NASA CR- 137897

AN ANALYTICAL STUDY FOR SUBSONIC OBLIQUE WING TRANSPORT CONCEPT

SUMMARY REPORT

JULY 1976

Prepared under Contract No. NAS 2-8686

by

THE LOCKHEED-GEORGIA COMPANY
A Division of Lockheed Aircraft Corporation
Marietta, Georgia

for

NASA

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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16. Abstract

The Oblique Wing Concept has been investigated for subsonic transport application for a cruise Mach number of 0.95. Three different mission applications were considered and the concept analyzed against the selected mission requirements. Configuration studies determined the best area of applicability to be a Commercial Passenger Transport Mission - payload 23,768 kg (200 passenger + 10,000 lb of cargo) for a range of 5560 km (3000 n mi). The critical parameter for the Oblique Wing Concept was found to be aspect ratio which was limited to a value of 6.0 due to aeroelastic divergence. Comparison of the concept Final Configuration was made with fixed winged configurations designed to cruise at Mach 0.85 and 0.95. The crossover Mach number for the Oblique Wing Concept was found to be Mach 0.91 for takeoff gross weight and direct operating cost. Benefits include reduced takeoff distance, installed thrust and mission block fuel and improved community noise characteristics. The variable geometry feature enables the Final Configuration to increase range by 10% at Mach 0.712 and to increase endurance by as much as 44 percent. The Oblique Wing Concept Final Configuration is also shown to have alternate mission capability as an Air Force tanker and a Navy ASW airplane.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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By Edward S. Bradley
Lockheed-Georgia Company

INTRODUCTION

Studies of the Oblique Wing Concept have demonstrated the feasibility and potential of the concept for aircraft designed to fly at speeds of Mach 1.2. The inherent advantage of the Oblique wing is due to the ability to vary geometry which enables induced drag to be reduced at takeoff and landing and during loiter and yet permits good flight efficiency during cruise. When applied to subsonic designs these advantages are realized in lower takeoff gross weight, improved airport performance and community noise characteristics, and better mission flexibility and speed matching than the corresponding conventional configuration.

These advantages have both commercial and military implications and the study summarized herein establishes the mission/configuration combination best suited to the concept. This was achieved by first conducting a survey of commercial and military missions from which a number of mission possibilities were applied to the Oblique Wing Concept. The missions chosen for investigation were a Commercial Passenger Transport, an Executive Transport and a large Military Cargo Transport Mission.

Parametric sizing analyses and configuration studies were performed from which the characteristics were obtained for the development of suitable configurations. The technology time-frame for the study is consistent with an introduction-into-service date of 1985 for which technology levels have been established from previous studies, References 1 and 2.

At the completion of the configuration studies an Oblique Wing Configuration was developed for each mission, the problem areas of each configuration were identified, an assessment of the complexity of each problem was made and solutions determined. On the basis of this evaluation the mission/configuration combination having: a) the lowest number of problem areas, and b) problem areas accessible to simple solution, was selected as having the best suitability to the Oblique Wing Concept.

Assessing the relative complexity of the problem areas and the simplicity of the solutions led to the selection of the Commercial Passenger Transport Mission/Configuration as the best combination for the Oblique Wing Concept.

Following the selection of the mission/configuration combination for the Oblique Wing Concept, a Final Configuration was developed based on the configuration used for concept evaluation. The Final Configuration incorporated a number of refinements and improvements which included relocation of external engine nacelles and an increase in the swept aspect ratio from 5.0 to 6.0 as indicated by the Aeroelastic Analyses conducted by the NASA Ames Research Center. The Final Configuration definition and development includes configurational and structural design data and generation of performance and acoustic characteristics data.

Conventional Configurations for cruise at Mach 0.85 and 0.95 were also developed and provided the basis for establishing the benefits arising from the Oblique Wing Concept.

The domain of the Subsonic Oblique Wing Concept was found to be in the cruise Mach number region above 0.91.

Comparison of the Final Configuration with the data of the Conventional Configuration identified substantial improvement in the Oblique Wing Concept weight, performance and acoustic characteristics, and in the off-design and alternate mission capability.

Wing aspect ratio, either swept or unswept, emerges as the dominant parameter from the study, and structures and materials technology as the critical technology area. Achievement of high aspect ratio divergence-free wings relies upon utilization of filamentary composite materials to the maximum possible level and the ability to design efficient structures in composite materials to obtain maximum structure weight reduction is fundamental to the success of the concept.

This report is a summary of the study Final Report NASA CR-137896, published July, 1976.

STUDY PLAN

The objectives of the study are: a) The definition of an Oblique Wing Concept which satisfies the Statement of Work; b) The identification of key parameters and the sensitivity of the design to changes in each of the parameters, and c) An assessment of the impact of the application of advanced technologies and the definitions of critical research areas associated with the concept.

The study plan devised to achieve the objectives was divided into four related elements. The plan, Figure 1, consists of: 1) mission selection, 2) configuration design and analysis, 3) final analysis, and 4) technical

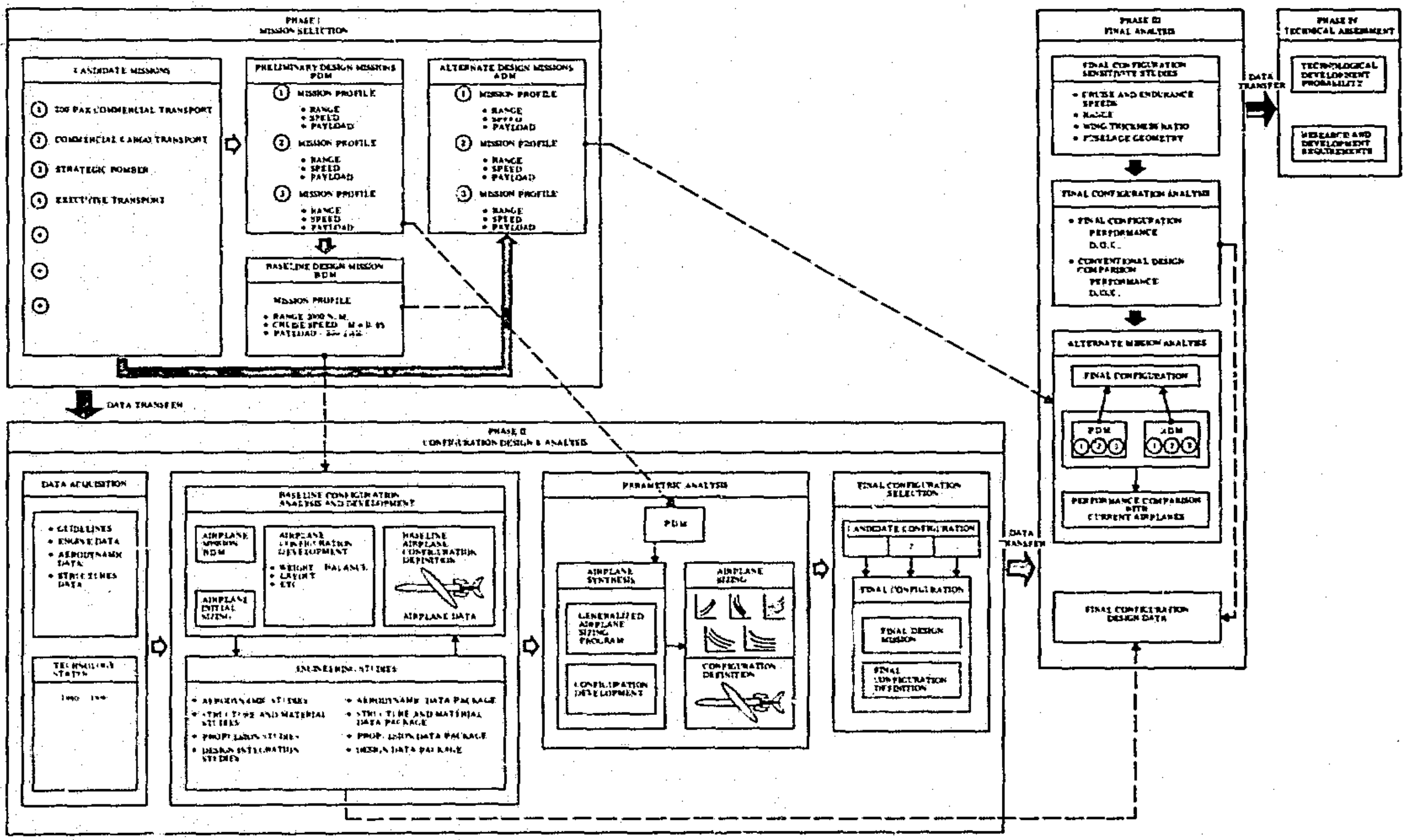


FIGURE 1 STUDY PLAN

assessment.

The technical approach used to implement the plan required a survey of suitable missions both commercial and military, analysis of the Oblique Wing Concept performing the chosen missions, the selection of the mission/configuration combination best suited to the concept, and the development and analysis of the selected configuration performing primary and alternate missions. A comparison of the Oblique Wing Concept with a Conventional Configuration to identify benefits and a technological assessment concluded the study.

MISSION ANALYSIS

A list of candidate missions, both commercial and military, was compiled and is shown on Table I. These data were obtained from numerous commercial and military sources and involved the review of approximately 1,700,000 government and private technical abstracts of possible interest using the Lockheed DIALOG Computerized Data Retrieval System.

The list of candidate missions was reduced to three Preliminary Design Missions (PDMs) namely:

- o Commercial Passenger Transport Mission
- o Executive Transport Mission
- o Military Cargo Transport Mission

Data for each of these missions are given on Table II. In addition, alternate missions corresponding to each PDM are identified.

CONFIGURATION STUDIES

Configuration studies were conducted for each mission using the following procedure:

- o Development of characteristics for an Initial Configuration
- o Development of a Baseline Configuration
- o Development of a Cycled Baseline Configuration

Parametric sizing analyses performed for each mission established the characteristics of each Initial Configuration based on estimated geometric relationships. These relationships were checked by configuration design and where found to be deficient were revised. Each revised configuration

TABLE I CANDIDATE MISSIONS

Mission	Speed	Payload	Range	Takeoff Distance	Altitude	Remarks
Commercial Passenger	M 0.95	200 Passengers + 4,534 kg (10,000 lb)	5560 km (3000 n mi)		9,144 - 12,192 m (30-40,000 ft)	Baseline design mission.
Commercial Cargo	M 0.82	49,895 kg (110,000 lb) +	4815 km (2600 n mi) +	3,048 m (10,000 ft)	9,144 - 12,192 m (30-40,000 ft)	Must be compatible with military requirements.
Executive Passenger	M 0.82 +	15-18 Passengers + Baggage	7408 km (4000 n mi)	1,524 m (5,000 ft)	12,192 m (40,000 ft)	
Air Force Tanker	371 km/hr (200 k) TAS at 3,048 m (10,000 ft) M 0.88 at 11,887 m (39,000 ft)	81,648 - 113,400 kg (180-250,000 lb) and/or 27,216 - 36,288 kg (60-80,000 lb)	For 6482 km (3500 n mi) and/or For 10,186 km (5500 n mi)	3,048 m (10,000 ft)	3,048 - 10,668 m (10,35,000 ft)	
Missile Launcher	741 km/hr (400 k) TAS at 6,096 m (20,000 ft)	147,871, 178,942 or 220,672 kg (326,000, 394,500 or 486,500 lb)	6 hours at maximum TOGW and 12 hours with inflight refueling	3,048 m (10,000 ft)	9,144 m (30,000 ft) +	Could be smaller.
Military Cargo	556 km/hr (300 k) TAS +	158,757 kg (350,000 lb)	6482 km (3500 n mi) or 12,964 km (7000 n mi) or 6482 km (3500 n mi) radius with payload offload and no refuel at midpoint.	2,438 m (8,000 ft)	9,144 m (30,000 ft) +	80% of fleet owned by civil air carriers.
Command Post	For best endurance	Up to 45,360 kg (100,000 lb)	Max possible	1,829 m (6,000 ft)	9,144 m (30,000 ft) +	
Navy Carrier Aircraft, i.e., COD, ASW, Tanker, Early Warning, Attack Bomber	Best endurance to M 0.55 +	To 4,536 kg (10,000 lb)	To 3704 km (2000 n mi)	853 m (2,800 ft)	To 13,716 m (45,000 ft)	Several missions compatible with 1 basic airframe. Wing swung to fore and aft position gives deck storage advantage.

TABLE II PRELIMINARY DESIGN MISSIONS

1	2	3
Commercial Passenger Transport	Executive Passenger Transport	Military Cargo Transport
Payload - 200 Passengers + 4,536 kg (10,000 lb) Cargo Cruise Mach No. = 0.95 Range - 5560 km (3000 n mi) Takeoff Distance - 3,048 m (10,000 ft) Cruise Altitude - 9,144 - 12,192 m (30-40,000 ft) (gross weight, airfield performance)	Payload - 15-18 Passengers + Baggage Cruise Mach No. = 0.95 Range - 7408 km (4000 n mi) Takeoff Distance - 1,524 m (5,000 ft) Cruise Altitude - 12,192 m (40,000 ft) (gross weight, airfield performance, mission flexibility)	Payload - 158,750 kg (350,000 lb) Cruise Mach No. = 0.95 Range 1 6482 km (3500 n mi) 2 12,964 km (7000 n mi) Radius 1 6482 km (3500 n mi) Offload Payload at Midpoint. No Refuel at Midpoint. Takeoff Distance - 2,438 m (8,000 ft) Cruise Altitude - 9,144 m + (30,000 ft +) (gross weight, airfield performance)
CANDIDATE ALTERNATE DESIGN MISSIONS		
Tanker (endurance, flexibility, speed matching) Command Post (endurance, gross weight) Ground Based Navy Aircraft - ASW, Rescue/Search/Surveillance (endurance, flexibility)	Navy Carrier Aircraft, e.g., COD, ASW, Tanker, Early Warning, Trainer, Attack Bomber (all characteristics in various combinations)	Tanker (endurance, flexibility, speed matching) Missile Launcher (endurance, flexibility) Commercial Cargo (gross weight, airfield performance)

was then resized to become the Baseline Configuration. Further configuration studies and weight and balance analyses, together with results of a number of engineering studies, provided the information necessary to perform the final sizing iteration to establish a Cycled Baseline Configuration. The evaluation of the Oblique Wing Concept used the Cycled Baseline Configurations as the basis for comparison. The principal criterion for configuration selection was minimum takeoff gross weight for the design. Other criteria such as approach speeds not in excess of 259.3 km/hr (140 k) EAS, minimum fuel and acoustic characteristics were also considered.

Commercial Passenger Transport Configuration Development

The parametric sizing charts for the Commercial Passenger Transport are shown on Figure 2 and the characteristics for the Baseline Configuration indicated. Takeoff distance was limited to a maximum of 2743 m (9000 ft). At a wing loading slightly in excess of 5745 N/m^2 (120 lb/ft^2) and swept aspect ratio 6.0, the resulting configuration is takeoff distance/cruise/wing fuel volume matched. Approach speed is less than the 259.3 km/hr (140 k) EAS maximum. The configuration developed for these characteristics is shown on Figure 3. The configuration has a minimum landing gear fairing and symmetrically placed external engine nacelles. Configurational investigations indicated deficiencies in the area distribution curve, Figure 4a, which were corrected by incorporating the changes shown on Figure 4b. Preliminary aeroelastic analyses indicated that, in order to avoid wing divergence related weight penalties, reduction of swept wing aspect ratio

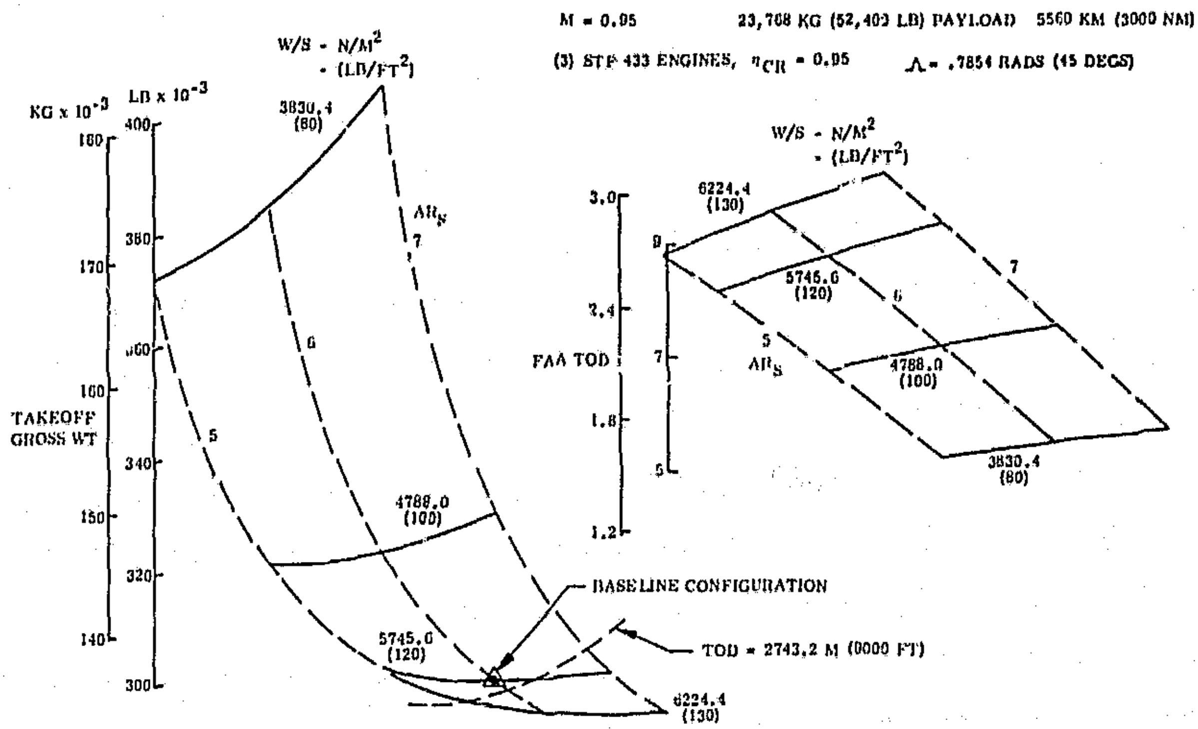


FIGURE 2 COMMERCIAL PASSENGER TRANSPORT SIZING CHART

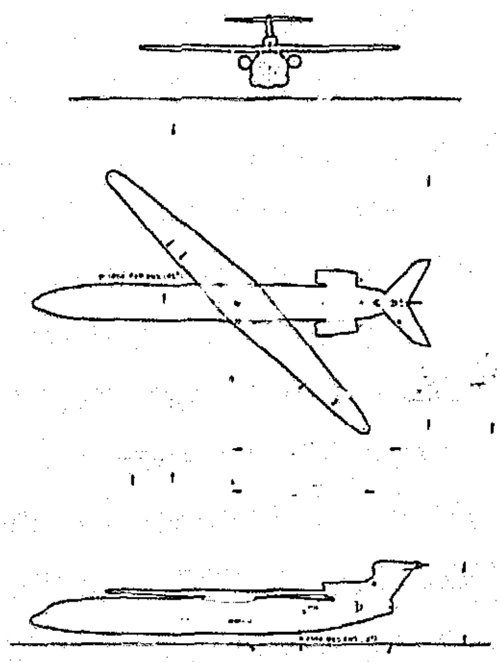


FIGURE 3 COMMERCIAL PASSENGER TRANSPORT BASELINE CONFIGURATION

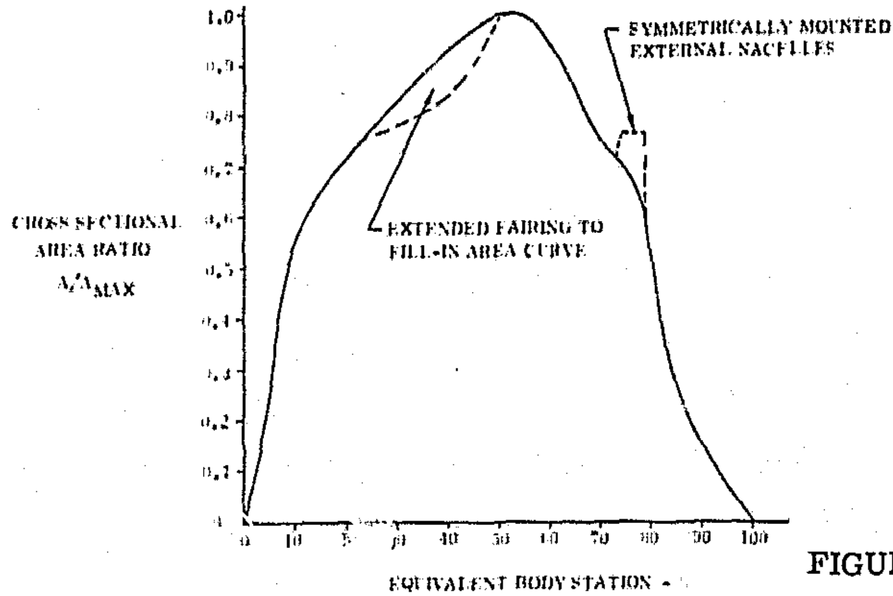


FIGURE 4a

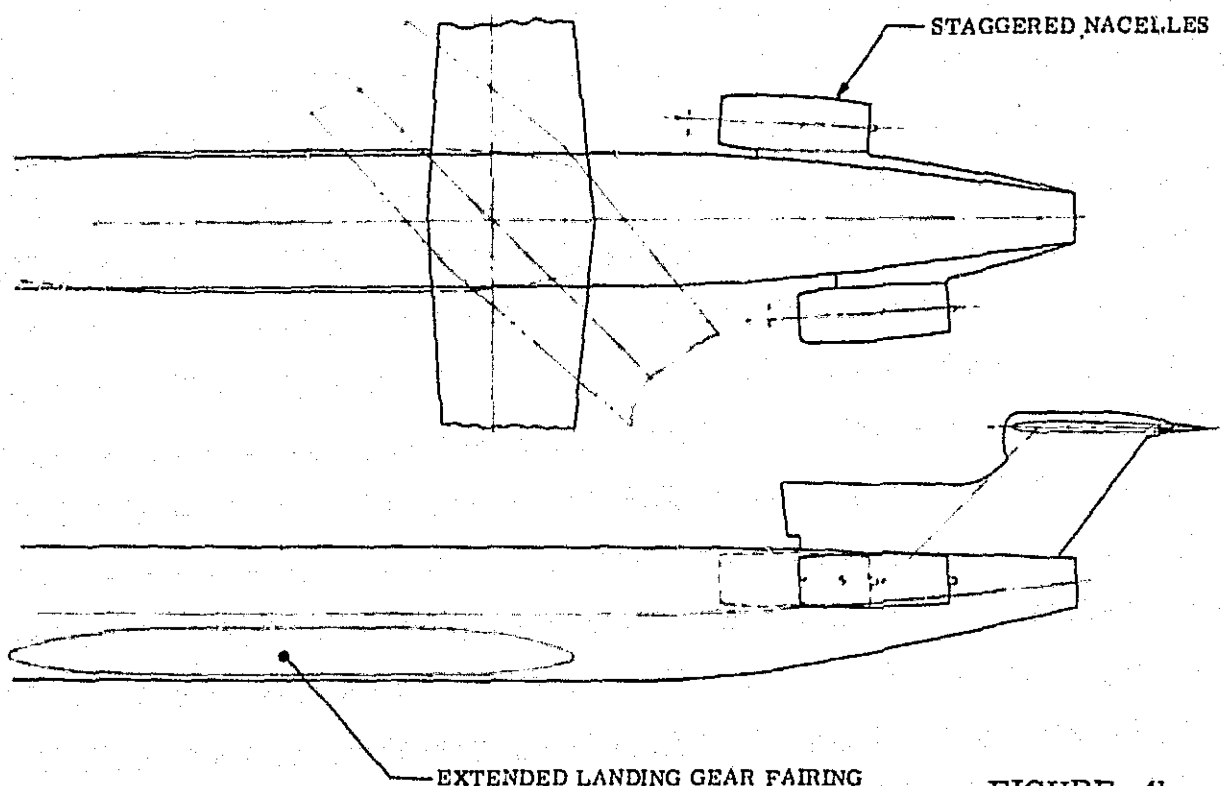


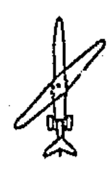
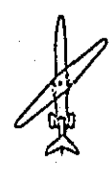
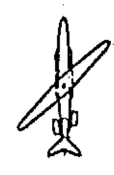
FIGURE 4b

FIGURE 4 COMMERCIAL PASSENGER TRANSPORT BASELINE CONFIGURATION DEVELOPMENT from 6.0 to 5.0 was necessary. Resizing the configuration with these changes resulted in the Cycled Baseline Configuration used for concept evaluation. The characteristics and performance of the configurations examined for the Commercial Passenger Transport are shown on Table III.

Executive Transport Configuration Development

The parametric sizing charts for the Executive Transport are shown on Figure 5. Data are included for sizing to the Preliminary Design Mission, Figure 5a, and for a Carrier-Compatible Configuration, Figure 5b The development of the Cycled Baseline Configuration, Figure 6, produced a configuration which exceeded Navy-carrier imposed limitations. A Carrier-Compatible Configuration was therefore developed to overcome the limitations and is shown on Figure 7. Characteristics and performance of the configurations developed are shown on Table IV.

TABLE III COMMERCIAL PASSENGER TRANSPORT CHARACTERISTICS AND PERFORMANCE

Cruise Mach No. 0.95 Payload - 23,768 kg (52,400 lb) * Payload for Initial Configuration - 23,133 kg (51,000 lb) Range - 5560 km (3000 n mi)	CONFIGURATION 1 	2 	3 
QUANTITY/PARAMETER	* I[illegible]AL	BASELINE	CYCLED BASELINE
Takeoff Gross Weight, kg (lb)	131,661 290,263)	136,937 (301,894)	141,126 (311,134)
Operating Weight, kg (lb)	68,785 (151,645)	71,272 (157,129)	71,824 (158,344)
Fuel Weight, kg (lb)	39,969 (88,118)	41,896 (92,366)	45,536 (100,391)
Wing Area, m^2 (ft^2)	199.5 (2,148)	224.3 (2,415)	215.7 (2,3[illegible]2)
Engine SLS Rating, N (lbf) (Uninstalled)	127,510 (28,448)	130,497 (29,337)	148,634 (33,161)
No. Engines/BPR	3/6.50	3/6.50	3/6.50
Swept Aspect Ratio	7	6	5
Sweep Angle, rad (deg)	0.785 (45)	0.785 (45)	0.785 (45)
Thrust Loading - T/W, N/kg	2.905 (0.294)	2.86 (0.291)	3.16 (0.32)
Wing Loading - W/S, N/m^2 (lb/ft^2)	6,224 (130)	5,772 (120.55)	6,200 (129.5)
Cruise Altitude, m (ft)	10,972.8 (36,000)	11,277.6 (37,000)	11,277.6 (37,000)
Cruise Lift/Drag Ratio - L/D	17.03	16.33	14.93
FAA Takeoff Field Length, m (ft) 305 K (90°F Day), 305 m (1000 ft)	2,580 (8,465)	2,700 (8,860)	2,544 (8,346)
Landing Distance, m (ft) 305 K (90°F Day), 305 m (1000 ft)	2,329 (7,643)	2,163.4 (7,098)	1,890 (6,201)
Approach Speed, km/hr (k) EAS	253.0 (136.6)	240.76 (130)	259.3 (140)

(2) STF 433 ENGINES   Λ = .7854 RADS (45 DEGS)

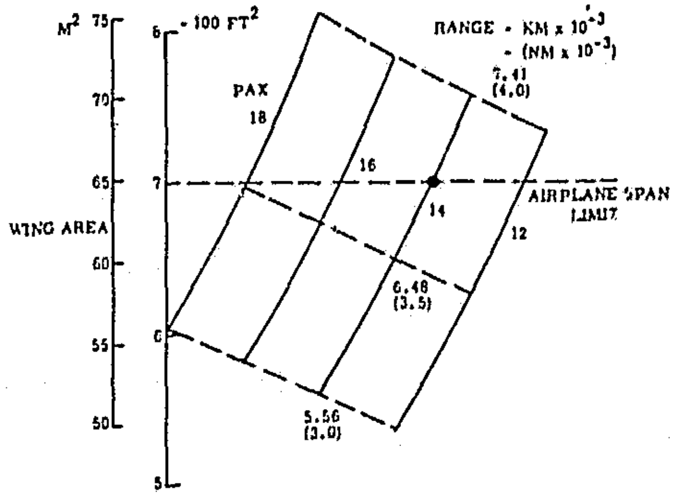
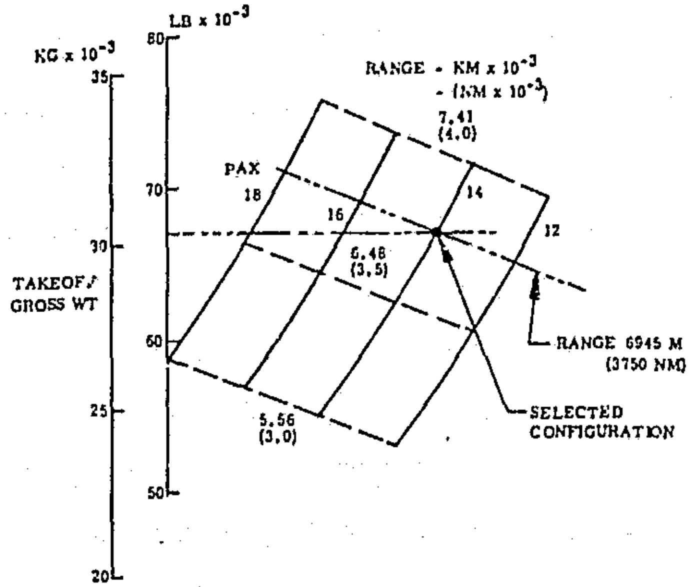


FIGURE 5b
CARRIER-COMPATIBLE
CONFIGURATION SIZING



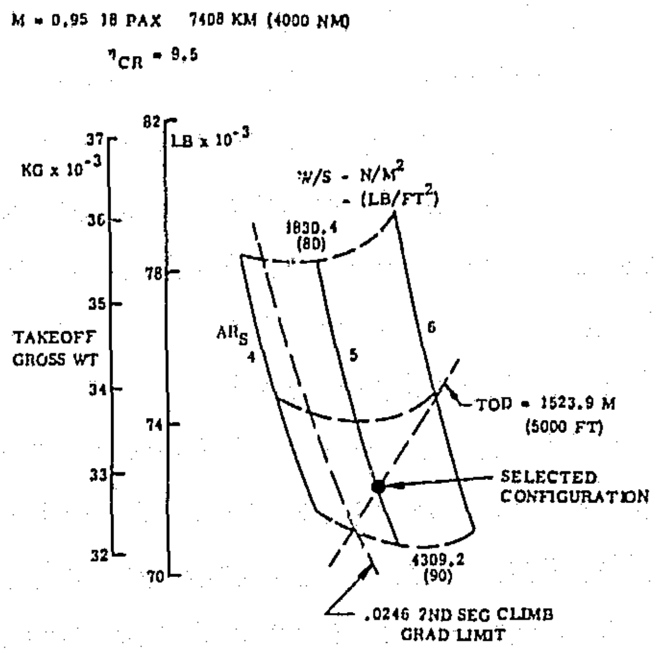


FIGURE 5a
PRELIMINARY DESIGN
MISSION SIZING

FIGURE 5 EXECUTIVE TRANSPORT SIZING CHARTS

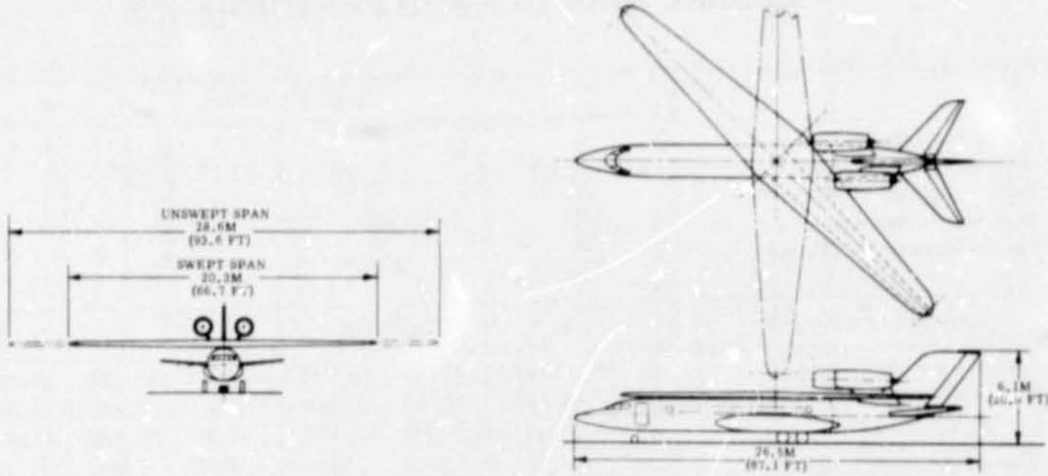


FIGURE 6 EXECUTIVE TRANSPORT - CYCLED BASELINE CONFIGURATION

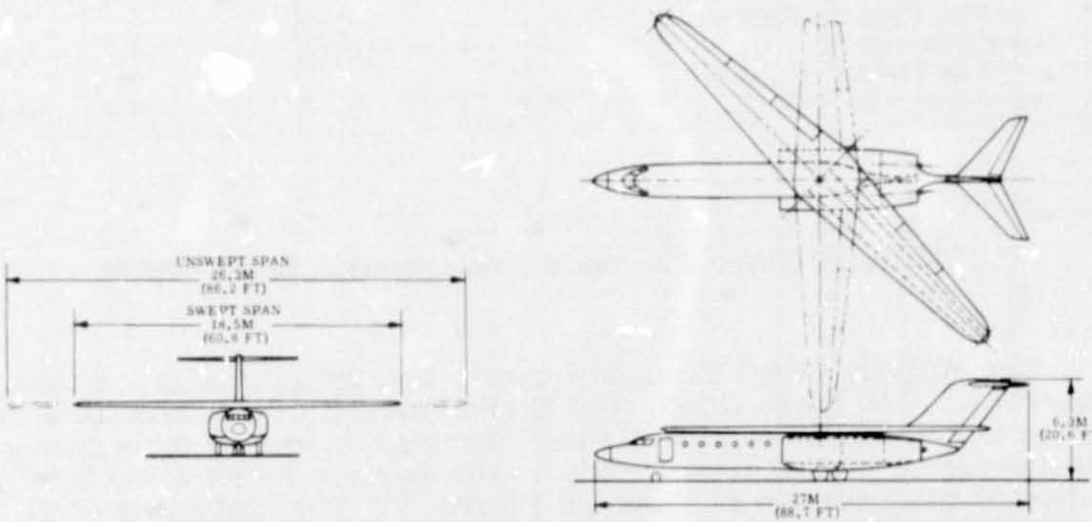
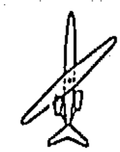
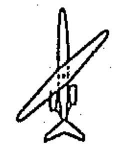
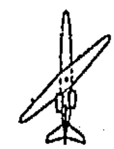
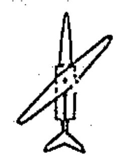


FIGURE 7 EXECUTIVE TRANSPORT - CARRIER-COMPATIBLE CONFIGURATION

TABLE IV EXECUTIVE TRANSPORT CHARACTERISTICS AND PERFORMANCE

	CONFIGURATION			
Cruise Mach No. 0.95 Payload - 18 Passengers Range - 7408 km (4000 n mi) * Payload - 14 Passengers Range - 6945 km (3750 n mi)	1 	2 	3 	4 
QUANTITY/PARAMETER	INITIAL	BASELINE	CYCLED BASELINE	* CARRIER COMPATIBLE
Takeoff Gross Weight, kg (lb)	32,778 (72,264)	34,389 (75,816)	36,745.5 (81,010)	30,186.0 (66,549)
Operating Weight, kg (lb)	15,989 (35,251)	16,712 (36,844)	17,622.5 (38,851)	15,185.4 (33,478)
Fuel Weight, kg (lb)	15,058 (33,197)	15,946 (35,156)	17,392 (38,343)	13,654.5 (30,103)
Wing Area, m^2 (ft^2)	73.5 (791)	75.53 (813)	80.64 (868)	65.0 (700)
Engine SLS Rating, N (lbf) (Uninstalled)	54,958 (12,355)	58,716.5 (13,200)	64,535 (14,508)	52,569 (11,818)
No. Engines/BPR	2/6.5	2/6.5	2/6.5	2/6.5
Swept Aspect Ratio	5.0	5.0	5.0	5.0
Sweep Angle, rad (deg)	0.785 (45)	0.785 (45)	0.785 (45)	0.785 (45)
Thrust Loading - T/W, N/kg	3.35 (0.342)	3.42 (0.348)	3.51 (0.358)	3.48 (.355)
Wing Loading - W/S, N/m^2 (lb/ft^2)	4,190.0 (87.5)	4,280.5 (89.4)	4,280.5 (89.4)	4,362.0 (91.1)
Cruise Altitude, m (ft)	11,277 (37,000)	11,277 (37,000)	11,277 (37,000)	11,277 (37,000)
Cruise Lift/Drag Ratio - L/D	13.9	13.59	13.21	13.32
FAA Takeoff Field Length, m (ft) 305 K (90°F Day), 305 m (1000 ft)	1,524 (5,000)	1,524 (5,000)	1,524 (5,000)	1,524 (5,000)
Landing Distance, m (ft) 305 K (90°F Day), 305 m (1000 ft)	1,399 (4,590)	1,411 (4,630)	1,407 (4,618)	1,432 (4,700)
Approach Speed, km/hr (k) EAS	177.8 (96.0)	179.5 (96.9)	178.72 (96.5)	183.35 (99.0)

Military Cargo Transport Configuration Development

The Military Cargo Transport parametric sizing charts are shown on Figure 8. The Initial Configuration characteristics obtained from Figure 8a relate to four engine configurations. Resizing to account for a change in the number of engines to six produced the data for the Baseline Configuration. A typical configuration is shown on Figure 9. The loadability of the configuration and the attendant balance problems are indicated on Figure 10 for engine location variations. From these it was evident that the only successful configuration would be one on which the propulsion system was located on the wing. The parametric sizing chart for the resulting Cycled Baseline Configuration is shown on Figure 8b and the selected configuration on Figure 11. The characteristics and performance data for the configurations studied are shown on Table V.

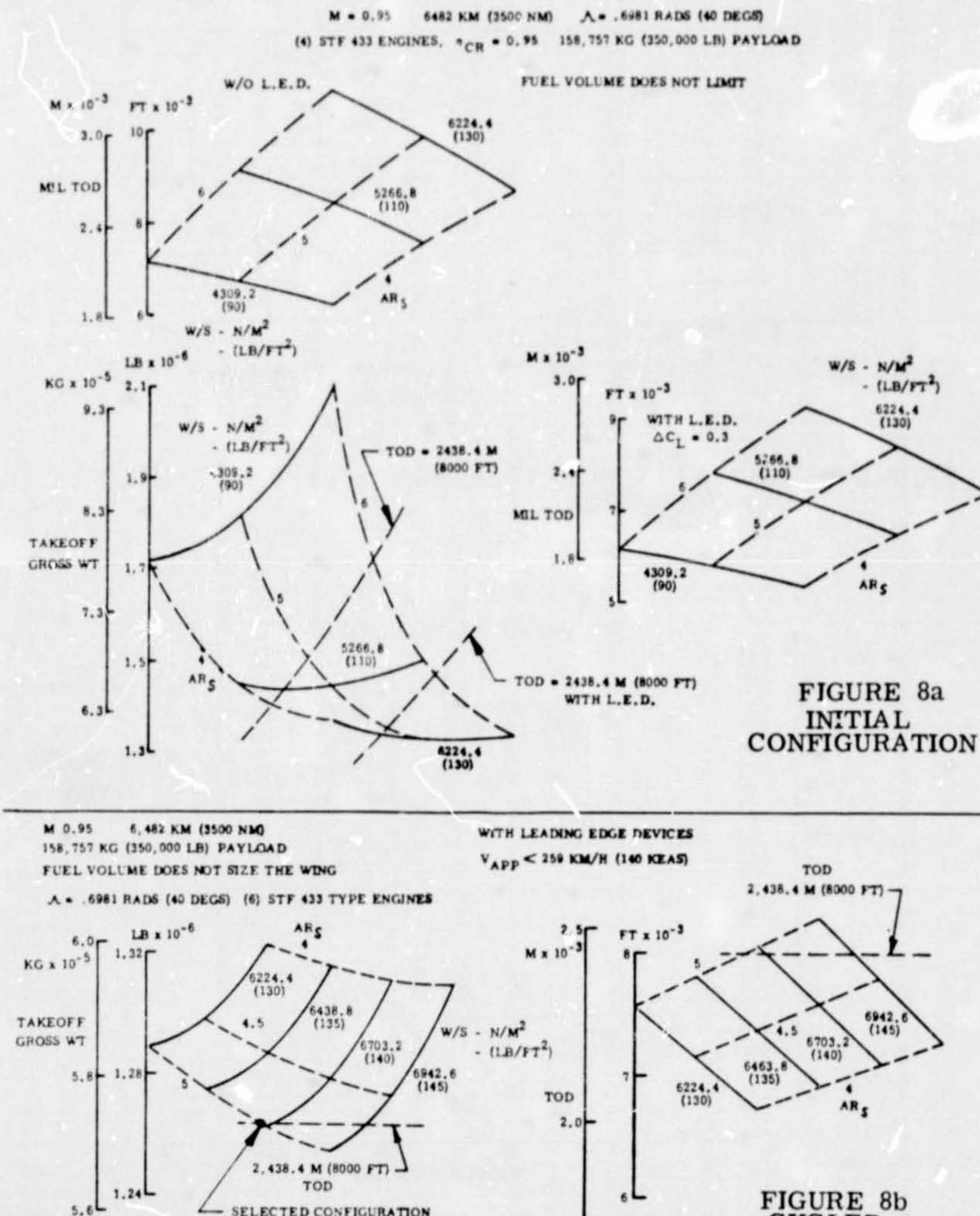


FIGURE 8a
INITIAL
CONFIGURATION

FIGURE 8b
CYCLED
BASELINE

FIGURE 8 MILITARY CARGO TRANSPORT SIZING CHARTS

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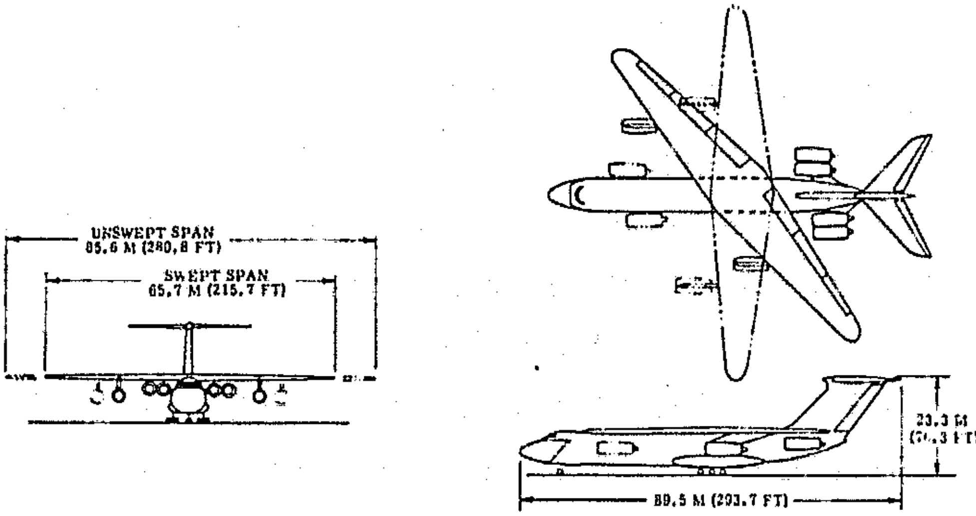


FIGURE 9 MILITARY CARGO TRANSPORT - TYPICAL BASELINE CONFIGURATION

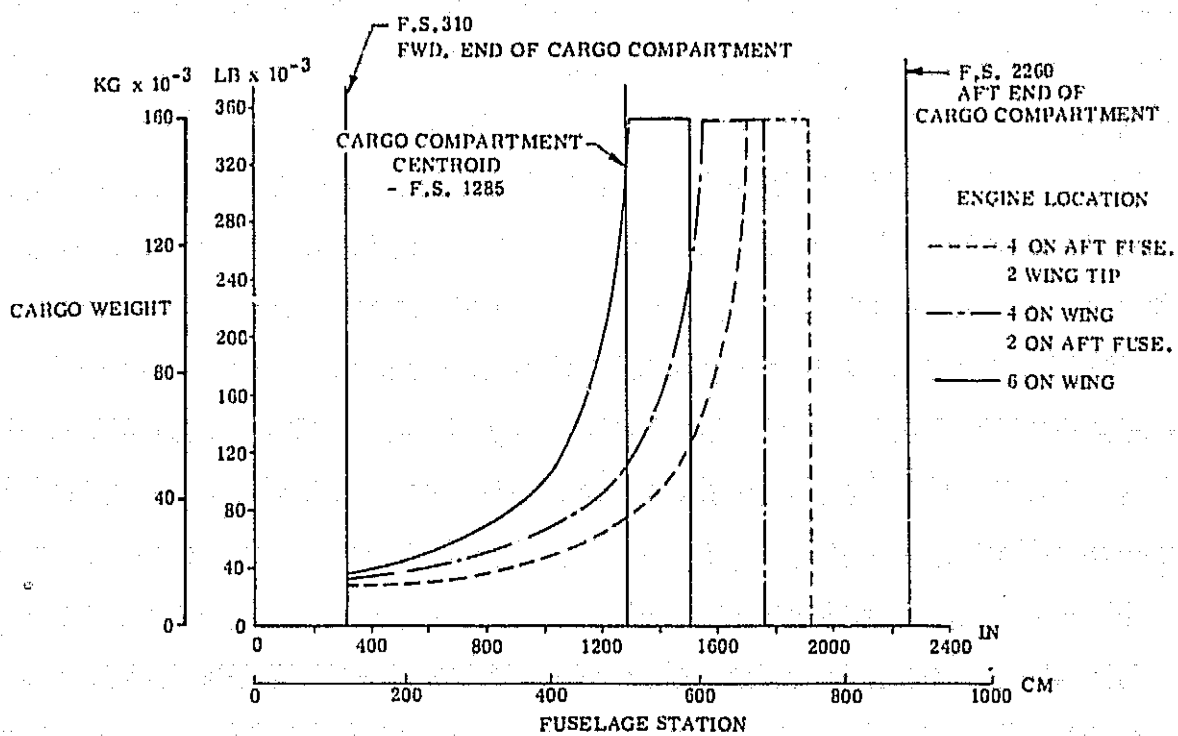


FIGURE 10 MILITARY CARGO TRANSPORT - LOADING DIAGRAM

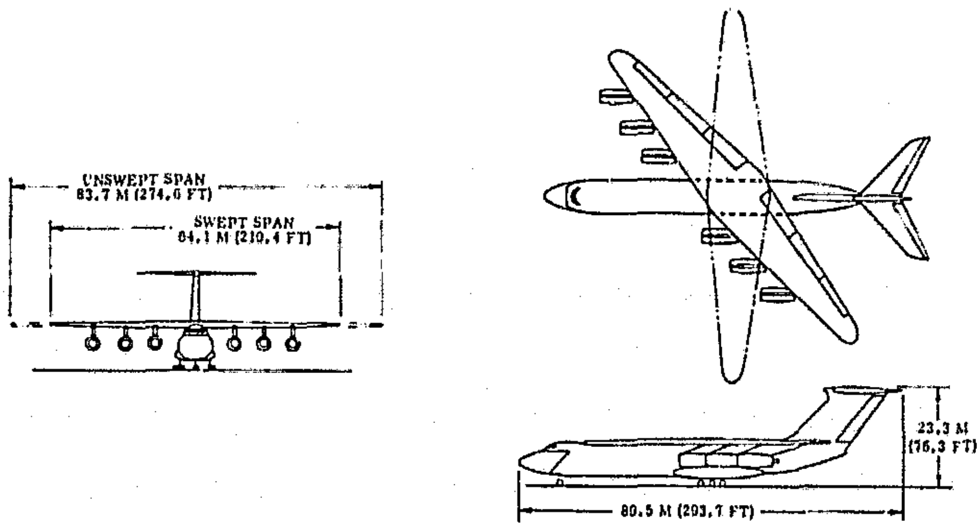
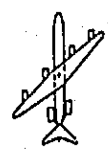
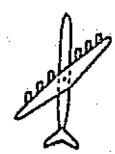


FIGURE 11 MILITARY CARGO TRANSPORT - CYCLED BASELINE CONFIGURATION

TABLE V MILITARY CARGO TRANSPORT CHARACTERISTICS AND PERFORMANCE

Cruise Mach No. 0.95 Payload - Cargo 158,757 kg (350,000 lb) Range 6482 km (3500 n mi)	CONFIGURATION 1 	2 	3 
QUANTITY/PARAMETER	INITIAL	BASELINE	CYCLED BASELINE
Takeoff Gross Weight, kg (lb)	608,720 (1,342,000)	614,081 (1,353,818)	574,998 (1,267,653)
Operating Weight, kg (lb)	247,661 (546,000)	251,575 (554,628)	227,359 (501,241)
Fuel Weight, kg (lb)	202,302 (446,000)	203,749 (449,190)	188,881 (416,412)
Wing Area, m^2 (ft^2)	959.0 (10,323)	937.7 (10,093)	822.2 (8,850)
Engine SLS Rating, N (lbf)	438,150 (98,500)	300,744 (67,610)	277,618 (62,411)
No. Engines/BPR	4.0/6.5	6.0/6.5	6.0/6.5
Swept Aspect Ratio	4.75	4.75	5.0
Sweep Angle, rad (deg)	0.70 (40)	0.70 (40)	0.70 (40)
Thrust Loading - T/W, N/kg	2.88 (0.293)	2.94 (0.30)	2.896 (0.295)
Wing Loading - W/S, N/m^2 (lb/ft^2)	6,225 (130)	6,225 (130)	6,655 (139)
Cruise Altitude, m (ft)	11,277 (37,000)	11,277 (37,000)	11,277 (37,000)
Cruise Lift/Drag Ratio - L/D	16.0	15.97	16.2
* Takeoff Field Length, m (ft)	2,440 (8,000)	2,440 (8,000)	2,440 (8,000)
* Landing Distance, m (ft)	—	2,103 (6,900)	1,158 (3,800)
* 305 K (90°F Day), 305 m (1000 ft)			
Approach Speed, km/hr (k) EAS	229.6 (124)	242.6 (131)	247.4 (133.6)

Mission/Configuration Evaluation

The evaluation of the mission/configuration suitability for the Oblique Wing Concept was based on the characteristics of the Cycled Baseline Configuration for each mission. In the case of the Executive Transport, the Cycled Baseline Configuration was replaced by the Carrier-Compatible Configuration.

The suitability evaluation data are shown on Table VI. It was concluded from this evaluation that the Commercial Passenger Transport offered the best mission application for the Oblique Wing Concept.

TABLE VI CONCEPT EVALUATION

COMMERCIAL TRANSPORT		
Configuration	Problem Area	Solution
Aft Fuselage Mounted Engine Nacelles	Wing T/E - Nacelle Wake Proximity Particularly with Flaps Deployed	Relocate Side Nacelles To Clear Wing T/E
BEST FOR CONCEPT SUITABILITY		

EXECUTIVE TRANSPORT		
Configuration	Problem Area	Solution
Aft Mounted Engines		
A) Side Mounted Nacelles	Wing T/E and Engine Nacelle Interference	Relocate Engines Above Fuselage but Slightly Behind Wing
B) Upper Fuselage Mounted Nacelles	Nacelle/Pylon Masking Horizontal and Vertical Tails	Relocate Horizontal Tail to Low Tail Position
C) Reconfigured Empennage to Low Tail	Increase Size of Empennage And Increase Empennage Weight and Airplane TOGW	Integrate Engines with Rear Fuselage and Revert to Tee-Tail
CONCEPT SUITABLE BUT Numerous Problems Unresolved, e.g. - Effect of Long Ducts on Engine Performance and Wing/Body Aerodynamics. Wing Size Too Small to Contain Mission Fuel Requiring Fuselage Tankage.		

MILITARY TRANSPORT		
Configuration	Problem Area	Solution
Aft-Fuselage Mounted Engines	Balance - Large C.G. Range - High Trim Drag	Relocate Engines on Wing
Wing Mounted Engines	A) Aerodynamic - Pylon/Wing Interference	Tailor Pylon/Wing Intersection for Individual Locations
	B) Reliability - Engine Swivelling Required - Misaligned Engine(s) Would Result in Catastrophic Failure	Highly Redundant Systems Incur Weight Penalties
CONCEPT UNSUITABLE		

FINAL CONFIGURATION DESIGN

Configuration Description

The mission selected from the evaluation and for the Final Configuration development was the Commercial Passenger Transport Mission of 200 passengers and 4536 kg (10,000 lb) of cargo for a range of 5560 km (3000 n mi). The design of the Final Configuration was influenced by the results of a NASA Ames Research Center conducted aeroelastic analysis which permitted an increase in the wing swept aspect ratio from 5.0 for the Cycled Baseline Configuration to 6.0 for the Final Configuration.

The Oblique Wing Final Configuration, shown on Figure 12, features a high wing, a tee-tail empennage, and is powered by three Pratt & Whitney STF 433 type turbofans each developing 135,235 N (30,402 lbf) of static thrust at SLS conditions. The engines are mounted in acoustically-treated installations - two in external nacelles on each side of the fuselage, and one integrated with the rear fuselage. The airplane is designed to cruise at Mach 0.95 at an altitude of 11,277 m (37,000 ft).

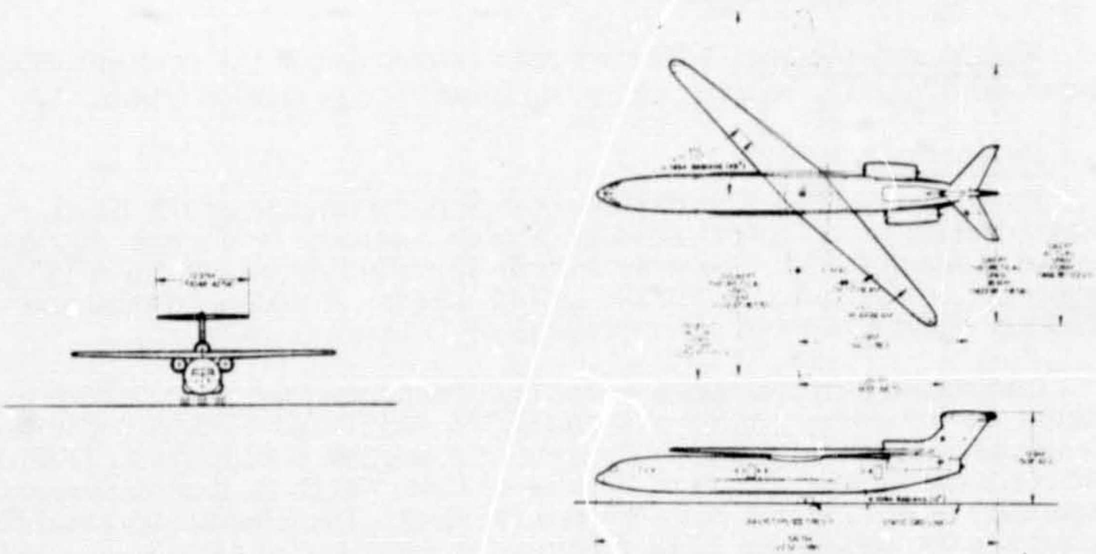


FIGURE 12 COMMERCIAL PASSENGER TRANSPORT FINAL CONFIGURATION

All mission fuel is contained in the wing in integral tanks and a single slotted Fowler type flap system, operative only with the wing unswept, is provided. A retractable landing gear consisting of a two-wheeled nose strut and two four-wheeled main gears mounted on the fuselage provide adequate ground clearance and tip-over angle.

The Configuration Characteristics and Characteristics and Performance of the Final Configuration are shown on Tables VII and VIII, respectively.

Structural Description

The structural design of the Final Configuration is predicated on the maximum utilization of composite filamentary materials. The technology level used results in a structure weight reduction of about 20 percent compared to the equivalent aluminum structure. Graphite-epoxy and Kevlar 49 are the principal materials used to fabricate large integrally molded panels for the fuselage, wing and empennage. In general, the construction consists of skin panels stabilized by stiffeners which are supported by frames in the fuselage and ribs and spars in the wing and empennage. Wing and empennage primary structures are single cell box beams. Wing attachment to the fuselage is by means of a pivot bearing and a circular track attached to the lower surface of the wing. The wing structure is shown on Figure 13. Structural analyses to establish wing pivot support frame structure and to determine aeroelastic characteristics of the wing were performed.

Weight and balance. - The weight breakdown for the configuration is shown on Table IX and the center-of-gravity diagram on Figure 14.

Performance. -

Payload-range. - The payload-range performance of the Final Configuration for a typical mission profile is shown on Figure 15, for cruise at Mach 0.95. The wing volume is sufficient to provide a 'Y' point capability of transporting 20,185 kg (44,500 lb) of payload a distance of 6204 km (3350 n mi) and a ferry range of 7149 km (3860 n mi).

Endurance performance. - The endurance performance is shown on Figure 16 for sweep angles of 0 and 0.785 rad (0 and 45 deg) for loiter on 3 engines. A typical mission starting at a weight of 129,274 kg (285,000 lb) and terminating at a weight of 85,593 kg (188,700 lb) has an endurance capability of 8.75 hours at 0.785 rad (45 deg). Unsweeping to 0 rad (0 deg) increases the endurance to 12.6 hours, an increase of 44 percent. Loiter is performed at a Mach number in the region of 0.6.

Takeoff performance. - FAR field length is shown on Figure 17. The data are computed for 305 K (90°F) (ISA + 17.22°C) day conditions at an airfield elevation of 305 m (1000 ft). At a takeoff gross weight of 139,253 kg (307,000 lb) the field length required is 2545 m (8350 ft).

TABLE VII FINAL CONFIGURATION - CONFIGURATION CHARACTERISTICS

Takeoff Gross Weight - kg (lb)		139,453 (307,441)
Component	Parameter	
Fuselage	Body Length - m (ft)	51.31 (168.83)
	Cabin Length - m (ft)	36.83 (120.83)
	Passenger Mix - FC/TC - %	15/85
	Seating - Min/Max Abreast - TC	5/7
	No. Aisles	2
	Fineness Ratio	10.03
Wing	Area - m^2 (ft^2)	217.78 (2344)
	Aspect Ratio - Swept	6.0
	*Pivot Normal Chord -%	38.5
	Thickness Ratio - Swept Root/Tip %/%	11.34/11.34
	Taper Ratio	0.33
	Pivot Location % Body Length	57.85
Empennage	Horizontal Area - m^2 (ft^2)	42.0386 (452.5)
	Aspect Ratio	4.0
	Sweep C/4 - rad (deg)	0.70 (40)
	Taper Ratio	0.4
	Volume Coef. V_H	0.705
	Thickness Ratio - %	9.5
	Vertical Area - m^2 (ft^2)	39.3 (422.7)
	Aspect Ratio	1.0
	Sweep C/4 - rad (deg)	0.742 (42.5)
	Taper Ratio	0.8
	Volume Coef. V_V	0.101
	Thickness Ratio - %	9.5
Propulsion	Engine Type	P & W STF 433
	No. Engines	3
	Location	AFT FUSELAGE
	Uninstalled S T SL Std Day - N (lbf)	135,235 (30,402)
	Cruise SFC - kg/hr/N (lb/hr/lb t)	0.0796 (.781)

* Pivot Location % Unswept Chord at Wing Center Line

TABLE VIII FINAL CONFIGURATION - CHARACTERISTICS AND PERFORMANCE

Cruise Mach No. 0.95
Payload - 23,768 KG (52,400 LB)
Range - 5560 km (3000 n mi)

QUANTITY/PARAMETER	
Takeoff Gross Weight, kg (lb)	139,453 (307,441)
Operating Weight, kg (lb)	72,184 (159,137)
Fuel Weight, kg (lb)	43,501 (95,904)
Wing Area, m^2 (ft^2)	217.78 (2344)
Engine SLS Rating, N (lbf)	135.235 (30,402)
(Uninstalled)	135,235 (30,402)
No. Engines/BPR	3/6.50
Swept Aspect Ratio	6.0
Sweep Angle, rad (deg)	0.785 (45)
Thrust Loading - T/W, N/kg	2.909 (0.297)
Wing Loading - W/S, N/m^2 (lb/ft^2)	6057 (126.5)
Cruise Altitude, m (ft)	11,277 (37,000)
Cruise Lift/Drag Ratio - L/D	16.05
FAA Takeoff Field Length, M (ft) 305 K (90° F Day), 305 m (1000 ft)	2483.8 (8149)
Landing Distance, m (ft) 305 K (90° F Day), 305 m (1000 ft)	1924.5 (6314)
Approach Speed, km/hr (k) EAS	259.28 (140.0)

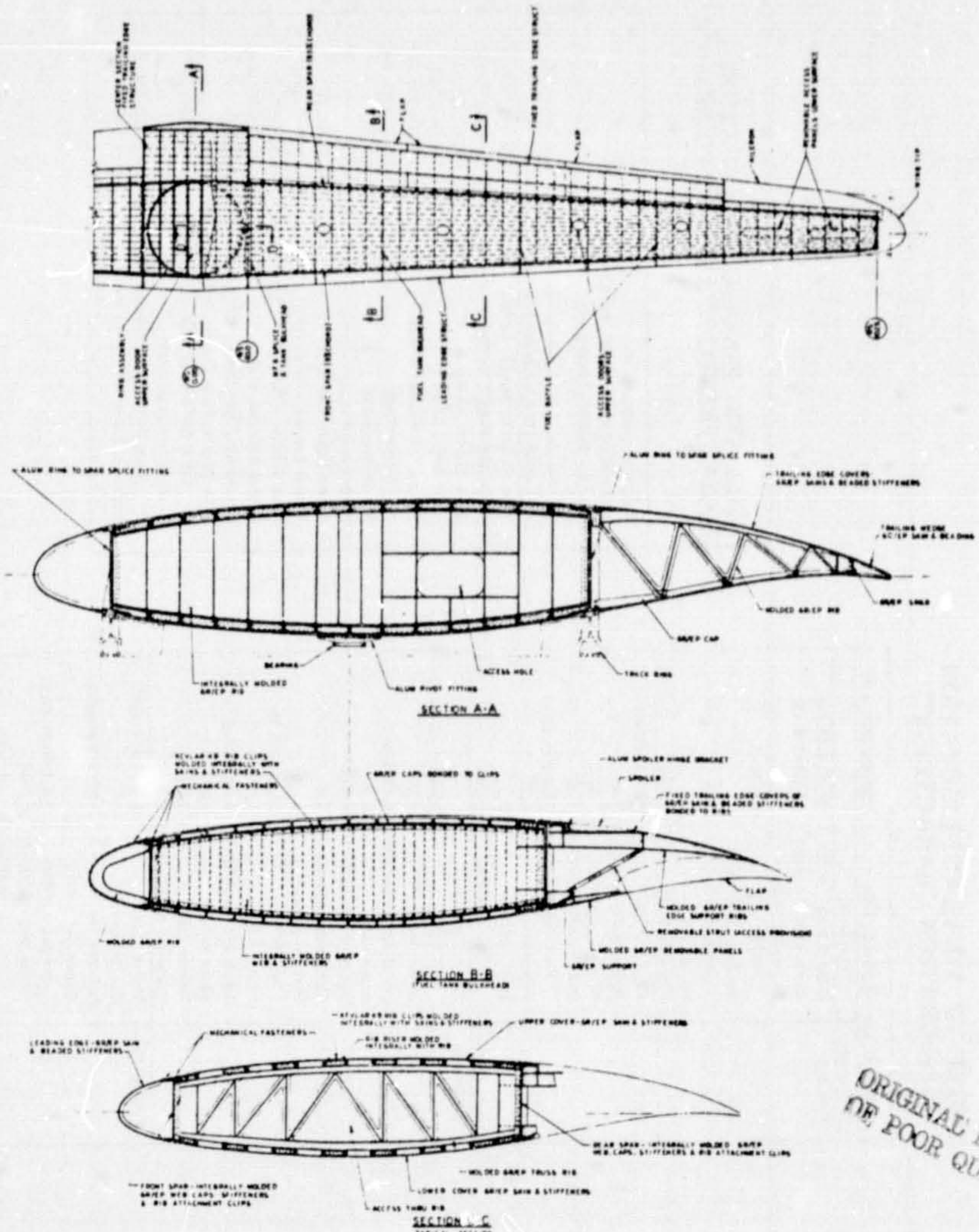


FIGURE 13 FINAL CONFIGURATION WING STRUCTURE

TABLE IX FINAL CONFIGURATION WEIGHT BREAKDOWN

ITEM	WEIGHT	
	kg	(lb)
WING	14,567	(32,114)
HORIZONTAL STABILIZER	1,151	(2,538)
VERTICAL STABILIZER	994	(2,190)
FUSELAGE	12,933	(28,513)
LANDING GEAR	6,172	(13,608)
NACELLE	2,508	(5,530)
PROPULSION	10,692	(23,572)
AUXILIARY POWER SYSTEM	266	(587)
SURFACE CONTROLS	1,207	(2,662)
INSTRUMENTS	396	(872)
HYDRAULICS AND PNEUMATICS	563	(1,241)
ELECTRICAL	2,134	(4,705)
AVIONICS	1,089	(2,400)
FURNISHINGS	8,636	(19,040)
AIR CONDITIONING AND ANTI-ICING	2,192	(4,832)
AUXILIARY GEAR SYSTEM	—	—
ARMAMENT	—	—
WEIGHT EMPTY	65,500	(144,402)
FUSELAGE FUEL SYSTEM		
OPERATING EQUIPMENT	6,684	(14,735)
OPERATING WEIGHT	72,184	(159,137)
PAYLOAD	23,768	(52,400)
ZERO FUEL WEIGHT	95,952	(211,537)
FUEL WING	43,501	(95,904)
FUEL FUSELAGE		
GROSS WEIGHT	139,453	(307,441)

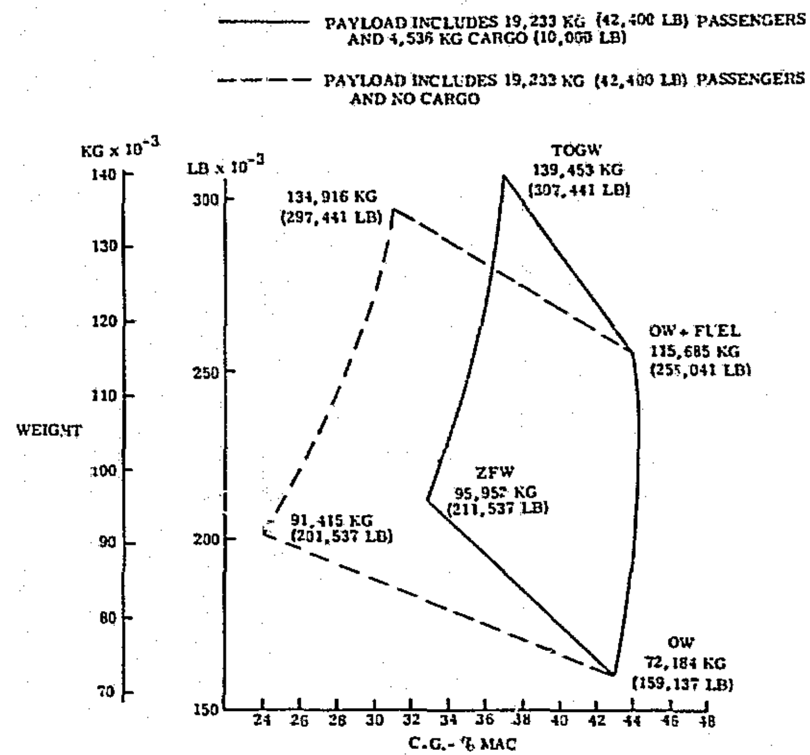


FIGURE 14 FINAL CONFIGURATION - CENTER-OF-GRAVITY DIAGRAM

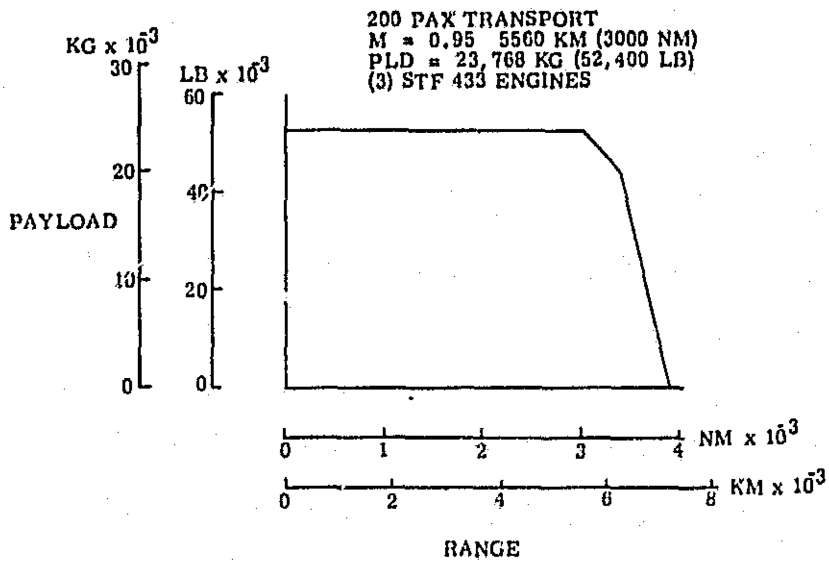


FIGURE 15 FINAL CONFIGURATION PAYLOAD-RANGE

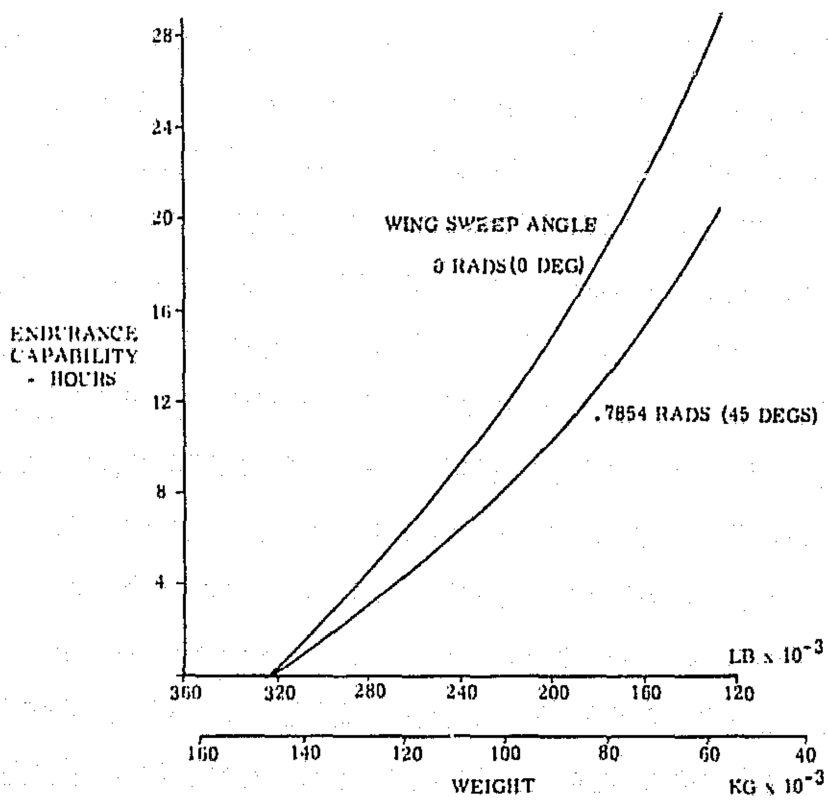


FIGURE 16 FINAL CONFIGURATION ENDURANCE PERFORMANCE

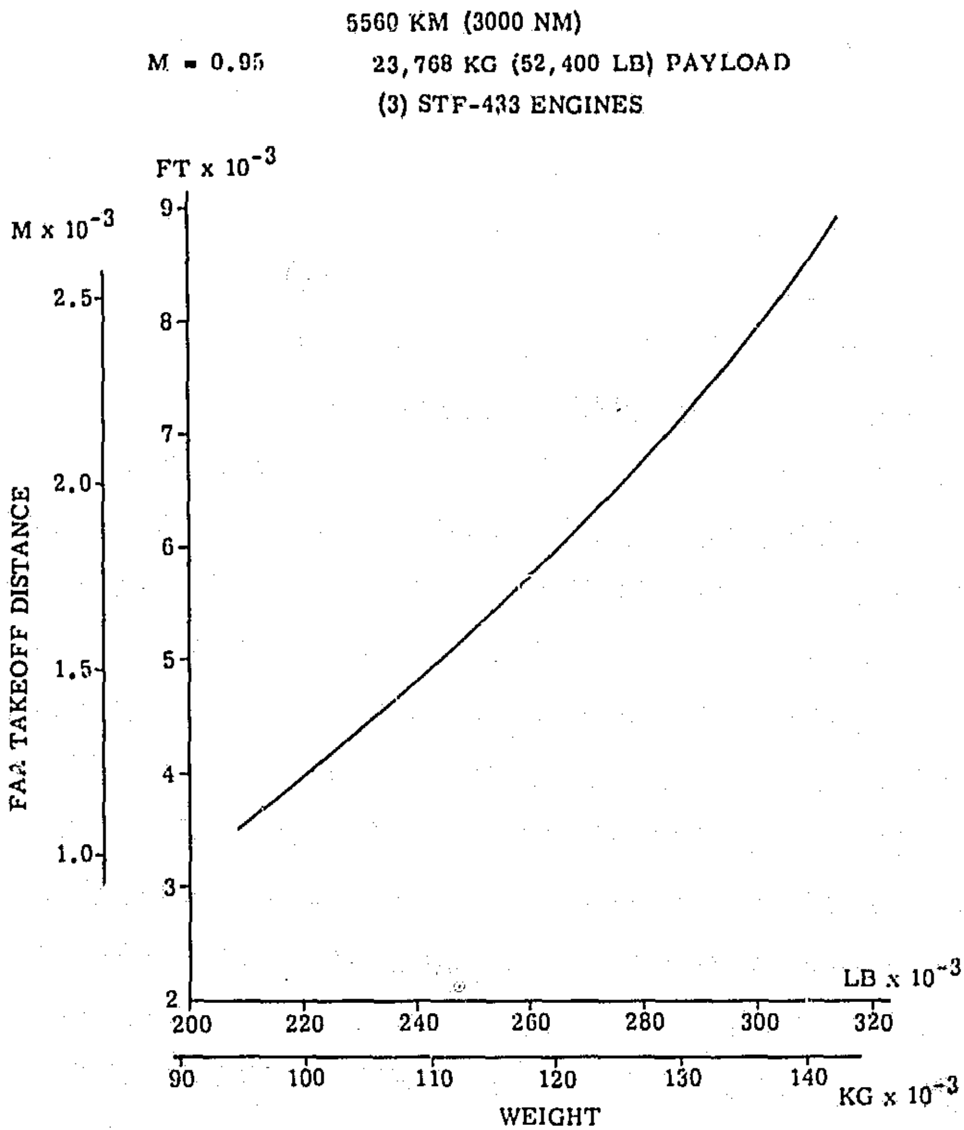


FIGURE 17 FINAL CONFIGURATION TAKEOFF PERFORMANCE

Off-design range performance. - The off-design range capability is shown on Figure 18. Maximum range is obtained at Mach 0.715 and is 6130 km (3310 n mi) or an increase of slightly more than 10 percent of the range at maximum cruise speed.

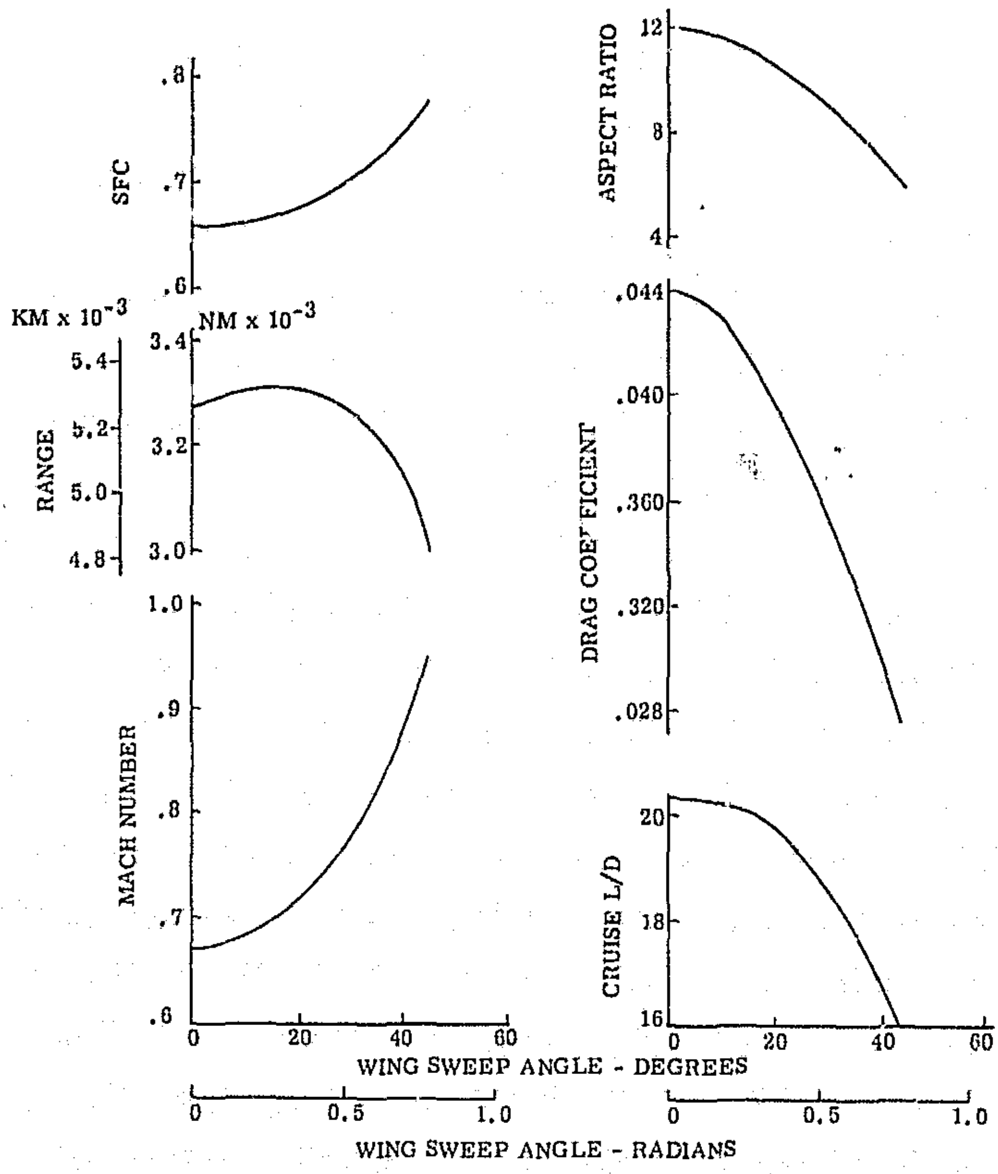


FIGURE 18 FINAL CONFIGURATION - OFF-DESIGN PERFORMANCE

CONVENTIONAL CONFIGURATION ANALYSIS

Conventional Configuration analyses were performed to establish configurations for cruise at Mach 0.85 and 0.95 to provide a basis for comparison with the Oblique Wing Concept. The configurations for both airplanes are shown on Figures 19 and 20.

CONCEPT EVALUATION

The principal characteristics of the four configurations for the concept evaluation are listed on Table X. The speed domain of the Oblique Wing Concept was established by comparing takeoff gross weight and direct operating cost. These data, shown on Figure 21, indicate the cross-over Mach number in the region of 0.91. The data of Table X also show for a cruise Mach number of 0.95 that the Oblique Wing Concept has the following advantages over the conventional Configuration:

- Takeoff gross weight 7 percent lower
- Mission block fuel 7 percent lower
- Installed thrust 10 percent lower
- Takeoff distance 3 percent lower
- Direct operating cost 5 percent lower

Payload-range comparison data are shown on Figure 22 and include the off-design range capability. The advantage of the Oblique Wing Concept is shown to occur at payloads above 14,515 kg (32,000 lb). The off-design capability of the Oblique Wing Concept provides:

- 10 percent increase in range
- 44 percent increase in endurance.

Acoustics characteristics comparisons. - Comparing the Oblique Wing Concept with the Conventional Configuration, it is found that at the FAR 36 measuring points the Oblique Wing Concept is superior as follows:

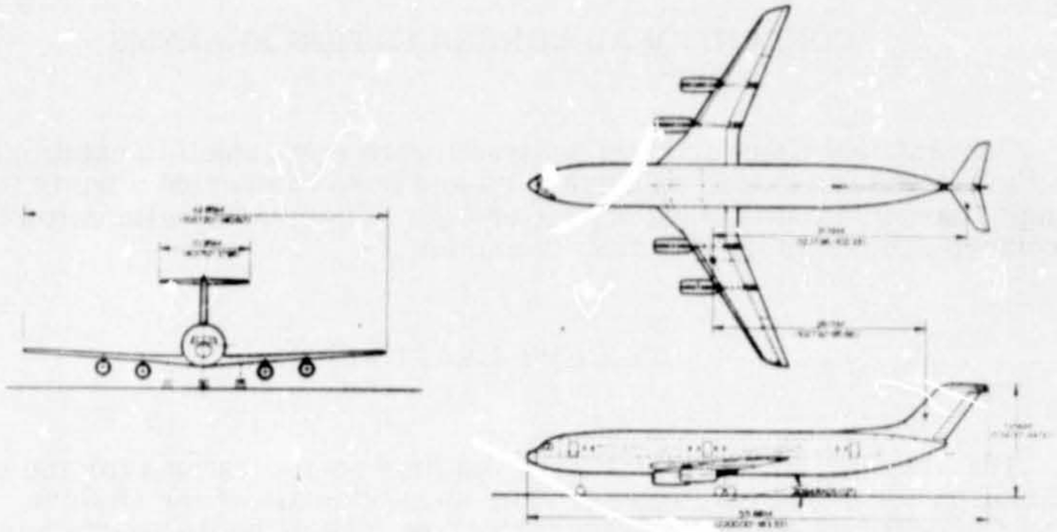


FIGURE 19 CONVENTIONAL CONFIGURATION - MACH 0.85

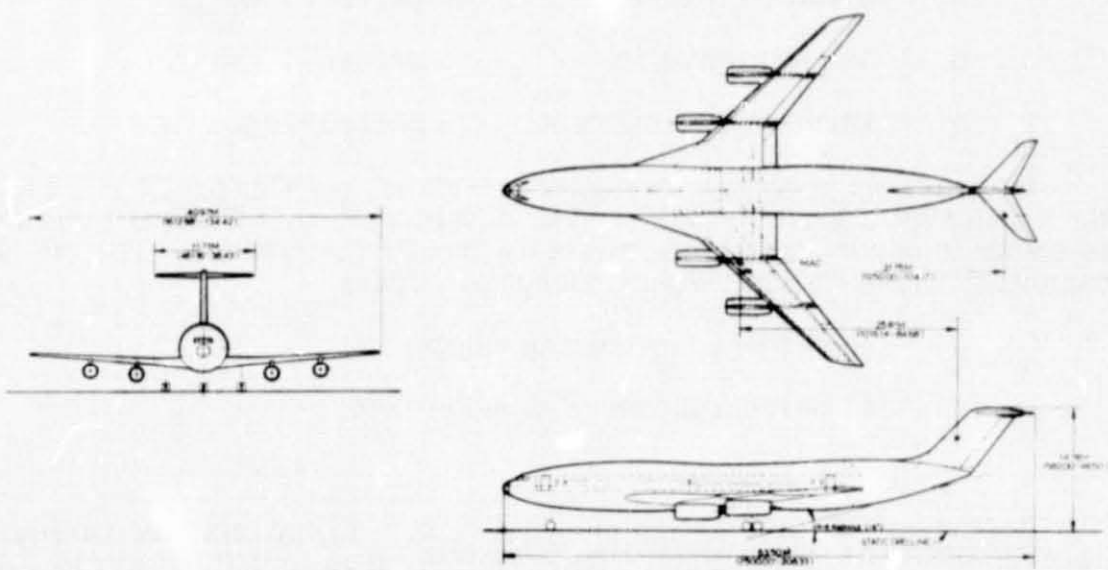


FIGURE 20 CONVENTIONAL CONFIGURATION - MACH 0.95

TABLE X OBLIQUE WING/CONVENTIONAL CONFIGURATION COMPARISON

QUANTITY \ CONFIGURATION	OBLIQUE WING				CONVENTIONAL			
	0.85		0.95		0.85		0.95	
TOGW, kg (lb)	135,695.3	(299,157)	139,453.0	(307,411)	125,031.4	(275,647)	149,793.4	(330,238)
Operating Weight, kg (lb)	69,720.8	(153,708)	72,183.3	(159,137)	66,006	(145,520)	79,173.6	(174,548)
Block Fuel Weight, kg (lb)	34,788.8	(76,696)	35,469.1	(78,196)	28,870.7	(63,649)	38,072.3	(83,935)
Wing Area, m^2 (ft^2)	230.3	(2,479)	217.76	(2,344)	222.60	(2,396)	291.05	(3,132.86)
Aspect Ratio Swept	6.0		6.0		8.25		6.25	
Wing Loading, N/m^2 (lb/ft^2)	5611	(117.2)	6057	(126.5)	5338	(111.5)	5262	(109.90)
Approach Speed, km/hr EAS(KEAS)	259.28	(140)	259.28	(140)	250.57	(135.3)	259.28	(140)
$C_{L_{MAX}}$ Takeoff/Landing	2.04/2.59		2.4/2.82		2.24/2.69		2.01/2.45	
Cruise L/D	16.25		16.05		18.79		16.32	
Total Installed Thrust, N (lb)	407,332.5	(91,572)	405,702	(91,206)	306,928	(69,000)	451,334.4	(101,464.0)
Takeoff/Landing Distance, m (ft)	2689/1947	(8824/6388)	2483.8/1924.5	(8149/6314)	2920/1897.4	(9580/6225)	2555.4/1874	(8384/6148)
Direct Operating Cost, ¢/km (¢/st mi)	1.457	(2.344)	1.409	(2.267)	1.322	(2.127)	1.483	(2.386)

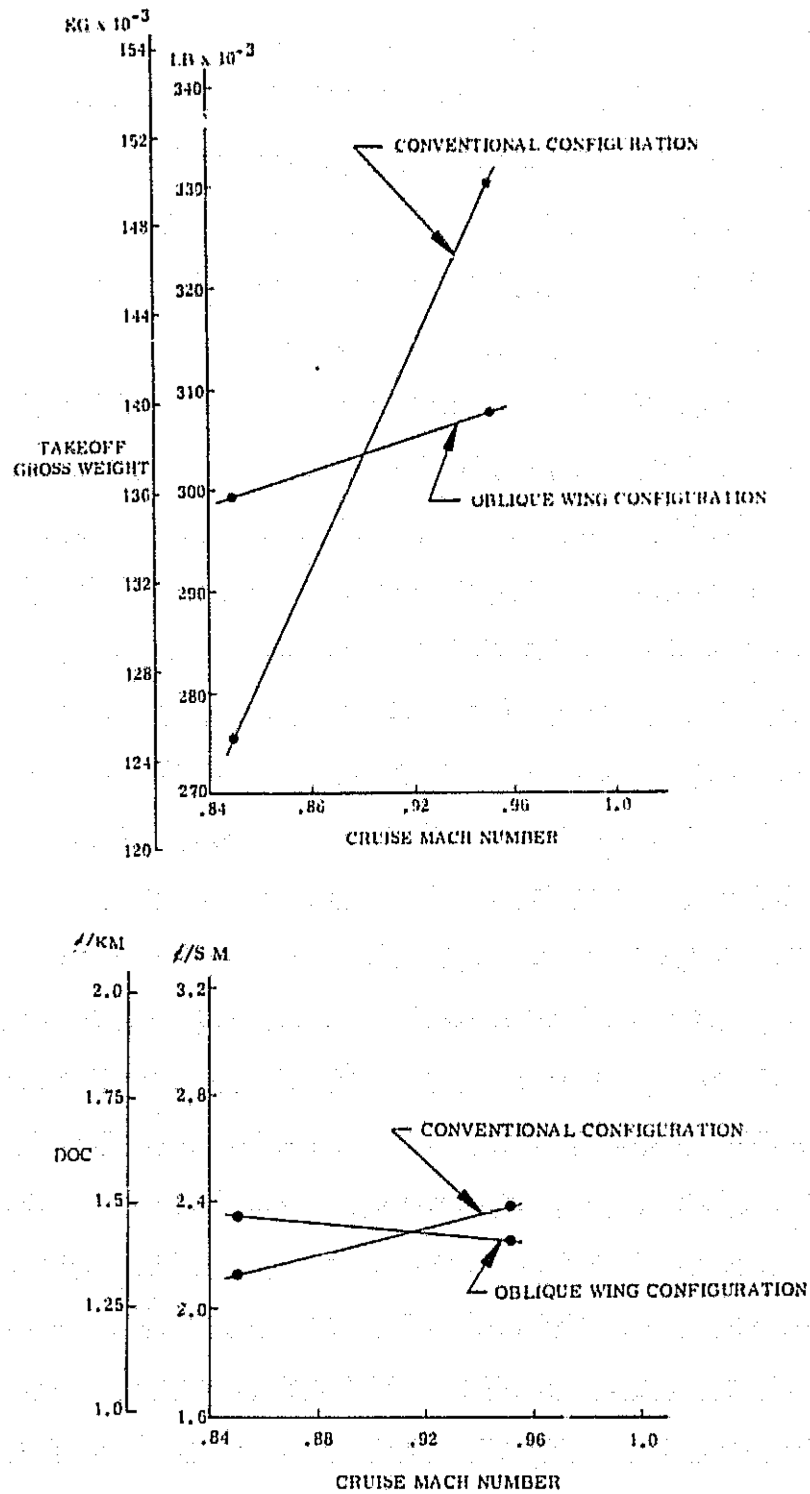


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FIGURE 21 CONFIGURATION COMPARISON

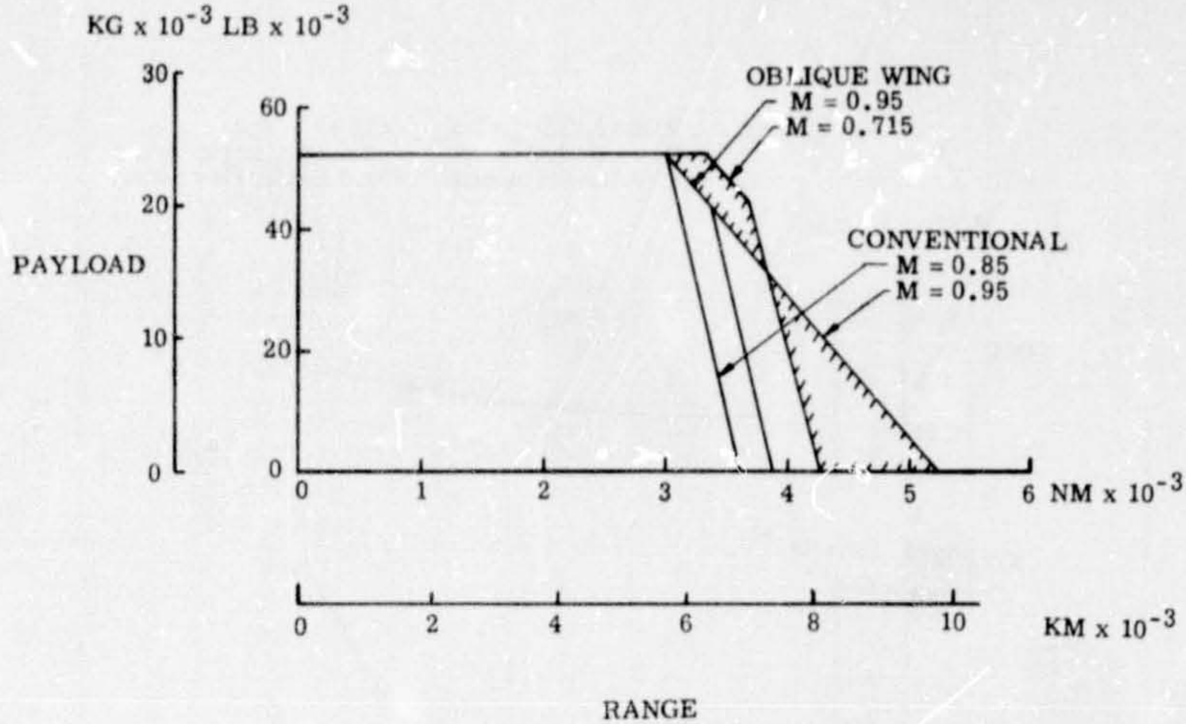


FIGURE 22 FINAL CONFIGURATION PAYLOAD-RANGE COMPARISON

- o Takeoff sideline noise - 0.5 EPNdB lower
- o Takeoff flyover noise - 2.5 EPNdB lower
- o Approach flyover noise - 8.5 EPNdB lower
- o Airframe self noise - 2.0 EPNdB lower

The 90 EPNdB acoustic soundprint for the Oblique Wing Concept is significantly smaller than the Conventional Configuration, 9.065 x 10^6 m^2 (3.5 mi^2) compared to 19.17 x 10^6 m^2 (7.4 mi^2).

Weight/DOC-range sensitivity - The sensitivity of the Oblique Wing Concept is shown on Figure 23 for takeoff gross weight and DOC as a function of 'X' point range for a mission payload of 23,768 kg (52,400 lb). At a range of 5560 km (3000 n mi) the configuration is cruise/takeoff/approach speed/fuel volume matched. Below this range the design is constrained by approach speed, and above 5560 km (3000 n mi) the wing is designed by mission fuel requirements.

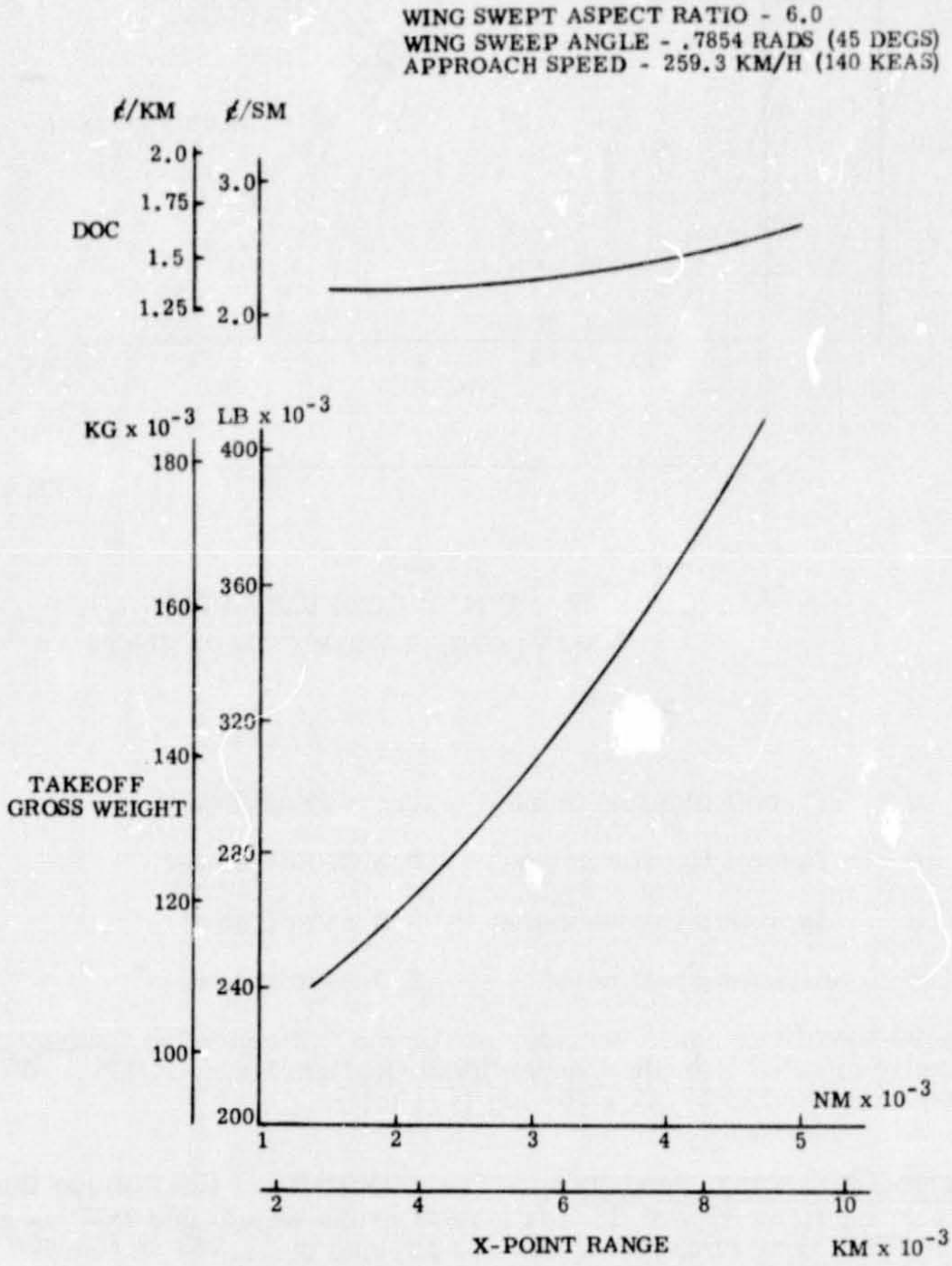


FIGURE 23 OBLIQUE WING CONCEPT
WEIGHT/DOC RANGE SENSITIVITY

The weight changes are also reflected in the DOC change. Between 2778 km (1500 n mi) and 5560 km (3000 n mi) the change in DOC is 3.0 percent. From 5560 km (3000 n mi) to 8334 km (4500 n mi) the increment is 13.0 percent. The increase in wing weight is therefore the dominant factor in accelerating takeoff gross weight and DOC increments.

Alternate Mission capability. - The capability of the Oblique Wing Concept performing Air Force tanker and Navy ASW missions is shown on Figure 24 . The tanker mission takes advantage of the overload limit load factor of 2.0g to provide fuel off-load capability. In the case of the Navy ASW mission the limit load factor requirement of 3.0g forces a reduction in takeoff gross weight which reduces the airplane capability for the mission.

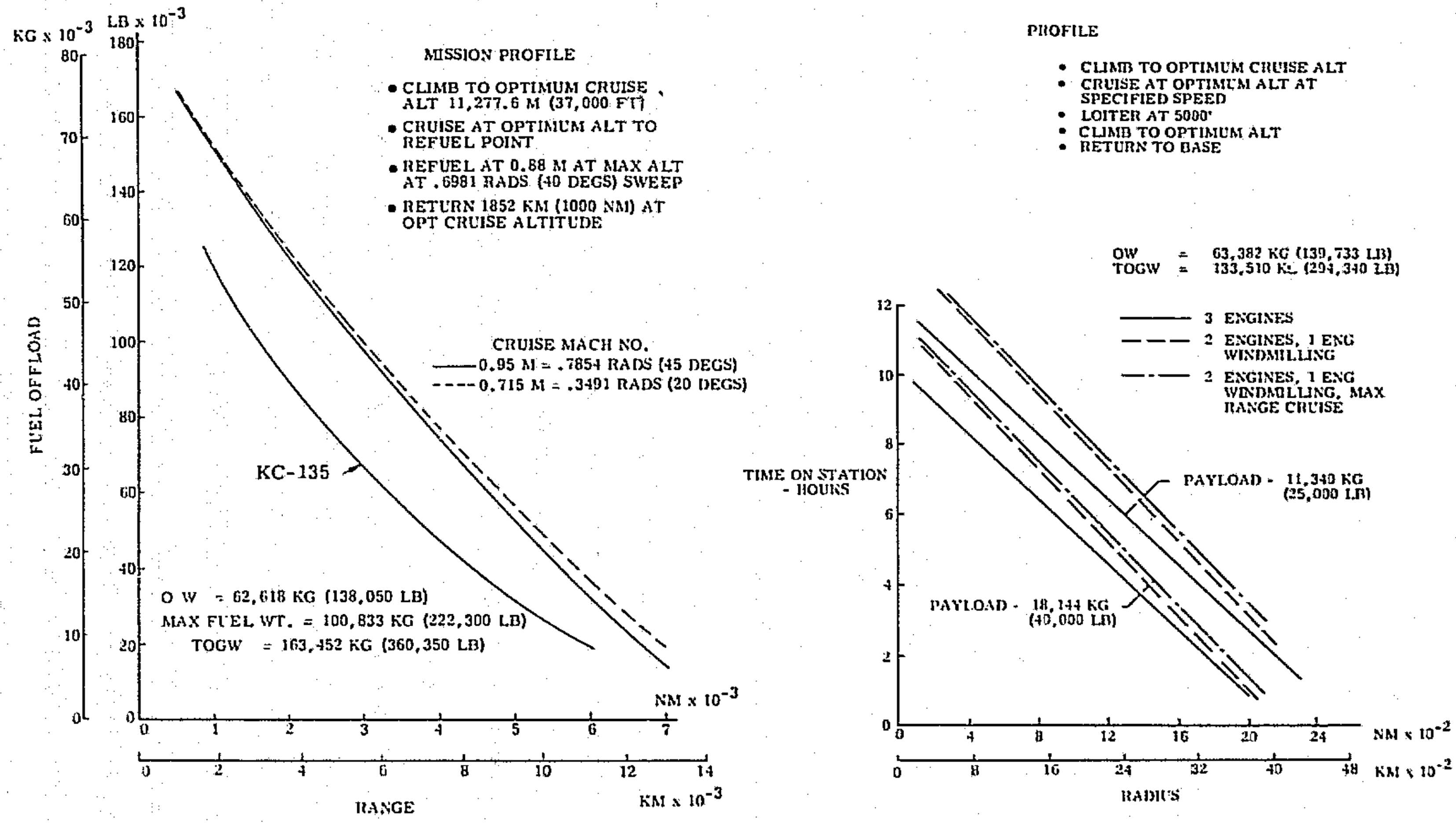
Technological Requirements

The technology areas emerging as critical to the achievement of the Oblique Wing Concept are:

- Aerodynamic technology - supercritical airfoil for maximum wing thickness at Mach 0.95.
- Structures and materials technology - composite materials and structures to achieve aeroelastic stability without weight penalty and improved technology level to achieve maximum weight reduction.
- Propulsion technology - the Pratt and Whitney STF 433 high bypass ratio turbofan was chosen as representative of 1985 propulsion technology. The engine features low weight, reduced emissions, and is designed to minimize noise levels.
- Active control technology - the introduction of active controls as a means of achieving higher aspect ratio has potential for the Oblique Wing Concept through an active aeroelastic instability suppression system for strength designed wings as an alternative to the addition of material to increase structural stiffness.

Summary of Results

The study results are summarized on Table XI. The Oblique Wing Concept shows improvements over the Conventional Configuration for cruise at Mach 0.95, in weight, cost, thrust, airport performance, community noise characteristics, and off-design capability.



(a) AIR FORCE TANKER MISSION

(b) NAVY ASW MISSION

FIGURE 24 FINAL CONFIGURATION ALTERNATE MISSIONS CAPABILITY

TABLE XI SUMMARY OF RESULTS

Parameter	Oblique Wing Concept Configuration	Conventional Configuration	Change From Conventional Configuration
Takeoff Gross Weight, kg (lb)	139,453 (307,411)	149,793 (330,238)	7% Less
Direct Operating Cost, ¢/km (¢/st mi)	1.409 (2.267)	1.483 (2.386)	5% Less
Total Installed Thrust, N (lb)	405,702 (91,206)	451,334 (101,464)	10% Less
Mission Block Fuel, kg (lb)	35,469 (78,196)	38,072 (83,935)	7% Less
Takeoff Distance, m (ft)	2,484 (8,149)	2,555 (8,384)	3% Less
Acoustic Soundprint Area 90 EPNdB m^2 (mi^2)	9.065×10^6 (3.5)	19.17×10^6 (7.4)	53% Less
Airframe Self Noise Approach EPNdB	91.5 Potential to 89.0	93.5	2 EPNdB Less
Takeoff Sideline EPNdB	—	—	0.5 Less
Takeoff Flyover EPNdB	—	—	2.5 Less
Approach Flyover EPNdB	—	—	8.5 Less
OBLIQUE WING CONCEPT OFF-DESIGN CAPABILITY			
Performance Item	Cruise Configuration	Off-Design Configuration	Performance Change
Range - km (n mi)	5560 (3000)	6112 (3300)	10% More
Cruise Mach No.	0.95	0.715	
Endurance - hrs	8.75	12.6	44% More

The study further shows the domain of the Oblique Wing Concept to be at speeds of Mach 0.91 and above.

The flexibility of the Oblique Wing Concept also provides alternate capability for military use.

Recommendations

- Conduct further aeroelastic analyses to determine structural characteristics of wings at aspect ratios greater than 6.0.
- Investigate active divergence suppression systems as a means of achieving higher aspect ratios.
- Continue development of the Commercial Passenger Transport to further improve the design and performance.
- Investigate the short haul potential of the Oblique Wing Concept.
- Further develop the Executive Transport Configuration with emphasis on the Navy carrier-borne applications.

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