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AIRCRAFT ENERGY EFFICIENCY
LAMINAR FLOW CONTROL
GLOVE FLIGHT CONCEPTUAL DESIGN STUDY

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16 Abstract
A conceptual design study of a laminar flow control glove applied to the wing of a short to medium range jet transport with aft mounted engines has been completed. Two suction surfaces were studied--aslotted aluminum glove concept and a woven stainless steel mesh porous glove concept. The laminar flow control glove and a dummy glove with a modified supercritical airfoil, ducting, modified wing leading and trailing edges, modified flaps and an LFC trim tab were applied to the wing after slot spacing suction parameters, and compression power were determined. The results of the study show that a laminar flow control glove can be applied to the wing of a jet transport with an appropriate suction system installed.

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GLOVE FLIGHT CONCEPTUAL DESIGN STUDY

BY

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SUMMARY

The first phase of a glove flight conceptual design study with Laminar Flow Control (LFC) applied to a partial span test section of the gloved wing has been completed. The objective of this study is to establish a base for realistic cost estimates and identify potential engineering problem areas for the LFC glove flight program of Phase II of the ACEE LFC Project.

The aircraft selected for study is a short to medium range jet transport with aft mounted engines. The glove flight design mission is for cruise at M = .8 at 11,580 meters (38,000 ft.) altitude. Chord Reynolds Number is 20,686,000 for a 3.74 meter (12.27 foot) chord length.

Two suction surfaces were studied--a slotted aluminum glove concept, and a dynapore (woven stainless steel cloth), porous glove concept.

The gloved wing concept appears feasible from an arrangement, structural, weight, and systems standpoint. Baseline information for cost estimates has been established and potential engineering problems are identified.

Aerodynamic performance and flight test plans were not addressed in this study.

DISCUSSION

GUIDELINES - Guidelines provided for the study are as follows:

Baseline:

- Aircraft - Short to medium range jet transport with aft mounted engines
- Suction surface - slotted
- Full chord laminarization
- Upper surface LFC only
- No leading edge cleaning device
- Instrumentation
  - o 4 spanwise stations - 20 pressure taps
  - o 10 surface film gauges chordwise on suction surface

- Plenum and duct pressures, temperature, mass flow
- Trailing edge boundary layer total pressure survey rake

Options to Analyze

- Upper and lower surface LFC
- Alternate suction surface (porous or perforated) for leading edge section and/or wing box
- Installation of leading edge section with alternate cleaning devices (spray nozzles, freezing point depressant dispensing strips, frost system).

LFC GLOVE FLIGHT ENVELOPE

The glove flight design point is 11,580 meters (38,000 ft.) altitude and M = .8. Off-design altitudes are 10,367 meters (34,000 ft.) and 12,800 meters (42,000 ft.). Chord and unit Reynolds Numbers for these altitudes are shown in table 1.

AIRCRAFT CONFIGURATION

The aircraft selected is a short to medium range jet transport powered by turbofan engines located on the fuselage aft of the wing. The wing has the following characteristics:

Span	28.44 meters (93.3 ft.)
Area	92.9 meter^2 (1,000 ft.^{2})
Sweep @ 1/4 chord	24°
Aspect ratio	8.7

The wing box is of conventional aluminum construction with 3 integral fuel tanks.

Wing control surfaces consist of full length leading edge slats, double slotted flaps, conventional outboard ailerons, and spoilers for both lateral control and speed braking.

BASELINE LFC GLOVE

Glove General Characteristics

The LFC glove is located on the upper surface of the left wing. A dummy glove is located on the right wing for symmetry. The upper surface glove extends from the wing root to η = .62 with a 2.13 meter (7 foot) wide test section at wing station η = .423. Only the 2.13 meter (7 foot) section has LFC suction applied to the surface. The remaining inactive gloving is required to achieve the desired supercritical flow over the test section.

The airfoil section used on the glove is shown in figure 1. The chord length of the glove is 104% of that of the original airfoil--the extension being in the leading edge only.

Suction is based on the suction and pressure coefficient plots for the YNRB 12-2-77 wind tunnel 2D airfoil (see figure 2). Suction is accomplished through 91 slots located in the upper surface of the test section from $\frac{x}{c}$ - .004 to $\frac{x}{c}$ - .948.

Location of the glove on the left wing is shown in figure 3.

LFC Glove and Ducting configuration

In order for an LFC glove with a supercritical airfoil to be incorporated on the wing, the wing must first be modified by removal of the following items:

inboard slats, both sides
inboard leading edge sections, both sides
spoilers
flaps
inboard trailing edge sections, both sides

The structural concept is shown in figures 4, 5, 6, and 7. It is a built-up LFC glove fastened to supports bonded to the upper surface of the wing box. The LFC section is extended forward and aft by new leading and trailing edge assemblies. Hat section and tee shaped supports are bonded to the wing box upper surface as shown in figures 5, 6, and 7. The LFC slotted and porous gloves and the non-sucked portion of the glove over the wing box are fastened to the hat section and tee supports with screw fasteners also shown in figures 5, 6, and 7. The capability must exist to remove the bonded supports and the residual bonding agent from the wing without damage to the wing box skin during restoration of the aircraft. New leading and trailing edges are attached to the front and rear spar flanges to complete the airfoil shape shown in figure 5. Attachment of the new leading edge to the front spar is shown in figure 7. The slotted leading edge is assembled on the bench with all parts and subsystems included, and is attached to the front spar as a slotted leading edge assembly. The LFC slotted panel over the trailing edge has spanwise "C" supports bonded to the underside in order to provide space for collector ducts. This LFC panel is fastened to the wing by mechanical fasteners through the new fabricated ribs and the bottom of the C channels. Access is from the bottom of the wing through access holes and past the split flap.

This structural and ducting concept allows a slotted glove to be flight tested, removed, and replaced with a porous glove for further flight testing. Items common to both concepts are:

- Supports bonded to the wing box
- New fabricated ribs in the trailing edge
- Mixing ducts
- Control valves and controls
- Trunk ducts
- Compressor (mass flows are approximately the same for each concept)

Slotted Concept Configuration - The LFC slotted glove configuration is shown in figures 4, 5, 6, and 7. It consists of a 7.62 mm (.3 in.) thick aluminum skin with a .81 mm (0.032 in.) skin bonded over the surface.

Plenums are cut into the 7.62 mm (.3 inch) aluminum skin and bleed holes are drilled from the plenum into the tributary duct. Slots are sawed in the .81 mm (0.032 in.) aluminum skin after it is bonded to the 7.62 mm (.3 inch) skin. These details are shown in figure 7. Tributary ducts and collector ducts are bonded to the inside surface of the skin as shown in figures 5 and 7. This concept allows bench suction and leak testing of the 3 LFC panels prior to their installation on the wing.

Each slot, plenum, tributary duct, and collector duct runs spanwise along a constant-percent-chord line.

Load sharing and relative strain levels between the stiff 8.4 mm (.332 inch) aluminum glove skin and the wing box skin were not addressed in this study. Use of non-metallic or built-up skin materials will reduce compressive load sharing and local stiffening of the wing.

Ducting Concept for Slotted Glove - Inboard of the test section the collector ducts over the wing box are turned forward and routed across the front spar. Mixing ducts with flow control valves combine the flow from all collector ducts forward of the rear spar into one forward trunk duct. This is shown in figures 4 and 6. Air flowing from the collector ducts aft of the rear spar is mixed in mixing ducts with flow control valves in the trailing edge inboard of the test section. This suction air is collected into one aft trunk duct as shown in figure 7. The forward and aft trunk ducts are routed inside the leading and trailing edges into the fuselage where they are joined into one trunk duct. Space behind the landing gear and wheel well is limited for the routing of an aft trunk duct on the selected aircraft. Since 2/3 of the suction air mass flow quantity is behind the rear spar the aft trunk duct diameter is 17.2 cm (6.77 inches). No way was found to route this large duct around the landing gear without penetrating the wing tank.

A single stage centrifugal compressor powered by an air turbine driven by engine bleed air is located aft of the pressurized cabin. Suction flow is controlled by approximately 24 flow control valves in the mixing ducts.

Control Console - A control console is required in the cabin for operating flow control valves, compressor controls, trimming LFC trim tab, and for data readout and collection. It is assumed that the control console has the following functions:

- 30 control functions, valves, turbine controls, etc.
- 150 measurements/readouts; RPM, temperature, pressure. All readouts are digital. Some commutation of measurements may be required.
- 30 valve position indicators
- 10 laminar/turbulent indicator lights
- Multichannel tape recorder for storing airborne data, both LFC and non LFC flight conditions; e.g., airspeed, altitude, angle-of-attack, pressure, propulsion engine data. (There will be no telemetry.)

It is further assumed that no onboard digital computer will be required.

Wing Controls - The ailerons and outboard slats are retained. An LFC trim tab is provided aft of the test section to account for changes in angle-of-attack of the LRC airfoil. (See figure 4) It is assumed that the trim tab will be adjusted in-flight from the control console in order to obtain an accurate setting and to conduct tests at several angles-of-attack during a single flight test. A split flap with 23° travel is provided as shown in figure 3.

Airfoil - A supercritical airfoil,(designated YNRB) designed for the LFC wind tunnel model and shown in figure 2, was initially selected because of potential advantages as an LFC section. The airfoil chord dimension was extended 10% beyond that of the selected aircraft. When the YNRB airfoil was fitted over the existing wingbox airfoil streamwise with the trailing edges coincident, there was insufficient clearance on the bottom at the front spar and on the top in the center of the wing box for a glove. A minimum glove thickness of 3.05 cm (1.2 inch) was estimated to be required for installation of the suction surface on both the upper and lower surface.

At this point a decision was made to limit suction to upper surface only and to make the lower surface of the wing box coincident with the lower surface of the gloved airfoil. This would allow utilization of a supercritical airfoil with sufficient clearance on the upper surface for the suction glove without a significant increase in the chord length beyond that of the unmodified wing.

Another airfoil (designated IABA), shown in figure 1, was selected to replace the YNRB airfoil. This airfoil, with a chord length of 104% of the unmodified wing, was fitted over the original airfoil with the trailing edges in the same vertical plane (the IABA leading edge extended 4% beyond the original airfoil leading edge) with the lower surfaces in the wing box region nearly coincident. The lower surfaces of the two airfoils ahead and behind the wing box were faired together. This procedure was repeated at 6 wing stations from $\eta = .105$ to $\eta = .62$.

LFC Suction Requirement - A comparison of suction coefficients for the LRC wind tunnel model with the YNRB airfoil and the glove wing with the same airfoil is shown in figure 8. The pressure coefficient plot for this airfoil is shown in figure 2. Since the coordinates for the upper surface of the IABA airfoil are approximately the same as those of the YNRB, the suction coefficients for the YNRB were selected as representative for the glove flight.

Chord Reynolds Number, Rc, for the wind tunnel model is 15,000,000 compared to a value of 20,686,000 for the glove flight configuration. The coefficients were decreased to account for the difference in Reynolds Number. The model sweep angle is 35° compared to 24° sweep of the glove wing. A 15% reduction of suction is estimated for the leading edge section and the aft section of the wing (aft of X/C - .5) as a result of the difference in sweep angle.

Suction Slot Spacing - The suction slot spacing was estimated, based on the foregoing suction requirement.

The slot Reynolds Number, based on the X-21 design criteria, (Reference 1) was defined to be between 70 and 100 over most of the suction surface, except in the aft 19 slots where it ranged from 100 to 105. The Reynolds Numbers of the first four slots at the leading edge ranged from 50 to 65. Slot spacing varied from 11.02 cm (4.339 inches) in the forward part of the wing to 1.52 cm (0.6 inches) in the aft 20% of the suction surface.

Tabulation of parameters relative to the slot spacing are shown in table 2. No attempt was made to determine slot widths and velocities and plenum dimensions. Knowledge of the boundary layer sucked height dimension is required for these determinations. Since no boundary layer analyses were performed for the gloved wing the required sucked height is unknown. The subsequent mass flow calculation is based on the slot Reynolds Number; i.e. the product of slot width, velocity, density, and reciprocal of viscosity.

Mass Flow Distribution - Mass flow for each slot or series of slots was calculated using the slot Reynolds Number and slot length, $\bar{l}$.

The slot length decreases from 2.43 meters (95.65 inches) to 1.56 meters (61.3 inches) as chord increases. Mass flow was calculated for a flight altitude of 11,580 meters (38,000 ft.).

Total mass flow, upper surface only	.2216 Kg/sec. (.4885 lbm/sec.)
Total suction area	6.45 M^2 (69.39 ft.^{2})
Average Cq for upper surface suction area.	.0004372

Mass flow quantities are shown in table 3.

Duct Sizes - The tributary and collector ducts were sized based on the slot mass flow and the airfoil pressure coefficients for the YNRB airfoil, figure 2. Tributary duct velocity was assumed to be 6.1 meters/second (20 feet/second) for the slotted concept and 15.24 meters/second (50 feet/second) for the porous concept. Collector duct velocity was assumed to be 29.5 meters/second (96.8 feet/second) (approximately $M = 0.1$). Ducts were sized for the 11,580 meters (38,000 ft.) altitude and duct air temperature of 240.2°K (432.4°R). Pressure drop through the slot and plenum was assumed to be 6% of surface pressure. Duct sizes required for the slotted concept are shown in table 4.

The last collector duct requires an area slightly larger than the space available by approximately 11%. This results in a proportional increase in duct velocity.

Compressor - All suction air is compressed by a single stage centrifugal compressor, driven by an air turbine, through a compression ratio of 2.61. Suction power required is 11.73 Kw (15.72 HP) assuming the mass flow quantity is increased by 20% to .2659 Kg/sec. (0.5862 lbm/sec.) to provide a positive margin. The compressor/turbine is located in the fuselage aft of the aft pressure bulkhead. Compressor exhaust air is assumed to expand adiabatically through a nozzle to a total pressure of that of the freestream, and exit at a velocity of 235 meters/sec. (771 ft/sec.). Freestream velocity is 236.1 meters/sec. (774.5 ft/sec.).

Bleed air is supplied to the air turbine from the main propulsion engine bleed air system. It is assumed that bleed air will not be required for the engine inlet and empennage hot air deicing systems during periods of LFC compressor operation.

Compressor characteristics and requirements are shown in Appendix A.

OPTIONS EXAMINED

Porous Glove Concept - The LFC transport porous panel concept which was derived in the LFC Phase I studies (described in reference 2) is readily adaptable to the glove wing configuration. Suction distribution (figure 8) for the porous glove was assumed to be the same as for the slotted glove. The design goals were: 1) to be able to test the porous glove panels as separate units from the wing to determine tributary and collector duct flow characteristics, and 2) to be capable of installation on the same wing structure and interface with the same ducting as the slotted glove.

The porous glove concept is shown in figures 9 through 13. Attachments of the panels are virtually the same as those described for the LFC transport porous glove (reference 2). The center section between the spars, shown in figures 9 and 10, is composed of 3 panels. Flutes are diagonal as in the LFC transport glove design. Tributary and collector ducts which are bonded to the bottom of the porous panel run spanwise. These ducts must bridge the diagonal joint shown in figure 9. The leading edge configuration is similar to the porous glove configuration over the wing box. Views of porous leading edge attachments to the front spar and the collector duct are shown in figure 11. The porous fluted panel only is shown and that is aft of X/C- 7.9%. The complete porous leading edge design includes a fluted panel and a honeycomb panel in the nose with the fluid cleaning system integrated therein (figure 14). The porous leading edge is assembled on the bench with all parts and subsystems included, and is attached to the front spar as a porous leading edge assembly. Leading edge cleaning is discussed in the next section. Trailing edge configuration is shown in figures 12 and 13. In order to provide spanwise stiffness and space for collector ducts the porous panel on the trailing edge has spanwise "C" supports bonded to the undersurface. This panel is fastened to the wing by mechanical fasteners through the new ribs and the bottom of the "C" channels. Access is from the bottom of the wing through access holes and past the split flap.

In locating the spanwise porous panel supports and defining the width of collector ducts no attempt was made to prevent outflow due to chordwise surface pressure gradient. This must be considered in the detailed design of a glove.

Airflow is collected at the inboard end of the test section for the leading edge, trailing edge, and wing box section and routed through the ducting system described in the section on ducting concept for slotted glove.

Leading Edge Cleaning System
The leading edge cleaning system integrated into the porous panel leading edge is shown in figure 14. The fluid dispensing system consists of two high flow manifolds for initial leading edge wetting and a continuous flow network for keeping the leading edge wet during climbout and descent. Leading edge cleaning surface encompasses the area from 4.55% of chord on the lower surface to 0.4% chord on the upper surface. The porous suction surface continues aft from 0.4%

The system would provide fluid flow from the high flow system for a period of 5 seconds during takeoff and from the continuous flow system for 2 to 4 minutes during takeoff and climbout and 10 minutes during descent. Fluid quantity required was not calculated but is not expected to be excessive. A fluid storage tank is assumed to be located in the forward cargo bay. Electrically driven pumps would provide pumping power for high flow and continuous flow modes.

General Flow of Major Hardware Activities - The major hardware activities required for fabrication, aircraft modification, installation, and aircraft restoration to a passenger transport configuration are listed in appendix B.

IDENTIFICATION OF POTENTIAL ENGINEERING PROBLEMS

Potential engineering problems associated with the assumptions of this study and installation of a glove on the aircraft are discussed as follows:

1. Boundary layer analyses were not performed for the 2 D airfoil considered in this study. Just how reasonable the slot spacing and slot Reynolds Numbers are cannot be ascertained until the "sucked height" is known. Such an analysis is beyond the scope of this study effort.

2. Internal duct flow and pressure drop calculations were not performed. This analysis is of necessity a computer analysis which takes into account many variables. Pressure drop was conservatively assumed to be 6% of surface pressure in the collector ducts and 20% of the surface pressure at the compressor face. Ducts and the compressor were sized based on the pressure assumptions. Such an analysis will be required as part of the glove system preliminary design.

3. Routing of the aft trunk duct past the landing gear and wheel well must be resolved on future glove wing designs which have large suction air mass flows aft of the rear spar.

4. Removal of the inboard slats eliminates all leading edge hot air deicing for the gloved wing. One environmental test condition is fluid deicing of the 2.3 meters (7 foot) test section. It may be necessary, therefore, to provide electrical resistance heating deicing the full length of the dummy glove leading edge. There would be no deicing on the remaining slats.

CONCLUDING REMARKS

The ACEE LFC Glove Flight Conceptual Design Study findings are as follows:

0 The gloved wing concept on the selected aircraft appears to be feasible from the arrangement, structural, weight, and systems standpoint. Both porous and slotted glove panels appeared feasible with suction and ΔP considerations somewhat more severe with the porous.

0 Combined upper and lower surface suction is not feasible on a glove with either airfoil section with a reasonable chord extension over the original airfoil.

0 It appears that a leading edge fluid cleaning system can be integrated into the porous panel leading edge in the gloved wing.

0 A split flap with limited travel can be integrated into the new trailing edge.

0 This study showed that suction is feasible to 94.8% of chord, however, suction aft of the rear spar results in the following difficulties:

o Close slot spacing of 1.54 cm (.6 inches) from X/C = .75 to X/C = .948 can create manufacturing difficulties.

o A large aft trunk duct is required because of the large number of slots and resultant high suction air mass flow quantities.

The magnitude of these difficulties must be considered in establishing the extent of suction aft of the rear spar.

REFERENCES

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TABLE 1

CHORD AND UNIT REYNOLDS NUMBERS

LFC GLOVE WING

Chord Reynolds No. $Rc = \dfrac{\rho_\infty V_\infty C}{\mu_\infty}$

Chord length, C = 3.74 meters (12.27 ft.) (104% of chord at $\eta = .423$)

Unit Reynolds No., $R'_\infty = \dfrac{\rho_\infty V_\infty}{\mu_\infty}$

Altitude		Rc	R'_∞	
Meters	(Feet)		Per Meter	(Per Foot)
10,367	(34,000)	24,368,000	6,516,000	(1,986,000)
11,580	(38,000)	20,686,000	5,531,000	(1,686,000)
12,800	(42,000	17,066,000	4,564,000	(1,391,000)

TABLE 2

SLOT SPACING PARAMETERS; YNRB 12-2-77; UPPER ONLY

C = 3.740 meters (147.226 inches) Rc = 20,686,000

X/C	X Meters (Inches)	Δ Cn Cm (Inches)	Cq	Rs
.004	.0152 (.6)	1.52 (.6)	.000661	50.47
.01	.0381 (1.5)	2.286 (.9)	.00052	59.55
.021	.0787 (3.1)	4.064 (1.6)	.00031	63.12
.041	.155 (6.1)	7.62 (3.0)	.000170	64.9
.065	.244 (9.6)	8.89 (3.5)	.000163	72.6
.095	.354 (13.939)	* 15 @ 11.02 (4.339)	.000163	90.0
.507	1.897 (74.685)		.000173	95.52
.528	1.973 (77.685)	* 4 @ 7.62 (3)	.000203	77.5
.589	2.202 (86.685)		.000264	100.78
.602	2.253 (88.685)	* 3 @ 5.08 (2)	.000285	72.53
.629	2.354 (92.685)		.00039	99.26
.64	2.392 (94.185)	* 4 @ 3.81 (1.5)	.00043	82.08
.67	2.507 (98.685)		.000521	99.45
.677	2.533 (99.743)	* 5 @ 2.687 (1.058)	.000538	71.89
.706	2.641 (103.975)		.00064	86.17
.712	2.663 (104.835)	* 8 @ 2.18 (0.86)	.000673	73.65
.753	2.816 (110.855)		.000902	98.71
.757	2.831 (111.455)	* 47 @ 1.524 (0.6)	.00092	70.24
.948	3.547 (139.655)		.001376	105

ΔCn = Slot spacing

* Number of slots with same spacing

Cq = Suction coefficient, $\frac{\rho s\ Vs}{\rho_\infty U_\infty}$

TABLE 3

MASS FLOW QUANTITIES, YNRB 12-2-77, UPPER ONLY

Slot length, $\bar{T}$		Ncn	$\bar{R}s$	$\overset{\circ}{m}$	
Meters	(Inches)			Kg/sec.	(lbm/sec)
2.430	(95.65)	1	50.47	.001926	(.004245)
2.424	(95.43)	1	59.55	.002267	(.004997)
2.414	(95.03)	1	63.12	.002393	(.005274)
2.395	(94.29)	1	64.9	.002441	(.005381)
2.368	(93.23)	1	72.6	.002706	(.005965)
2.155	(84.85)	15	90	.04570	(.100752)
1.918	(75.5)	4	89.14	.010737	(.02367)
1.864	(73.4)	3	85.9	.007545	(.016633)
1.828	(71.98)	4	90.765	.010424	(.022980)
1.794	(70.64)	5	79.03	.011134	(.024545)
1.757	(69.16)	8	86.18	.020505	(.045206)
1.646	(64.79)	47	85.475	.103817	(.228874)
		91		.2216 Kg/sec.	(.4885 lbm/sec.)
			X1.2 =	.2659 Kg/sec.	(.5862 lbm/sec.)

Ncn = Number of slots with same spacing

$\overline{Rs}$ = Mean slot Rs for given group of slots

TABLE 4

SURFACE PRESSURE AND DUCT AREAS REQUIRED

Psurf = $P_\infty + C_p$ ($\frac{1}{2}\rho V^2$); P = 20,713 N/M^2 (432.6 psf); Tduct = 240.2°K (432.4°R);
Vel. in trib. duct = 6.096 M/sec (20 ft/sec); Vel. in collector duct is 29.5 M/sec (96.8 ft/sec)

X/C	Cp	Psurf N/M^2 (psf)	Rs	Atd Cm^2 (in.^{2})	T Meters (in.)	Acd Cm^2 (in.^{2})
* .004	.441	24,121 (503.79)	50.97	1.445 (.2239)	2.430 (95.65)	2.379 (.3688)
* .01	0	20,714 (432.62)	59.55	1.985 (.3076)	2.424 (95.43)	3.261 (.5055)
* .021	-.476	17,036 (355.80)	63.12	2.558 (.3965)	2.414 (95.03)	4.186 (.6489)
* .041	-.809	14,463 (302.06)	64.9	3.098 (.4802)	2.395 (94.29)	5.030 (.7797)
* .065	-.925	13,566 (283.33)	72.6	3.695 (.5727)	2.373 (93.43)	5.945 (.9214)
.083	-.936	13,481 (281.56)	90	4.609 (.7144)	2.357 (92.78)	7.361 (1.141)
.1	-.93	13,528 (282.53)	90	4.594 (.712)	2.341 (92.16)	7.290 (1.130)
.15	-.9	13,759 (287.37)	90	4.516 (.70)	2.295 (90.35)	7.026 (1.089)
.2	-.89	13,836 (288.98)	90	4.491 (.6961)	2.249 (88.53)	6.845 (1.061)
.25	-.87	13,991 (292.21)	90	4.441 (.6884)	2.202 (86.71)	6.781 (1.051)
.30	-.86	14,068 (293.82)	90	4.417 (.6846)	2.156 (84.89)	6.458 (1.001)
.35	-.85	14,146 (295.44)	90	4.392 (.6808)	2.110 (83.07)	6.283 (.9738)
.4	-.83	14,300 (298.67)	90	4.345 (.6735)	2.064 (81.25)	6.080 (.9424)
.45	-.81	14,454 (301.89)	90	4.299 (.6663)	2.018 (79.44)	5.881 (.9115)
.5	-.78	14,687 (306.74)	90	4.231 (.6558)	1.972 (77.62)	5.655 (.8765)
.55	-.76	14,841 (309.96)	100	4.652 (.7211)	1.925 (75.8)	6.072 (.9412)
.60	-.74	14,996 (313.19)	100	4.604 (.7136)	1.879 (73.98)	5.865 (.9091)
.65	-.69	15,382 (321.26)	100	4.488 (.6957)	1.833 (72.16)	5.577 (.8645)
.70	-.62	15,923 (332.56)	100	4.336 (.6721)	1.787 (70.34)	5.252 (.8141)
.75	-.54	16,541 (345.47)	100	4.174 (.6469)	1.741 (68.53)	4.925 (.7634)
.80	-.41	17,546 (366.45)	100	3.935 (.6099)	1.694 (66.71)	4.521 (.7007)
.85	-.2	19,171 (400.39)	100	3.284 (.509)	1.648 (64.89)	3.670 (.5688)
.9	-.003	20,691 (432.14)	105	3.337 (.5172)	1.602 (63.07)	3.625 (.5618)
.95	.12	21,641 (451.99)	105	3.190 (.4945)	1.556 (61.25)	3.365 (.5216)

NOTES:
1. Duct pressure assumed to be 94% of surface pressure. (-6% Δp)
2. Tributary duct length is .3048 M (1 foot)
* 3. Represents individual slots.
4. Airfoil is YNRB, upper surface

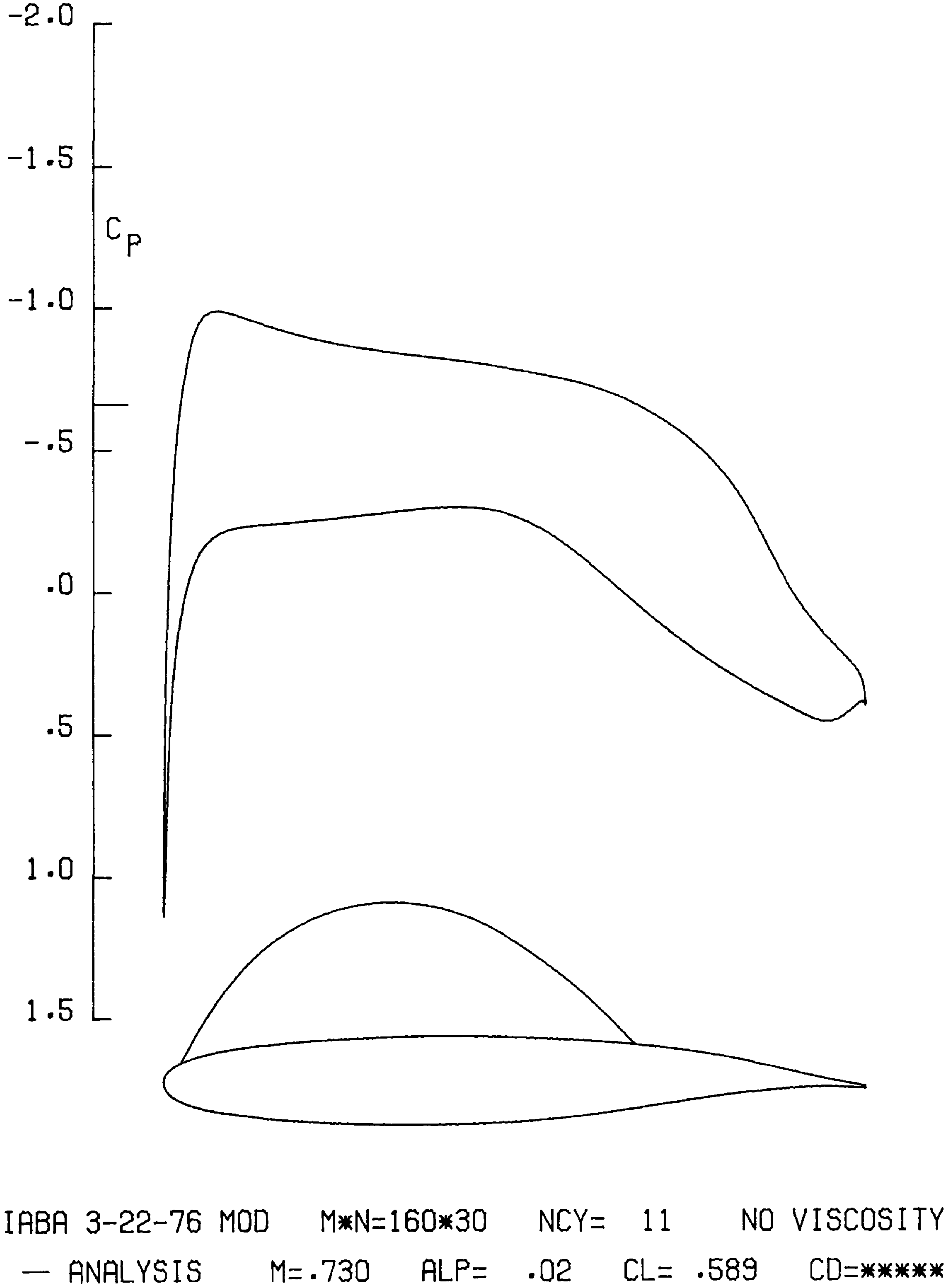
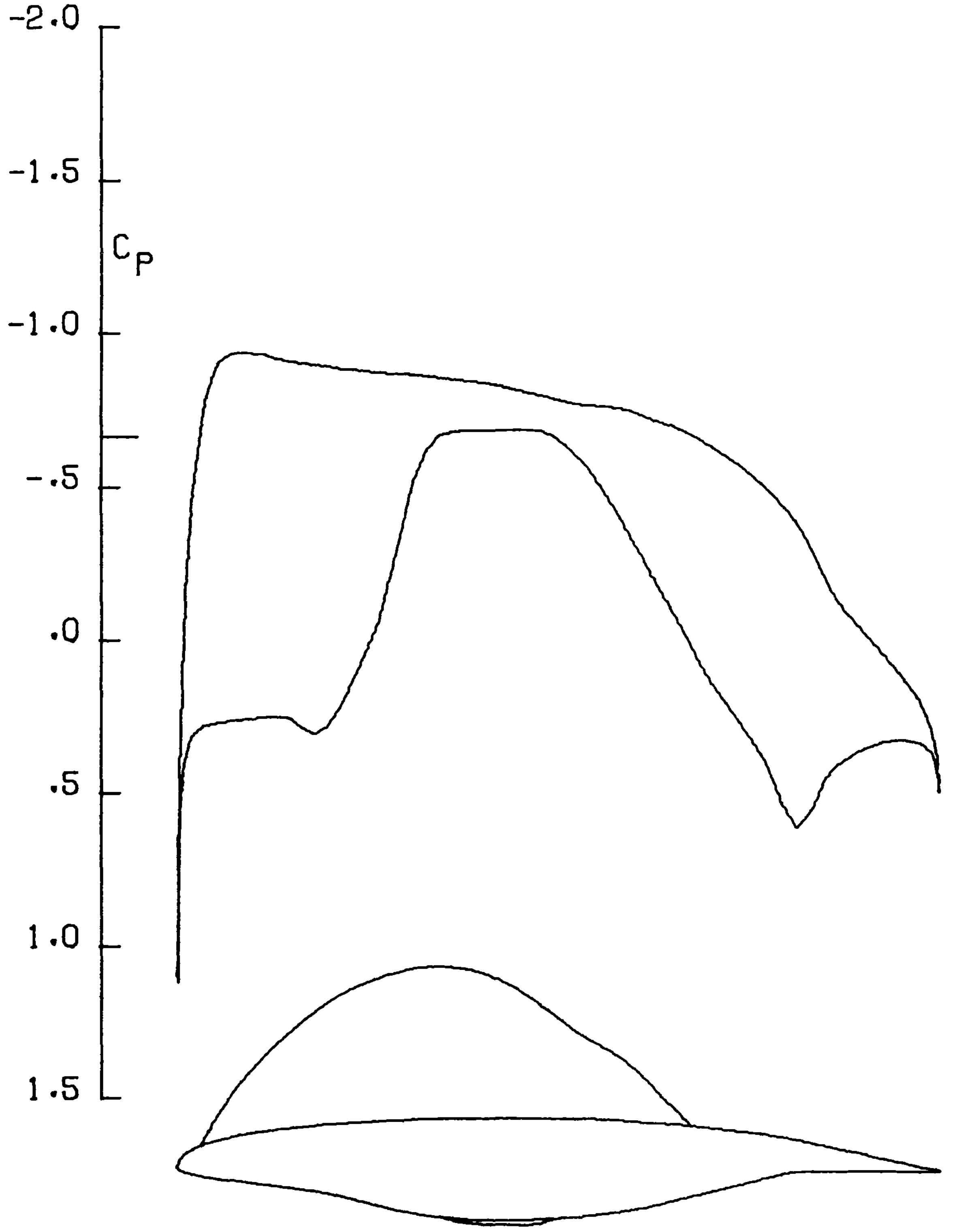


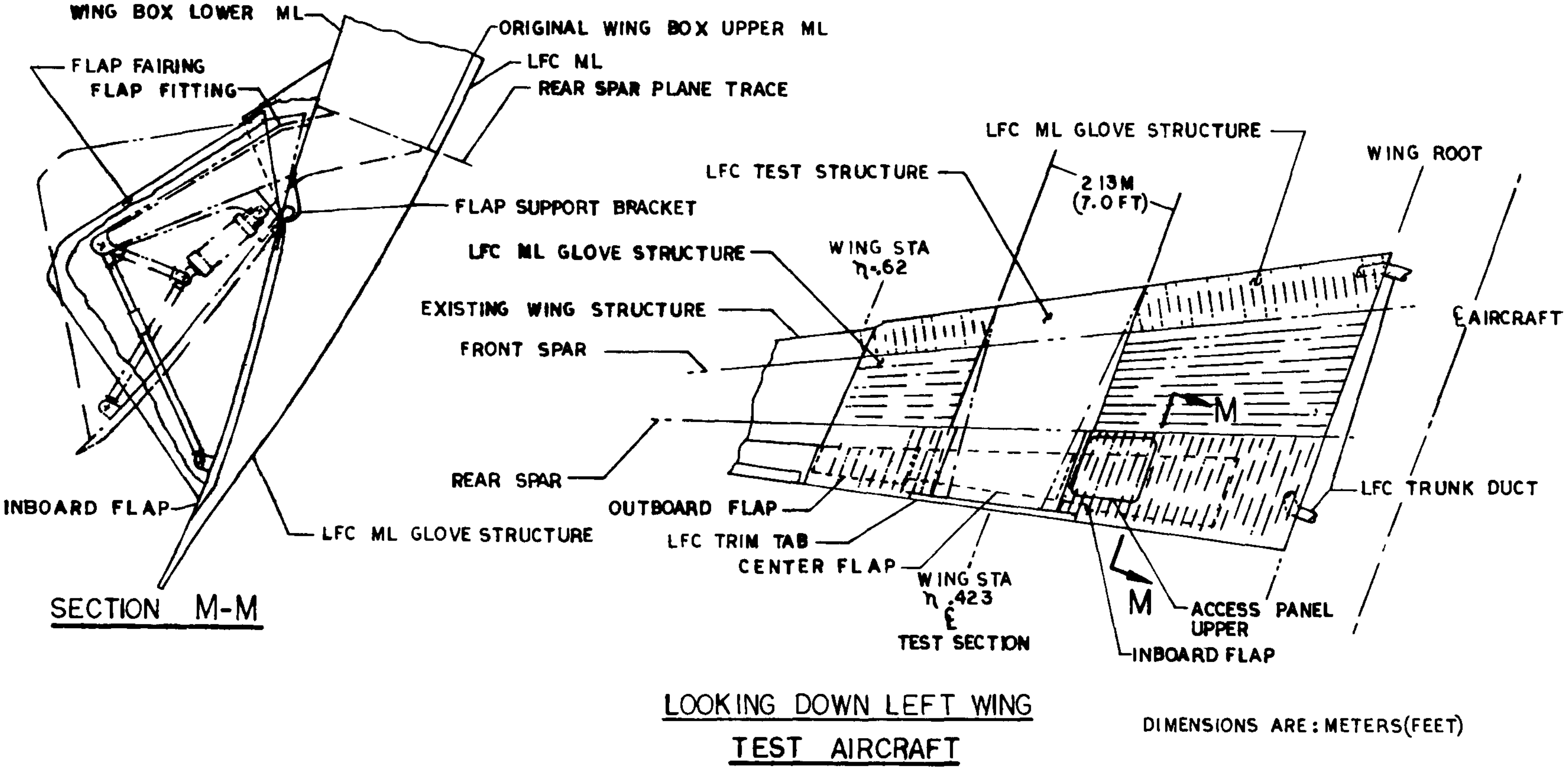
FIGURE 1 - GLOVE WING AIRFOIL



YNRB 12-2-77 M*N=160*30 NCY= 10 NO VISCOSITY

— ANALYSIS M=.730 ALP= .09 CL= .600 CD=*****

FIGURE 2 - WIND TUNNEL MODEL AIRFOIL

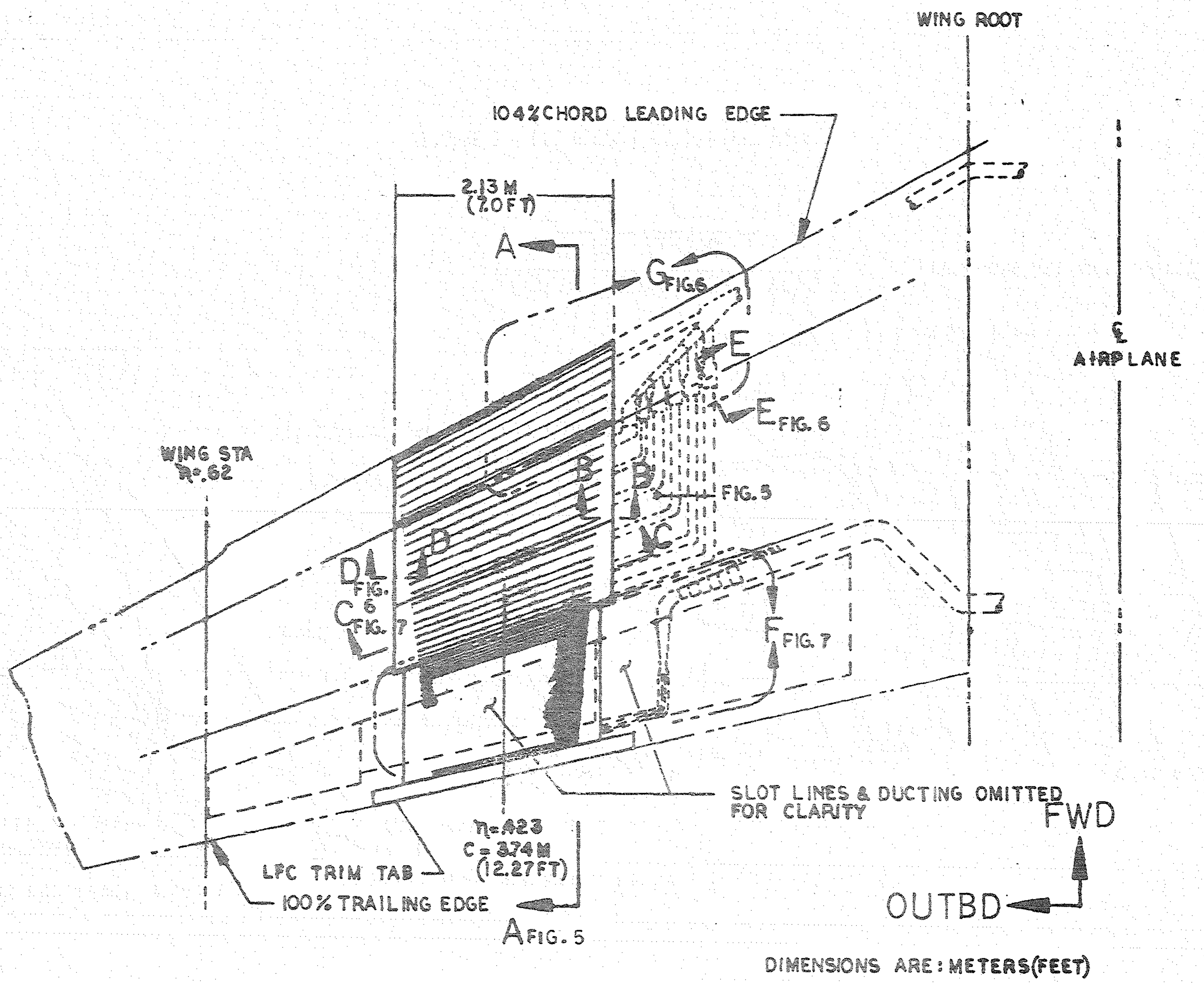


SECTION M-M

LOOKING DOWN LEFT WING

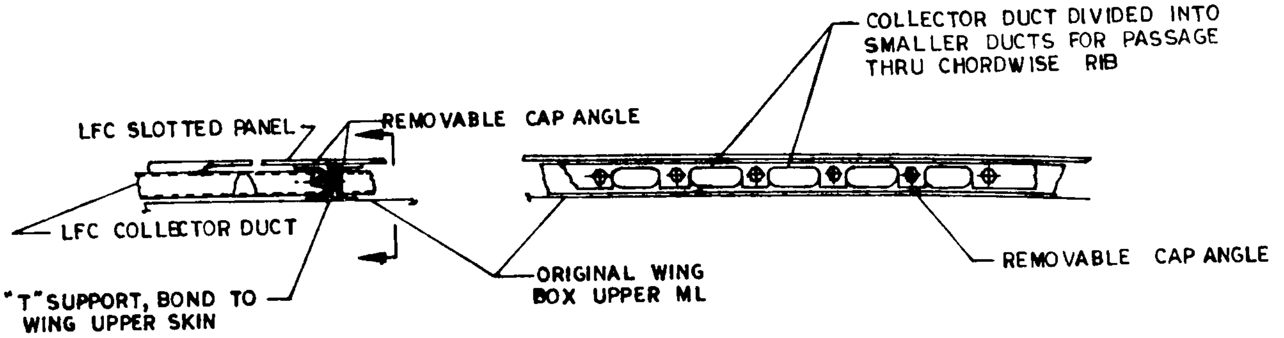
TEST AIRCRAFT

FIGURE 3 - LFC GLOVE LOCATION-LEFT WING

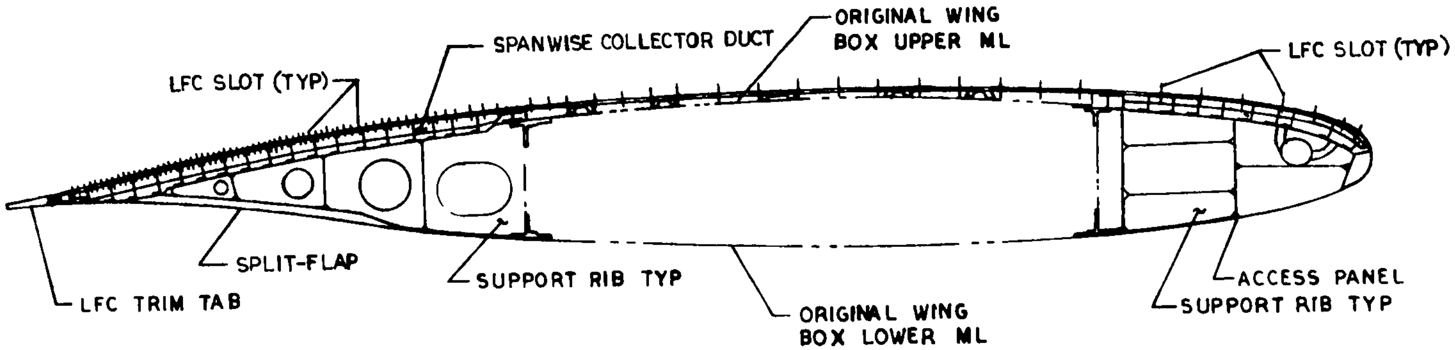


LOOKING DOWN LEFT WING
TEST AIRCRAFT

FIGURE 4 - SLOTTED GLOVE CONFIGURATION - PLAN VIEW

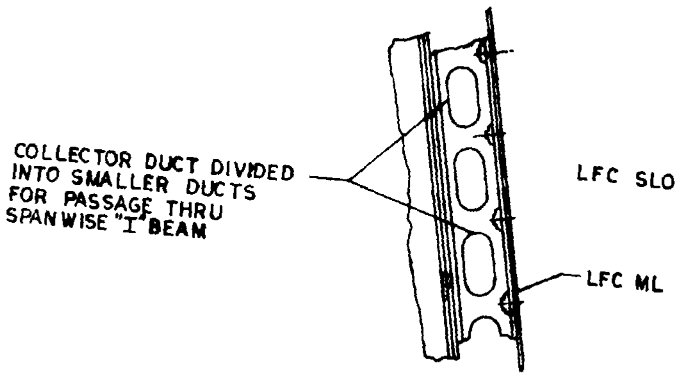


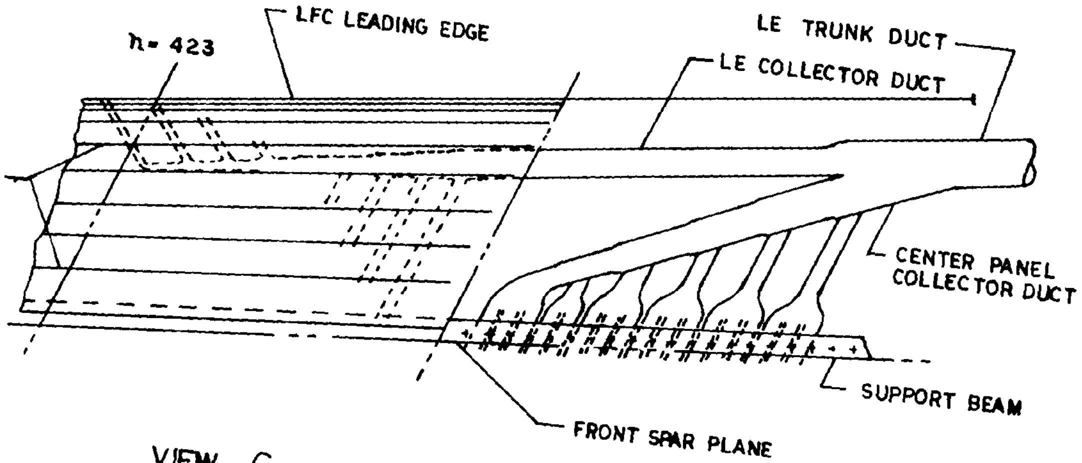
SECTION B-B FIG. 4



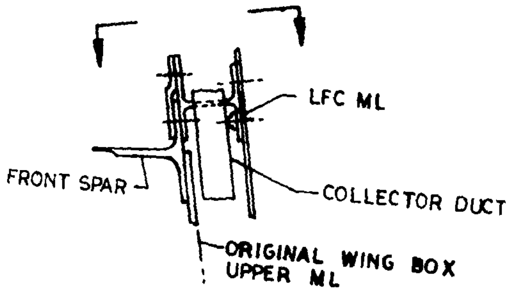
SECTION A-A FIG. 4

FIGURE 5 - SLOTTED GLOVE CONFIGURATION - SECTIONS A-A AND B-B

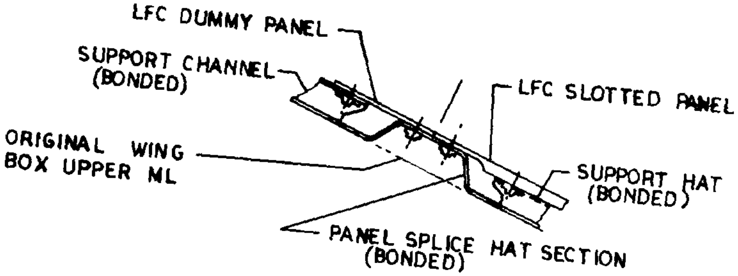




VIEW G FIG. 4

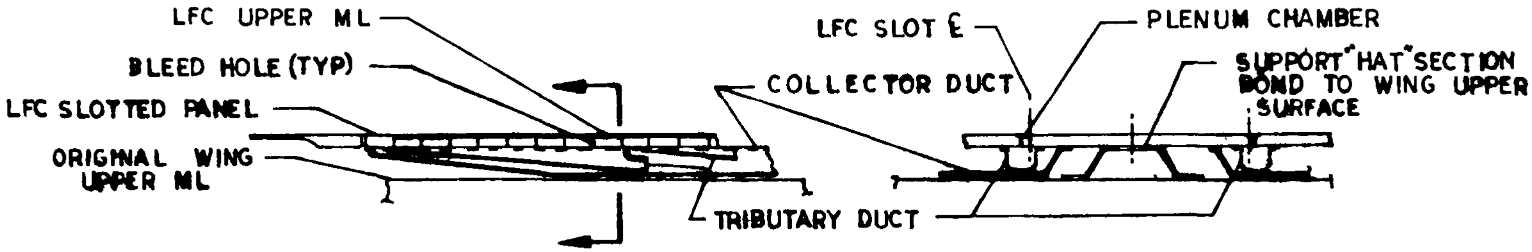


SECTION E-E FIG 4

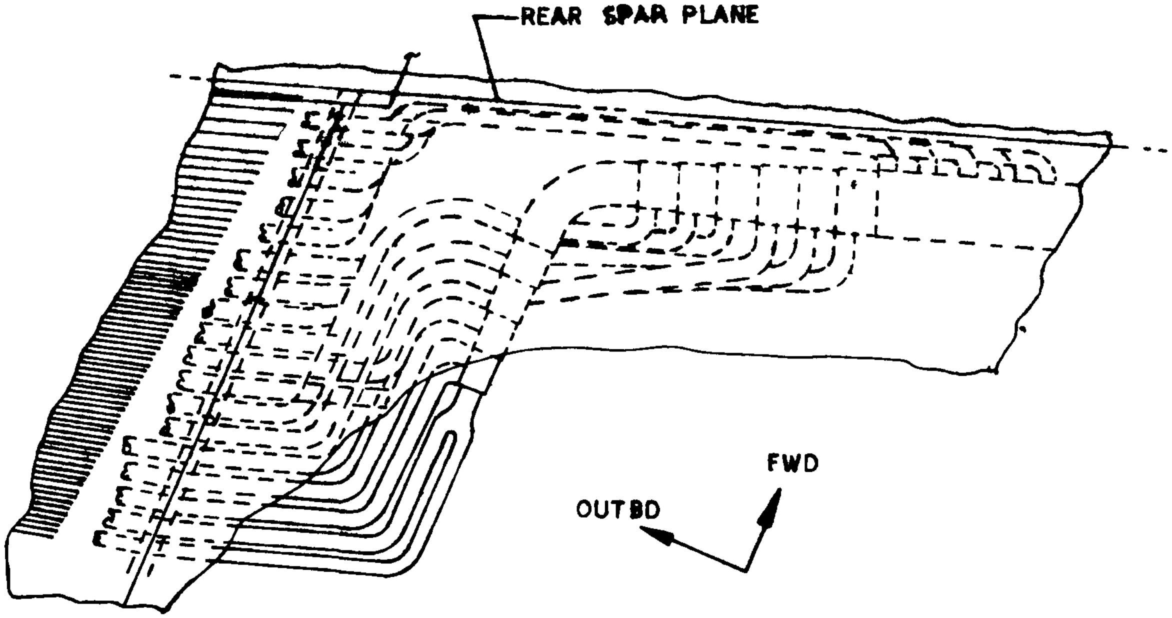


SECTION D - D FIG. 4

FIGURE 6 - SLOTTED GLOVE CONFIGURATION - SECTIONS D-D, E-E, AND VIEW G



SECTION C-C FIG. 4



VIEW F FIG. 4

FIGURE 7 - SLOTTED GLOVE CONFIGURATION -
TRAILING EDGE AND SECTION C-C

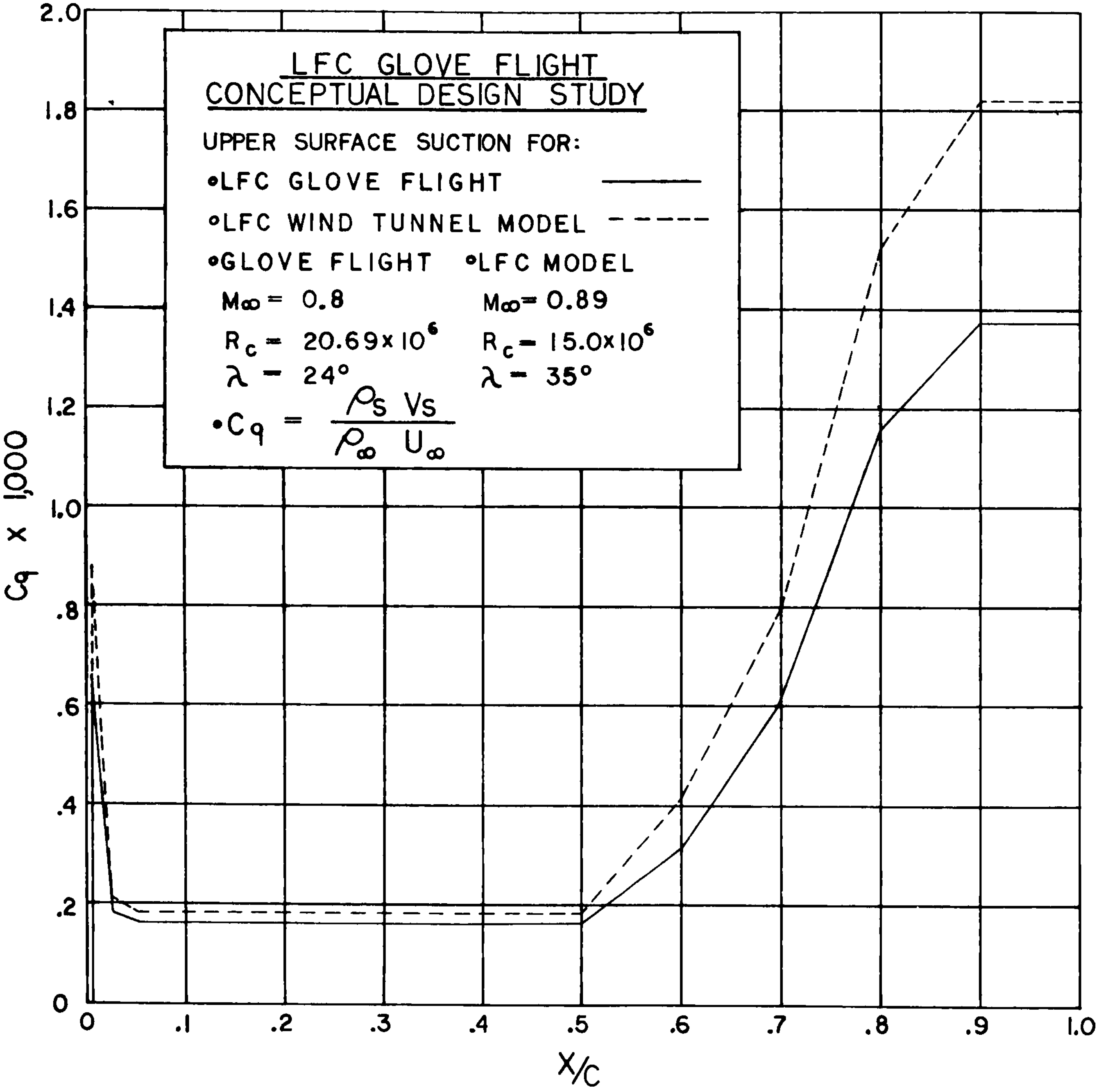
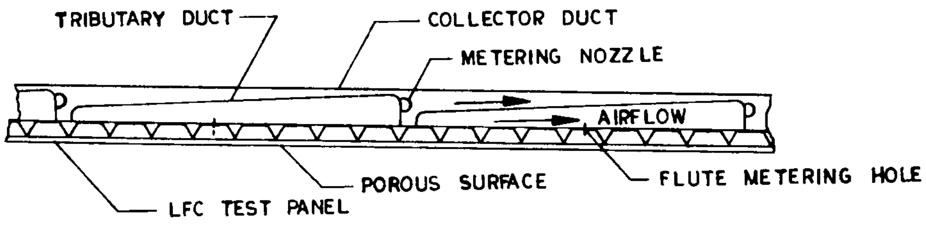
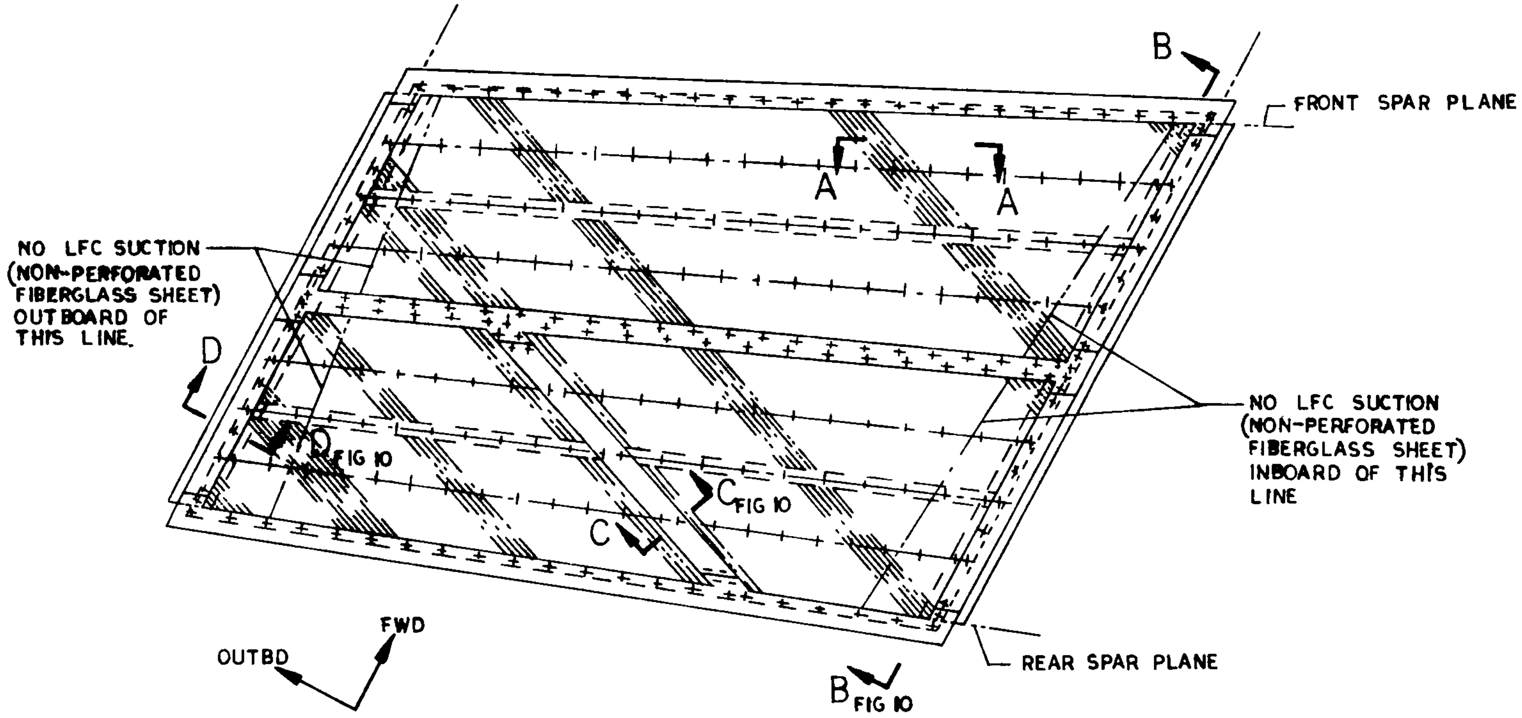


FIGURE 8 - LFC GLOVE FLIGHT AND LFC WIND TUNNEL MODEL SUCTION COEFFICIENTS



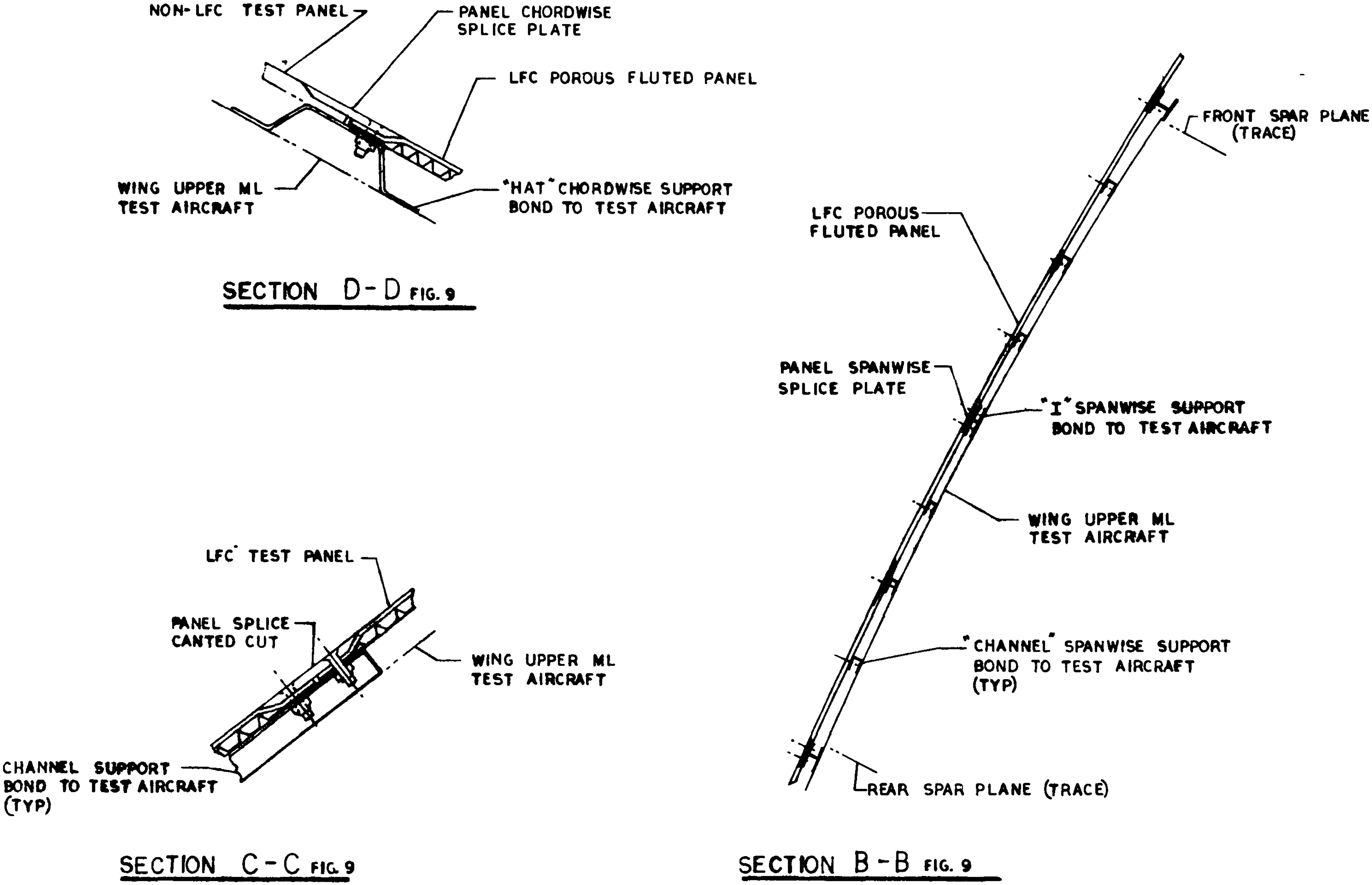
SECTION A-A



LOOKING DOWN AT WING UPPER SURFACE

LFC POROUS SURFACE PANEL

FIGURE 9 - POROUS GLOVE CONCEPT-CENTER PANEL



SECTION D-D FIG. 9

SECTION C-C FIG. 9

SECTION B-B FIG. 9

FIGURE 10 - POROUS GLOVE CONCEPT-CENTER PANEL SECTIONS

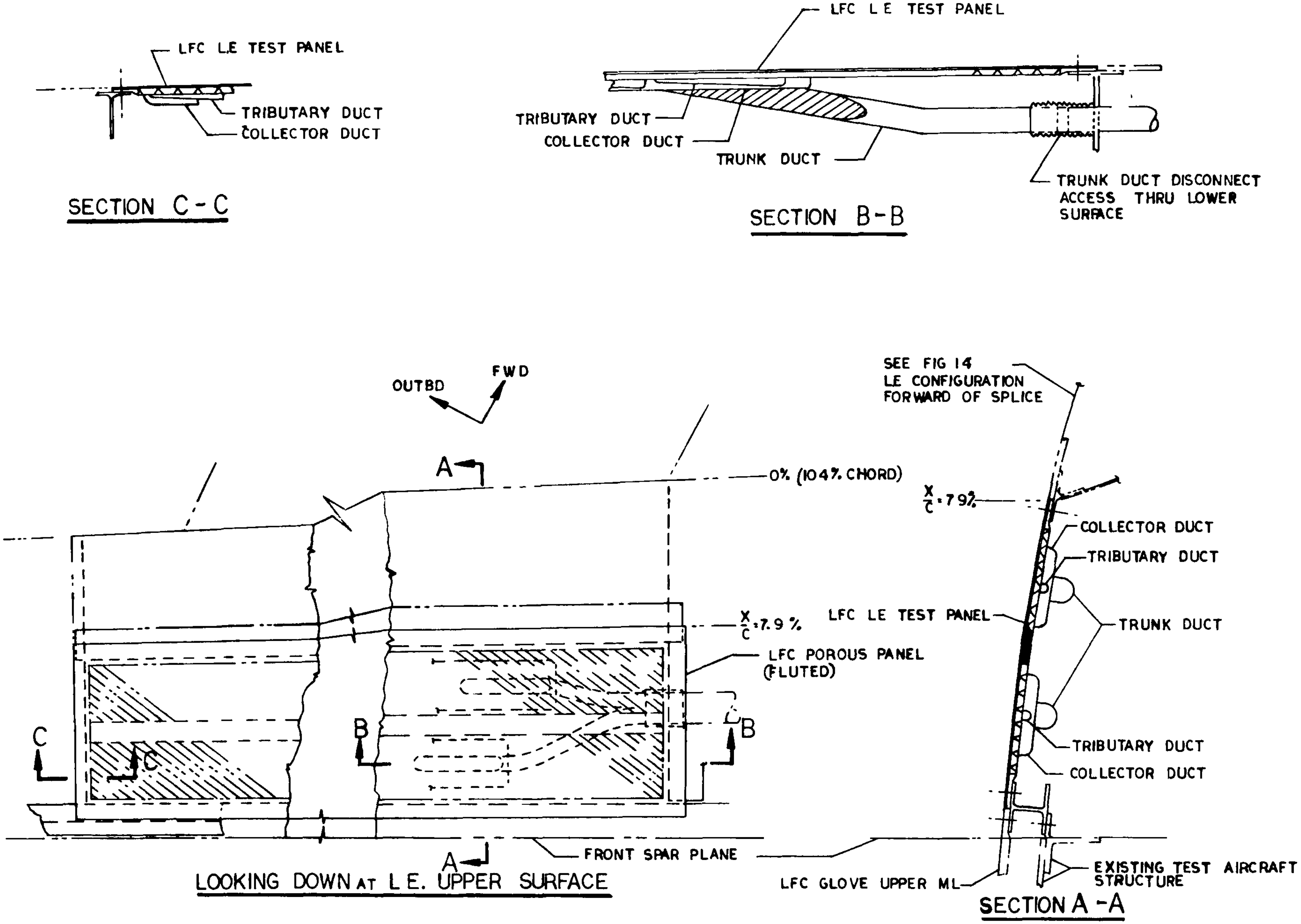
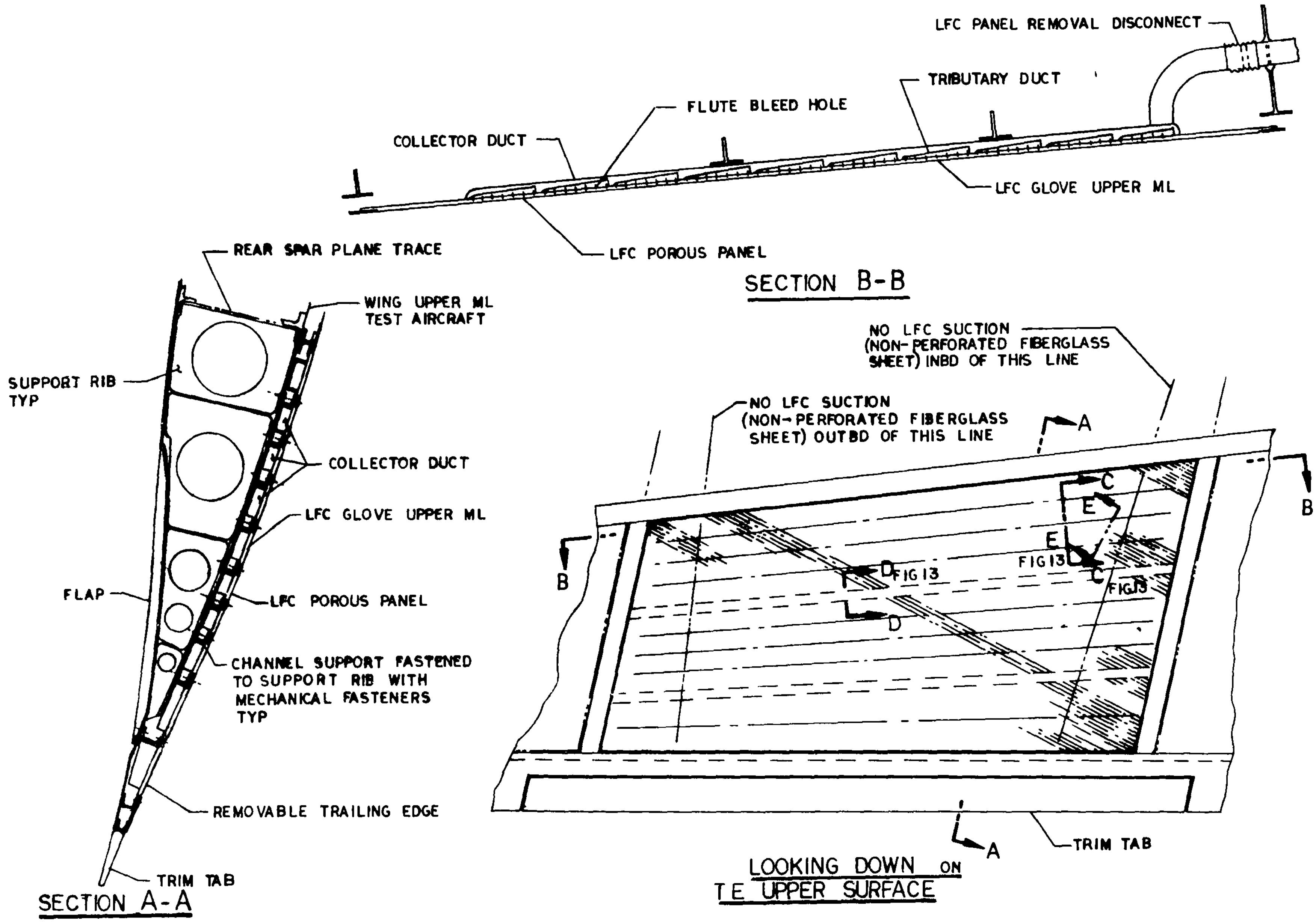


FIGURE 11 - POROUS GLOVE CONCEPT-LEADING EDGE

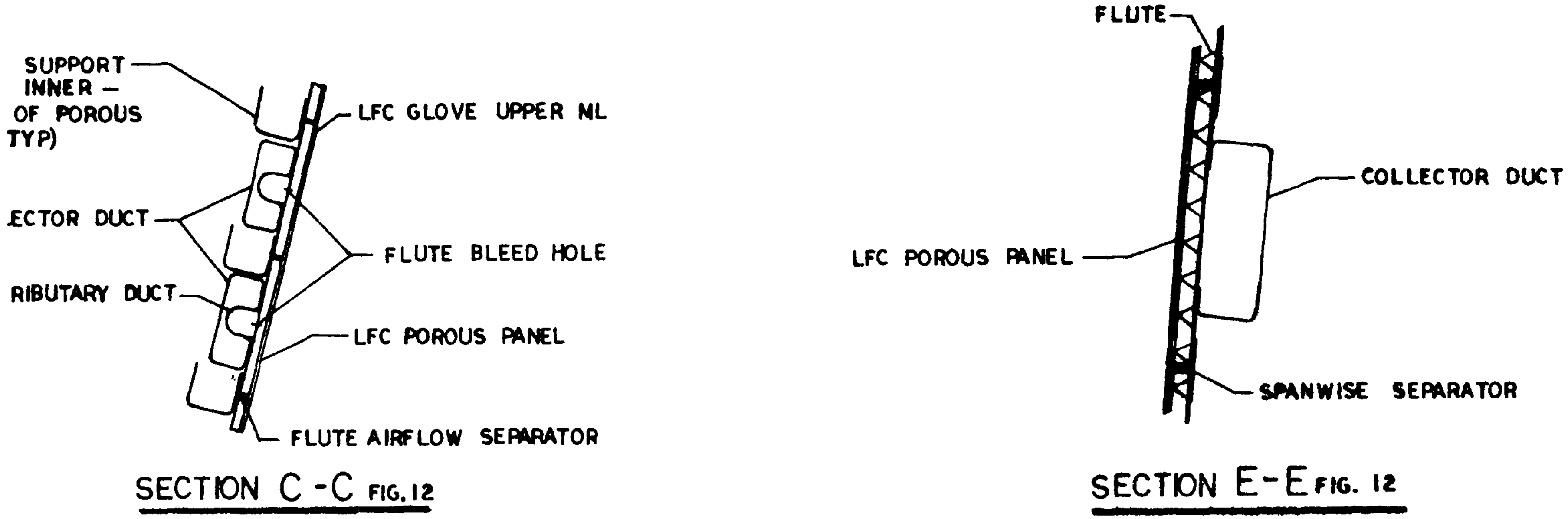


SECTION B-B

SECTION A-A

LOOKING DOWN ON T E UPPER SURFACE

FIGURE 12 - POROUS GLOVE CONCEPT-TRAILING EDGE



SECTION C-C FIG. 12

SECTION E-E FIG. 12

FIGURE 13 - POROUS GLOVE CONCEPT-TRAILING EDGE SECTIONS

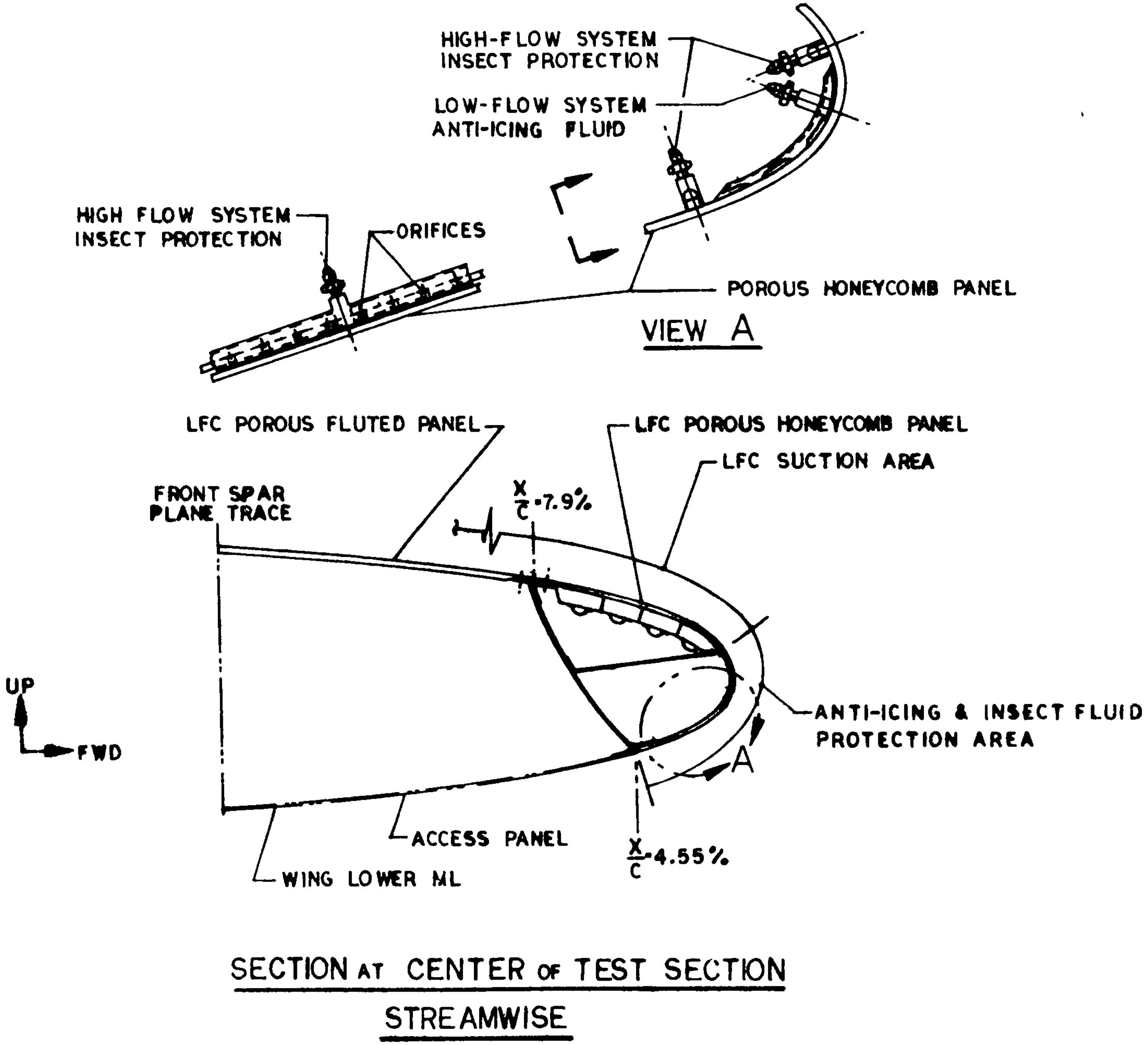


FIGURE 14 - LEADING EDGE CLEANING-POROUS GLOVE CONCEPT

APPENDIX A

GLOVE FLIGHT CONCEPTUAL DESIGN STUDY
REQUIREMENTS FOR COMPRESSOR/TURBINE

Compressor - Will be a single centrifugal compressor

Location - Inside fuselage behind aft pressure bulkhead

Inlet Conditions - At 11,580 M (38,000 ft.): Pi = 10,773 N/M^2 (225 psfa), Ti = 240°K (432°R), Vi = 30.48 M/Sec(100 ft/sec.). Inlet distortion - Assumed to be similar to that of the X-21 low pressure compressor.

Outlet Conditions - At 11,580 M (38,000 ft.): Ptc = 28,153 N/M^2 (588 psfa), Ttc = 328°K (590°R) Outlet air is expanded through a nozzle and duct to total pressure of freestream:

p_∞ = 20,732 N/M^2 (433 psfa)   Tex = 300.5°K (541°R)
V_∞ = 236 M/S (774.5 ft/sec.)   Vex = 235 M/S (771 ft/sec.)

Mass Flow -

	Altitude Meters (ft.)	$\dot{M}$ Kg/sec. (lbm/sec.)
	10,367 (34,000)	.238 (.525)
Design Point	11,580 (38,000)	.2216 (.489)
	12,800 (42,000)	.205 (.452)

Mass flows between 85% and 130% of design point are assumed at each altitude.

Compression Ratio - 2.61

Compression Power - 9.77 Kw (13.1 HP) @ 11,580 M (38,000 ft.) and 100% of design mass flow

Drive Turbine - Air turbine driven by engine bleed air. Air turbine bleed air requirements are unknown.

APPENDIX B

ACEE LFC GLOVE FLIGHT CONCEPTUAL DESIGN STUDY

General Flow of Major Hardware Activities

1. Obtain aircraft.
2. Perform A/C periodic maintenance because wing box items may be covered up by glove.
3. Remove wing items including wing root fairing, aileron control cables, all slat cables. (Retain ailerons and 2 outboard slats)
4. Remove seats.
5. Preserve as necessary and store removed items.
6. Fabricate LFC and dummy gloves, ducting, new flap.
7. Procure compressor/turbine; 24, + spare, control valves.
8. Procure/fabricate/assemble control console.
9. Procure/obtain airborne tape recorder.
10. Penetrate fuselage pressure hull ahead and behind wing box center section.
11. Route forward suction ducting around wing box.
12. Route after suction ducting through hull.
13. Route both ducts through aft baggage compartment.
14. Install compressor and turbine aft of pressure bulkhead. Hook up inlet ducts.
15. Route compressor and turbine exhaust ducts out of the aircraft.
16. Route engine bleed air lines from engine to air turbine aft of pressure bulkhead.
17. Bond glove supports to top of wing box from root to near $\eta = .62$ both sides.

18. Install glove sections to wing box.

19. Reinstall leading edge cables and pulleys, and rerig.

20. Bench assemble mixing ducts and control valves.

21. Install leading edge and duct assemblies to front spar.

22. Install wing box duct turns and joints.

23. Reinstall trailing edge control cables, pulleys, and guides: rerig.

24. Install trailing edge LFC section and duct assemblies to rear spar. (Duct assembly and control valves to be bench assembled.)

25. Install forward and rear trunk ducts.

26. Install wing root fairing.

27. Install dummy glove, both wings.

28. Fill and smooth LFC wing as required.

29. Measure LFC section waviness and roughness.

30. Install control console and tape recorder in cabin.

31. Install all cables, wires, power, etc.

32. Install new split flaps.

33. Test suction system for leaks, seal as required.

34. Perform functional test of compressor/turbine and suction system.

35. Checkout control console and instrumentation.

36. Make aircraft data tape and run through ground data system to establish data compatibility.

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37. Flight test program

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38. Remove all glove hardware, dummy glove, leading edge, trailing edge, ducting, split flap, from A/C.

39. Remove leading and trailing edge cables and pulleys.

40. Remove compressor/turbine and sled and fuselage ducting.

41. Remove control console and all cables from cabin and wing.

42. Install cover plates and seal all hull penetrations in aircraft fuselage. Pressure test for leaks.

43. Remove bonded-on supports from wing box. Remove all bonding agent, and decontaminate wing box upper surface of bonding agent contamination if present.

44. Inspect wing box as necessary for damage and check wing tanks for leaks.

45. Take removed items from storage and prepare for installation.

46. Install leading edge cables and pulleys.

47. Install leading edge, install removed slats.

48. Rerig slat cables.

49. Install flap fixed structural supports.

50. Install trailing edge.

51. Install wing root fairing.

52. Install flaps and spoilers.

53. Install trailing edge cables, pulleys, and guides.

54. Rerig trailing edge cables.

55. Install flap and spoiler hydraulic actuators, tubes, and hoses.

56. Re/check wing fuel tanks for leaks.

57. Checkout A/C and recertify as required.

End of Document