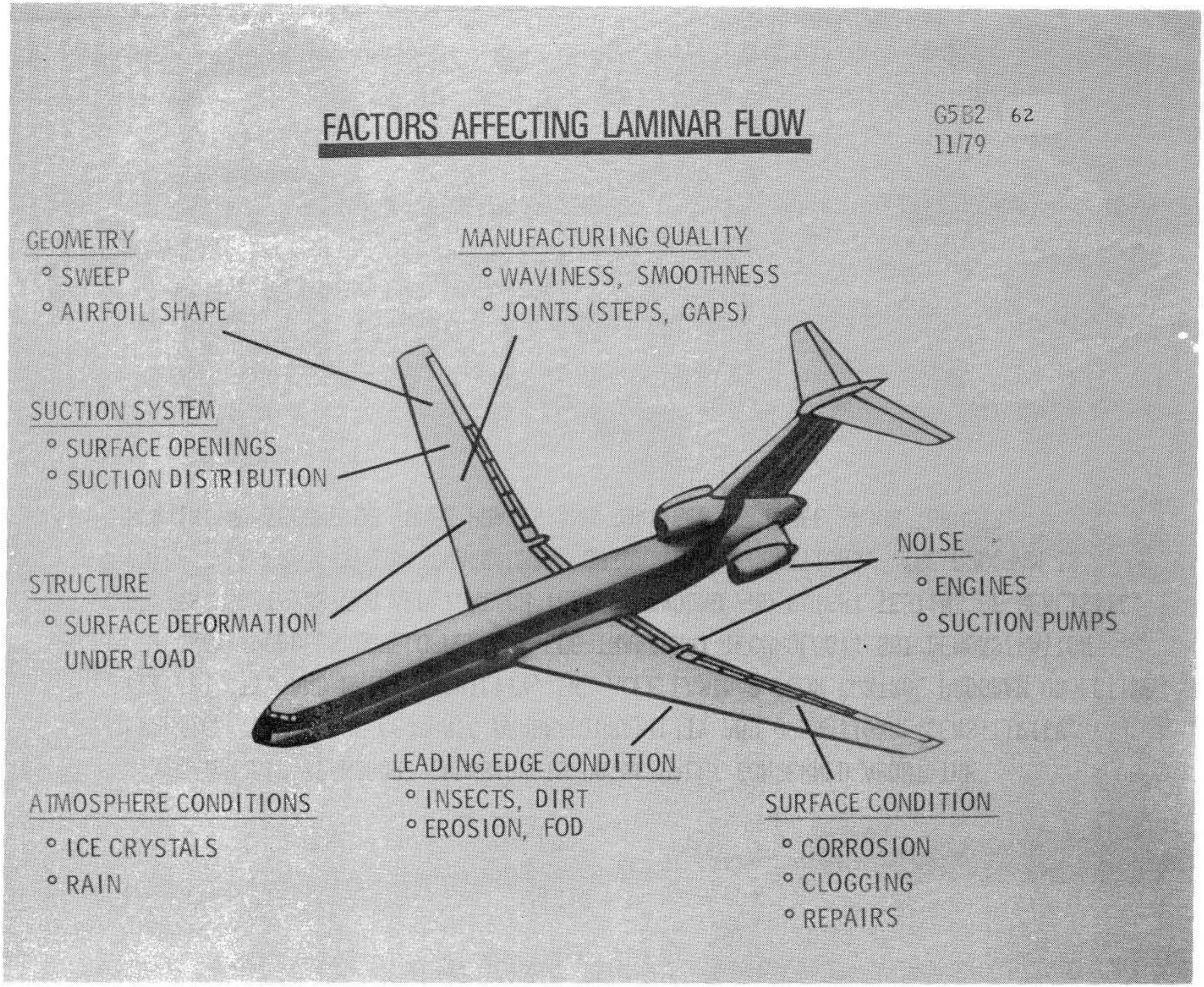
SLIDE 61

THE TECHNICAL FEASIBILITY OF MAINTAINING LAMINAR FLOW WITH SUCH A SYSTEM WAS AMPLY DEMONSTRATED BY FLIGHT TESTS IN THE AIR FORCE X-21 PROGRAM IN THE 1960'S. WHILE SPECIAL MAINTENANCE EFFORTS BETWEEN FLIGHTS WERE REQUIRED TO SMOOTH AND ADJUST THE SHAPE OF THE WING SURFACE, LAMINAR FLOW WAS CONSISTENTLY OBTAINED OVER SOME 96 PERCENT OF THE SLOTTED AREA OF A LARGE SWEPT WING REPRESENTATIVE OF SMALL TRANSPORT WINGS IN ITS SIZE AND GEOMETRY. THE ISSUES LEFT UNRESOLVED BY THE AIR FORCE RELATE TO THE RELIABILITY AND ECONOMIC PRACTICALITY OF A LAMINAR FLOW CONTROL SYSTEM.


61
G3B1
6/79
USAF X-21A AIRCRAFT
WING AREA 1250 sq. ft
SPAN 93 ft, 6 in
ASPECT RATIO 7.0
SWEEP AT .25C 30°
T. O. WT. 83 000 lb
37% OF TOTAL WETTED AREA IS LAMINAR

SLIDE 62

TO UNDERSTAND THESE ISSUES RELATIVE TO AIR TRANSPORTS, CONSIDER THE FACTORS AFFECTING LAMINAR FLOW. THEY INCLUDE WING SWEEP, WHERE EXPERIENCE WITH THE HIGH VALUES NEEDED IN HIGH SPEED TRANSPORTS IS VERY LIMITED, AND AIRFOIL SHAPE, WHERE NEW "SUPERCRITICAL" PROFILES MUST BE ACCOMMODATED. SUCTION DISTRIBUTIONS REQUIRED FOR THESE NEW PROFILES MUST BE DETERMINED AND ALTERNATIVES FOR SURFACE OPENINGS EXPLORED. NEW BONDED-AND COMPOSITE-STRUCTURES SHOULD BE MANUFACTURABLE TO THE NEAR-PERFECT SHAPE AND SMOOTHNESS REQUIREMENTS, BUT THIS MUST BE ACHIEVED WITHOUT EXCESSIVE COST. AND THE SURFACE MUST DEFORM VERY LITTLE UNDER LOAD. IN OPERATION, A LAMINAR BOUNDARY LAYER WILL BE VERY SENSITIVE TO LEADING EDGE ROUGHNESS FROM INSECTS, DIRT, EROSION, OR FOREIGN OBJECT DAMAGE AND MAY BE AFFECTED BY ENGINE NOISE. FURTHER, THE VERY FINE SURFACE OPENINGS OF THE SUCTION SYSTEM MUST NOT UNDULY CORRODE OR CLOG AND MUST BE CLEANABLE AND REPAIRABLE. FINALLY, THE DEGREE TO WHICH ATMOSPHERIC PARTICLES WILL IMPACT THE PERFORMANCE OF A FLEET OF LAMINAR FLOW CONTROL AIRCRAFT MUST BE KNOWN.


FACTORS AFFECTING LAMINAR FLOW
G5B2 62
11/79
GEOMETRY
° SWEEP
° AIRFOIL SHAPE
MANUFACTURING QUALITY
° WAVINESS, SMOOTHNESS
° JOINTS (STEPS, GAPS)
SUCTION SYSTEM
° SURFACE OPENINGS
° SUCTION DISTRIBUTION
NOISE
° ENGINES
° SUCTION PUMPS
STRUCTURE
° SURFACE DEFORMATION UNDER LOAD
LEADING EDGE CONDITION
° INSECTS, DIRT
° EROSION, FOD
ATMOSPHERE CONDITIONS
° ICE CRYSTALS
° RAIN
SURFACE CONDITION
° CORROSION
° CLOGGING
° REPAIRS

SLIDE 63

SINCE THE AIR TRANSPORT INDUSTRY IS PRINCIPALLY CONCERNED ABOUT THE PRACTICAL ISSUES OF ECONONIC MANUFACTURABILITY AND OPERATIONAL SENSITIVITY, RELIABILITY, AND MAINTAINABILITY, THE ACEE LAMINAR FLOW CONTROL PROGRAM OBJECTIVE NOT ONLY INCLUDES DEVELOPMENT OF LFC-TRANSPORT TECHNOLOGY, BUT DEMONSTRATION OF ITS READINESS FOR APPLICATION THROUGH GROUND AND FLIGHT TESTING OF REALISTIC, FULL-SCALE PROTOTYPE HARDWARE UNDER OPERATIONAL CONDITIONS. THE PROGRAM IS NOW IN THE SECOND OF THREE PHASES AND CONSISTS OF THREE MAJOR THRUSTS.

LAMINAR FLOW CONTROL (LFC)

OBJECTIVE

DEVELOP LFC TECHNOLOGY AND DEMONSTRATE READINESS FOR INDUSTRY APPLICATION TO FUTURE COMMERCIAL TRANSPORTS.

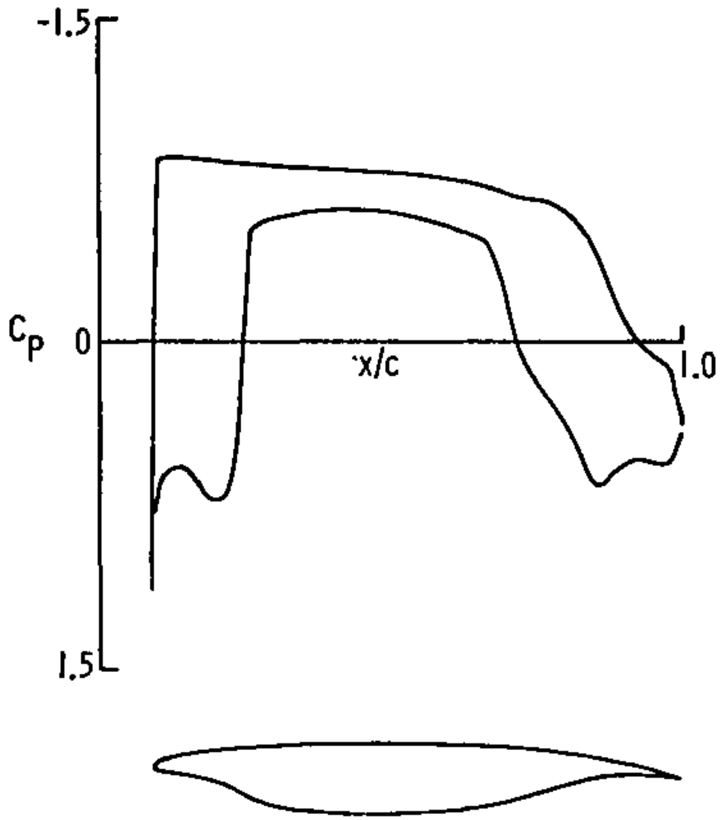
SLIDE 64

ONE OF THESE THRUSTS IS LARGELY AERODYNAMIC. IN ADDITION TO DEVELOPMENT OF COMPUTER CODES FOR BOUNDARY LAYER STABILITY ANALYSIS, IT INCLUDES NASA IN-HOUSE DEVELOPMENT AND EVAUATION OF AN ADVANCED LFC AIRFOIL. THE NASA AIRFOIL'S UNUSUAL SUPERCRITICAL GEOMETRY AND RESULTING PRESSURE DISTRIBUTION, SHOWN AT THE LEFT, IS CAREFULLY CONCEIVED TO REQUIRE NO SUCTION NEAR THE LEADING EDGE AND MINIMUM SUCTION ELSEWHERE FOR LAMINAR BOUNDARY LAYER STABILITY. IN ADDITION, THIS LFC AIRFOIL ACTUALLY OUT PERFORMS THE MOST ADVANCED TURBULENT-FLOW SUPERCRITICAL AIRFOILS IN ITS DESIRABLE COMBINATION OF HIGH THICKNESS-TO-CHORD (LENGTH) RATIO AND RELATIVELY HIGH MACH NUMBER M_{DD} AT WHICH RAPID PROFILE-DRAG GROWTH ("DRAG DIVERGENCE") BEGINS.

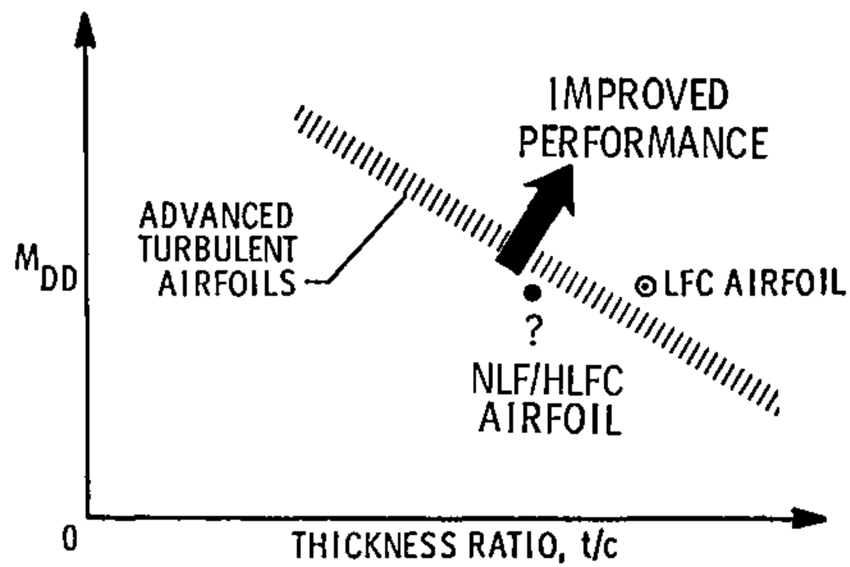
LFC ADVANCED AIRFOIL

M =.758 t/c=13.1% C_L = .58

AIRFOIL CHARACTERISTICS



COMPARATIVE PERFORMANCE



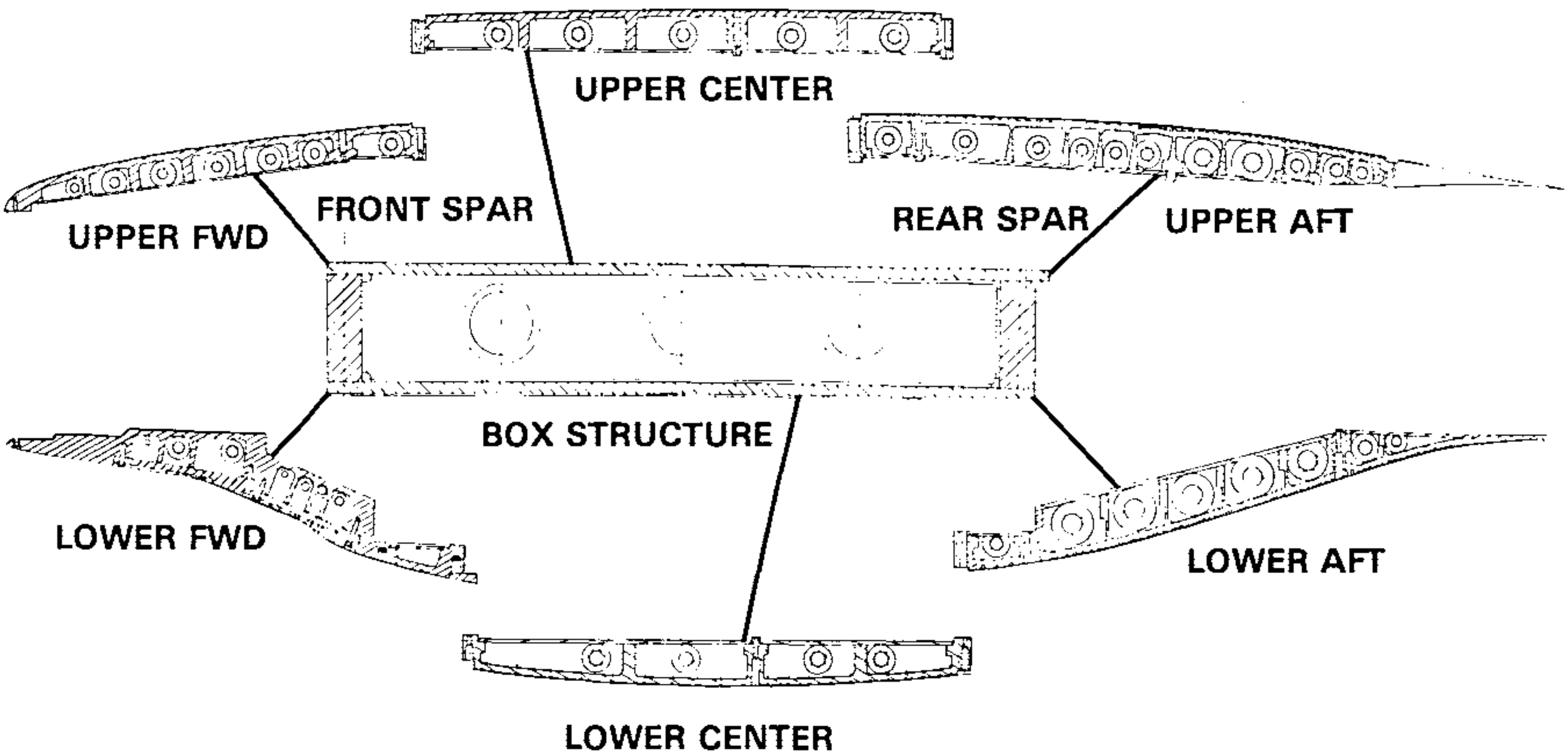
SLIDE 65

A SEVEN-FOOT-CHORD RESEARCH MODEL OF THE NASA AIRFOIL HAS BEEN CAREFULLY PREPARED FOR TEST IN NASA LANGLEY'S 8-FOOT TRANSONIC TUNNEL. ITS SIX SUCTION PANELS HAVE MANY SEPARATE SUCTION DUCTS, EACH SERVING A NUMBER OF SURFACE SLOTS AND PLENUMS WITH CAREFULLY SIZED METERING HOLES.

LFC

65 G8E2
8/79

MODEL SUCTION PANELS

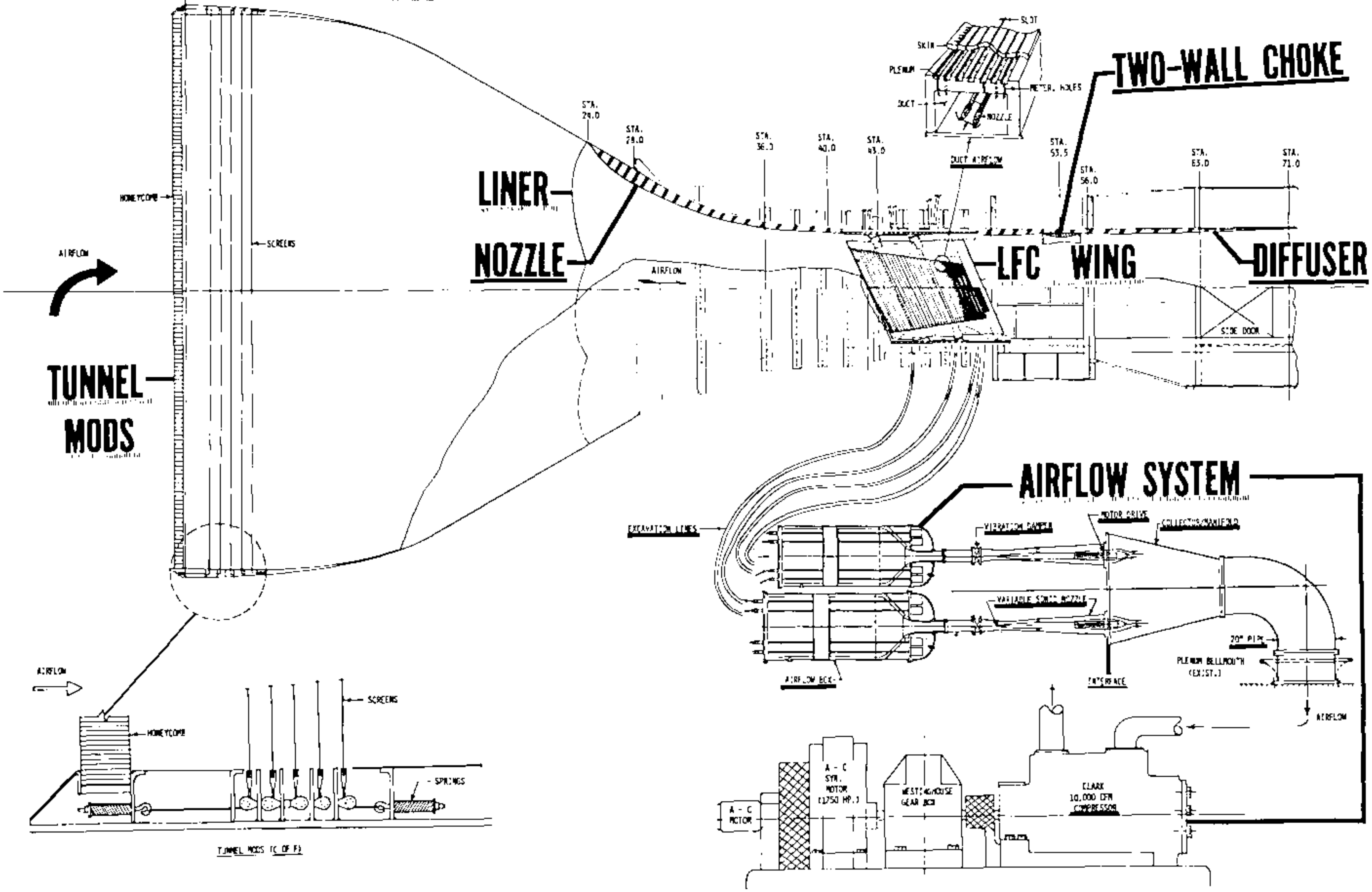


EACH SUCTION DUCT IN THE SWEPT LFC AIRFOIL MODEL WILL BE CONNECTED TO A SEPARATE AUTOMATED AIRFLOW CONTROL IN A CAREFULLY DESIGNED AND CONSTRUCTED SUCTION AIRFLOW SYSTEM TAILORED FOR THE PLANNED TESTS. THE LANGLEY 8-FOOT TRANSONIC TUNNEL HAS ALREADY BEEN MODIFIED TO REDUCE WIND TUNNEL BACKGROUND TURBULENCE TO LEVELS NEAR THOSE IN FREE ATMOSPHERIC FLIGHT. A SPECIALLY SHAPED LINER HAS BEEN DESIGNED, FABRICATED, AND INSTALLED IN THE TUNNEL TO ELIMINATE WALL INTERFERENCE AND ASSURE THE FLOW OVER THE MODEL WILL CORRESPOND TO FREE FLIGHT OF SWEPT CONSTANT-SECTION WING. TESTS TO CONFIRM THE PREDICTED PERFORMANCE AND REQUIRED SUCTION LEVELS OF THE NASA LFC AIRFOIL WILL BEGIN IN 1982. THESE WILL BE FOLLOWED BY TESTS TO RELATE SUCTION REQUIREMENTS TO KNOWN DEVIATIONS IN SHAPE AND SURFACE ROUGHNESS AND TESTS OF A SECOND SERIES OF UPPER SURFACE PANELS WITH PERFORATIONS INSTEAD OF SLOTS.

AERODYNAMIC DESIGN OF A LFC TRANSPORT WING AND SUCTION SYSTEM, ACCOUNTING FOR REALISTIC VARIATIONS IN WING GEOMETRY, IS PLANNED FOR FUTURE IMPLEMENTATION IN PHASE 2 OF THE ACEE/LFC PROGRAM.

TEST SETUP——LFC WING——8 FT TUNNEL

66 G8E3A
2/81

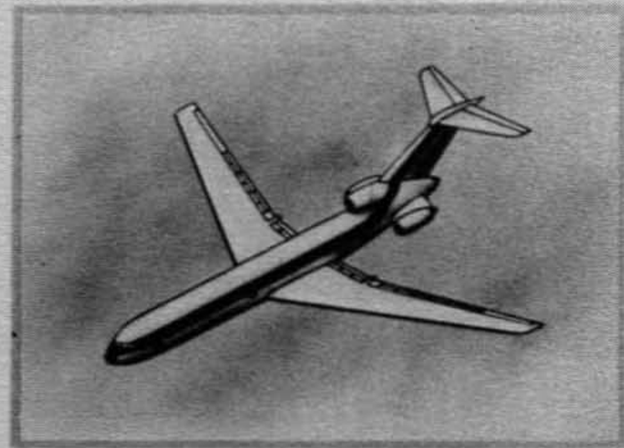


SLIDE 67

BUT SINCE THE PRINCIPAL ISSUES REQUIRING RESOLUTION RELATE TO THE PRACTICALITY OF LFC IN COMMERCIAL TRANSPORTS, MOST OF THE LFC PROGRAM EFFORT IS BEING CARRIED OUT BY THE COMMERCIAL TRANSPORT INDUSTRY UNDER CONTRACT TO NASA. IN PHASE I OF THE LFC PROGRAM, THE INDUSTRY'S EFFORTS WERE FOCUSED ON THREE CONCEPTUAL DESIGNS OF LFC AIRCRAFT FOR LONG RANGE MISSIONS WITH VARYING PASSENGER LOADS. THESE STUDIES IDENTIFIED TWO CRITICAL ADDITIONAL AREAS THAT ARE CURRENTLY MAJOR THRUSTS OF THE ACEE/LFC PROGRAM.

LAMINAR FLOW CONTROL CONFIGURATIONS AND MISSIONS

BOEING

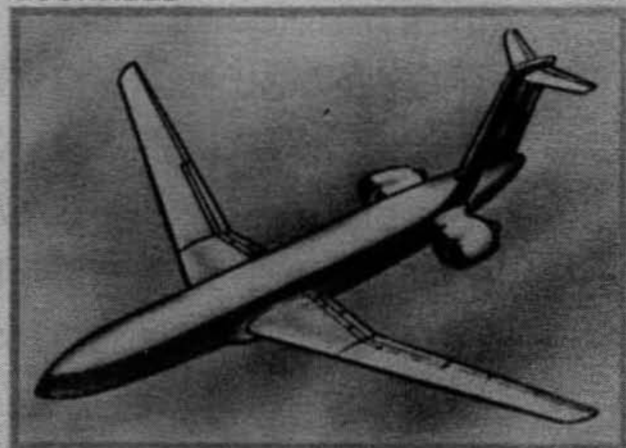


5500 n. mi. RANGE
200 PASSENGERS

DOUGLAS

5000 n. mi. RANGE
300 PASSENGERS

LOCKHEED



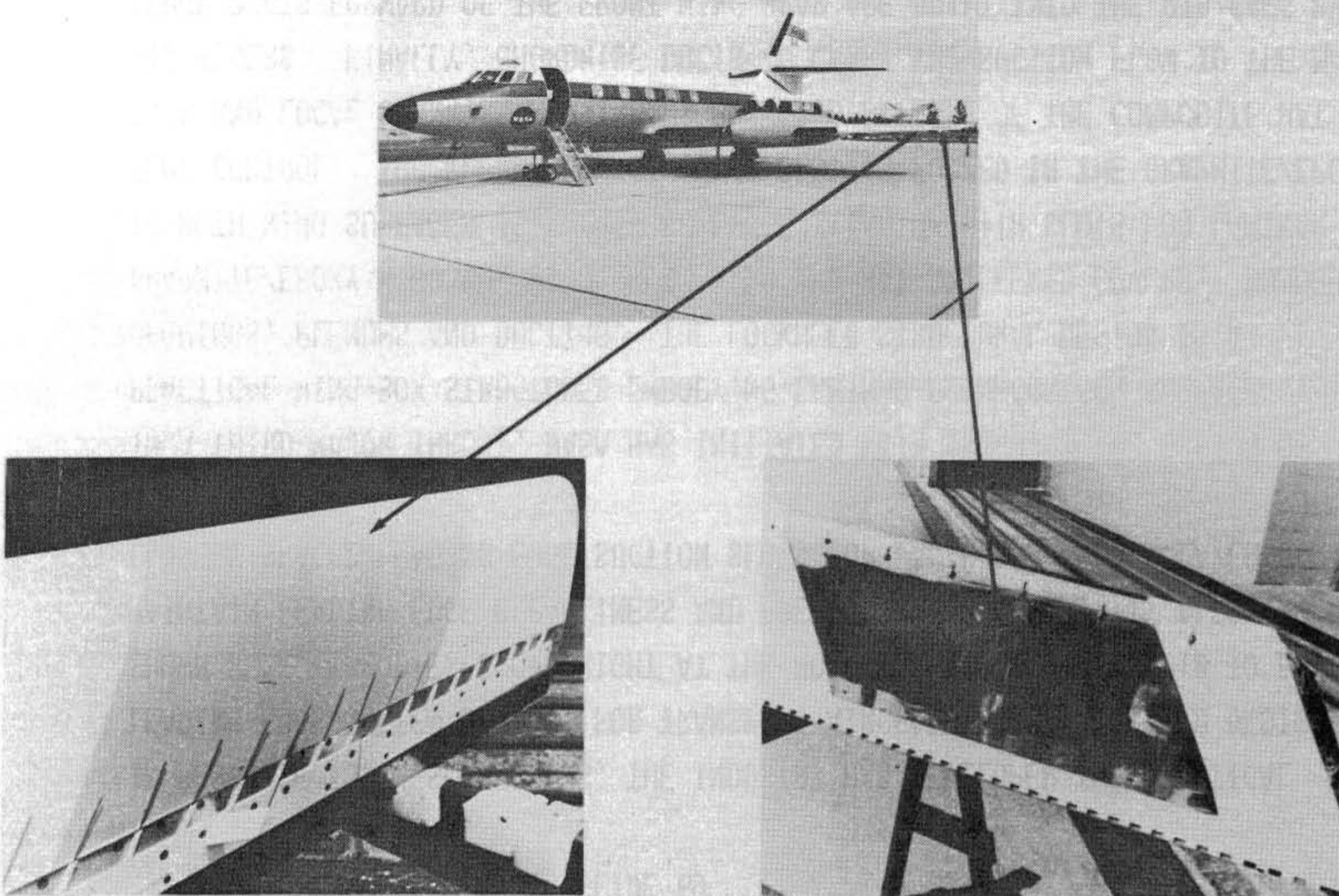
6500 n. mi. RANGE
400 PASSENGERS

SLIDE 68

ONE OF THESE TWO ADDITIONAL THRUSTS OF THE ACEE/LFC PROGRAM IS DEFINITION AND DEVELOPMENT OF THE SYSTEMS REQUIRED IN THE LEADING-EDGE REGIONS OF SWEPT WINGS WHERE LAMINAR BOUNDARY LAYERS ARE PARTICULARLY DIFFICULT TO MAINTAIN IN A STABLE CONDITION. FOR EXAMPLE, EXPLORATORY FLIGHT TESTS, CONDUCTED BY NASA'S DRYDEN FLIGHT RESEARCH CENTER EARLY IN THE LFC PROGRAM, SHOWED CLEARLY THE NEED FOR SOME FORM OF ACTIVE PROTECTION AND/OR CLEANING SYSTEM TO LIMIT CONTAMINATION OF LEADING EDGE SURFACES FROM IMPACT WITH INSECTS DURING TAKE OFF AND CLIMB TO CRUISE ALTITUDE. THESE TESTS ALSO SHOWED THAT A SIMPLE WASHING SYSTEM TO PREVENT INSECT CONTAMINATION IS FEASIBLE.

LEADING EDGE CONTAMINATION FLIGHT TEST

NASA JETSTAR



L.E. UPPER SURFACE BONDED TEFLON WITH TOTAL HEAD TUBES.

L.E. LOWER SURFACE POLISHED ALUMINUM WITH WATER SPRAY NOZZLES.

SLIDE 69

IN RESPONSE TO THESE RESULTS, THE INDUSTRY HAS DEVELOPED TWO PRACTICAL LEADING-EDGE-SYSTEM DESIGNS FOR TRANSPORT AIRCRAFT. THE LOCKHEED DESIGN, SHOWN HERE, EMBODIES SLOTS RIGHT AT THE NOSE FOR DISPENSING FLUID TO BOTH MAINTAIN LEADING EDGE CLEANLINESS AND PREVENT ICE BUILDUP. IT ALSO INCLUDES CLOSELY SPACED LEADING EDGE SUCTION SLOTS FOR LAMINAR BOUNDARY LAYER CONTROL.

IN A THIRD MAJOR THRUST, NASA HAS INITIATED WITH INDUSTRY THE DESIGN OF PRACTICAL WING-BOX STRUCTURES EMBODYING LAMINAR-FLOW-CONTROL SURFACE OPENINGS, PLENUMS AND DUCTING. THE LOCKHEED STRUCTURAL DESIGN IS A GRAPHITE/EPOXY WING BOX WITH TRUSS RIBS AND HAT-STIFFENED COVERS. BONDED TO BOTH WING SURFACES IS A THIN SHEET OF TITANIUM WITH SLOTS FOR LAMINAR FLOW CONTROL. THE PLENUM BENEATH EACH SLOT IS FORMED IN THE GRAPHITE/EPOXY SKIN AND LOCAL SPANWISE DUCTING IS PROVIDED BY SOME OF THE COMPOSITE HAT STIFFENERS. FINALLY, CHORDWISE DUCTS TO CARRY THE SUCTION FLOW TO THE MAIN TRUNK DUCTS FORWARD OF THE FRONT WING SPAR ARE BUILT INTO THE RIB CAPS BY MAKING THESE A BOX STRUCTURE. THIS CAREFUL INTEGRATION OF THE LFC SUCTION SYSTEM WITH THE STRUCTURE IS INTENDED TO MINIMIZE TOTAL WEIGHT.

LOCKHEED LFC WING STRUCTURAL DESIGN

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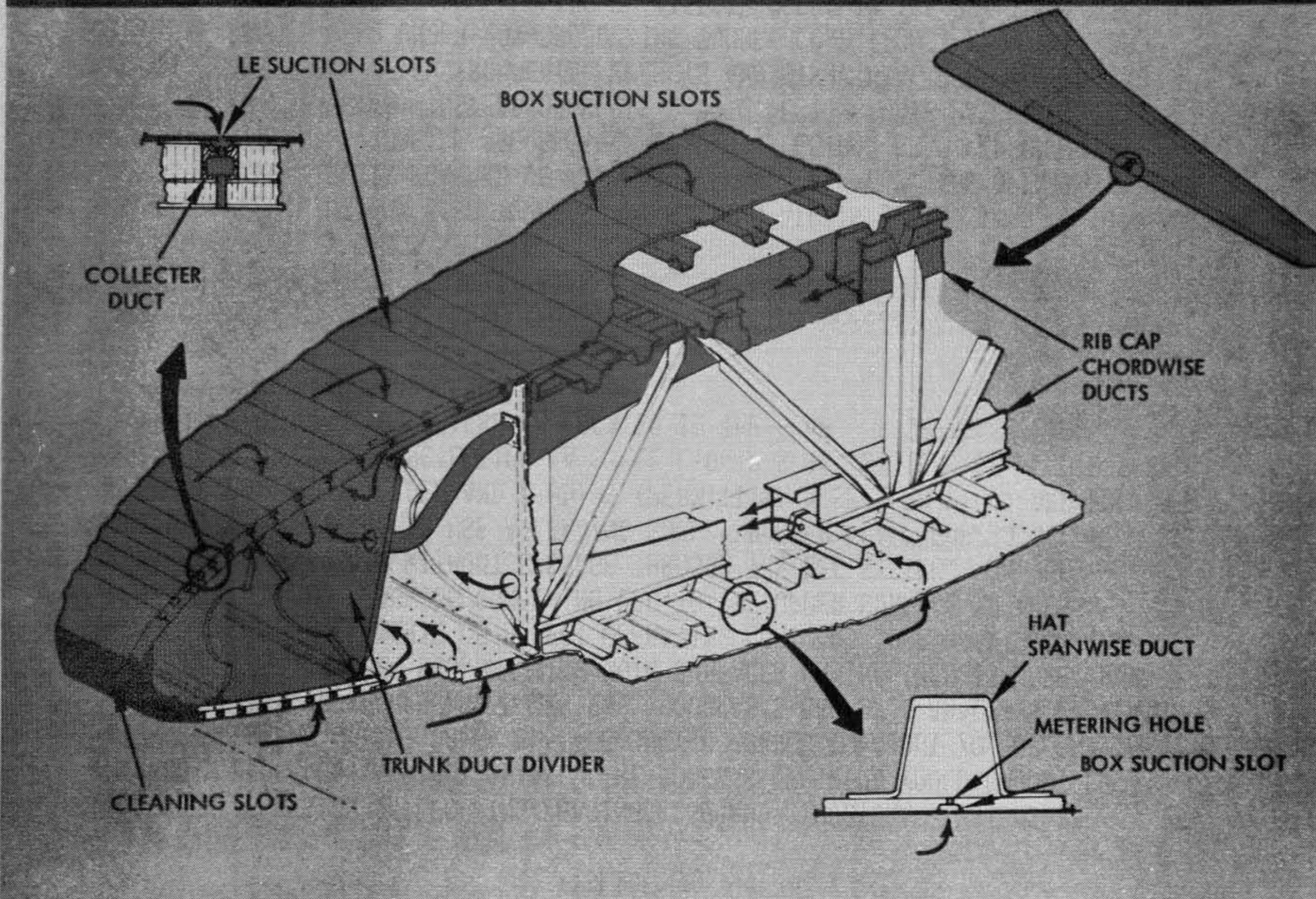
6/81



THE DOUGLAS DESIGN OF LFC-WING LEADING EDGE AND STRUCTURAL SYSTEMS IS MARKEDLY DIFFERENT. FIRST OF ALL, THE DOUGLAS LFC WING WOULD EMBODY LFC OVER 85 PERCENT OF THE UPPER SURFACE ONLY COMPARED TO ABOUT 70 PERCENT OF BOTH SURFACES IN THE LOCKHEED DESIGN. DOUGLAS'S ECONOMIC ANALYSIS INDICATES THAT THE GREATER FUEL ECONOMY WITH BOTH SURFACES LAMINARIZED IS MORE THAN OFFSET BY OTHER ELEMENTS OF DIRECT OPERATING COST AND CONSTRAINTS ON THE DESIGN. ONE ADVANTAGE OF CONFINING LFC TO THE UPPER SURFACE IS ACCESS TO THE WING INTERIOR WITHOUT PASSAGE THROUGH THE LFC SYSTEM. ANOTHER ADVANTAGE IS ABILITY TO USE A LEADING EDGE "KRUEGER FLAP" FOR BOTH LIFT AUGMENTATION ON TAKE OFF AND LANDING (PERMITTING A SMALLER WING) AND FOR LEADING EDGE INSECT PROTECTION: A SMALL LIQUID SPRAY SYSTEM, IF NEEDED FOR INSECT PROTECTION WOULD ALSO BE LOCATED IN THE FLAP. A SEPARATE LIQUID DEICING SYSTEM IS PROPOSED.

THE DOUGLAS LFC LEADING EDGE AND STRUCTURE SYSTEM DESIGNS ALSO DIFFER IN OTHER IMPORTANT WAYS. FIRST OF ALL, THE LFC SYSTEM IS NOT INTEGRATED WITH THE COMPOSITE WING BOX STRUCTURE, BUT IS CONTAINED IN A THIN LAYER EXTERNAL TO THE UPPER WING BOX STRUCTURAL SKIN; SUCTION AIR IS DUCTED THROUGH DIAGONAL DUCTS TO TRUNK DUCTS FORWARD OF THE FRONT SPAR. FINALLY, THE OPENINGS IN THE EXTERNAL TITANIUM SURFACE ARE CLOSELY-SPACED, ELECTRON-BEAM PERFORATIONS (0.0025 IN. DIAMETER) INSTEAD OF SLOTS. BOTH DESIGNS HAVE PASSED EXTENSIVE SMALL-SCALE TESTS OF ENVIRONMENTAL EFFECTS AND STRUCTURAL PERFORMANCE AND HAVE PERFORMED WELL UNDER LOW-SPEED WING TUNNEL CONDITIONS; BOTH WILL BE TESTED AT CRUISE SPEED ON THE LANGLEY AIRFOIL MODEL IN THE 8FT TRANSONIC TUNNEL.

DOUGLAS LFC WING STRUCTURE CONCEPT

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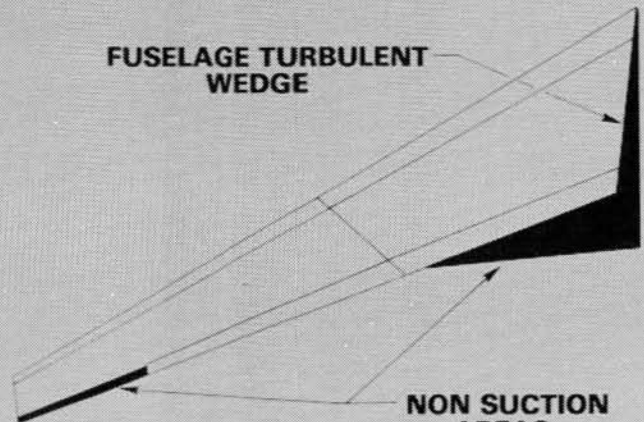
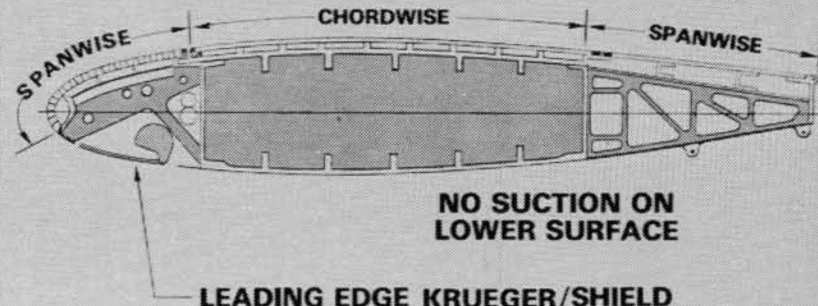
WING PANEL LAYOUTS

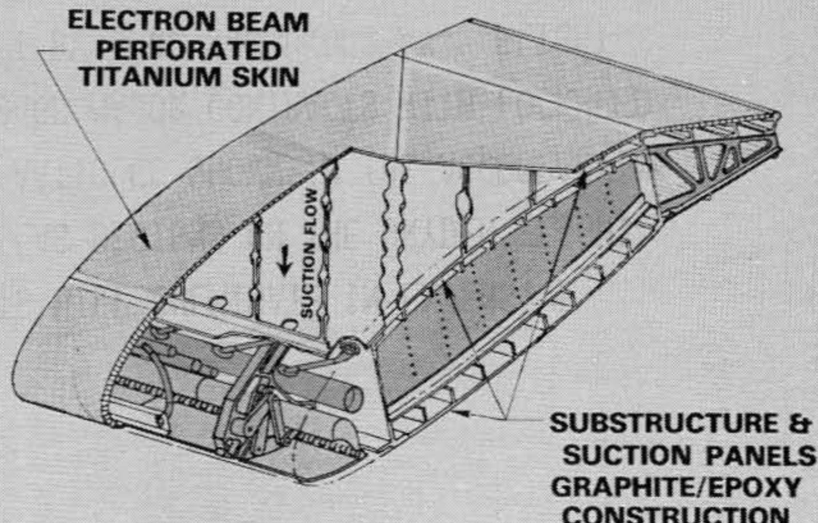


SUCTION PANELS AIRFLOW



DESIGN GOALS

- MINIMIZE NUMBER OF WING SUCTION PANELS
- WING ACCESS THRU TURBULENT LOWER SURFACE
- ALL INTERNAL FASTENERS FOR UPPER WING SURFACE SUCTION PANELS
- DAMAGE TOLERANT, AIRCRAFT-LIFE SUCTION PANEL

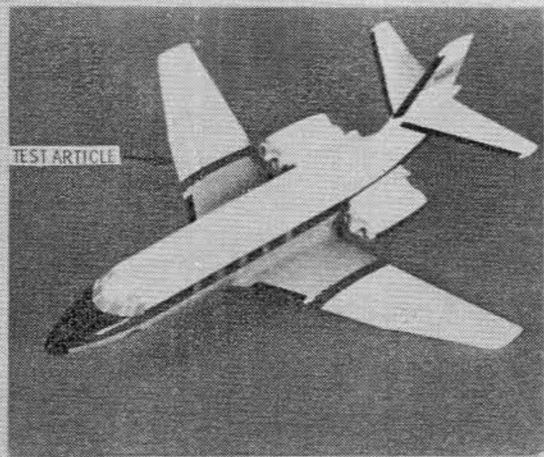


SLIDE 71

THE LEADING EDGE SYSTEMS DEVELOPMENT EFFORTS WILL CULMINATE IN EXTENSIVE FLIGHT-TESTING OF BOTH THE LOCKHEED AND DOUGLAS DESIGNS ON THE DRYDEN FLIGHT RESEARCH CENTER JETSTAR AIRCRAFT. THE TEST ARTICLES SHOWN IN THE ACCOMPANYING SKETCHES ARE CURRENTLY BEING FABRICATED THROUGH MAJOR CONTRACTS WITH LOCKHEED AND DOUGLAS AND MODIFICATIONS OF THE AIRCRAFT BY DFRC ARE UNDERWAY. FLIGHT TESTING WILL BEGIN IN 1983 AND WILL INCLUDE EXTENSIVE SIMULATION OF AIRLINE OPERATING CONDITIONS TO EXPLORE THE RELIABILITY OF LFC IN THE CRITICAL LEADING EDGE REGION.

LFC LEADING EDGE FLIGHT TEST

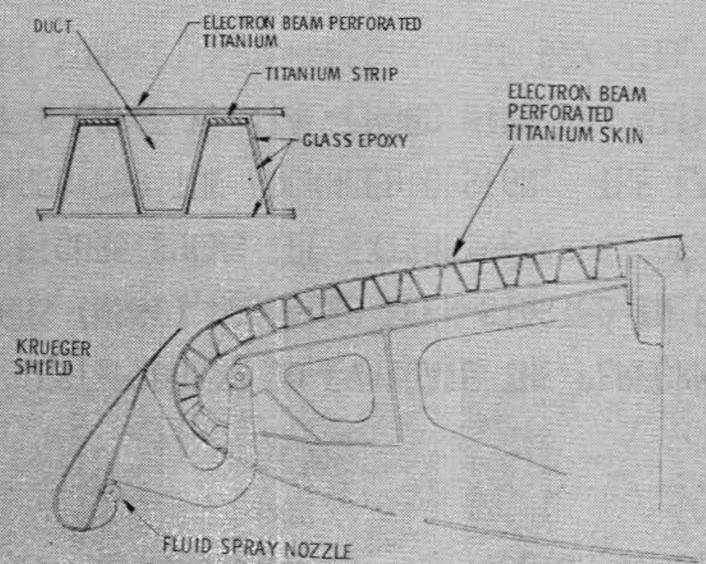
JETSTAR LEFT CONFIGURATION



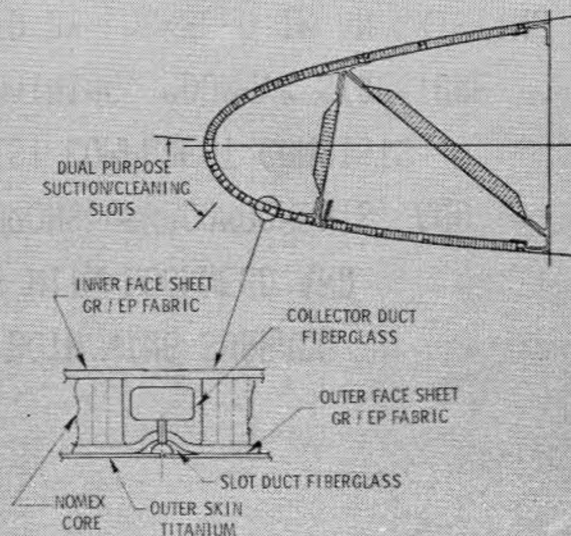
OBJECTIVE

DEMONSTRATE EFFECTIVENESS OF LEADING EDGE SYSTEMS TO MAINTAIN LAMINAR FLOW UNDER REPRESENTATIVE FLIGHT CONDITIONS

DOUGLAS TEST ARTICLE



LOCKHEED TEST ARTICLE



A MAJOR GROUND TEST PROGRAM TO EVALUATE THE PERFORMANCE OF BOTH WING SURFACE STRUCTURE DESIGNS (WSSD) HAS ALSO BEEN STARTED IN CONTRACTS WITH LOCKHEED AND DOUGLAS. THIS FIGURE SHOWS THE EXTENSIVE ARRAY OF TEST COUPONS, SUBCOMPONENTS, AND COMPONENTS PLANNED FOR THE LOCKHEED DESIGN. THE LARGEST TEST COMPONENT CONSISTS OF ONE COVER OF A LARGE PARTIAL-CHORD WING BOX WITH THE REMAINING, "DUMMY" STRUCTURE DESIGNED FOR THE CORRECT STIFFNESS. THIS BOX WILL BE TESTED BY LOCKHEED IN AN EXISTING LARGE TEST FIXTURE.

GELAC WSSD STRUCTURAL TEST PROGRAM

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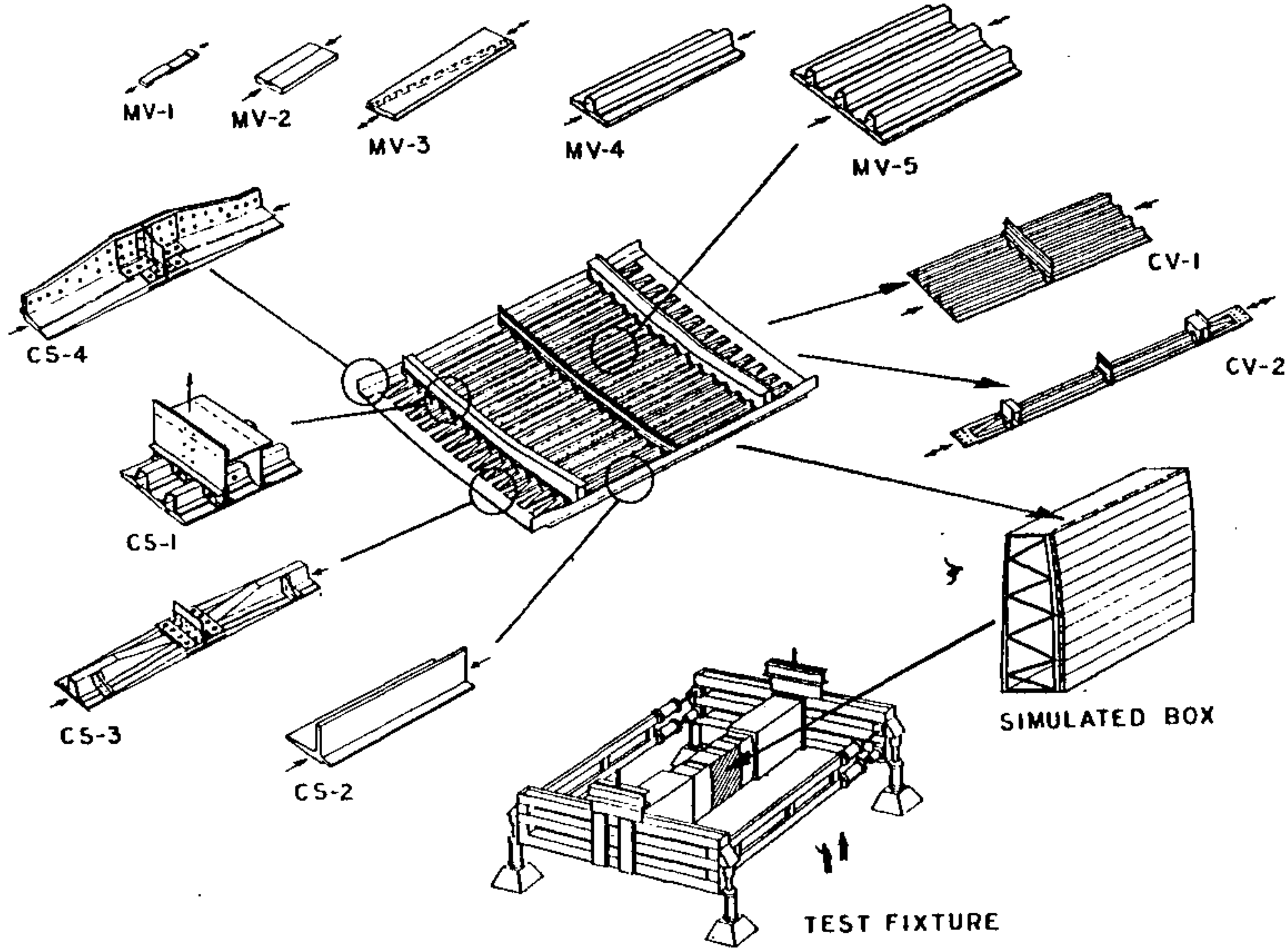
5/82

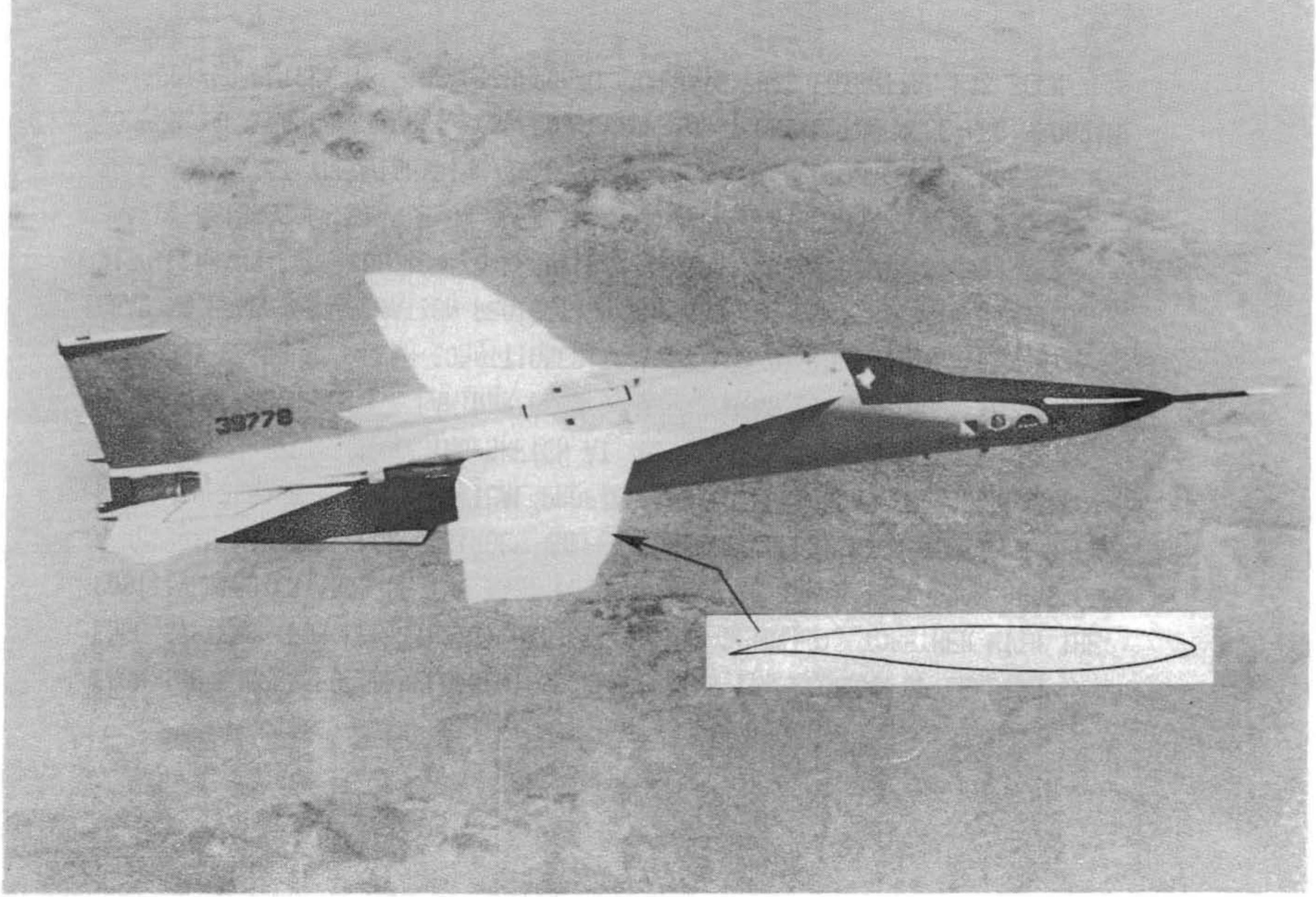


SLIDE 73

IN THE MEANTIME, OTHER ASPECTS OF TRANSPORT LAMINAR FLOW HAVE BEEN EXPLORED AS PART OF THE ACEE/EET AERODYNAMICS EFFORT. "NATURAL" LAMINAR FLOW (NLF) WINGS ARE WINGS WHOSE GEOMETRY IS CAREFULLY DESIGNED TO MAINTAIN THE BOUNDARY LAYER FLOW IN A LAMINAR STATE WITHOUT ACTIVE SUCTION. WING GEOMETRY IS LIMITED IN A NUMBER OF WAYS. AIRFOIL SHAPE MUST BE SUCH THAT PRESSURES OVER THE SURFACE VARY IN A FAVORABLE MANNER. IN PARTICULAR, WING SWEEP (AND THEREFORE CRUISE SPEED) MUST BE LIMITED TO MINIMIZE LEADING EDGE "CROSS FLOW" (FLOW PARALLEL TO THE LEADING EDGE) WHICH CONTAINS DISTURBANCES THAT QUICKLY GROW AND UPSET THE LAMINAR BOUNDARY LAYER. AND, OF COURSE, LEADING EDGE CLEANLINESS IS EVEN MORE CRUCIAL WITHOUT SUCTION. TO EXPLORE THE NLF POTENTIAL OF SUPERCRITICAL AIRFOILS AND NLF SWEEP LIMITS FOR SUCH AIRFOILS, NASA'S DRYDEN FLIGHT RESEARCH CENTER CONDUCTED A LIMITED NUMBER OF FLIGHT TESTS UNDER THE ACEE/EET PROGRAM OF A SUPERCRITICAL "GLOVE" ON THE VARIABLE-SWEEP "TACT" FLIGHT TEST AIRPLANE. THE RESULTS SUGGEST THAT NLF MAY BE FEASIBLE ON SUPERCRITICAL AIRFOILS WITH MODERATE SWEEP SUITABLE FOR SHORT-RANGE, MEDIUM-SPEED TRANSPORTS.

TACT NLF GLOVE

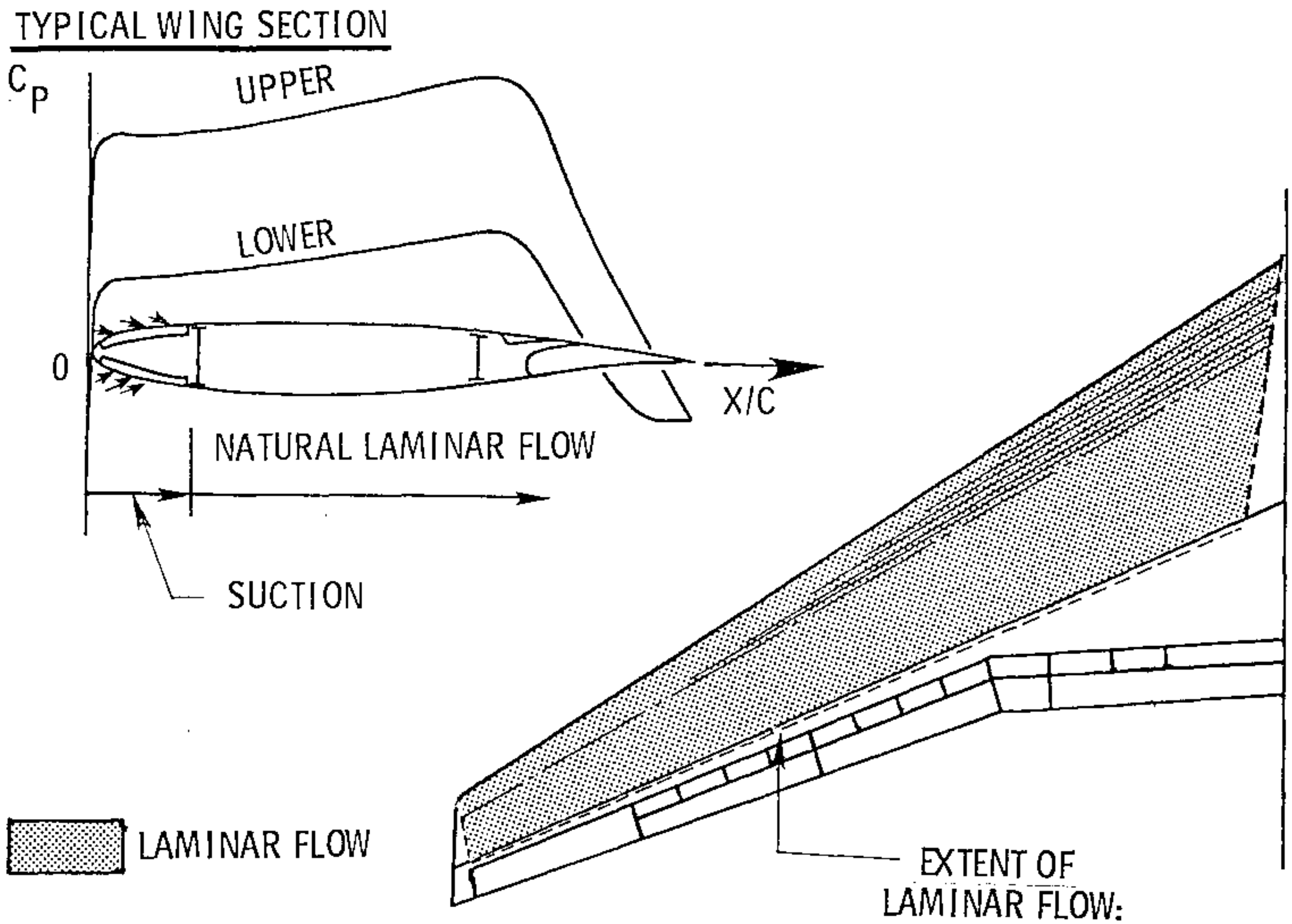
73



SLIDE 74

FROM THE SUCCESSFUL DEVELOPMENT SO FAR IN THE LFC PROGRAM OF LEADING EDGE SYSTEMS (FOR LFC, INSECT PROTECTION AND DEICING), TOGETHER WITH THE POSITIVE INDICATIONS OF THE TACT FLIGHT TESTS IN THE EET PROGRAM, HAS COME A "HYBRID LAMINAR FLOW CONTROL" (HLFC) CONCEPT ILLUSTRATED HERE. A HLFC WING WOULD HAVE A SUPERCRITICAL PROFILE AND CORRESPONDING PRESSURE DISTRIBUTIONS, TYPIFIED BY THE SKETCH AT THE UPPER LEFT, TO PROMOTE THE MAINTENANCE OF NATURAL LAMINAR FLOW OVER THE WING BOX REGION AFTER THE BOUNDARY LAYER HAS BEEN CONDITIONED TO VERY LOW DISTURBANCE LEVELS BY LEADING EDGE CONTAMINATION PROTECTION AND SUCTION SYSTEMS. IN PARTICULAR, WITH LEADING EDGE SUCTION TO KEEP LEADING EDGE CROSSFLOW DISTURBANCES SMALL, NATURAL LAMINAR FLOW OVER THE STRUCTURAL WING BOX REGION SHOULD BE FEASIBLE AT THE HIGH WING SWEEPS REQUIRED FOR MEDIUM-LONG-RANGE COMMERCIAL TRANSPORT CRUISE SPEEDS. THE ADDITION TO THE ACEE/LFC PROGRAM OF FURTHER FLIGHT TESTING AT DFRC TO EVALUATE THIS POTENTIAL HAS BEEN PROPOSED.

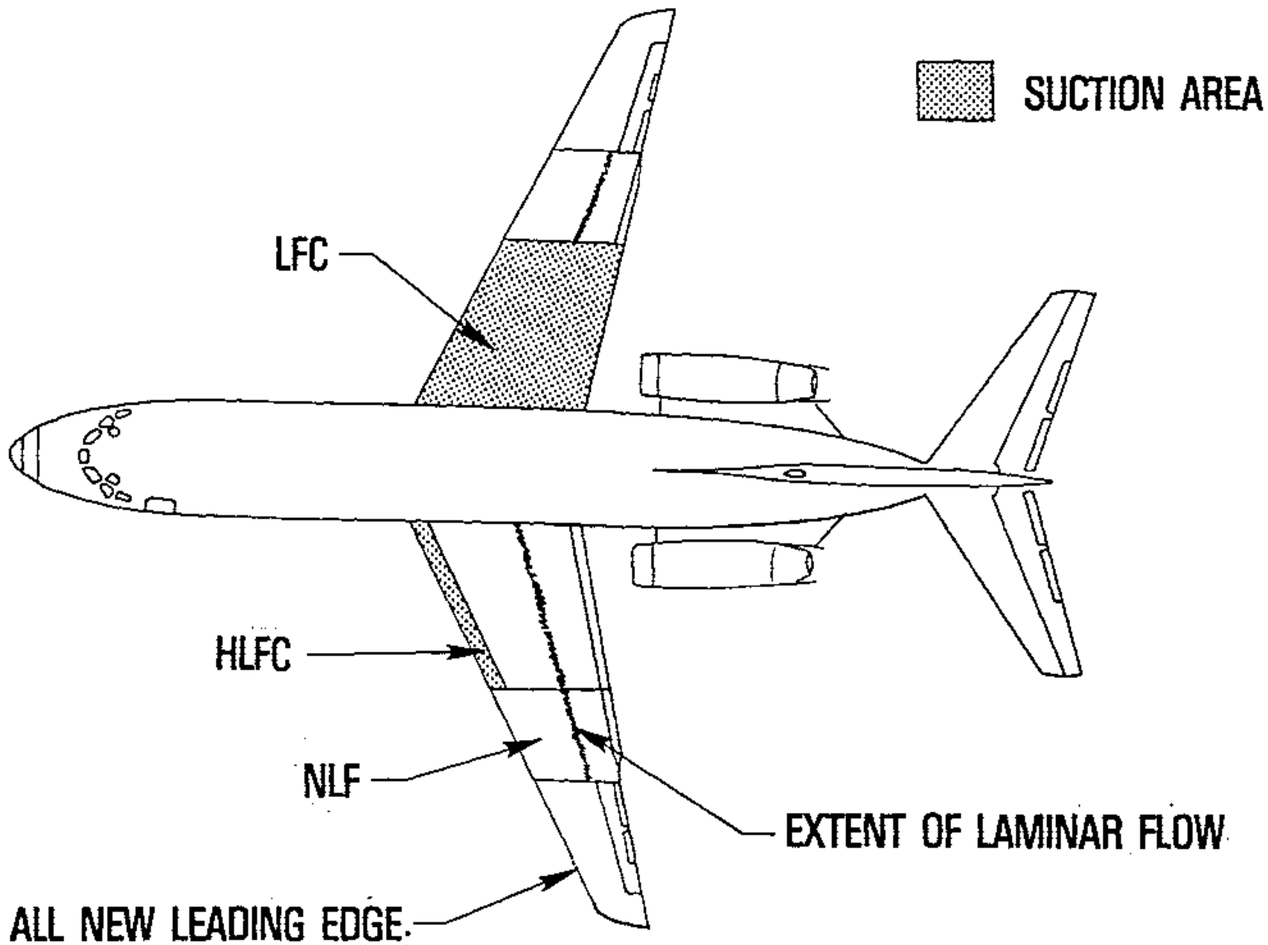
HYBRID LFC WING CONCEPT



FINALLY, A CURRENT CONCEPT, FOR THE FULL SCALE TESTING OF REALISTIC HARDWARE THAT IS REQUIRED TO ADDRESS THE AIR TRANSPORT INDUSTRY'S EXPRESSED CONCERNS, IS ILLUSTRATED HERE. THE SMALLEST (THEREFORE, CHEAPEST) AVAILABLE AIRCRAFT THAT PROVIDES LARGE ENOUGH WING SURFACES WITHOUT INTERFERENCE FROM WING-MOUNTED ENGINES IS A DOUGLAS DC-9-10; THUS, THAT AIRCRAFT IS SHOWN IN THIS ILLUSTRATION. FURTHER, FOR COST SAVING, IT IS ASSUMED THAT THE SUPERCRITICAL LAMINAR FLOW AIRFOIL PROFILES AND TEST HARDWARE ARE "GLOVED" OVER THE EXISTING WING BOX STRUCTURE. IT IS ALSO RECOGNIZED THAT DESIGNERS OF FUTURE LAMINAR FLOW TRANSPORTS WILL HAVE TO TRADE THE EXTRA WEIGHT AND LOSS OF WING-STRUCTURE DEPTH ATTRIBUTABLE TO FULL-CHORD LFC AGAINST THE GEOMETRIC CONSTRAINTS (INCLUDING, CONSTRAINTS ON WING DEPTH) THAT WILL ACCOMPANY DESIGN FOR HLFC OR NLF. MOREOVER, THE OPTIMUM LAMINAR FLOW TRANSPORT MAY WELL EMBODY A COMBINATION OF LFC, HLFC, AND NLF. THUS, SIMULTANEOUS TEST OF ALL THREE FORMS OF TRANSPORT AIRCRAFT LAMINAR FLOW IS POSTULATED.

THE PROPOSED FUTURE "THIRD PHASE" OF THE NASA ACEE/LFC PROGRAM IS NOW AIMED TOWARD SUCH TESTING. IMPLEMENTATION OF THIS PHASE WILL BE DEPENDENT ON THE OUTCOME OF PHASE II EFFORTS. AND, AS WITH ALL UNFUNDED PLANNED ACTIVITY, ITS TIMING AND VERY EXISTENCE ARE UNCERTAIN.

LAMINAR FLOW WING FLIGHT RESEARCH AIRCRAFT



AFTER SOME FIVE YEARS OF ADVANCED AIRFRAME TECHNOLOGY DEVELOPMENT AND DEMONSTRATION EFFORTS, THE CURRENTLY EXPECTED AND IDENTIFIABLE BENEFITS FROM THIS HALF OF THE NASA ACEE PROGRAM ARE SUMMARIZED HERE. INDUSTRY IS ALREADY APPLYING ACTIVE WING LOAD ALLEVIATION AND COMPOSITES TO SECONDARY STRUCTURE IN DERIVATIVE AND NEW AIRCRAFT AS A RESULT OF THE ACEE PROGRAM WITH ABOUT 5 PERCENT POTENTIAL FUEL SAVINGS. BY 1990, ACEE DEVELOPED TECHNOLOGY WILL PERMIT APPLICATIONS ALSO OF ADVANCED SUPERCRITICAL WINGS, WINGLETS, ACTIVE STABILITY AUGMENTATION, AND (ASSUMING CONTINUATION OF THE ACEE/CPAS PROGRAM AS PLANNED) COMPOSITE WING STRUCTURE FOR TOTAL SAVINGS IN THE 20 PERCENT RANGE. FINALLY, ASSUMING THE THIRD PHASE OF THE ACEE/LFC PROGRAM IS IMPLEMENTED, THE TECHNOLOGY FOR APPLICATION OF LFC OR HLFC TO LONG RANGE TRANSPORTS WILL BE AVAILABLE IN THE LATE 1990'S AND WILL BOOST FUEL SAVINGS, RELATIVE TO CURRENT AIRCRAFT, TO MORE THAN 40 PERCENT FROM ADVANCES IN AIRFRAME TECHNOLOGY ALONE.

ACEE AIRFRAME TECHNOLOGIES

B5A
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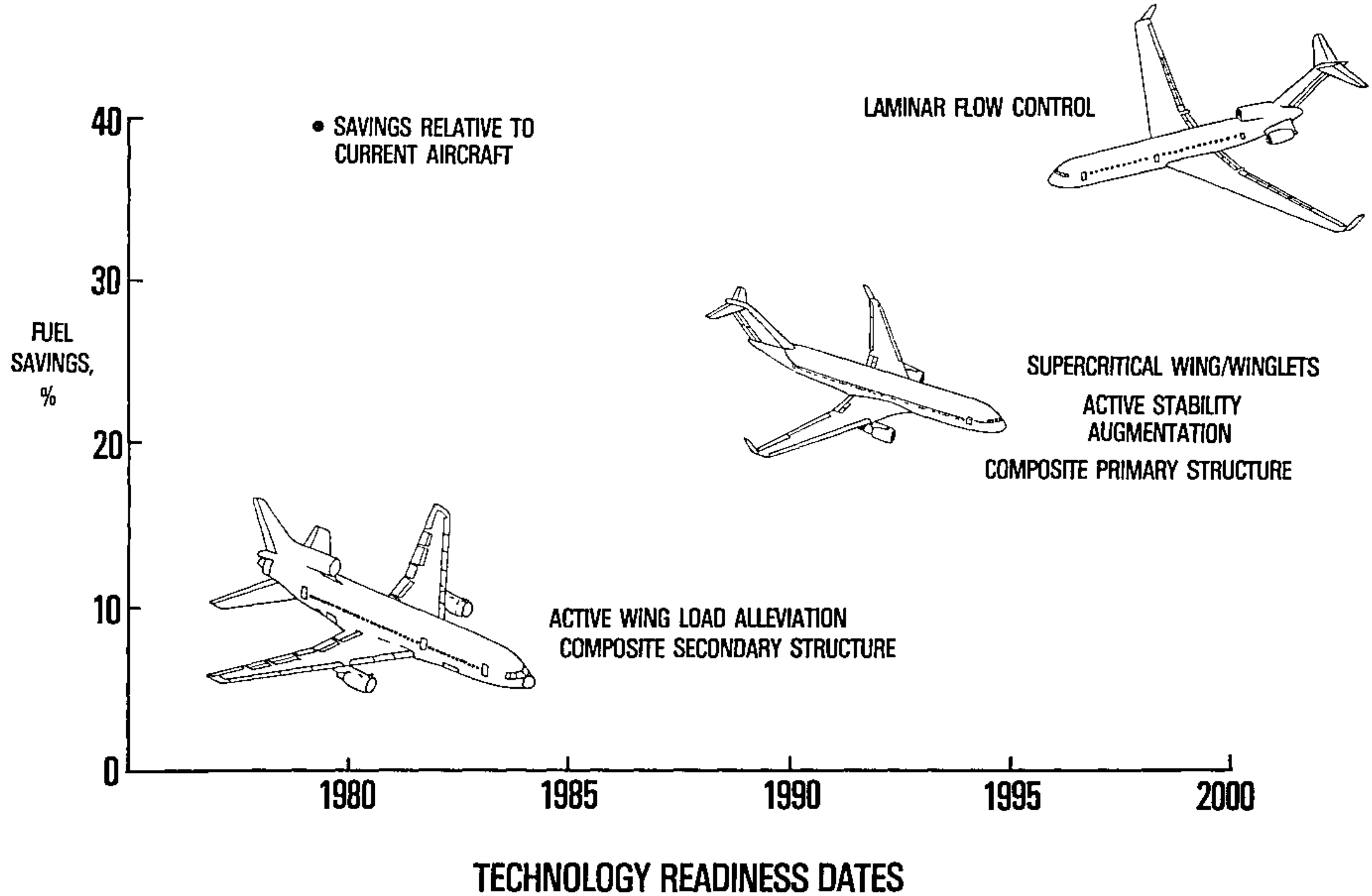
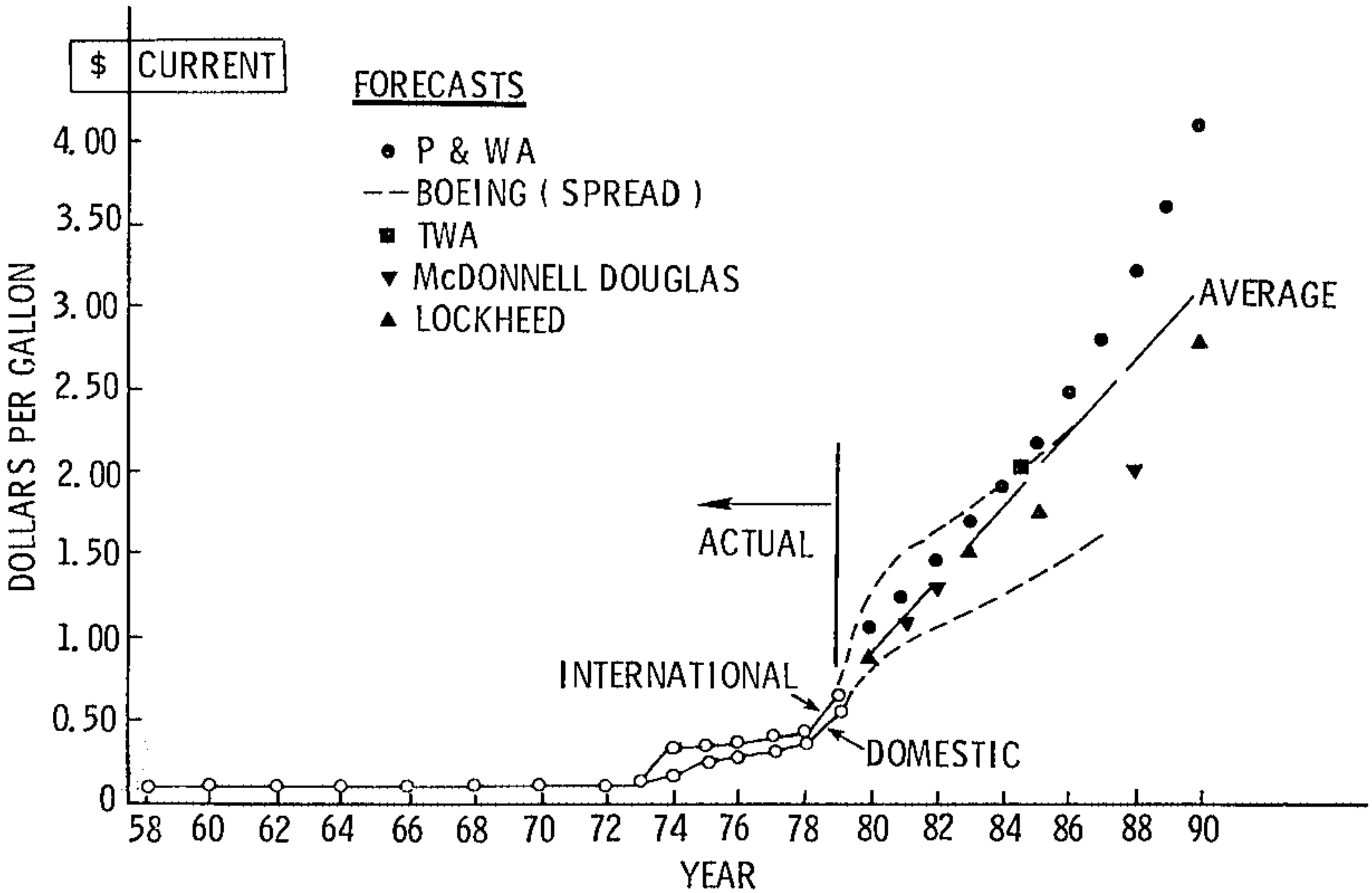
PROJECTED FUEL SAVINGS &
TECHNOLOGY READINESS DATE



SLIDE 77

EVEN AT TODAY'S FUEL PRICES (ABOUT $1.00 PER GALLON), EACH PERCENT FUEL SAVING IS WORTH ABOUT $20,000 PER YEAR ON EVERY 727-SIZE TRANSPORT AIRCRAFT OR $70,000 PER YEAR ON EACH WIDE-BODY AIRCRAFT. BUT, FUEL PRICES ARE EXPECTED TO CONTINUE TO RISE. THE FORECASTS ON THIS PLOT WERE COMPILED BY THE AIR TRANSPORT ASSOCIATION AND SUGGEST THAT, BY 1990, FUEL MAY BE $3.00 PER GALLON. ASSUMING THIS FIGURE, THE PROJECTED 20 PERCENT FUEL SAVINGS FROM APPLICATION OF ACEE AIRFRAME TECHNOLOGIES IN 1990 TRANSLATES INTO SAVINGS OF 4 MILLION DOLLARS PER WIDE-BODY AIRCRAFT PER YEAR. LATER INTRODUCTION OF LFC IN LARGE LONG RANGE TRANSPORTS CAN BE EXPECTED TO MORE THAN DOUBLE THIS FIGURE.

FUEL PRICE FORECAST



CONCLUDING REMARKS

IN ITS AIRCRAFT ENERGY EFFICIENCY PROGRAM, NASA HAS EXPENDED APPROXIMATELY 200 MILLION DOLLARS TOWARD DEVELOPMENT AND APPLICATION OF ADVANCED AIRFRAME TECHNOLOGIES TO UNITED STATES' COMMERCIAL TRANSPORTS. UNITED STATES MANUFACTURERS HAVE ALREADY BEEN GIVEN A SIGNIFICANT BOOST TOWARD EARLY APPLICATION OF ADVANCED COMPOSITE MATERIALS TO CONTROL SURFACE AND EMPENNAGE STRUCTURES AND TOWARD SELECTED APPLICATIONS OF ACTIVE CONTROLS AND ADVANCED AERODYNAMIC CONCEPTS. IN ADDITION, SIGNIFICANT PROGRESS IN DEFINITION AND DEVELOPMENT OF INNOVATIVE, BUT REALISTIC SYSTEMS FOR LAMINAR FLOW CONTROL OVER THE WINGS OF FUTURE TRANSPORTS HAS ALREADY BEEN MADE.

POTENTIAL FUEL SAVINGS FROM THESE TECHNOLOGIES RANGE FROM 5 PERCENT NOW TO OVER 40 PERCENT BY THE TURN OF THE CENTURY. OVER THE SAME PERIOD, THE WORLD MARKET FOR NEW TRANSPORT AIRCRAFT IS EXPECTED TO EXCEED 200 BILLION DOLLARS AND RETENTION OF A DOMINANT SHARE OF THIS MARKET BY UNITED STATES MANUFACTURERS IS CRUCIAL TO OUR BALANCE OF PAYMENTS. SINCE FUEL PRICES OVER THIS PERIOD ARE EXPECTED TO CONTINUE TO RISE, FUEL EFFICIENCY WILL CONTINUE TO DOMINATE PURCHASE DECISIONS BY THE WORLD'S AIRLINES. THUS, THE IMPORTANCE OF CONTINUING THE ACEE AIRFRAME EFFORTS TO THEIR PLANNED CONCLUSIONS AND OF CONTINUING TO SUPPORT THE UNITED STATES COMMERCIAL TRANSPORT INDUSTRY IN ITS APPLICATION OF ADVANCED AIRFRAME TECHNOLOGIES CANNOT BE OVERSTATED.

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15. Supplementary Notes		

16. Abstract

In its Aircraft Energy Efficiency Program, NASA has expended approximately 200 million dollars toward development and application of advanced airframe technologies to United States' commercial transports. United States manufacturers have already been given a significant boost toward early application of advanced composite materials to control surface and empennage structures and toward selected applications of active controls and advanced aerodynamic concepts. In addition, significant progress in definition and development of innovative, but realistic systems for laminar flow control over the wings of future transports has already been made.

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