SAND2019-5606C

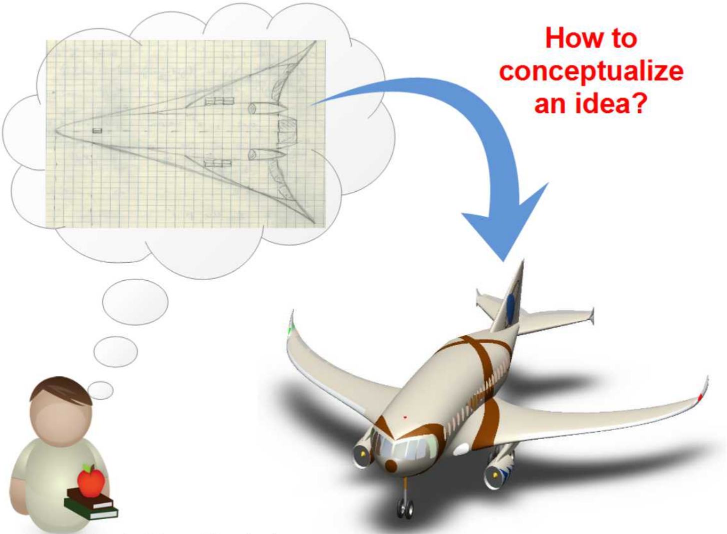
Rapid Sizing for Aircraft Design

Conceptualization and Performance Analysis

Leonardo D Le
Scrimmage | Military Systems Analytics

MORS 87th Symposium, Colorado Spings, CO
6/20/2019

From an Idea to a Concept



Overview

Sandia National Laboratories

General Design Procedures

Preliminary Sizing

Conceptualization

Performance Analysis

Conclusion Remarks

Conceptualization Procedures

1. Establish the design objective and the requirements to meet the objective
2. Perform statistcal design (zero-level sizing)
3. Perform trade-study to establish the design space (optimal sizing)
4. Conceptualize the new concept
5. Performance analysis and validation testing (beyond the scope of this discussion)

Design Objective and Requirements

- Design objective: What tasks and mission do we want the new concept perform - i.e., commercial service, surveillance, battle engagement, etc.?
  - Customer's demands
  - Market survey
  - Exploratory purposes

- Design requirements: What features must the concept have to accomplish the tasks and the mission?
  - It must fly.
  - It has enough room for the payload and fuel.
  - It must be capable to perform demanded manuever.

Case Study: Design a Commercial Jet Aircraft

Sandia National Laboratories

Design Objectives

- Task: Commercial jet transport
- Payload: 200 passengers
- Range: 3,000 nautical miles
- Cruise speed: Mach 0.85 at 38,000 ft ICA

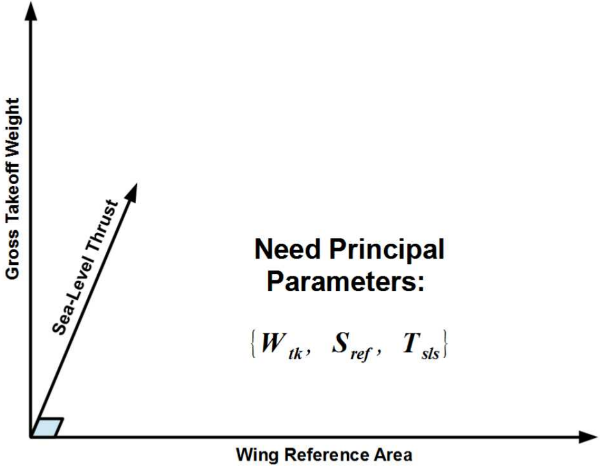
Design Requirements

- Takeoff distance: Less than 6,400 ft at 6,000 ft above sea level
- Time to climb: Less than 20 minutes
- Approach speed: Less than 130 knots
- Meet FAR takeoff climb requirements
- Wing span limit for airport operation

Principal Parameters

Sizing an aircraft is to determine its:

- Gross takeoff weight
- Referenced wing area
- Required sea-level static thrust



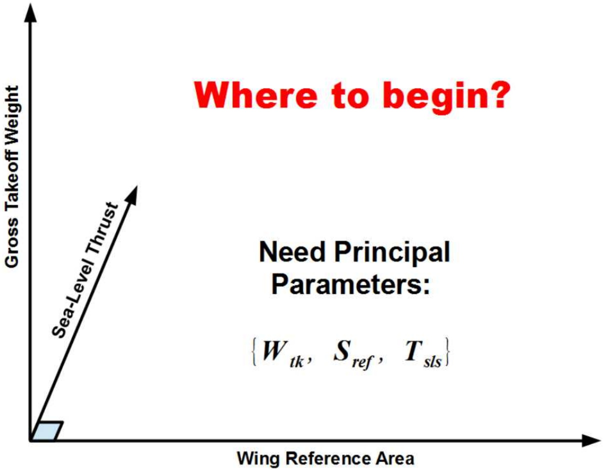
Need Principal Parameters:

$$\{W_{tk},\ S_{ref},\ T_{sls}\}$$

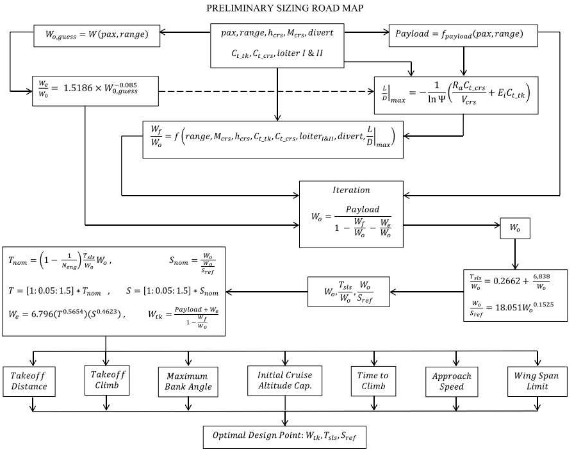
Principal Parameters

Sizing an aircraft is to determine its:

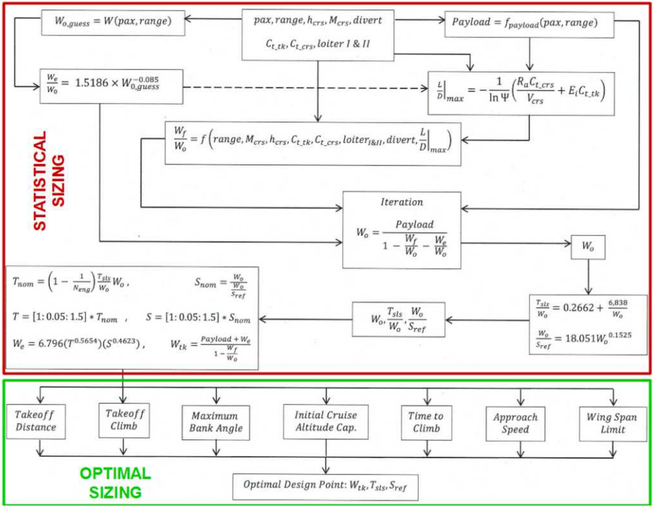
- Gross takeoff weight
- Referenced wing area
- Required sea-level static thrust



Preliminary Sizing Roadmap



Preliminary Sizing Roadmap



Statistical (Zero-Level) Sizing

- Gross takeoff weight

$$W_0 = W_{empty} + W_{payload} + W_{fuel}$$

- Thrust-to-weight ratio

$$\frac{T_{sls}}{W_0} = \frac{6,838}{W_0} + 0.2662$$

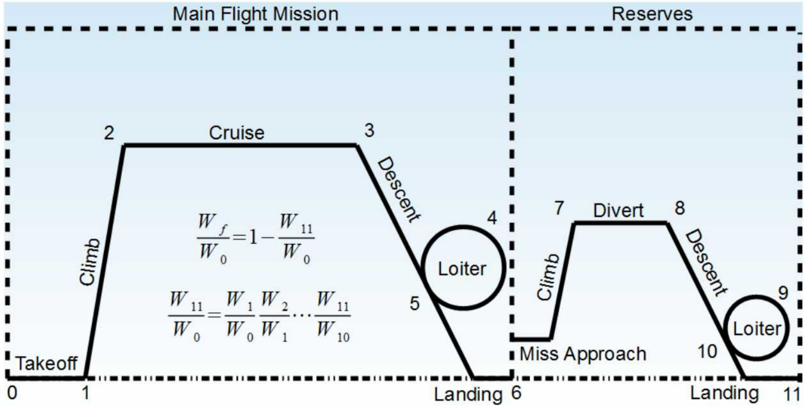
- Wing loading

$$\frac{W_0}{S_{ref}} = 18.051 \times W_0^{0.1525}$$

The key is to estimate the gross takeoff weight.

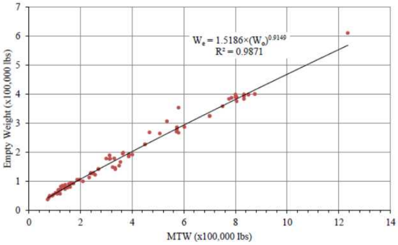
Fuel Weight

The fuel weight is empirically estimated from the flight mission.



Empty Weight and Initial Guess of Takeoff Weight

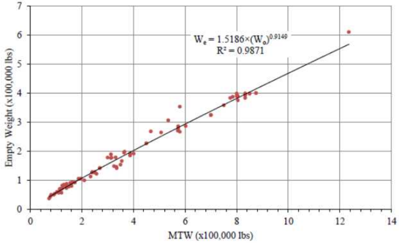
Empty Weight vs Takeoff Weight



$$W_e = 1.5186 \times W_0^{0.9149}$$

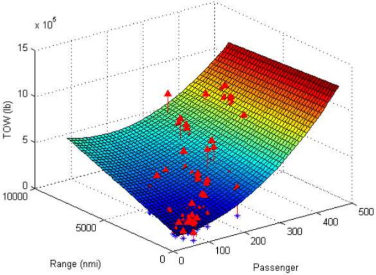
Empty Weight and Initial Guess of Takeoff Weight

Empty Weight vs Takeoff Weight



$$W_e = 1.5186 \times W_0^{0.9149}$$

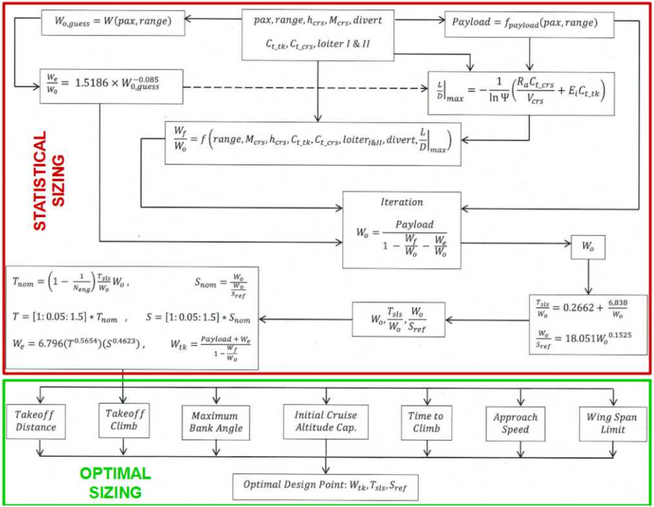
Initial estimate of takeoff weight



Iteration to Solve for the Initial Takeoff Weight

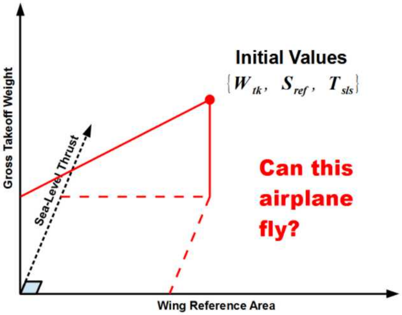
$W_{0,guess}$	Payload	W_{empty}	W_{fuel}	$W_{0,calc}$
262,292	57,470	162,114	89,101	308,686
308,686	57,470	153,907	85,771	297,148
297,148	57,470	155,761	86,524	299,755
299,755	57,470	155,333	86,350	299,153
299,153	57,470	155,431	86,390	299,291
299,291	57,470	155,409	86,380	299,259
299,259	57,470	155,414	86,383	299,266
299,266	57,470	155,413	86,382	299,265
299,265	57,470	155,413	86,382	299,265

Preliminary Sizing Roadmap



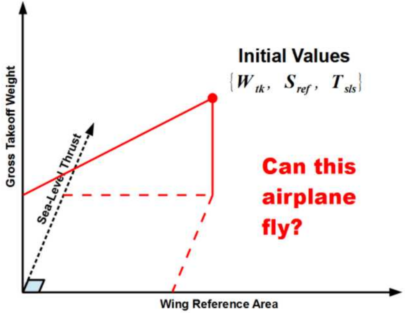
Optimal Sizing

The need of optimal sizing

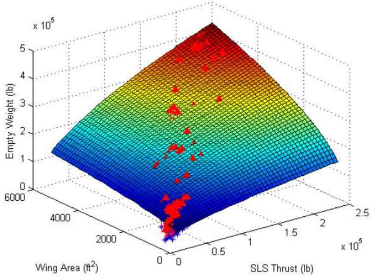


Optimal Sizing

The need of optimal sizing

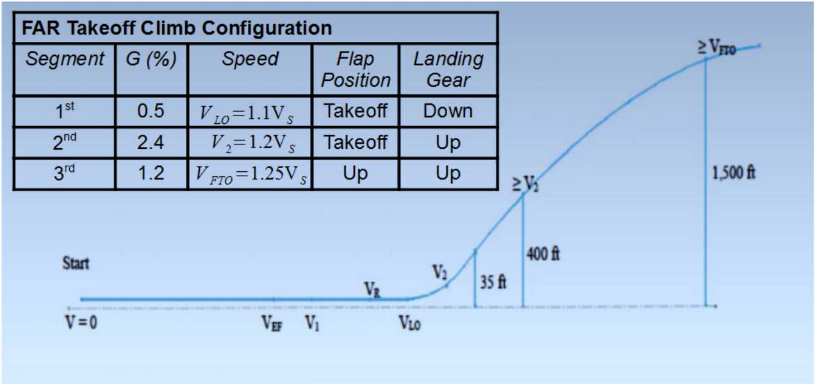


The important of empty weight



Takeoff Requirements

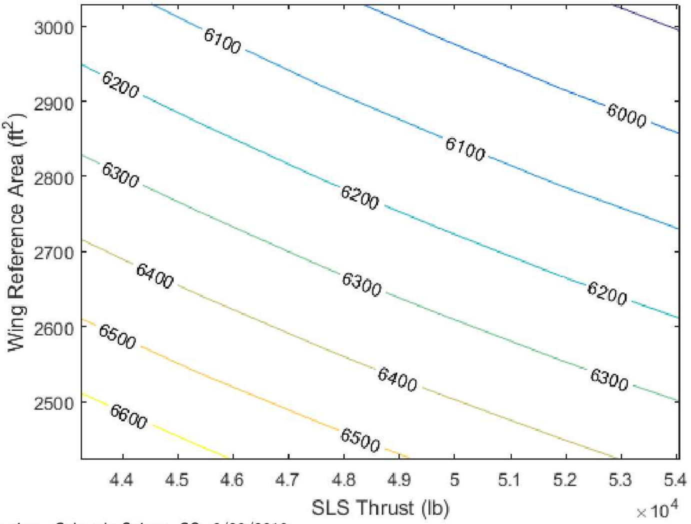
Sandia National Laboratories



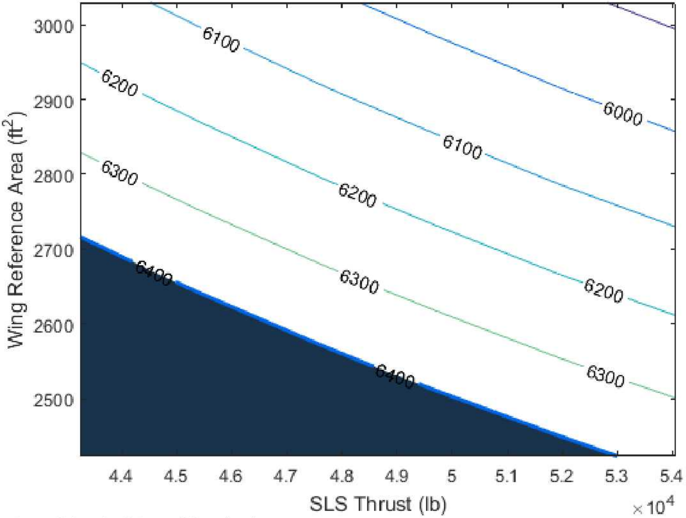
FAR Takeoff Climb Configuration				
Segment	*G (%)*	*Speed*	*Flap Position*	*Landing Gear*
1st	0.5	$V_{LO}=1.1V_S$	Takeoff	Down
2nd	2.4	$V_2=1.2V_S$	Takeoff	Up
3rd	1.2	$V_{FTO}=1.25V_S$	Up	Up

Takeoff path and takeoff climb requirements

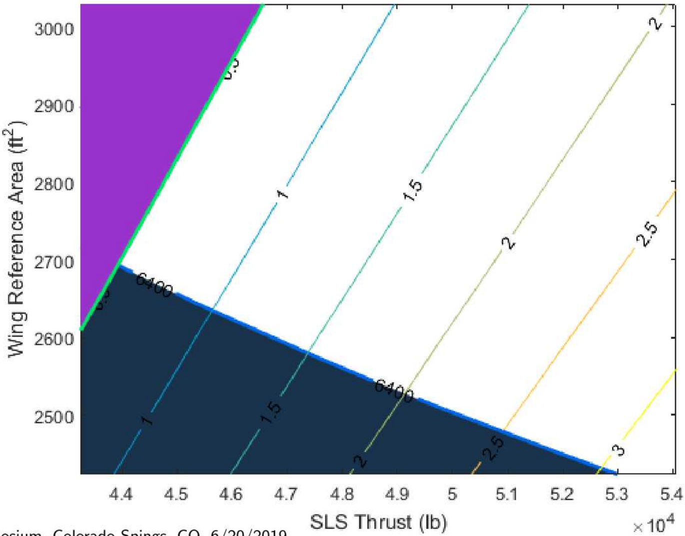
Takeoff Ground Roll at 6,000 ft



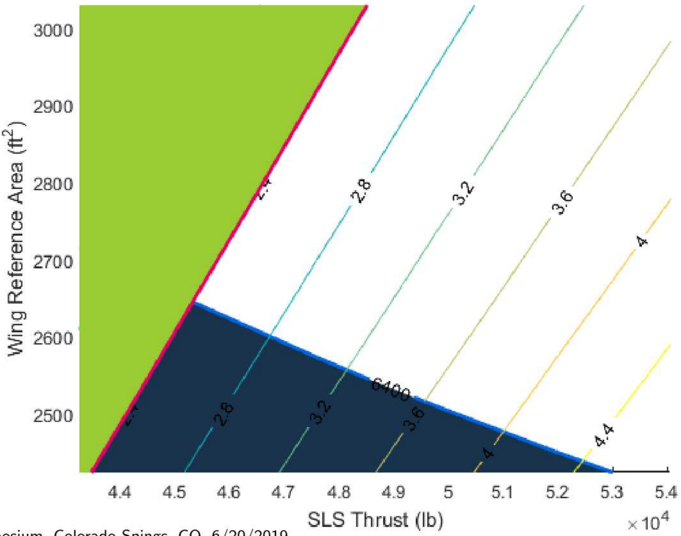
Takeoff Ground Roll Distance $\leq$ 6,400 ft at 6,000 ft



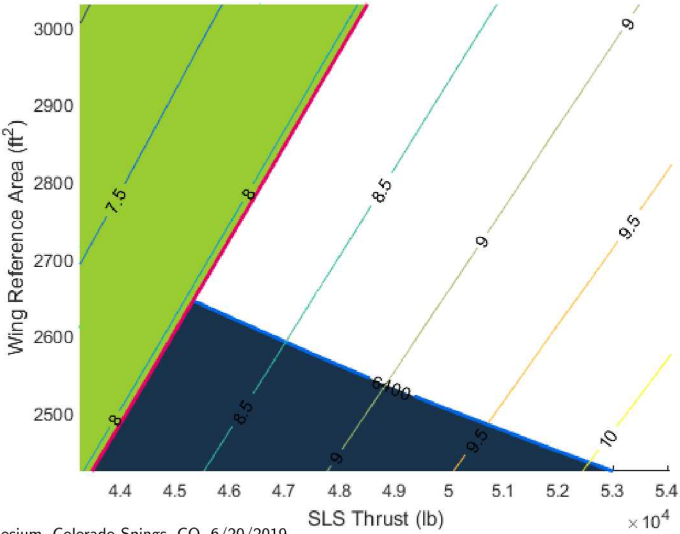
Takeoff Climb Gradient ≥ 0.5% in 1st Segment



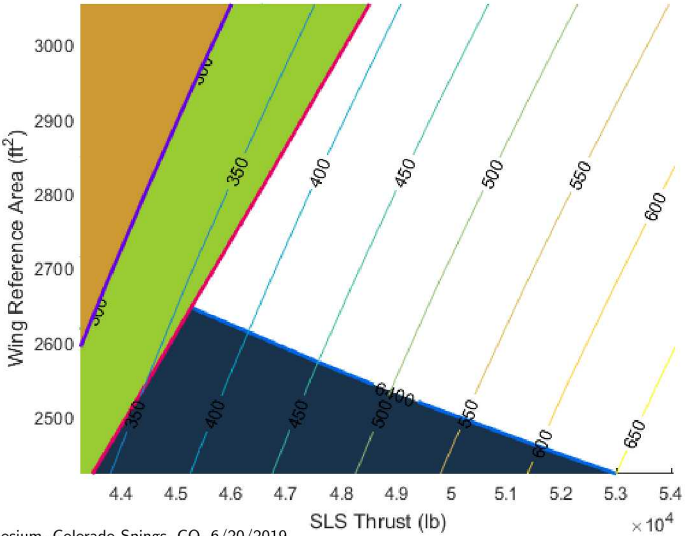
Takeoff Climb Gradient $\geq 2.4\%$ in 2nd Segment



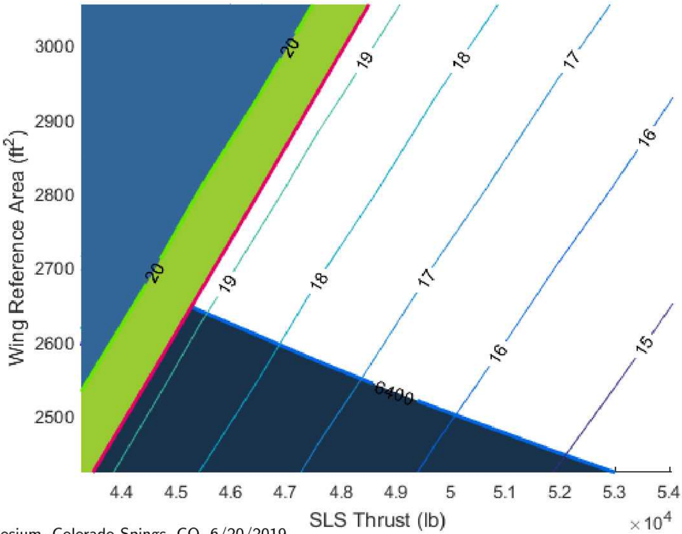
Takeoff Climb Gradient ≥ 1.2% in 3rd Segment



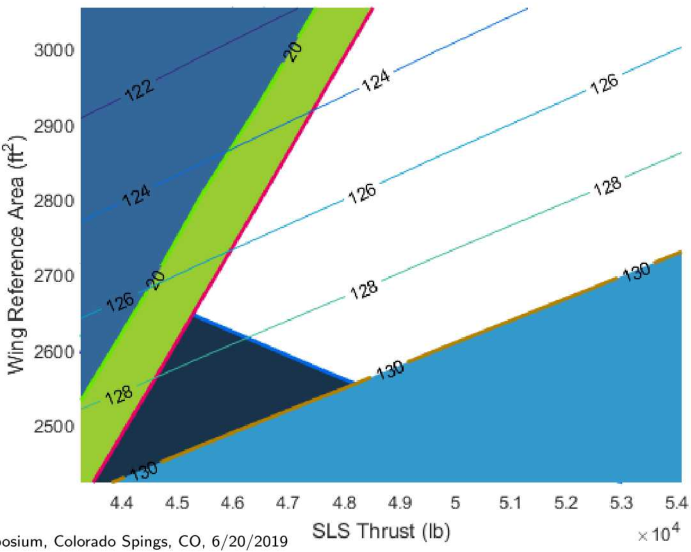
Rate of Climb $\geq$ 300 fpm at 38,000 ft ICA



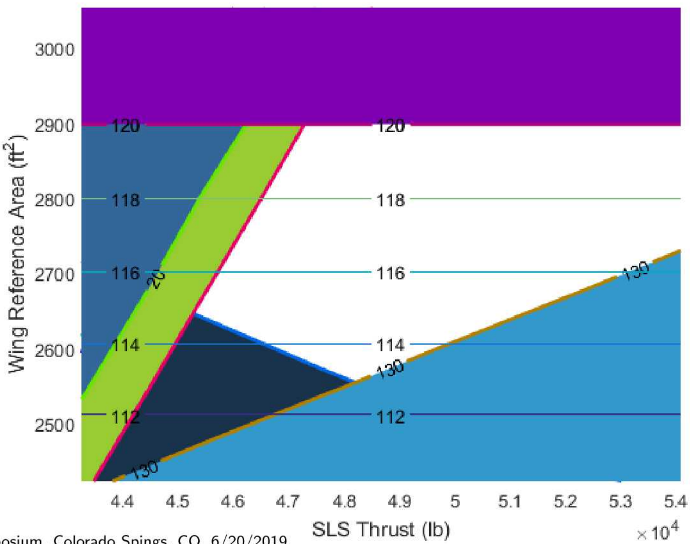
Time to Climb $\leq$ 20 mn from 1,500 ft to 38,000 ft



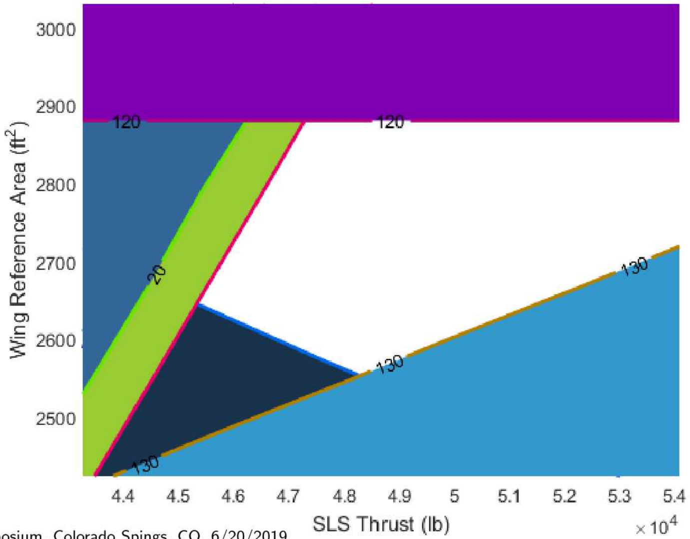
Approach Speed $\leq$ 130 kts for Landing at 6,000 ft



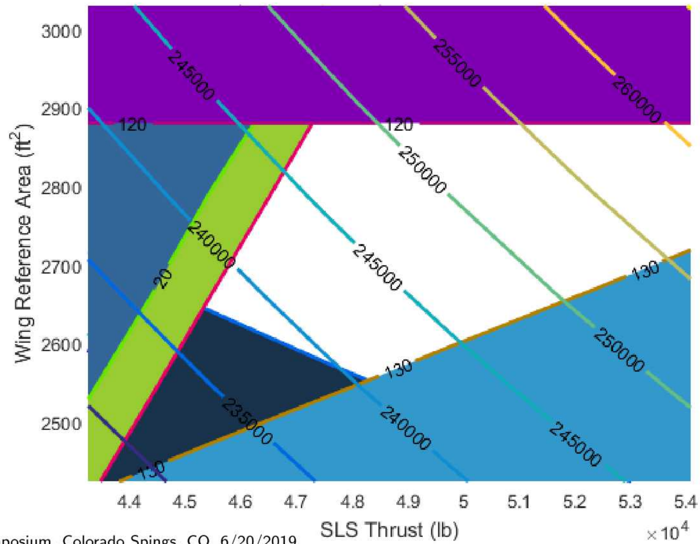
Wing Span Limit $\leq$ 120 ft



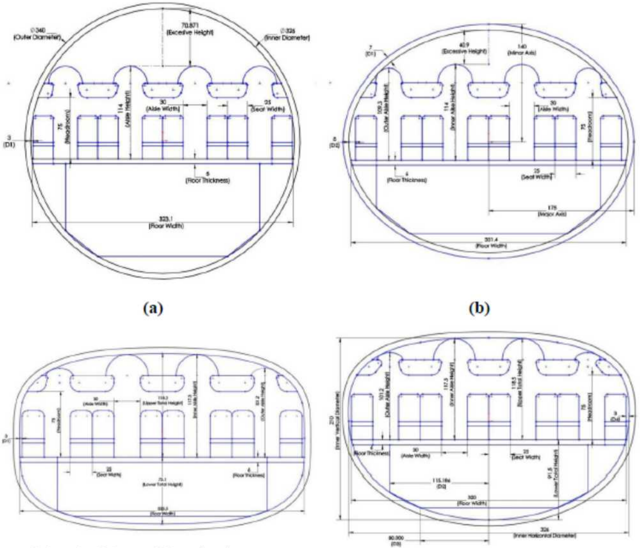
Design Space



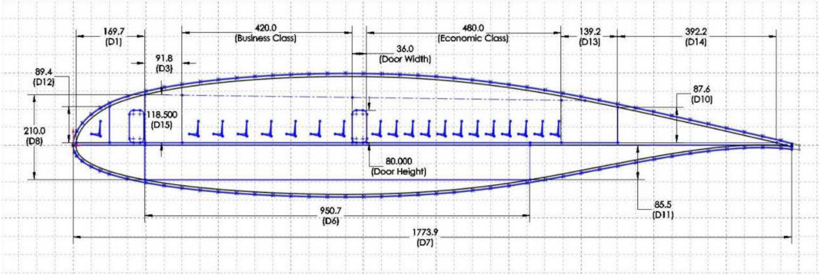
Optimal Design Point: Minimum Principal Parameters



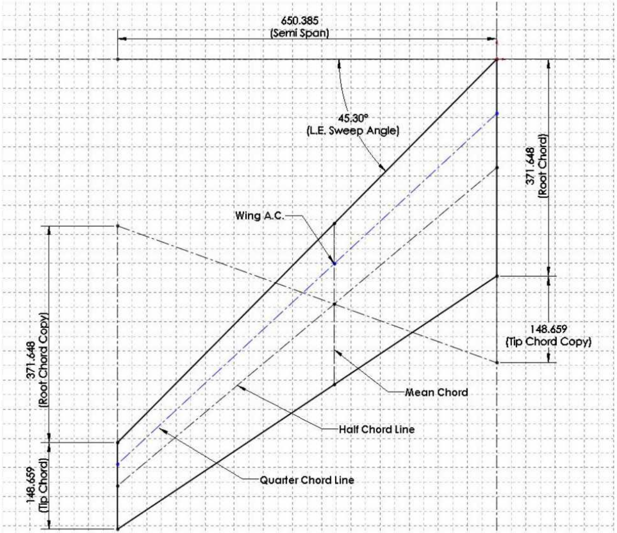
Pressurized Compactment Cross Sections



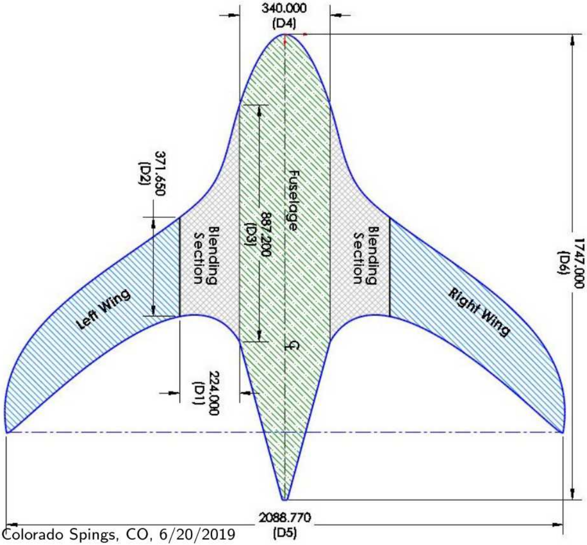
Fuselage Shape



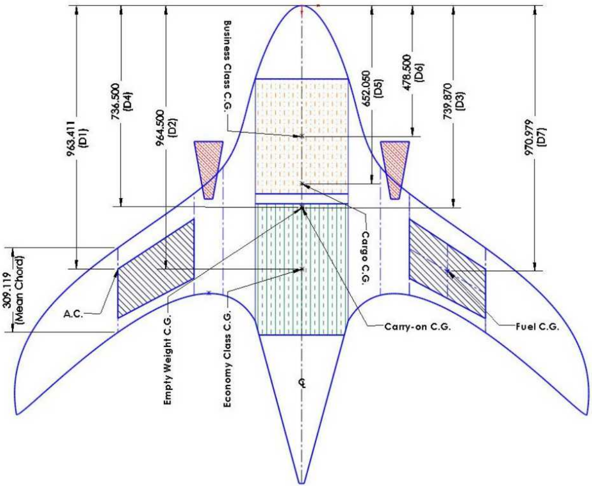
Main Wing Geometry



First Assembly

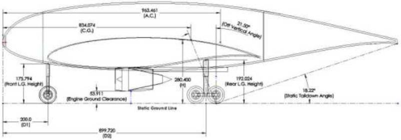


Engine Placement and First Calculation of C.G.

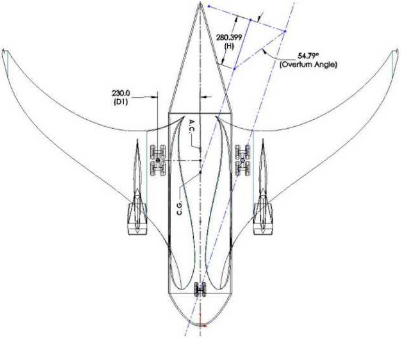


Landing Gear Design

Static Taildown Angle

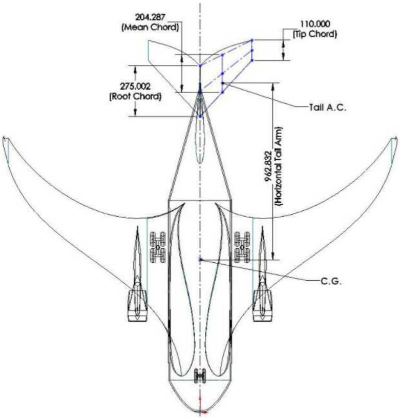


Overturn Angle

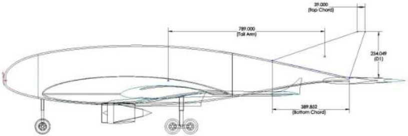


Tail Design

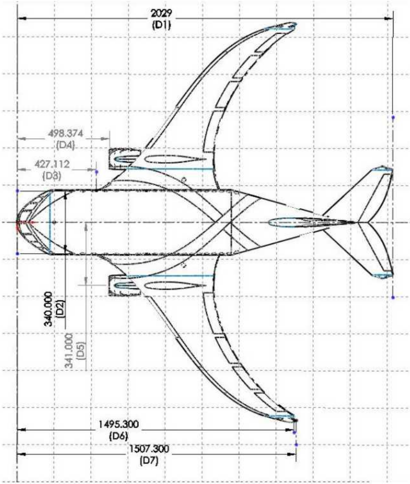
Horizontal Tail

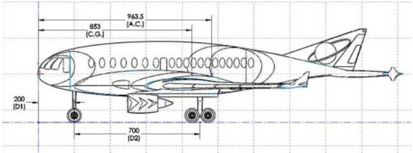


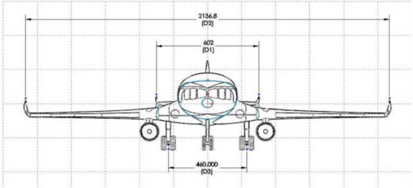
Vertical Tail



Complete Design







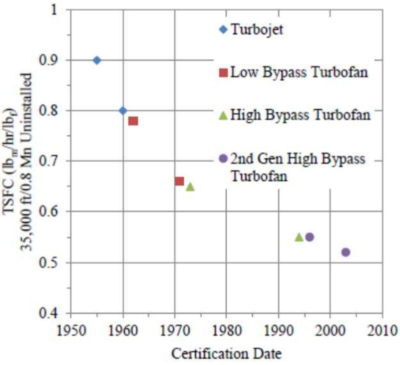
Airworthiness Analysis

Breguet Range Equation

$$R = \frac{V_\infty}{c_t}\frac{L}{D} ln\left(\frac{W_0}{W_0 - W_f}\right)$$

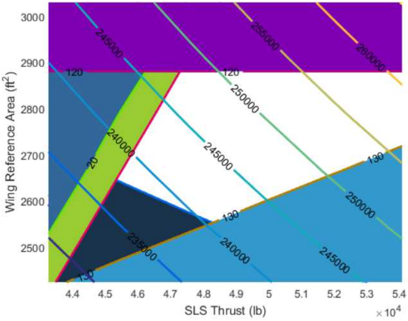
- W_f: Fuel weight
- c_t: Specific fuel consumption
- L/D: Aerodynamic efficiency
- W_0: Gross takeoff weight
- V_∞: Cruise speed

Turbojet Efficiency Evolution

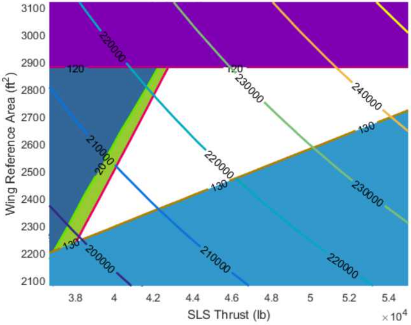


Optimal Design Point vs Aerodynamic Efficiency

Concept with $L/D = 18$

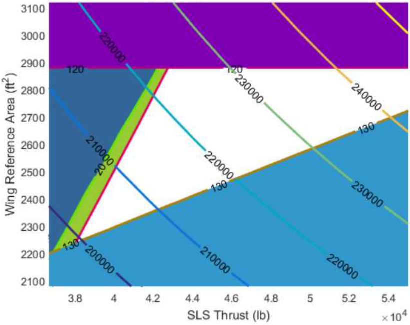


Concept with $L/D = 24$

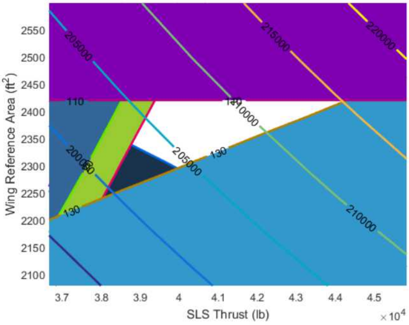


Design Space vs Tighter Constraints

Concept with $L/D = 24$**,**
$d_{TO} \leq 6,400ft$**,** $b \leq 120ft$

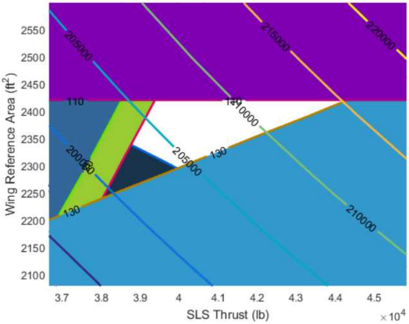


Concept with $L/D = 24$**,**
$d_{TO} \leq 6,200ft$**,** $b \leq 110ft$

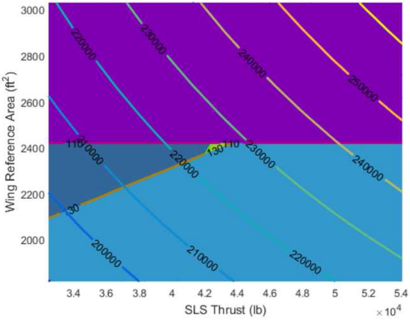


Design Space vs Tighter Constraints

Concept with $L/D = 24$**,** $d_{TO} \leq 6,200ft$**,** $b \leq 110ft$



Concept with $L/D = 18$**,** $d_{TO} \leq 6,200ft$**,** $b \leq 110ft$



Summary

- Establish design objective and requirements
- Begin statistical design with historical data
- Perform optimal design to meet all requirements
- Conceptualize the concept: structure feasibility and dynamic stability
- Perform preliminary performance analysis

References

- Le, L. D., *Preliminary Design of Commercial Aircraft from the Academic Perspective*, College of Science and Engineering, University of Minnesota, Minneapolis, MN, May 2012.
- Anderson, J. D., *Aircraft Performance and Design*, McGraw-Hill, Boston, MA, 1999.
- Raymer, D. P., *Aircraft Design: A Conceptual Approach 4th Edition*, AIAA Education Series, Reston, VA, 2006.
- Pope, A., *Basic Wing and Airfoil Theory*, Dover, Mineola, NY, 2009.

Q & A