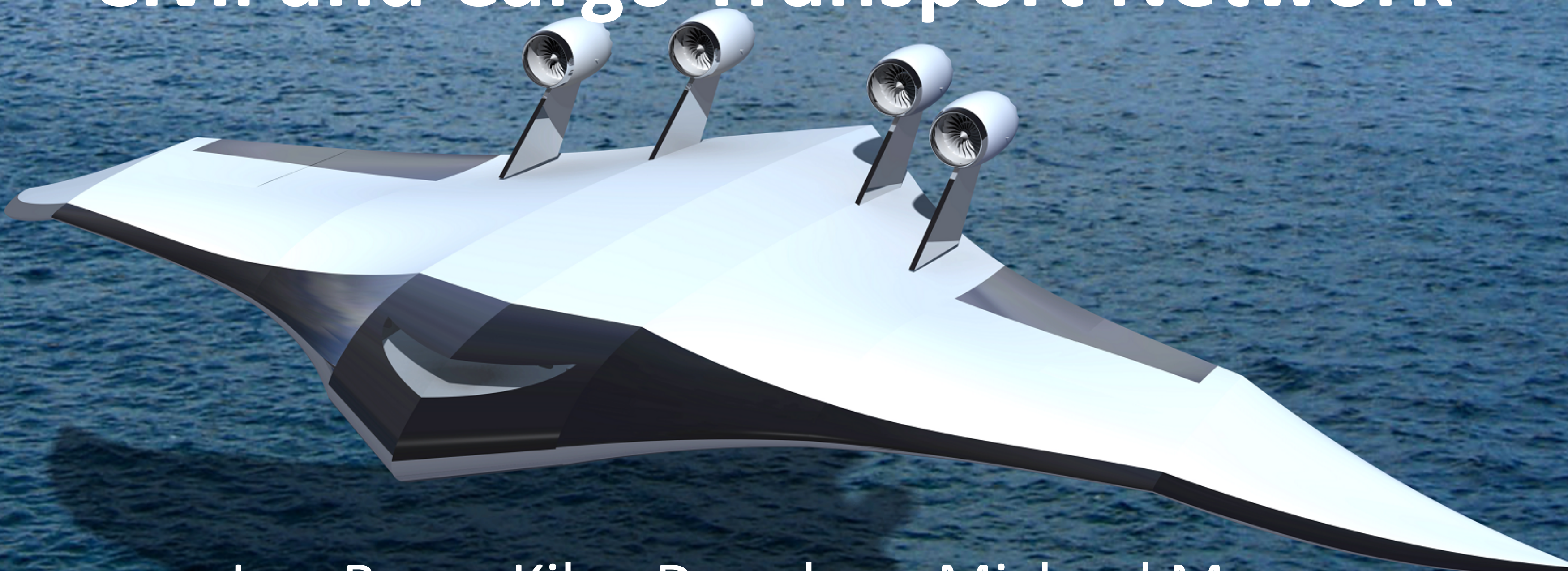
Ground Effect Vehicle Transoceanic Civil and Cargo Transport Network



Leo Byun, Kiley Donohue, Michael Mayo,
Julian McCafferty, Ruth Miller
Mentor: Mike Dudley

August 21, 2014

Problem

Current transoceanic transport is inefficient, fuel dependent, slow (freight ships), and expensive.

Solution

Low-flying, large transport aircraft utilizing ground effect to achieve increased fuel efficiency.

Background

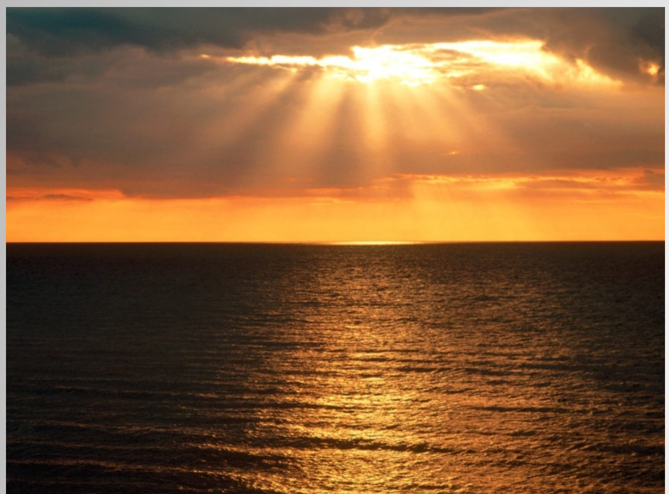
Ground Effect

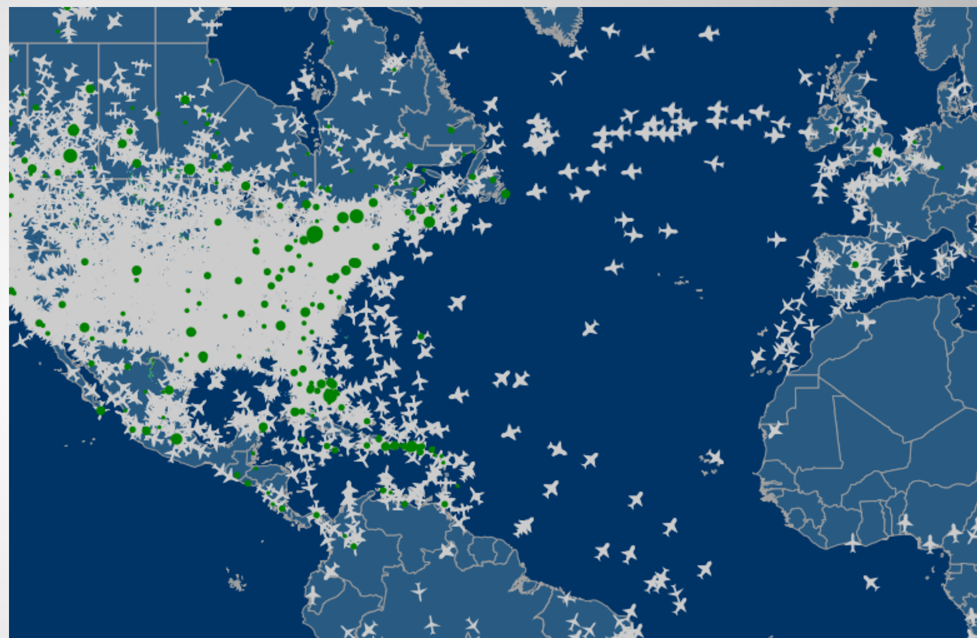
- Fly close to the ground.
- Ground disrupts wing tip vortices.
- Increases lift.
- More fuel efficient.

Perfect for reducing fuel costs in aviation!

Benefits

Economic and environmental benefits





Benefits

Passenger

Cargo

Previous Attempts

Ekranoplan and Spruce Goose Video

Previous Attempts

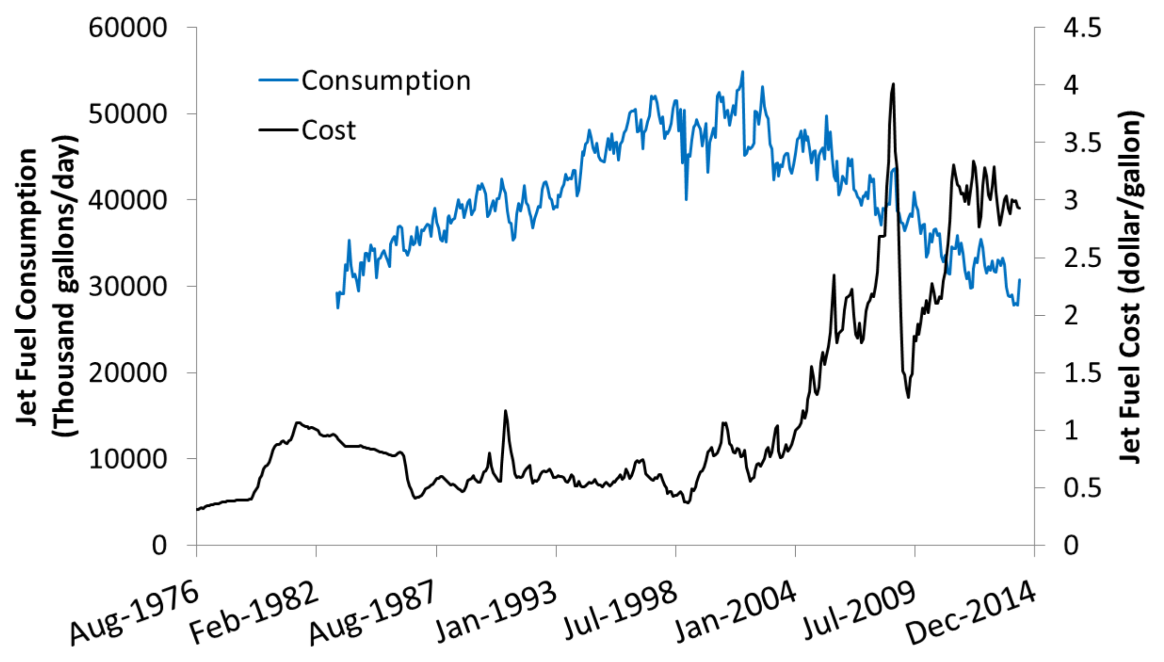
Boeing Pelican ULTRA

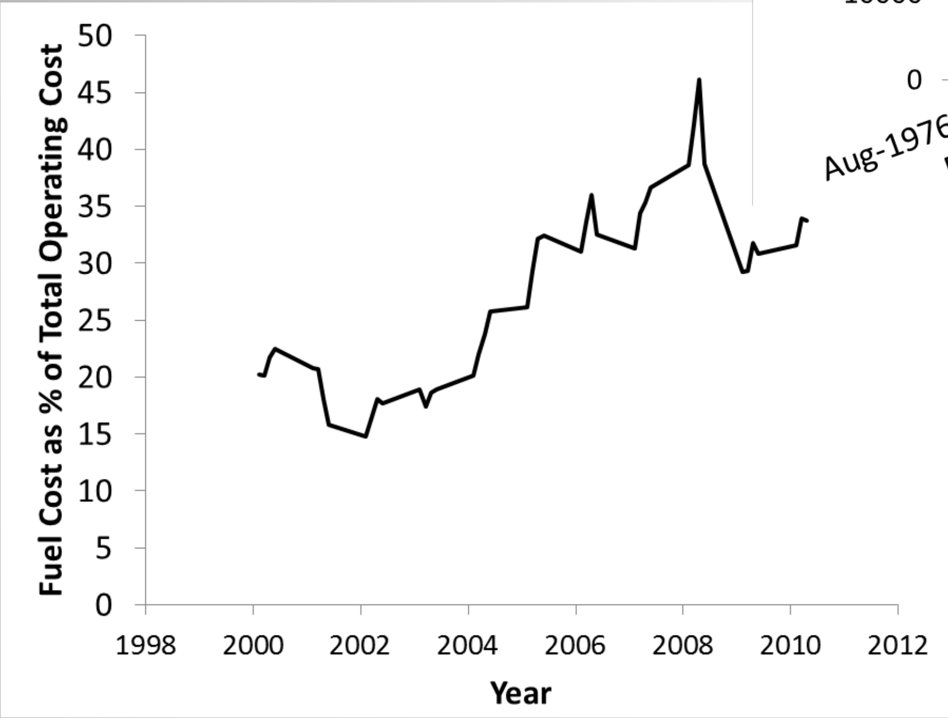
- Wingspan: 152 m
- Water and land
- L/D = 25-30
- Outboard wings tilt for efficiency

Image Credit: boeing.com

Fuel Costs

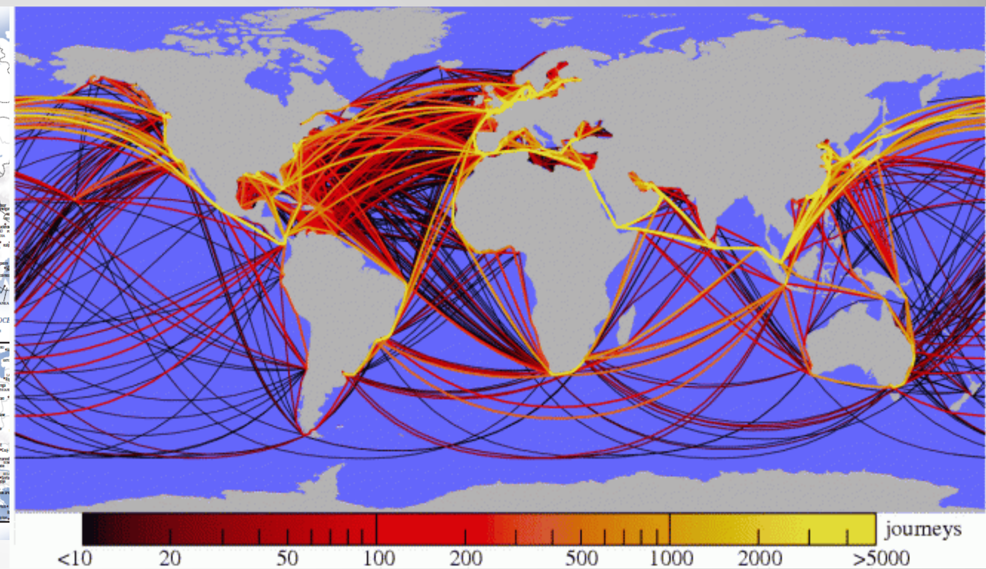
Fuel costs dominate!





Trend towards smaller aircraft.

Air Traffic Integration

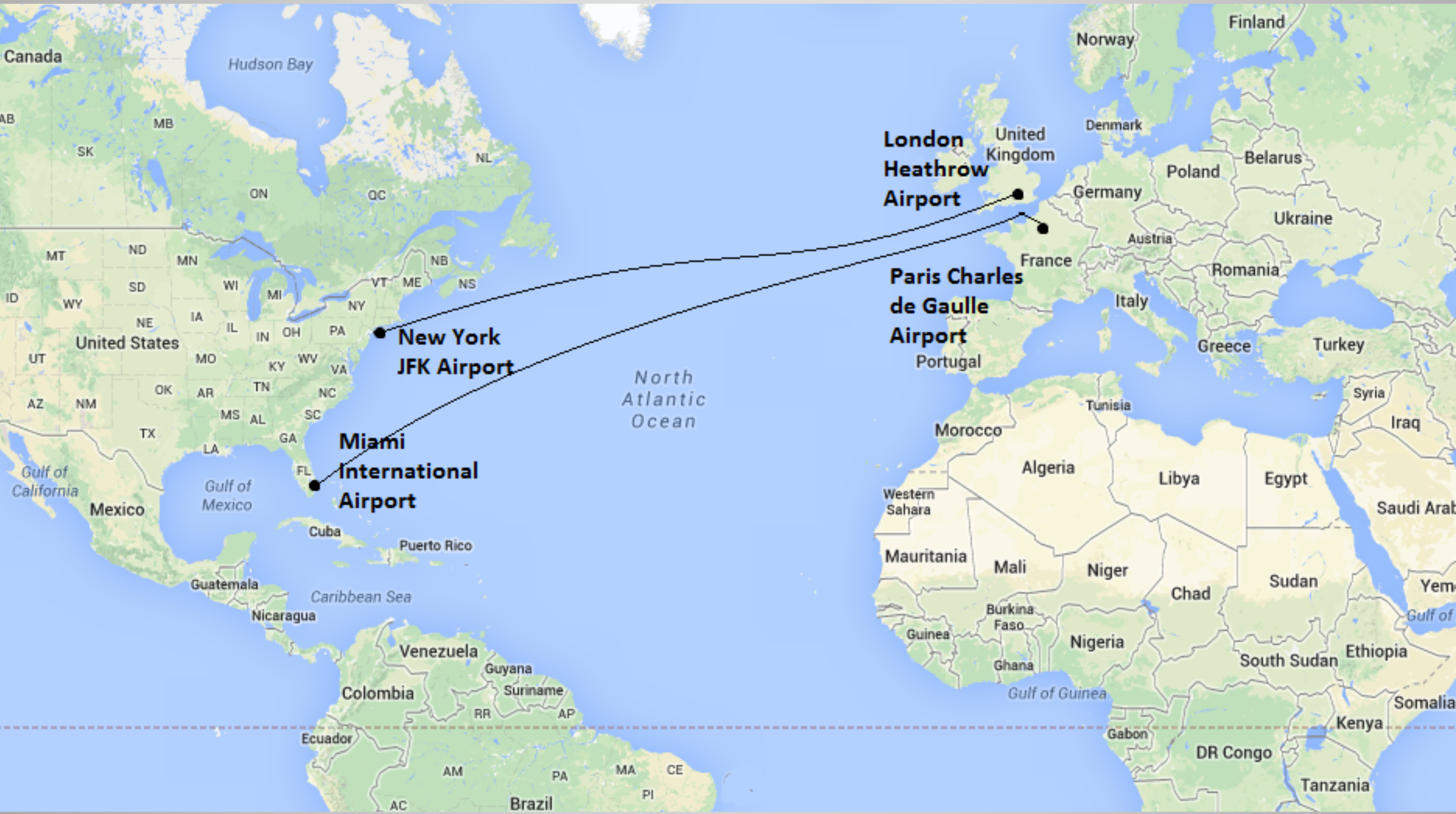


Selection criteria:

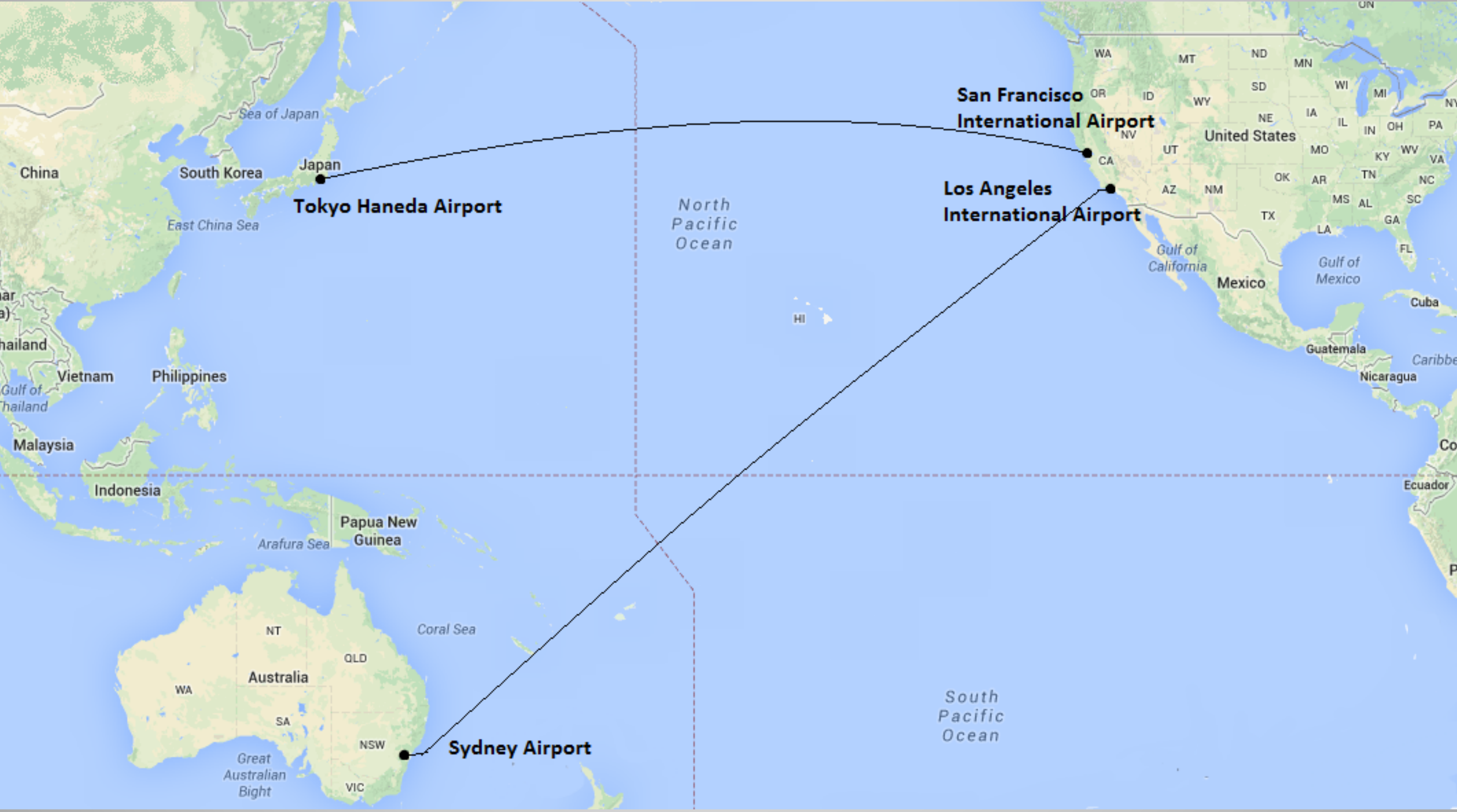
- International passengers
- Cargo traffic
- Elevation
- Distance inland
- Maximum supported wingspan

Image Credit: united.com, longshoreshippingnews.com

Proposed Initial Routes

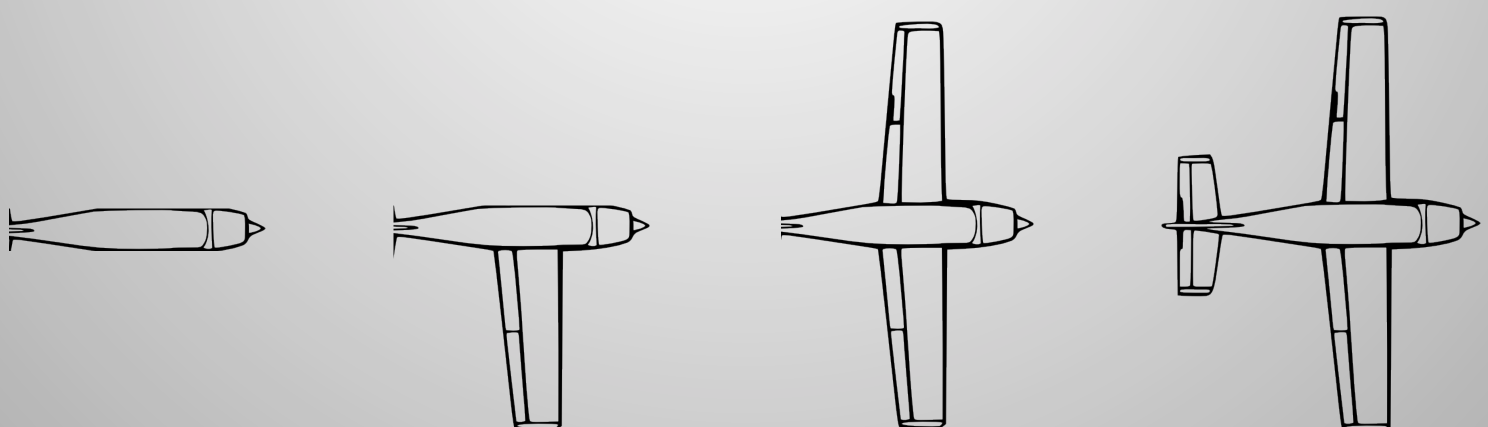


Proposed Initial Routes

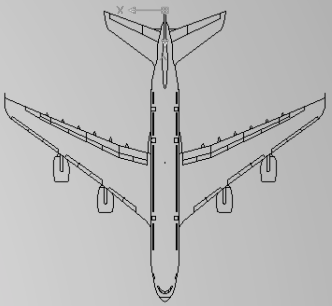


Preliminary Aircraft Design

1) Aircraft Weight Sizing
2) Takeoff Weight Sensitivities
3) Performance Constraint Analysis
4) Engine Selection and Placement



Preliminary Aircraft Design



GE Cruise Air Conditions		
Air Temp, T	60.0	°F
Air Pressure, P	2140	lb_f/sq.ft
Air Density, ρ	0.0024	slugs/cu.ft
Sound Speed, a	662.0	kts (nmi/hr)

Aircraft Specifications & Requirements		
Desired Range	7500	nmi
Cruise Altitude	100	ft
L/D_{CRUISE}	32	-
V_{CRUISE}	350	kts (nmi/hr)
$Mach_{CRUISE}$	0.5287	-
SFC	0.520	lb_T/lb_F/hr

Preliminary Aircraft Design

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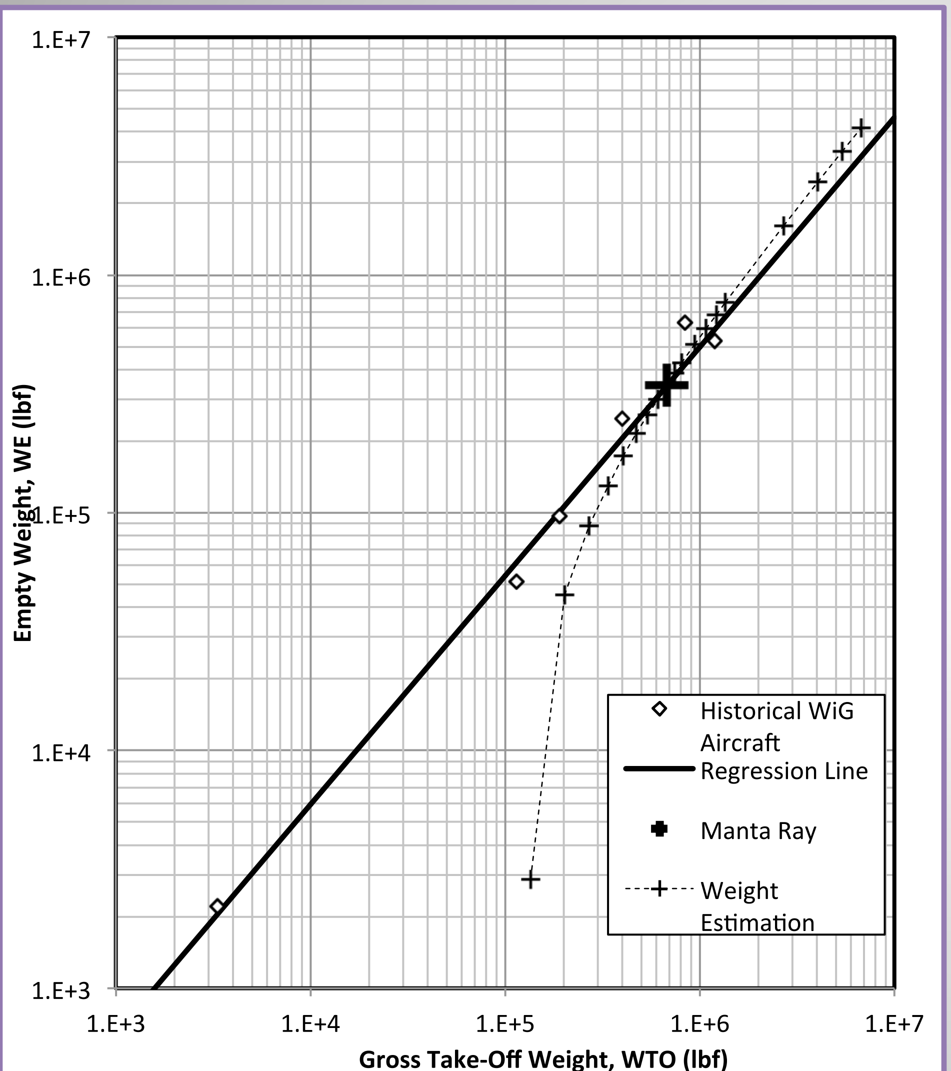
NASA

Aircraft Weight Sizing

Designation	Nickname	Weight			Wing Span, b	Wing Area, S	Aspect Ratio, AR	Thrust	Cruise Speed
		Empty, W_E	Payload W_P	Take Off, W_{TO}					
		lb_f	lb_f	lb_f	ft	ft^2	-	lb_f	kts
Ekranoplan	Duck	630500	302000	837757	144.3	5900	3.53	228800	243
KM	Caspian Sea Monster	529000	300000	1199315	123.3	7131	2.13	286700	232
RFB X-114		2205	-	3307	23.0	75.6	7.00	-	81
VVA-14	Bartini Beriev	51119	36700	114400	98.5	2344	4.14	30124	346
H-4	Sproose Goose	250000	-	400000	320.9	11430	9.01	-	217
A-40	Albatros	96783		189630	136.5	2153	8.65		388
A-90	Orlyonok	-	61730	308647	103.3	3272	3.26	80481	240
Pelican*	ULTRA	-	2800000	5400000	500.0	43000	5.81		216
Be-2500*	Super-Heavy Seaplane	-	2204620	5000000	-	-	-	-	-

*Theoretical Aircraft not included in weight sizing

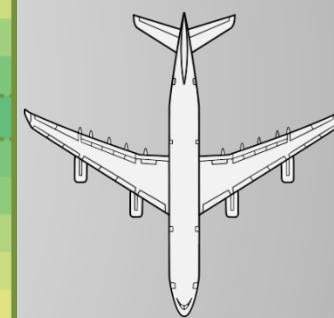
Preliminary Aircraft Design



W_{TO}	W_{FUEL}	$W_{OE\ TENT}$	$W_{E,REGRESS}$	% Diff
lb_f	lb_f	lb_f	lb_f	%
67500	25059	-39559	37234	206.24%
135000	50118	2882	72588	96.03%
202500	75177	45323	107265	57.75%
270000	100235	87765	141510	37.98%
337500	125294	130206	175438	25.78%
405000	150353	172647	209115	17.44%
472500	175412	215088	242584	11.33%
540000	200471	257529	275876	6.65%
607500	225530	299970	309015	2.93%
675000	250589	342411	342019	0.11%
742500	275647	384853	374900	2.65%
810000	300706	427294	407671	4.81%
945000	350824	512176	472920	8.30%
1080000	400942	597058	537824	11.01%
1215000	451059	681941	602429	13.20%
1350000	501177	766823	666769	15.01%
2700000	1002354	1615646	1299874	24.29%
4050000	1503531	2464469	1920866	28.30%
5400000	2004708	3313292	2534120	30.75%
6750000	2505886	4162114	3141684	32.48%

$W_{TO\ GUESS}$	**675,000**	lb_f
W_{FUEL}	250,589	lb_f
W_{PL}	82,000	lb_f
$W_{OE\ TENT}$	342,411	lb_f
$W_{E,REGRESS}$	342,019	lb_f

306,175 kg

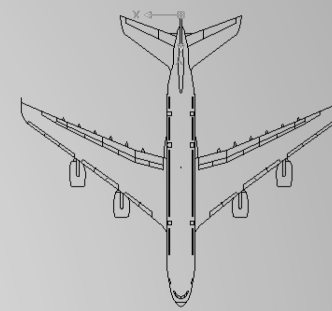


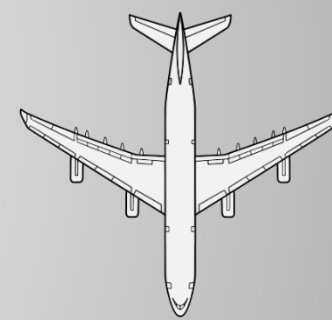
Weight estimate for 400 Passengers

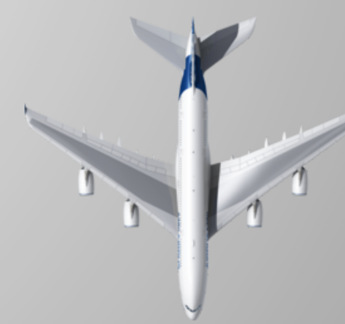
Preliminary Aircraft Design

Passengers and Takeoff Weight Comparison

Civil Transport	Number of Passengers	Max Takeoff Weight, W_{TO}	Takeoff Weight per passenger (W_{TO}/pass)
Boeing 747-8	467 (2-class)	975,000 lb_f	2088 lb_f/pass
Boeing 747-400	524 (2-class)	910,000 lb_f	1737 lb_f/pass
Boeing 777-9X	407 (3-class)	775,000 lb_f	1904 lb_f/pass
Boeing 787-10	323 (3-class)	557,000 lb_f	1724 lb_f/pass
Airbus A380-800	644 (2-class)	1,268,000 lb_f	1969 lb_f/pass
NASA Manta-Ray	***400***	***675,000 lb_f***	**1688 lb_f/pass**







Ground effect weight estimation yields **~10%** *less* weight per passenger than current civil transports

Preliminary Aircraft Design

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Takeoff Weight Sensitivities

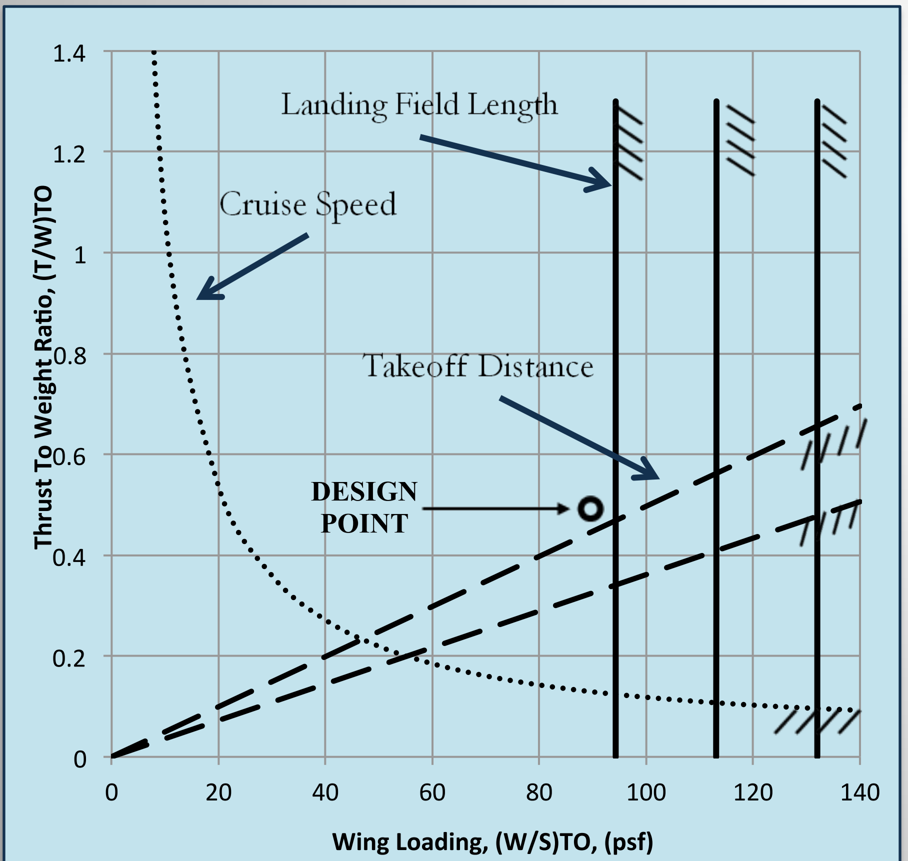
Takeoff Weight Sensitivity	$\frac{\partial W_{TO}}{\partial W_{PL}}$	$\frac{\partial W_{TO}}{\partial W_{E}}$	$\frac{\partial W_{TO}}{\partial R}$	$\frac{\partial W_{TO}}{\partial V}$	$\frac{\partial W_{TO}}{\partial c_p}$	$\frac{\partial W_{TO}}{\partial L/D}$
Parameter	Payload	Empty Weight	Cruise Speed	Range	Cruise Speed	Lift to Drag Ratio
Unit	~	~	lb_f / hr	lb_f / kts	lb_f – hr	lb_f
Value	7.11	2.05	140	-3,000	1,698,019	-32,849

Additional **16,980 lbs** takeoff weight *saved* per **0.01** *decrease* in SFC
Additional **32,849 lbs** takeoff weight *saved* per **unit** *increase* in L/D

Engine efficiency and L/D benefit from Ground Effect are critical!

Preliminary Aircraft Design

Performance Constraint Analysis



Constraints based on:

- Takeoff Distance
- Landing Field Length
- Cruise Speed

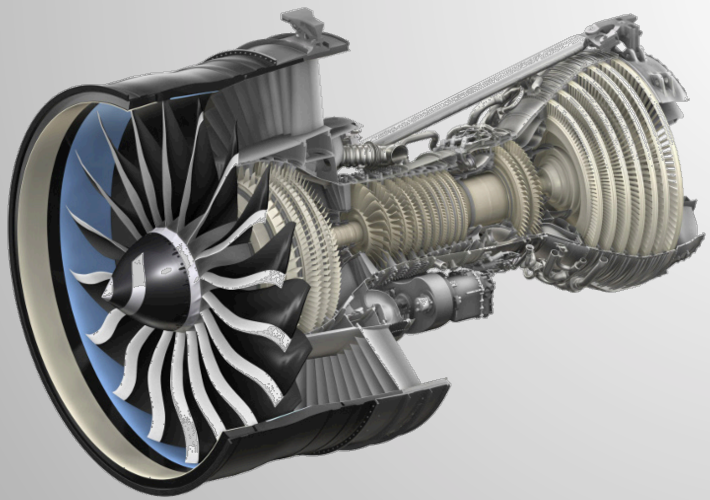
Design Parameter	Value
Takeoff Wing Loading	94 psf (4.5 kPa)
Takeoff Thrust to Weight Ratio	0.45
Takeoff Thrust	303,750 lb (137,779 kg)
Aspect Ratio	5
Wing Span	189.5 ft (57.8 m)
Wing Area	7181 ft^2 (667 m)

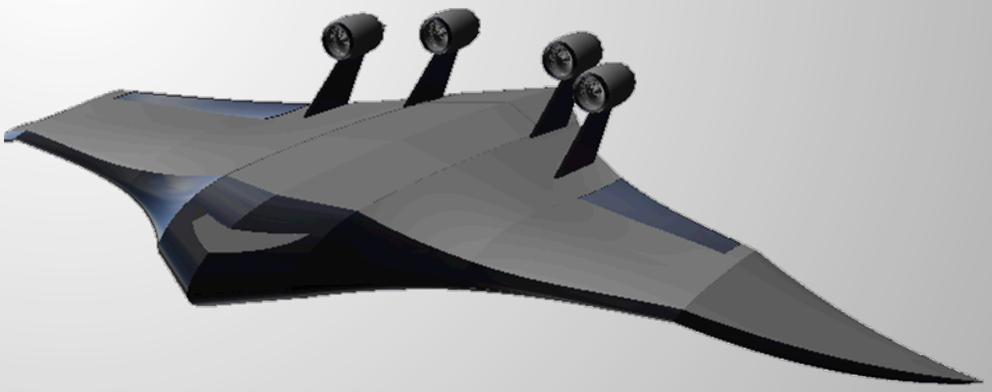
Preliminary Aircraft Design

Engine Selection and Placement

Required Takeoff Thrust: 303,750 lb (1,351 kN)

Selected Engine: 4 x Genx-1B74 Turbofan Engines

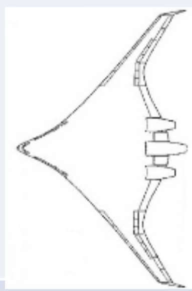
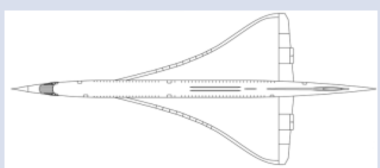
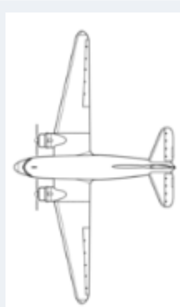




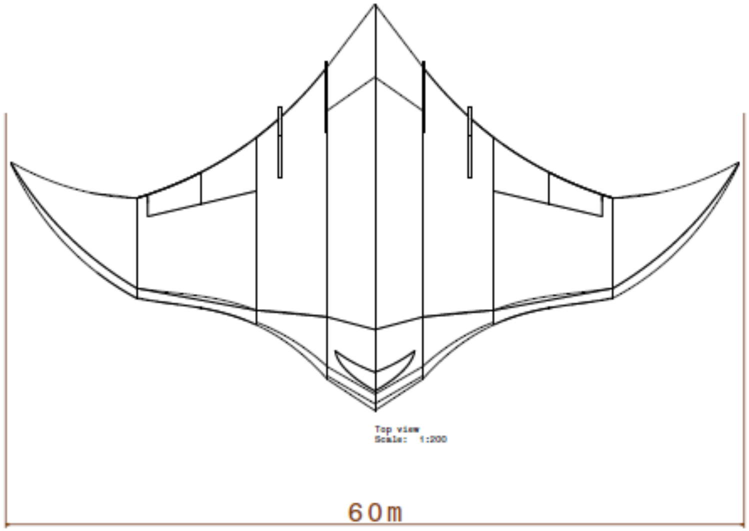
76,100 lb (338.5 kN) Takeoff Thrust each,

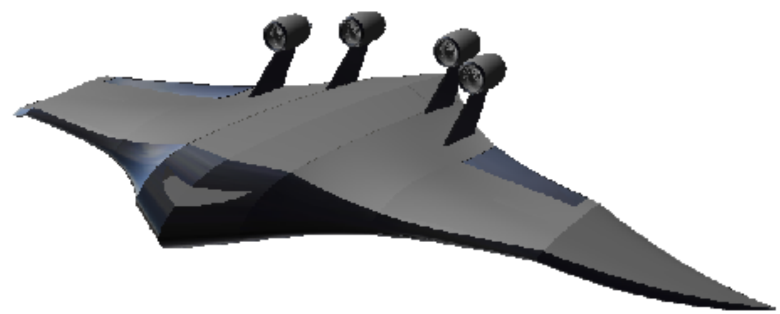
304,400 lb (1,354 kN) Total Takeoff Thrust

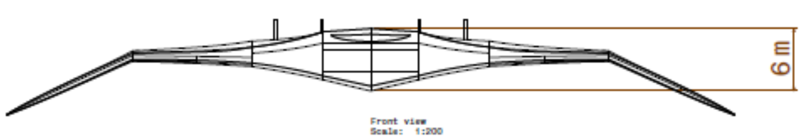
Preliminary Aircraft Design

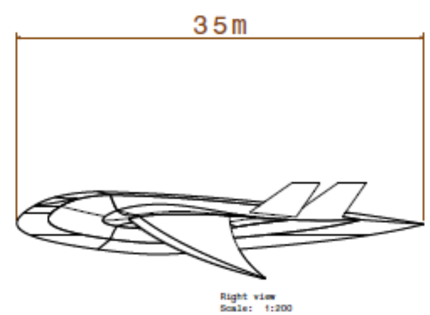
Configuration		Pros	Cons
Conventional		• Well-tested • Passenger accepted	• Engine placement causes sea water intake
Blended Wing Body		• Low drag • Fuselage shields engines from sea	• Requires fly-by-wire • Untested in rough weather conditions
Delta Wing		• High maneuverability • High stall angle	• Low L/D in subsonic flight • Poor stability
Wide-Span Wing		• High lift • Maintains ground effect at high altitude	• Complex wing support structure

Preliminary Aircraft Design

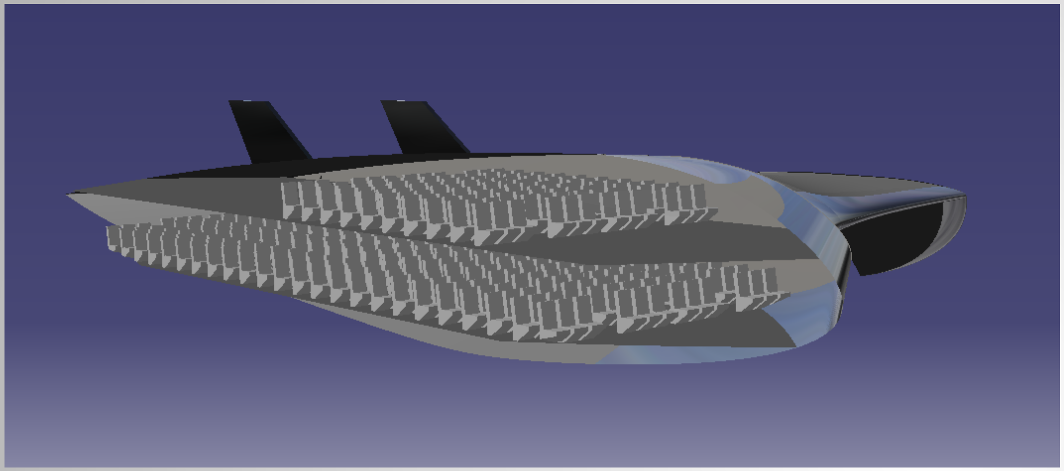






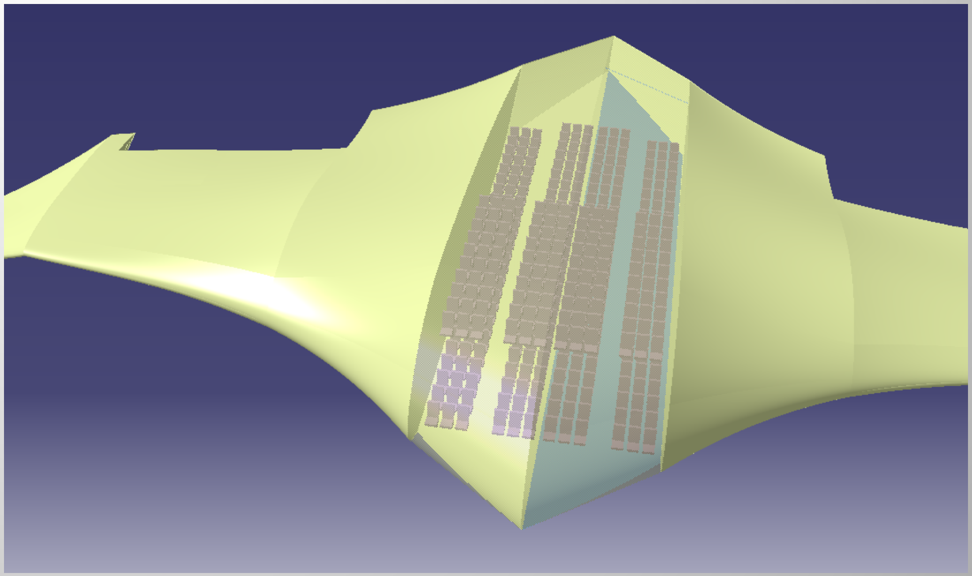


Preliminary Aircraft Design



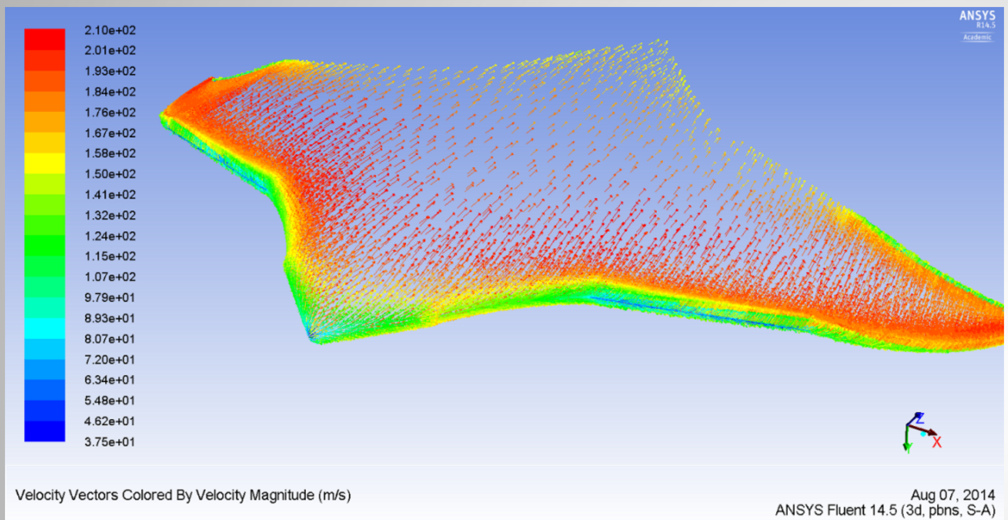
Cabin Layout – Double decker seats 400

Rows of 3 on each side
Row of 6 down the middle
120 seats on upper deck
280 seats on lower deck



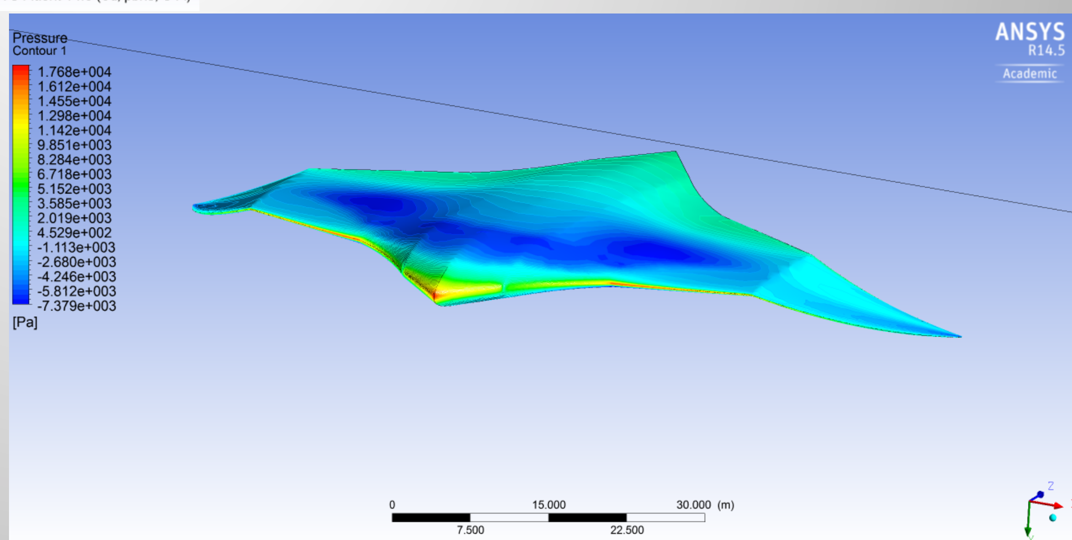
Preliminary Aircraft Design

CFD Analysis using ANSYS Fluent



Velocity Vectors
Colored by Magnitude

Pressure Contours

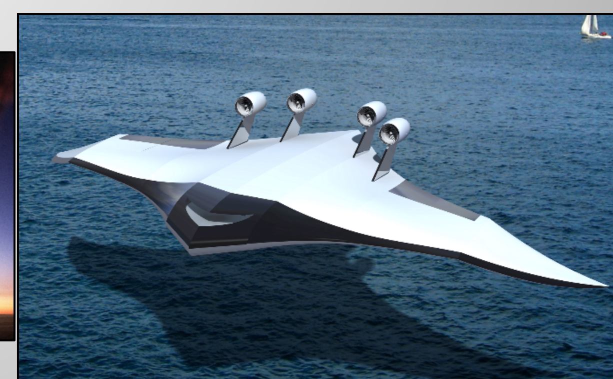


Conclusions

Commercial ground effect planes will lead to more fuel efficient trans-oceanic flights.

- Cheaper flights.
- More accessible.
- Less pollution.
- Revolutionize aviation design.





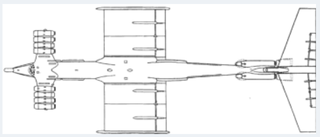
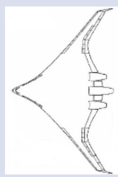
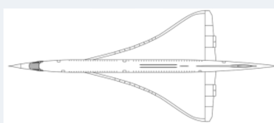
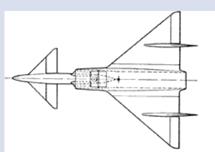
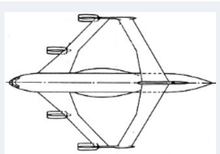
Questions?

Appendix

References:

Izagirre, V. (Jan 29 2013). *The first flight of the spruce goose* [Video file]. Retrieved from http://www.youtube.com/watch?v=wGNyAd2uffg.

Igorks. (May 20, 2009). *Ekranoplan KM – Caspian Sea Monster* [Video file]. Retrieved from http://www.youtube.com/watch?v=Ydhe70Wig3k.

Configuration	Pros	Cons
Conventional 	Well-tested, passenger acceptance	Engine placement causes sea water intake
Caspian Sea Monster 	Good stability, designed for amphibious takeoff/landing	Designed for short flights
Blended Wing Body 	Low drag, good cargo carrying capability, fuselage can shield engines from sea water	Requires fly-by-wire, untested in rough weather conditions
Delta Wing 	High maneuverability, high stall angle	Low L/D in subsonic flight, poor stability
Delta Canard 	Canard increases lift, improved low speed handling	Low L/D in subsonic flight, poor stability
Box Wing 	High effective wingspan, lighter wing	Difficult to manufacture
Wide-Span Wing 	High lift, can maintain ground effect at high altitude	Complex Wing Support Structure