TWIN-FUSELAGE GIANT SEAPLANE TRANSPORT

Ryoichi ONISHI
Safety Science Research Div.
Mitsubishi Research Institute, Inc.
2-3-6 Otemachi Chiyoda, Tokyo 100-8141, Japan

Keywords: *Aircraft Design, Transport Airplane, Flying Boat,Multi Fuselage,Catamaran,Trimaran*

Abstract

The high-speed long-range giant seaplanes that have two and three fuselages carrying 1,000 to 1,500 passengers were studied. The twin-fuselage seaplane with one inboard wing connecting the fuselages located at both wing tips has 1.6Mlb Maximum Takeoff Weight (MTOW) and carries 170Klb payload in the 7,000nm range. The triple-fuselage seaplane that has forward and rear wings connecting left, center, and right fuselages has 2.5Mlb MTOW and carries 260 to 300Klb payload in the same range. Fuselage bottoms of the two aircrafts are configured as the double shallow-step hydroplanes. The aircraft use in coordination with large ships that provide loading/unloading and refueling services on the ocean, which is called the integrated air and marine freight service in this paper, is expected to renovate the global transportation of heavy shipments now handled by low-speed ocean and land freighters. This paper describes the design variations and mission capabilities of the aircraft as well as the innovative transportation services accomplished by it.

Nomenclature

B	Hull width (ft)
K	Lift-induced-drag factor
L	Hull length (ft)
R	Resistance (lb)
S	Wing area (ft^2)
T	Thrust (lb)
V	Aircraft speed (ft/sec)
Vg	Aircraft lift-off speed (ft/sec)
W	Aircraft weight (lb)

1 Introduction

Major aircraft companies made the market forecasts of the commercial aircrafts [1]-[3], and predicted that the huge demand for 5,000 wide-body jets around the year 2020 was expected. Table 1.[4] summarizes the forecasts revealing future demand for the large jets accommodating more than 400 seats is estimated to reach almost 1,000.

Table 1. Aircraft Market Forecasts Around 2020

CATEGORY	BOEING	JADC	AIRBUS
LARGE JET	889	788	1138
TWIN-AISLE WIDE-BODY	5437	5002	3842
SINGLE AISLE NARROW-BODY	13647	12431	10201
REGIONAL JET	4303	5614	
TOTAL	24276	23835	15181

Predictions made in 2001-2003

JADC: Japan Aircraft Development Corporation

Primary objective of this research is to study the effective means that meet this requirement by enlarging the aircraft size. As described in the former research[5]-[7], the aircraft is designed as a seaplane because it can greatly reduce the economical and environmental issues of constructing runways which are required to be 1.5 to 2.5 times larger in size than the current largest one. Multiple-fuselage configuration was employed because it reduces the overall length of an aircraft along with the maximum bending moment in the wing root sections. Also the endplate effects of the fuselages and vertical tails located at both wing tips alleviate tip vortex, increase effective aspect ratio and hence reduce the induced drag[8]-[11]. In Fig.1., the induced drag factors are compared among the twin fuselage, triple fuselage, Airbus A380[12]-[14], and Boeing 747-400X[15]. From the figure, a multi-fuselage aircraft would have smaller wingspan than a conventional single fuselage aircraft with less induced drag. As a consequence, multi-fuselage configuration can be expected to reduce the width and length of an aircraft. Table 2. is the size comparison of single-fuselage and twin-fuselage configurations of the transport aircraft that has the 1.575Mlb MTOW and 950 seating capacity, depicting the size (or the parking area) of a multi-fuselage is almost 60% of a single-fuselage aircraft. Additionally the control, electrical, and electronic systems of each fuselage provide doubled or tripled systems to the aircraft. In the loss of control accident, only one survived fuselage system can backup the other failed systems and aircraft maintains a control.

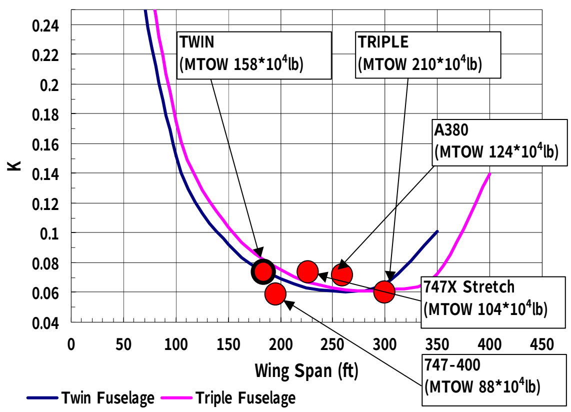


Fig. 1. Induced Drag Factors.

Table 2. Size Comparisons of Single- and Twin-Fuselage Configurations.

(MTOW=157.5*10^{4}lb, 960 seats)

Configuration	Cabin Length (ft)	Span (ft)	Parking Area(ft^2)
Single-Fuselage-Twin-Deck	156	286.6	44710
Twin-Fuselage - Single-Deck	139.3	180	25074

2 Design Descriptions

2.1 General Arrangement of the Aircraft

Twin and triple fuselage aircrafts are compared with A380 and B747 family in Table 3. and Fig.9., and the general arrangements of the several variations are presented from Fig. 9. to 11. The aircrafts were designed for the maximum Mach number of 0.89 and 35,000ft altitude[6]. Bottom face of each fuselage is designed as the high L/B boat hulls having two shallow steps.

Table 3. Size and Performance Comparisons of the Multi-Fuselage Configurations with Airbus and Boeing Large Jets[12]-[15].

	MTOW 10^{4}lb	PAYLOAD 10^{4}lb	RANGE nm	T/W	W/S lb/ft^2	ENGINE Numbers*Thrust(lb)	SPAN ft	LENGTH ft	ASPECT RATIO
TWIN	157.5	17	6752	0.3	155	5～6*93700	180	225	4.83
TRIPLE	210	26	6600	0.4	175	9*93700	300	225	9.43
A380	123.9	8.82	7650	0.2	131	4*67000	262	240	7.53
747X Stretch	104		7820	0.3	153	4*68000	229	263	7.62
747-400	88	9	6857	0.3	155	4*56750	196	225	7.39
A340-600	80		7500		171	4*56000	208	247	9.21

The two aircrafts have super-critical section inboard wings. Wings accommodate extra cabins and fuel tanks. Table 4. shows the capacities of wing internal fuel tanks.

Table 4. Maximum Capacities of Wing Internal Tanks.

TYPE	WING	FUEL TANK (10^{4}lb)	
		Center+Inboard +Outboard	RESERVE
Twin-158	MAIN	60.9	27.6
Triple-250	FORWARD	55	16.5
	REAR	55	16.5

The weights of fuselage, wing and engines as well as aerodynamic lift yield bending moments in a wing. Fig.2. and 3. show the bending moment diagrams of lift and weights, used for estimating required wing thickness. A tandem wing configuration[16] was employed for the triple fuselage aircraft in order to reduce a wingspan. When the aircraft is designed as a conventional monoplane with its aspect ratio of

11, wingspan become 424ft, meaning the aircraft of doubled B747 width. Therefore separating one large wing into smaller forward and rear high aspect ratio wings is considered to be advantageous in reducing a wingspan of a very large aircraft. Forward and rear wings have individual elevators, elevons, high-speed ailerons, and spoilers. Major characteristics appeared in the general arrangements, such as the high wings, T-tails, and the engines mounted on upper wing surfaces, were come from avoiding water impingement and ingestion during takeoff and landing. Engine selection was done among the available large thrust engines. GE90-94B producing the 93,700 lb maximum takeoff thrust was selected. Twin-fuselage aircraft uses 5 to 6 GE90s, and the triple-fuselage uses 9 to 10 of those.

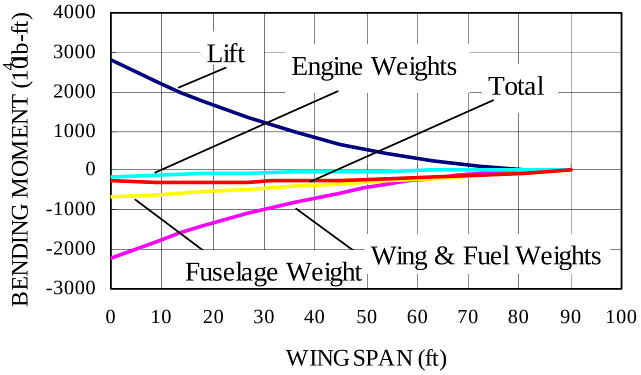


Fig. 2. Bending Moment Diagrams of the Twin-Fuselage Aircraft.

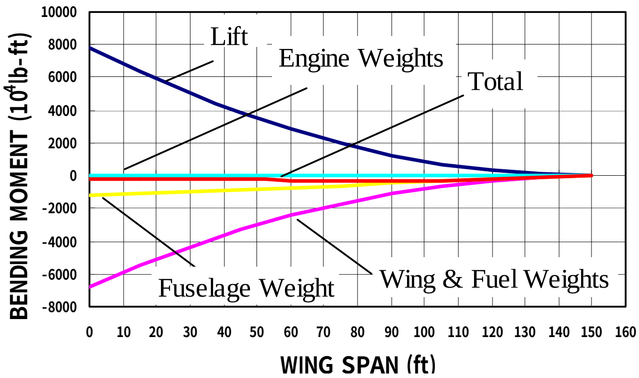


Fig. 3. Bending Moment Diagrams of the Triple-Fuselage Aircraft.

2.2 Hydrodynamic Design and Performance

Hulls employ a large length-to-beam ratio shallow-step configuration. Table 5. is the geometry and performance parameters yielded from the NACA hull models[17]-[21].

Table 5. Hull Configurations of the Twin- and Triple-Fuselage Aircrafts.

Type	Twin	Triple	
Maximum Take-Off Weight (Mlb)	1.575	2.50	
Fuselage	Tip	Center	Tip
Length (ft)	225.2	255.2	225.2
Beam (ft)	21.3	21.3	21.3
Hump Froude Number	2.75	2.3	2.7
Hump Resistance Coefficient	0.25	0.25	0.26
Hump Speed Coefficient	0.5	0.38	0.46
Getaway Resistance Coefficient	0.15	0.11	0.13
Dead Rise Angle (degree)	22.5	25	24
Aft-Body Keel Angle (degree)	5.5	7	7.5
Load (10^4lb)	78.8	90.4	79.8
Load Coefficient	1.28	1.47	1.29
Length to Beam Ratio	10.56	11.97	10.56
Step Location to Length Ratio	0.46	0.5	0.55
Step Height to Beam Ratio	0.025	0.025	0.025

Triple-fuselage aircraft has a center, left, and right fuselages. A center fuselage is made larger than the left and right fuselages, taking larger water loads and having different hydrodynamic characteristics designated as the different Froude number or resistance coefficient. A shallow-step design was employed for the reduction of aerodynamic drag. Fig. 4. and 5. are the take-off resistances of the twin- and triple-fuselage aircrafts, showing total thrusts are enough higher than hydrodynamic and aerodynamic drags, ensuring enough power for lift off. A takeoff distances computed from Fig. 4. and shown in Fig. 6. become about 35,000ft with 5 engines and 20,000 ft with 6 engines for the twin fuselage aircraft.

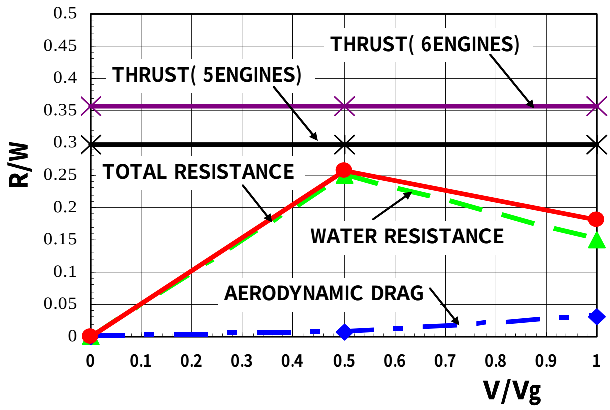


Fig. 4. Takeoff Thrust and Resistance of the Twin-Fuselage Aircraft. (MTOW=158*10^4lb., engine; GE90-94B)

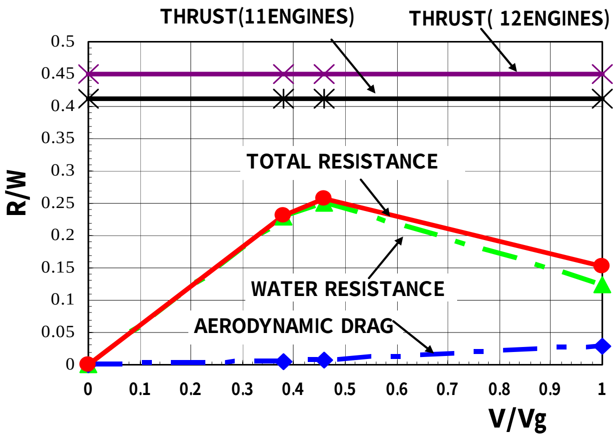


Fig. 5. Takeoff Thrust and Resistance of the Triple-Fuselage Aircraft.(MTOW=250*10^4lb., engine; GE90-94B)

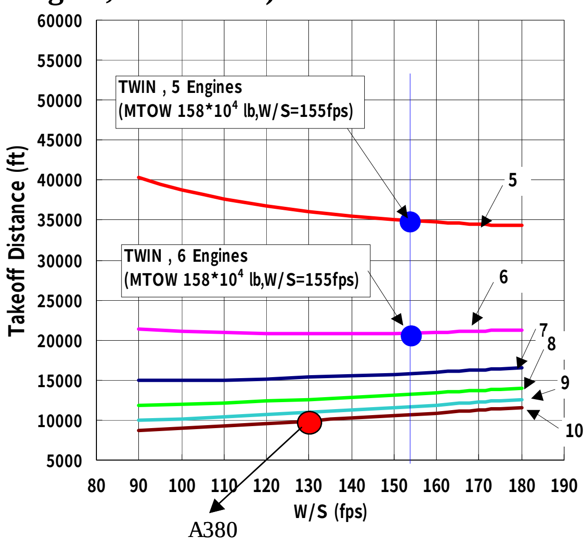


Fig. 6. Takeoff Distance, Wing Loading, and the Number of Engines of the Twin-Fuselage Aircraft.

3 Applications to Civil and Military Missions

3.1 Passenger and Cargo Transportations

A payload-range for Mach 0.89 at 35,000ft altitude is shown in Fig. 7. The triple-fuselage aircrafts with the 2.1Mlb MTOW and the 2.5Mlb MTOW can fly the transpacific routes between Tokyo and New York with almost three times (270Klb) and four times (350Klb) payloads of B747-400. Twin-fuselage aircraft with the 1.58Mlb MTOW can fly between Tokyo and New York with almost 2.5 times payloads (230Klb) of B747-400. As shown in the figure, payloads of the multi-fuselage aircrafts are greatly increased while ranging same as the A380 and B747-400 variants.

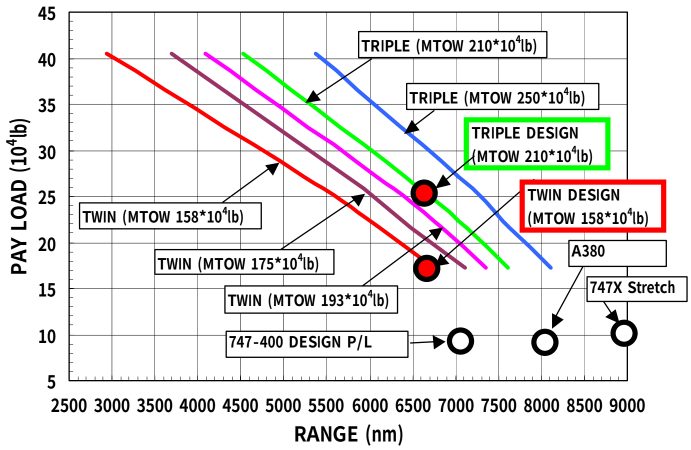


Fig. 7. Payload and Range of Twin- and Triple-Fuselage Aircrafts.

The global coverage of a twin fuselage aircraft launched from the seashore near the Los Angels International Airport is shown in Fig. 8. A maximum payload version with 3,500nm ranging capability covers North America, Canada, and Hawaii with a payload of 400Klb. A medium payload/range version with 4,000–5,000 nm ranging capability covers entire North America and Canada, Alaska, Middle South America, Hawaii, and Marshall Islands with a payload of 300-350Klb. A maximum range version with 6,500 nm ranging capability covers almost all continents with a payload of 170Klb instead of Antarctica, the eastern part of Australia, and the southern part of Africa continents. If the aircrafts can get fuel supply on the sea, operational ranges of the aircraft will be greatly expanded. Aircraft does not need to carry the fuel more than required for flying to the next supply base where the tanker ships are waiting, which means a fuel-to-weight fraction is largely decreased, and it can carry larger payload without sacrificing long-range characteristics. It might be available to deliver the maximum payload up to 400 Klb to every continent seashores and inland waters of the world.

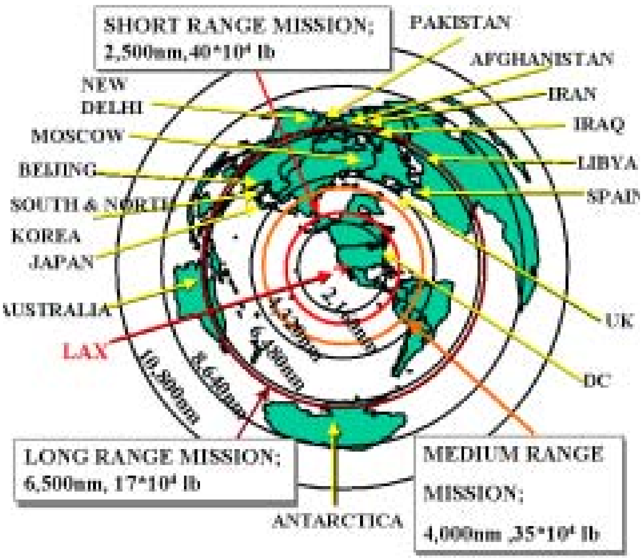


Fig. 8. Global Coverage of the 1.58Mlb Twin Fuselage Transonic Seaplane.

Fig. 9., 10. and 11. are the variation examples of all economy seating layouts of the triple and twin fuselage aircrafts. Fig. 9. shows the triple-fuselage of 10-abreasts-and-two-aisles seating arrangements of the center, left, and right fuselages along with the size comparisons with the twin-fuselage and A380. Fig. 10. shows the medium payload/range variant (4,000nm, 350Klb) of the twin-fuselage aircraft. Cabins in the both fuselages and wing boxes accommodate 960 seats. Lower cargo compartments of the both fuselages carry 64 LD3 containers. Wing box cabins accommodating extra 100 seats are created by removing outboard and reserve fuel tanks, and connected to the main decks through the stairs. 20 cabin attendants serve for both fuselages and the cockpit section is located in the port side fuselage. Fig. 11. shows the some variants of the maximum range configuration. A medium payload/range version utilizes the wing volumes as the outboard and reserve fuel tanks instead of wing box cabins. Also the passenger and cargo combi-version is shown in the figure. The aircraft has the left fuselage carrying 400 passengers and the right fuselage carrying 10 10-ft containers. Cargo area in the both lower decks has a volume for the 64 LD3 containers.

3.2 Integrated Air-Marine Freight Service

A mid-sea refueling capability promises the high-speed long-range seaplanes claiming great payload over 400Klb to dramatically improve the global transportation of large shipments. Aircraft operations in coordination with the large ships that provide loading/unloading and refueling services on the ocean might renovate the global transportation of heavy machines, large construction materials, automobiles, or natural resources now handled by low-speed ocean or land freighters through the fast delivery capability.

3.3 Heavy Air-Mobility and Fast-Deployment

Heavy payload and extended range of the aircraft are also valuable for military missions. Table 6. demonstrates the applicability of the twin fuselage aircraft to the heavy air-mobility and fast-deployment missions. The helicopter carrier version is shown in Fig. 10. Armoured vehicles and attack helicopters are carried from far continent to hostile land within a short period and deployed safely from offshore area enough far from combat zone. Land-based cargo plane needs to find or construct a large airfield in the friendly countries, requiring many days of preparation. Cargo seaplanes can cut the months for the preparations.

Table 6. Heavy air-mobility Fast-Deployment Examples of the 1.6Mlb Twin-Fuselage Aircraft. The number of vehicles and helicopters carried are shown corresponding to the range variations.

Range(nm)	M1A1*1	M2*1	MLRS*1	LVTP*1	HUMVEE*1	AH64*3
3000	2	1 to 2				
	1	4 to 5				
		6				2
		8				
				8		
			6			1 to 2
		4	3			1
5,000		4				2 to 4
	1	1				3 to 4
			4			2
				4	12	
6,000					36	
					18	3
		2				4
6500						6 to 8
					18	
		2				4

*1; Combat Load *2; MTOW *3; MTOW, Longbow Radar

M1A1: M1A1 Abrams Main Battle Tank
M2: M2 Bradley Infantry Fighting Vehicle
MLRS: M270 Multiple Launch Rocket System
LVTP : LVTP 7A1 Amphibious Personal Vehicle
HUMVEE: M-998 HMMWV Multipurpose Wheeled Vehicle
AH-64: AH-64 Apache (with Longbow radar)

An airborne tanker would be the attractive application due to the large fuselage volumes that are utilized as the fuel tanks containing doubled or tripled fuels as KC-135 and enable the aircraft to provide refuelling services to the larger number of the fighter planes. The aircraft is also utilized as the detection, tracking and command-and-control platform for the Ballistic Missile Defence (BMD) missions. Single aircraft can cover the entire missions of early warning and detection of a missile in the boost phase by infrared array, tracking a missile in the post-boost phase by airborne radar, and commanding anti ballistic missile units on the ground or sea. Current US systems are composed of the separated airborne systems such as RC-135 signal intelligence aircraft, E-3 airborne warning and control system or EC-135 command post aircraft. Proposed seaplane integrates long-range airborne radar, electro-optical sensor, and C^3I suite in one system, providing seamless and responsive BMD services.

4 Conclusion

An innovative concept of the seaplane has been studied. Further investigations are planned on the followings.

(1) Detailed analysis of the aerodynamics of multi-fuselages, inboard wings, and hull substructures such as chine, step, and keel.

(2) Aeroelasticity of the inboard wings that might have the large torsion created by the wing tip fuselages.

(3) Stability and control issues raised by large roll and yaw inertias.

(4) Sea worthiness during the takeoff and landing from the rough water of the sea-state 6 (about 12-18ft wave height).

(5) Analysis of asymmetric landing, a one-sided ditching case that yields a water impact concentrated on the one fuselage.

(6) Investigation on the infra systems that support coordinated operations of the large seaplanes and ocean vessels. i.e. Mid-sea fuel supply system, seashore terminal, maintenance facilities such as washing facility, hangers, and mass-transportation means to inland hub airports.

References

[1] “Market Forecast of Ultra-Large Commercial Aircraft 2001”, Japan Aircraft Development Corporation, 2002.

[2] “Global Market Forecast 2001-2020”, AIRBUS SAS., Sept. 2002.

[3] “Current Market Outlook 2003”, Boeing Commercial Airplanes, June, 2003.

[4] Onishi,R. “Japanese Aircraft Industries’ Attitudes toward the Coming “Air-Battle” of Commercial Aircrafts.” ,Mitsubishi Research Institute, Inc., http://safety.mri.co.jp/index.html, 2003.

[5] Onishi,R. "Preliminary Study of Ultra-Giant Multi-Fuselage Flying Boat Concept", AIAA-2003-3806, June, 2003.

[6] Onishi R., "Ultra-Large Multi-Fuselage Flying Boat Concept.",1D10,The 41st Aircraft Symposium, The Japan Society for Aeronautical and Space Sciences ,Oct., 2003.

[7] Onishi,R. "Flying Ocean Giant: A Multi-Fuselage Concept for Ultra-Large Flying Boat.", AIAA-2004-0696, Jan., 2004.

[8] Orr,M.,Magill,S.A., Schetz,J.A., Marchman III,J.F., Mason,W.H. and Grossman,B.", Experimental Study of the Aerodynamic Properties of the Inboard Wing Concept.", AIAA-2001-0577

[9] Houbolt,J.C. ",Why Twin-Fuselage Aircraft?", Astronautics and Aeronautics, April 1982.

[10] Spearman,M.L. ",An Airplane Design Having a Wing with a Fuselage Attached to Each Tip.", AIAA 2001-0536

[11] Spearman,M.L. ",An Airplane Configuration with an Inboard Wing Mounted Between Twin Fuselage s.", AIAA 98-0440

[12] "Airbus-Aircraft Families – A380F Characteristics", http://www.airbus.com/product/a380f_specifications.asp

[13] "A380 Airplane Characteristics for Airport Planning", Airbus S.A.S., Jan. 2002.

[14] "A380 Facility Planning Manual / Maintenance Facility Planning MFP-Preliminary Issue", L.MFP, Airbus S.A.S., Jan. 2004.

[15] "747-400 Airplane Characteristics for Airport Planning",D6-58326-1, Boeing Commercial Airplanes, Dec. 2002.

[16] Onishi, R. ",A Study of Canard configuration Large Transport Aircraft", Mitsubishi Research Institute, Inc.,1997

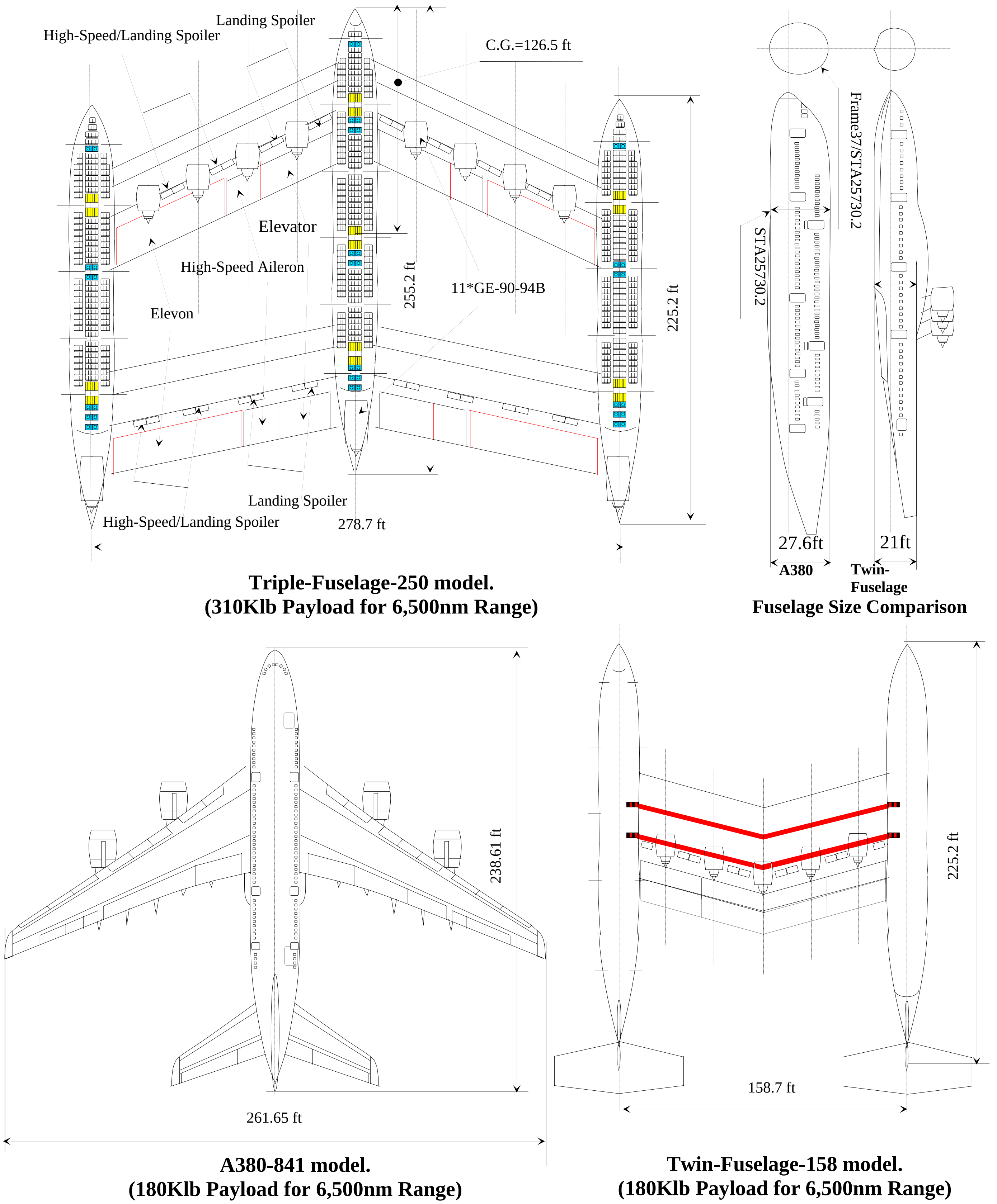
[17] Diehl, W.S.",A Study of Flying-Boat Take-Off", NACA T.N. No. 643, April 1938.

[18] Truscott, S., Parkinson, J. B., Ebert, Jr., J.W. and Valentine, E. F.", Hydrodynamic and Aerodynamic Tests of Models of Flying - Boat Hulls Designed for Low Aerodynamic Drag N.A.C.A. Models 74,74-A,and 75", NACA T.N. No. 668,October 1938.

[19] Yates, C.C. and Riebe, .M ", Effect of Length-Beam Ratio on the Aerodynamic Characteristics of Flying-Boat Hulls", NACA T.N. No.1305, June 1947.

[20] Milwitzky, B. ", A Generalized Theoretical and Experimental Investigation of the Motions and Hydrodynamic Loads Experienced by V-Bottom Seaplanes During Step-Landing Impacts", NACA T.N. No.1516,Februaly 1948.

[21] Carter, A.W. and Haar, M.I. ",Hydrodynamic Qualities of a Hypothetical Flying Boat with a Low-Drag Hull Having a Length-to-Beam Ratio of 15", NACA T.N. No.1570,April 1948



Triple-Fuselage-250 model.
(310Klb Payload for 6,500nm Range)

Fuselage Size Comparison

A380-841 model.
(180Klb Payload for 6,500nm Range)

Twin-Fuselage-158 model.
(180Klb Payload for 6,500nm Range)

Fig. 9. General Arrangements and size comparison of the Triple-fuselage, Twin-Fuselage, and A380.

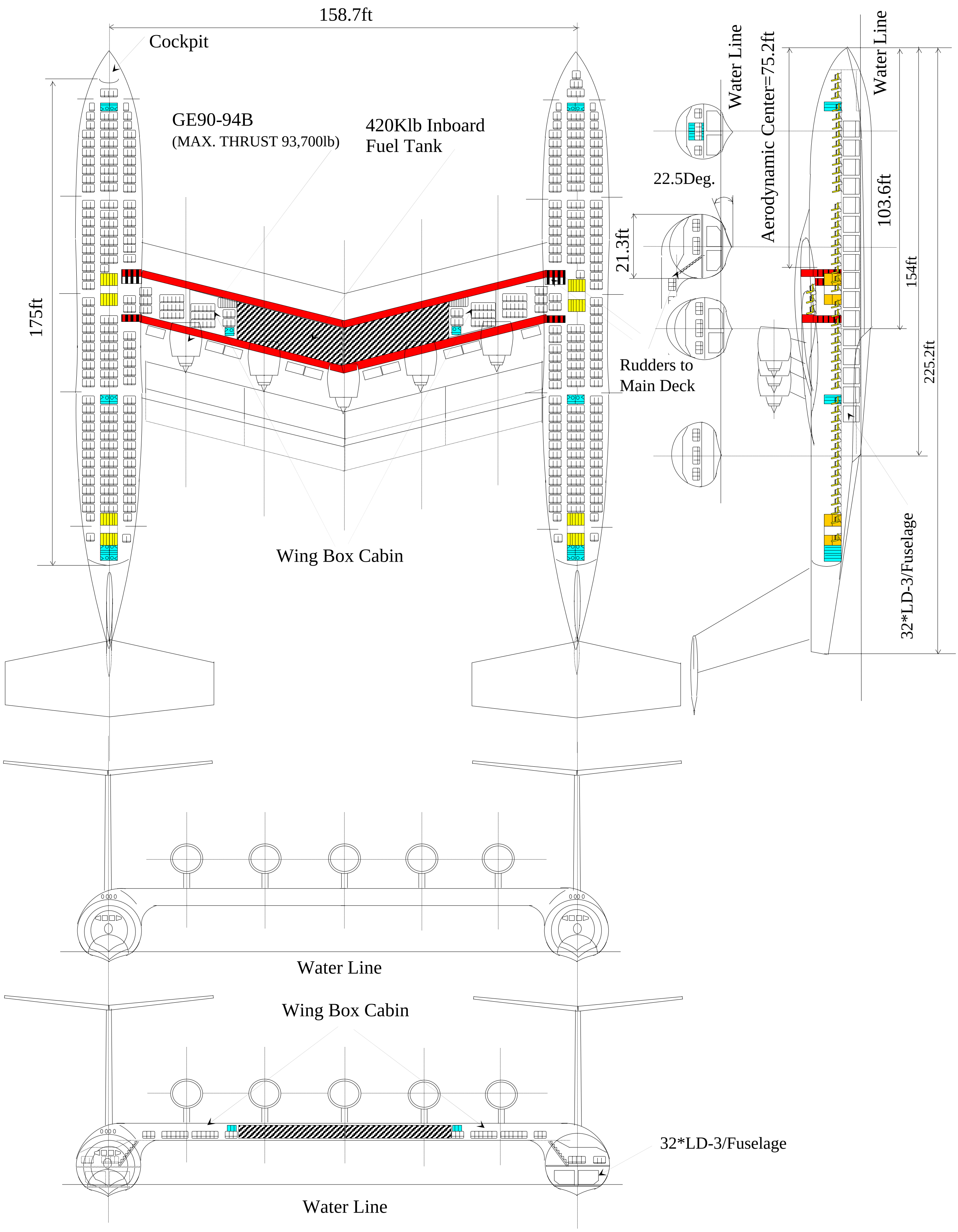
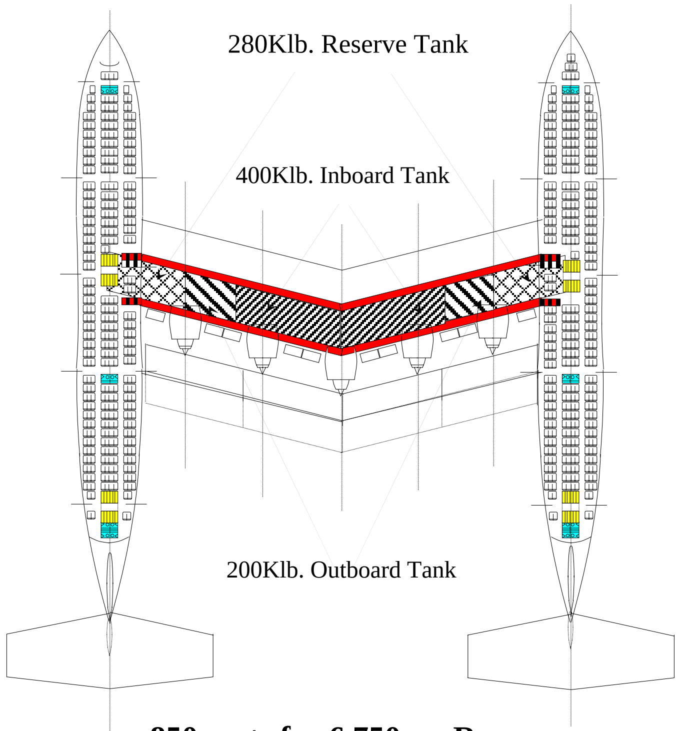
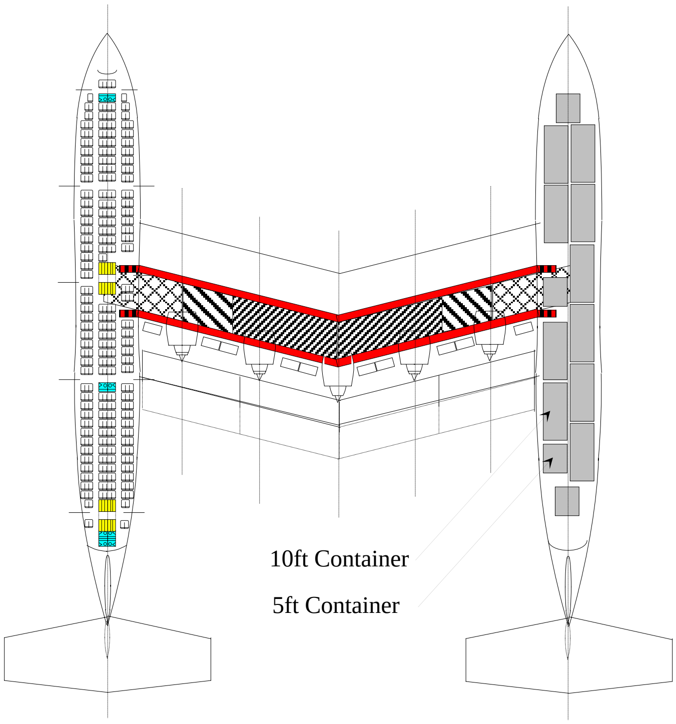


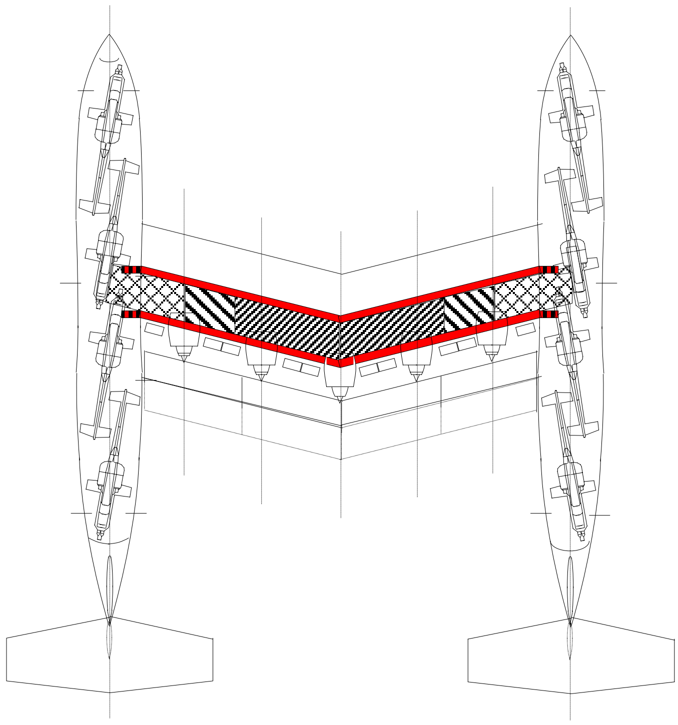
Fig. 10. General Arrangement of the Medium Payload/Range Variation of the Twin-Fuselage. (950 seats, 350Klb Payload, 4,000nm Range)



850 seats for 6,750nm Range.



420 seats and 10*10ft containers with 4*5 ft containers for 6,750nm Range.



8 Attack Helicopters for 6,750nm Range.

Fig. 11. Variation Examples of the Maximum Range Configurations.