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Preliminary Study of Ultra-Giant Multi-Fuselage Flying Boat Concept.

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Abstract

Multi-fuselage configuration for the flying boat which has heavy payload and long range capabilities was studied, and the applications of the aircraft to civil and military missions were investigated.

The aircraft is configured as a seaplane with two or three fuselages. Multi-fuselage configuration is considered to be advantageous in both aerodynamics and structures for a large aircraft to reduce size and weight. According to the end-plate effect of the tip-mounted fuselages and fins, size reduction can be achieved by employing low aspect ratio short span wing without degrading L/D. Weight reduction from the reduced bending moment created by fuselage weight at each wing tip is another benefit.

In this study, size and performance goals were determined by comparing the proposed design with the existing large aircraft designs of Airbus A380 and Boeing B747-X Stretch, and superior mission capability of the proposed design to them was revealed.

This article describes motivation of the research, aerodynamic and hydrodynamic designs, and applications to civil and military aircrafts. For a civil transport aircraft, capabilities of flying transpacific routes with doubled or tripled payload of B747-400 is described. For a military cargo aircraft, long-range fast-deployment capability of various payloads such as combat vehicles or attack helicopters is also described.

Nomenclature

CLmax	Maximum Lift Coefficient
L/D	Lift to Drag Ratio
Length to Beam Ratio	L/B
Load Coefficient	W/wBL^2
t/c	Thickness to Chord Ratio
T/W	Thrust to Weight Ratio
W/S	Wing Loading (lb/ft^2)

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Introduction

Application of a Seaplane to Ultra-Large Aircraft

It is known that aircraft direct operating cost is minimized by increasing payload, however, the problems associated with enlarged weight and size arise the difficulties and costs for constructing large run-ways. Figure 1 indicates the balanced field length for Maximum Take-Off Weight (MTOW). Run-way length for the aircraft which has three times heavier MTOW than B747–400 is predicted to exceed 35,000ft (about 10Km). The idea to utilize water surface as an infinite airfield is expected to eliminate the problem of finding large airfield on the ground hence ultra-large flying boat was pursued in the past(1). According to additional weight and drag of a hull, large flying boat was viewed as inefficient and more importance was put on a land based aircraft. In the US, the latest flying boat is the Martin P6M Seamaster which was developed in 1950`s(2). Since then, many advancements were made in aircraft technologies, and employing them will provide great efficiency to old one.

Generally speaking, weight and drag problems of the hull become negligible when the aircraft's payload is greatly increased. Also the availability of limitless run-way length allows aircraft to have large wing-loading, leading to reduced wing area(3)(4). Additionally the modern high bypass ratio turbo-fan engines and aerodynamic optimization technology will more improve the seaplane's efficiency. Future seaplane is expected to surpass the land plane in terms of productivity measured by (PAYLOAD)* (BLOCK SPEED)(5).

From operational view, flying boat can be utilized in more flexible way than land based aircraft. Landing area for refueling can be easily found in the vast ocean. Mid-sea refueling, easier than aerial refueling, will largely extend the aircraft's range coverage. By hopping waypoints in the ocean for refueling, large payload can be transported to far distant place by one aircraft. Also the very long endurance of a large flying boat is beneficial to patrol, AEW, and tanker missions.

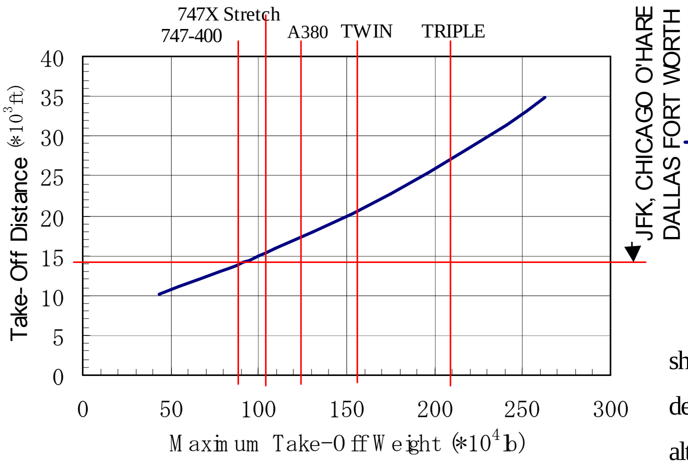


Figure 1 Maximum Take-Off Weight and Balanced Field Length. (no high lift device)

Multi-Fuselage Configuration

Multi-fuselage big aircraft was ever built. The German bomber Heinkel He111Z Twilling(Twin) (6) was built by connecting two He111s adding 1 engine and used as a towing plane of gigantic glider Messerschmitt Me 321 "Gigant". Several examples of multi-fuselage can be found in a small size category such as F-82 "Twin Mustang" (6). In this study, multi-fuselage is employed in order to reduce size of a large aircraft. The fuselages and vertical tails located at both wing tips create end-plate effect which alleviates tip vortex, increases effective aspect ratio and reduces induced drag(7)- (10) The end-plate effect shown in Figure 2 allows aircraft to reduce aspect-ratio and wing span with small increase in lift-induced drag coefficient over A-380 or B747-400X(11). A fuselage at each wing tip brings another benefit of reducing bending moment of a wing. Therefore a wing weight and thickness are further reduced.

Additionally, multi-fuselage configuration eliminates tip floats or fuselage bulges.

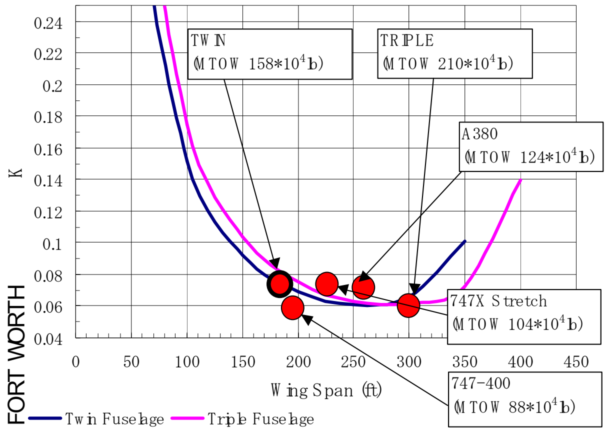


Figure2 Induced Drag Coefficient and Wing Span

Description of the design

General specification and arrangement of the aircraft are shown in Table 1 and Figure 11, respectively. The aircraft was designed for maximum Mach number of 0.89 and cruise altitude of 35,000ft. Bottom face of each fuselage is designed as the two step, high L/B flying boat hull.

Table 1 Size and Performance of Twin- and Triple-Fuselage Configurations.

	MTOW 10^4lb	MAX PAYLOAD 10^4lb	RANGE nm	T/W	W/S lb/ft^2	ENGINE (GE90)	SPAN ft	LENGTH ft
TWIN	157.5	17	6752	0.3	155	5	180	225
TRIPLE	210	26	6600	0.36	175	8	300	225

Figure 3 presents internal arrangement of a wing. Wing employs a super critical section, and provides the volume for fuel tanks and additional passenger compartments. Maximum fuel capacity of 61*10^4 lb with additional 28*10^4 lb for reserve is contained in the center, inboard, and outboard wing tanks enabling to attain the 7,000nm maximum range cruise mission. Inboard and outboard tank areas are also utilized as wing-box cabins which contain extra passengers in short- and mid-range cruise missions.

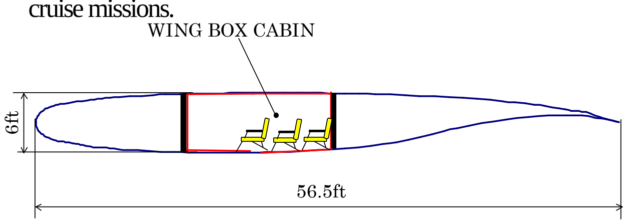


Figure 3 Wing Internal Arrangement for the Mid-Range Cruise Mission.

Figure 4 shows the lift coefficient across a half of wing span, which was used for estimating lift-induced bending moment. Total bending moment of the wing lift, fuel weight, wing structural weight, engine weight, and fuselage weight was estimated . Conventional type aircraft has the thickened root in order to provide the wing spars enough buckling strength for the bending moment concentrated in the wing root. Inboard wing configuration does not need thickened root and wing thickness is kept constant across span. A wing thickness was computed through estimating bending moment and shear force.

In order to avoid water impingement and ingestion , aircraft has a high wing, T-tails, and upper-wing engines. Power plants are 5 GE90s producing total thrust of $72*10^4$ lb and providing take-off T/W of 0.3.

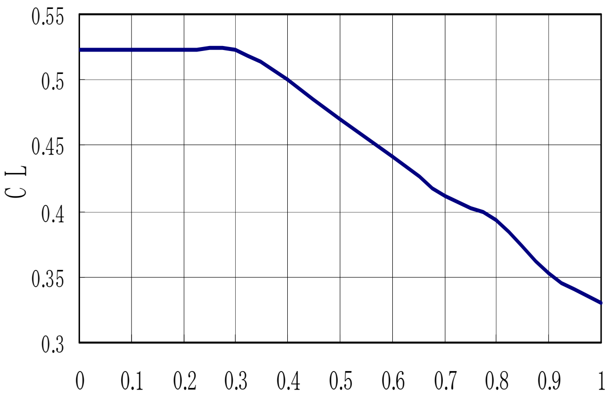


Figure 4 Span-wise Lift Distribution of a Wing.

Hydrodynamic Design of a Hull

A large L/B and low depth step design is employed in a hull configuration. Prior to the design work, geometry and performance correlations were investigated using the test data of NACA hull models[12][13], and configuration parameters were defined as shown in Table 2.

Table 2 Hull Configuration

Maximum Take-Off Weight	157.5	10^4lb
Length	225.2	ft
Beam	21.3	ft
Hump Froude Number	2.75	
Hump Resistance Coefficient	0.25	
Hump Speed Coefficient	0.5	
Getaway Resistance Coefficient	0.15	
Dead Rise Angle	22.5	degree
Aft-Body Keel Angle(1st, 2nd)	5.5, 9.0	degree
Load	78.75091	10^4lb
Load Coefficient	1.28	
Length to Beam Ratio	10.56	
Step Location to Length Ratio	0.46	
Step Height to Beam Ratio	0.025	

Although old flying boat has a high depth step for creating a cavity to separate water in take-off, it creates drag in the air. This design employs the low depth step(step height to beam ratio=0.025) and aft-fuselage shaped to make a smooth air-flow for creating separation cavity. Martin Seamaster has the low depth step and shaped aft-fuselage.

Figure 5 is the take-off resistance revealing water resistance and aerodynamic drag are enough low to the total thrust at hump speed (speed in which water resistance reaches maximum value). Figure 6 is the takeoff distance computed from the results of water resistance which is shown in Figure 5. Takeoff distance of twin fuselage with $157.5*10^4$ lb MTOW is about 35,000ft. with 5 engines and 2,000 ft with 6 engines.

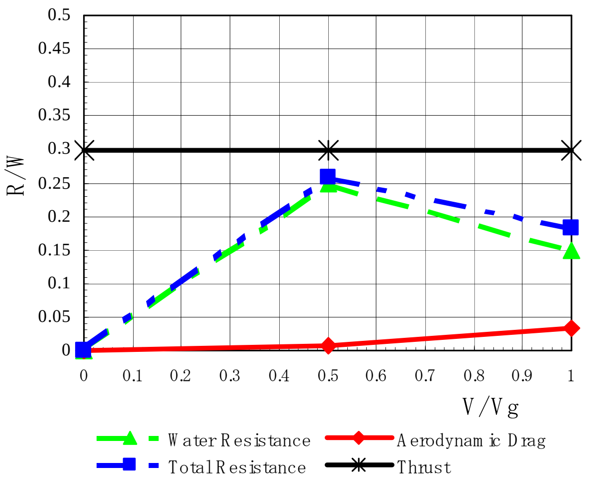


Figure 5 Takeoff Resistance.

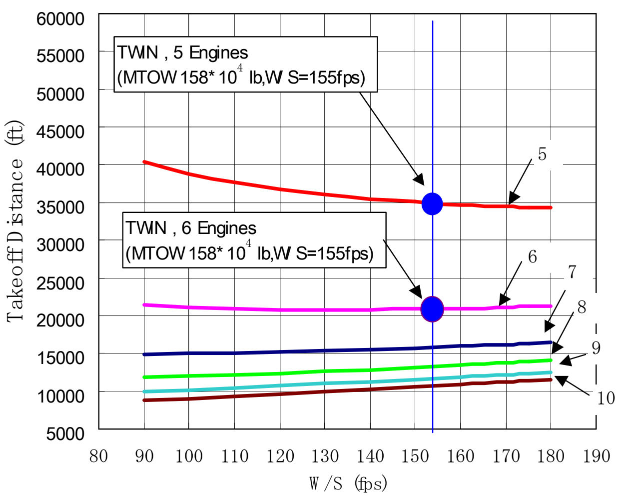
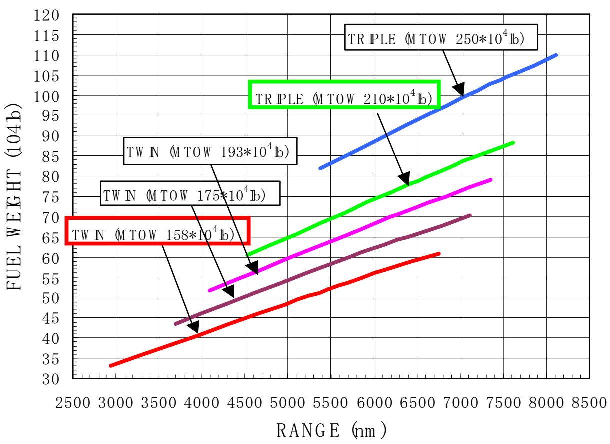


Figure 6 Takeoff Distance, Wing Loading, and Number of Engines of Twin-Fuselage Configuration .

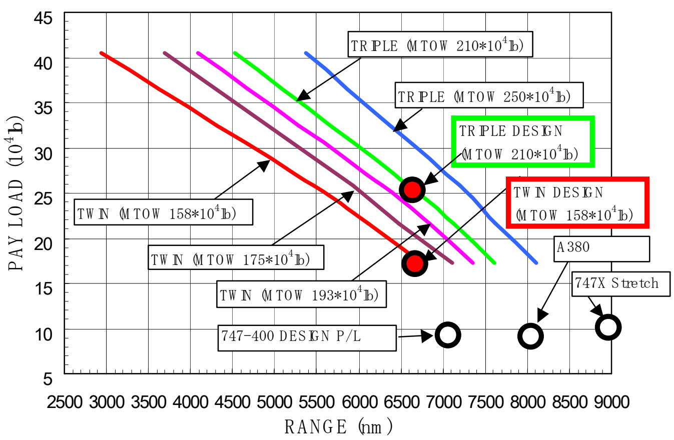
Weight,Payload,Range,and Mission Capability

Civil Applications

The payload-range performance for a mission cruise speed of Mach 0.89 at 35,000ft altitude is shown in Figure 7. A three-fuselages configuration aircraft can fly the transpacific routes between Tokyo and New York with tripled payload weight ($27*10^4$ lb) of B747-400, and the route between Seoul and New York can be flown with almost twice payload ($17*10^4$lb) of B747-400. Twin-fuselage aircraft can fly between Tokyo and New York with doubled payload ($17*10^4$lb) of B747-400. As an initial sizing , the designs of $157.5*10^4$ lb MTOW and $262.5*10^4$ lb MTOW for two and three fuselages aircrafts were selected, respectively. As shown in the figures, almost same range performance as the reference aircrafts can be available with great enhancement of payload. From Figure 2, wing span of 180 ft and 300ft were selected for the twin- and triple configurations.



Fuel-load and Range



Payload and Range

Figure 7 Payload and Range Performance of Twin- and Triple-Fuselage Aircrafts.

Figure 8 and 9 are the variation examples of all-economy seating layouts of civil transport aircraft. Figure 8 shows the medium range (4,000nm) heavy payload ($35*10^4$lb) configuration. Cabins in the both fuselages and wing boxes contain about 900 seats. Lower cargo compartments for two fuselages hold a capacity for 64 LD3 containers. Wing box cabins containing 100 seats are derived from eliminating outboard and reserve fuel tanks and connected to the main decks by the stairs. 10 cabin attendants serve for one fuselage and the cockpit section is located in the port side fuselage in convenience for mooring at the pier. Figure 9 shows some variants of the long range (6,750nm) configuration. In this variation, wing box cabins of the mid-range version are utilized as the area for outboard and reserve fuel tanks. In the figure, the example of a combination of passenger and cargo fuselage is shown. The figure illustrates about 400 passengers and 10 10-ft containers are transported on main decks. Cargo area in the lower deck has a volume for 32 LD3 containers.

Military Applications

Table 3 demonstrates the applications to the fast deployment cargo aircrafts. Armored vehicles and attack helicopters are transported from far continent to hostile land in a short time and deployed safely from off-shore area enough far from combat zone. Figure 9 demonstrates the helicopter carrier. Land based cargo plane would require to construct a large airfield in the adverse area such as forests or mountains, which requires many days of preparation.

Aerial tanker would be other application to utilize large volumes of fuselages which can contain about twice fuel as KC-135 with 7,000nm range coverage.

Table 3 Examples of the Fast Deployment Cargo Variations.

Range(nm)	M1A1*1	M2*1	MLRS*1	LVTP*1	Hummby*1	AH64*3
3,000	2	1-2				
	1	4-5				
		6				2
		8				
				8		
			6			1-2
		4	3			1
5,000		4				2-4
	1	1				3-4
			4			2
				4	12	
6,000					36	
					18	3
		2				4
6,500						6

*1; Combat Load, *2; MTOW   *3; MTOW, Longbow
M1A1 Abrams,
M2 Bradley
LVTP 7A1 Amphibious Personal Vehicle
AH-64 Apache (with Longbow radar)

Conclusion

A preliminary study of the gigantic flying boats has been conducted. In this study, twin and triple fuselage configurations have been evaluated referring to the B747-400, A380, and B747X Stretch. Followings are the major subjects which are planned to be investigated in the future.

As a seaplane, seaworthiness of state code up to 3 (about 4ft wave height) is a standard requirement, and takeoff and landing capability on more rough sea surface would be required. STOL capability is required for this objective. A high lift device which provides large Clmax should be investigated.

Detail estimation of aerodynamic drag associated with the hull and unusual multi-fuselage low aspect ratio configuration is required.

Large rolling inertia will affect on maneuverability and passengers' ride quality.

Also asymmetric landing is the problem in the multi-fuselage configuration.

Massive transportation means from sea shore area to hub airports in the land area will be required.

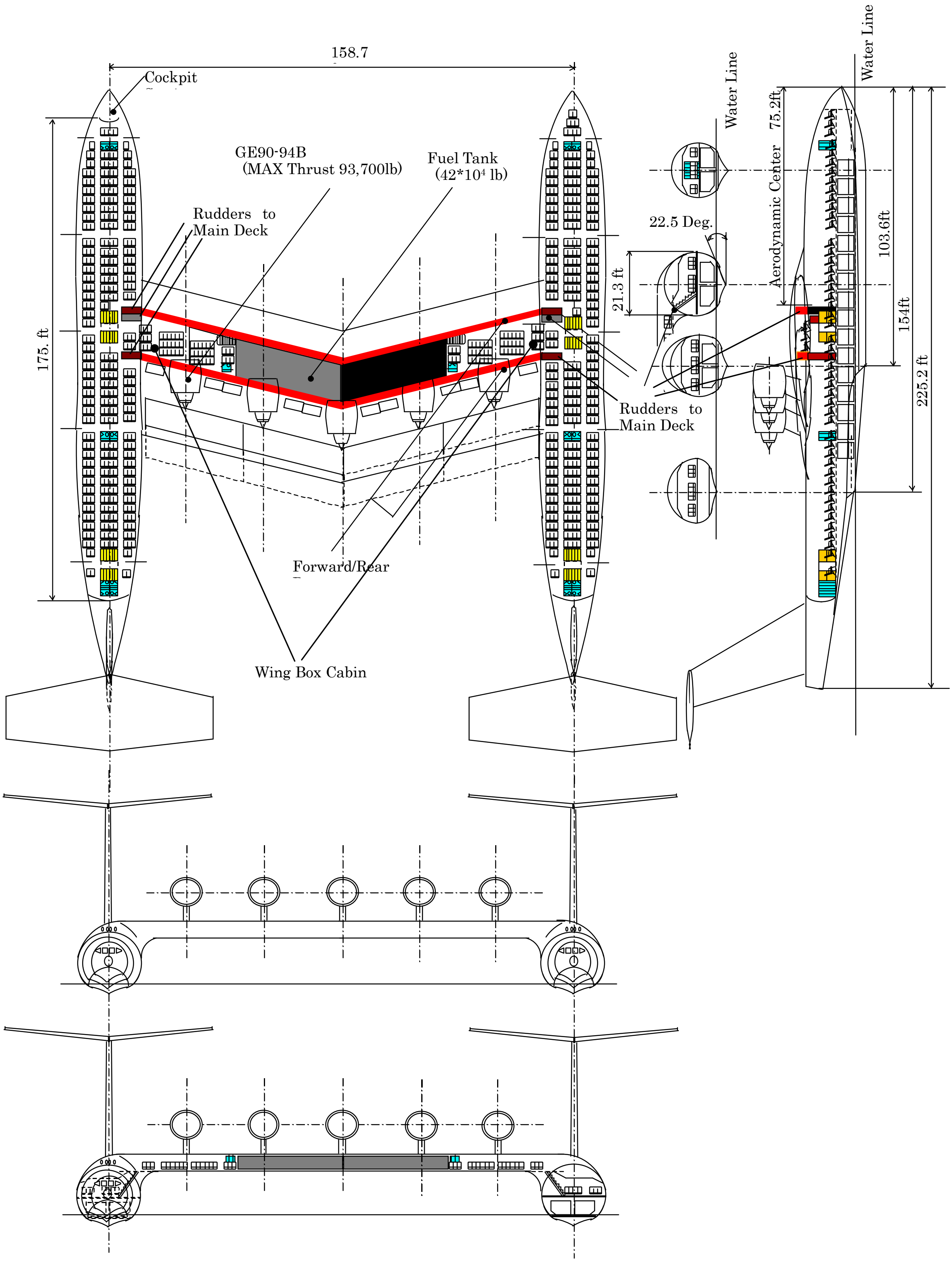
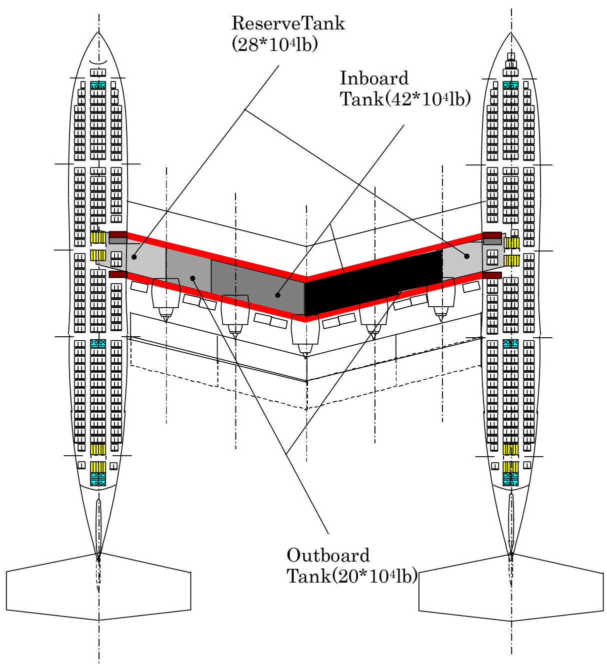
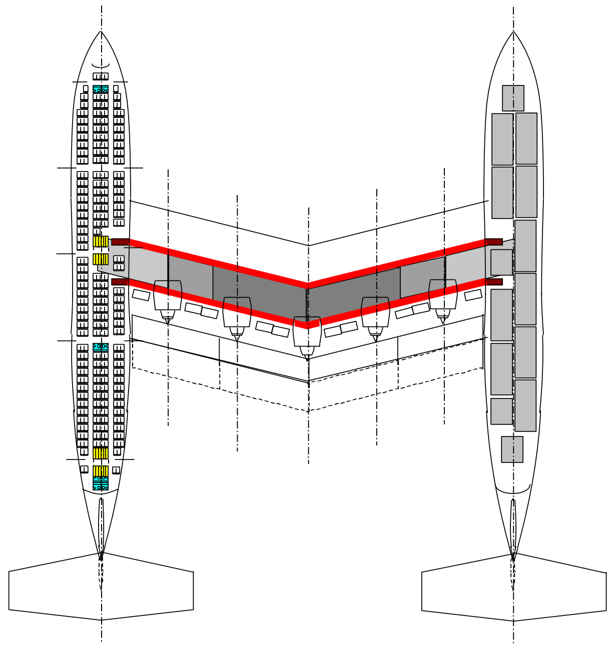


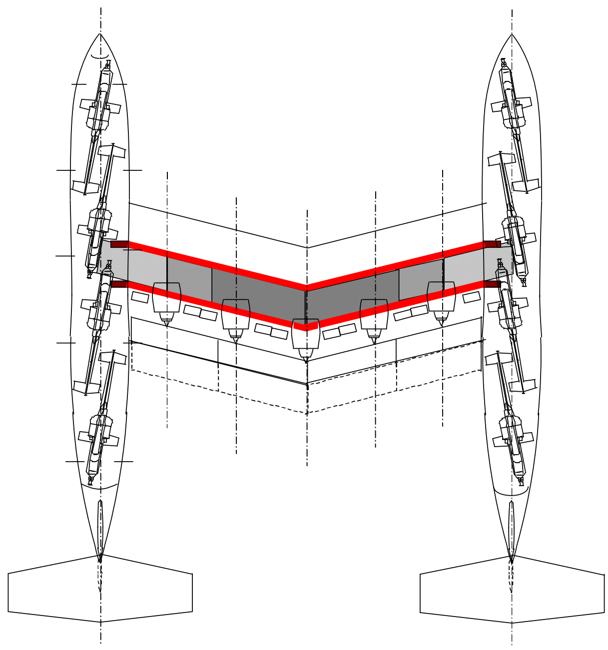
Figure 8 General Arrangement of Medium Range Cruise Mission Airplane. (950 seats, $35*10^4$lb Payload, 4,000nm Range)



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.

Figure 9 Internal Arrangement Examples of Long Range Configurations.

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