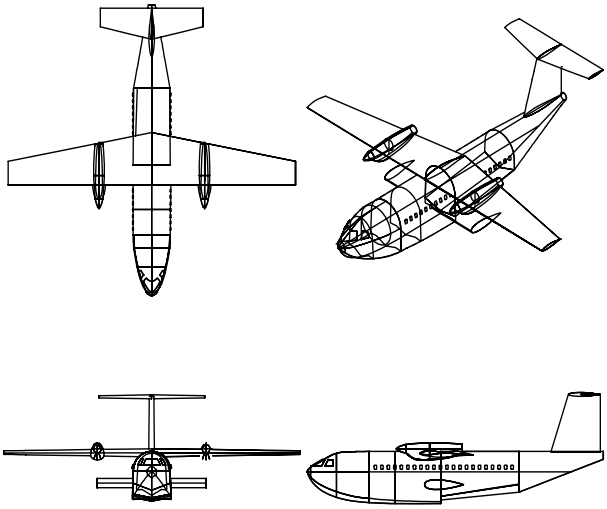
Airplane Design



Lecture Topics

- Design steps
- Conceptual design
- Preliminary design
- Detailed design
- Weight estimation

Preliminary Comments

- There are as many ways to design airplanes as there are airplane designers
- Design is an iterative process
- It has to be cost-effective

Finance

Boeing 777

Seven years to production cost $10B

~ $50M profit per airplane

=> 200 airplanes to break even

=> 50 months @ 4 airplanes / month

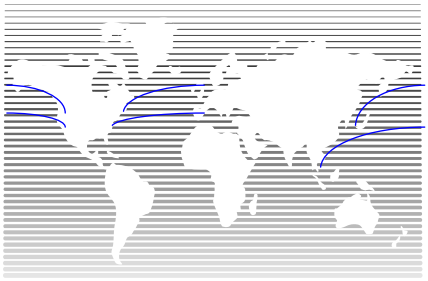
=> 11.2 years break even w/ bank yield

(In 11 years bank yield would be ~ $7B @ 5%)

Decision to Build

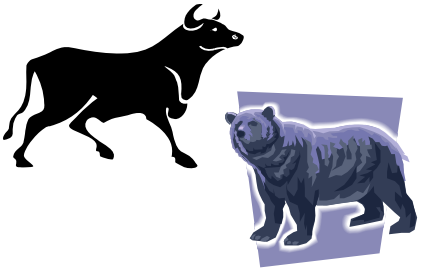
- Market Analysis
- Design Specifications
- Costs
- Labor
- Competition

Market



- Airlines
- Military
- General Aviation

- Demand
- Growth
- Economy



Civilian

- Airlines need to make money
- New routes sometimes profitable
- Boeing 767 was hub & spoke "buster" for North Atlantic
- Boeing 777 & Airbus A340 try to do same for Pacific

Military

- Old Method
  - Military makes detailed specifications
  - High cost
- New Method
  - Minimal specs from military
  - Companies must create internal specs.
- Future Method
  - still in flux

Airplanes Become Complex

- Up to mid 1940's integration of all design elements was under direction of one person
- B-29 was so complex that no one person could comprehend it all
- Russians kept 3 B-29s after WWII
  - They tore one apart & had each component duplicated.
  - 2 yrs later they were flying exact duplicates
  - One Russian official claimed that these airplanes were so similar that "their engines caught fire too"

Design Specifications

?

- Specs passed on to engineering dept.
- Engineers come up w/ design to meet performance goals
- In some cases, not all specs can be met

General Design Specifications

- **Payload**
  - Large size, High power, Low weight
- **Cruising Speed**
  - Low drag, Small size, High power
- **Range / Endurance**
  - Low weight, Low drag
  - Low fuel consumption, Large fuel capacity
- **Airports of Operation**
  - Takeoff distance
    - High power, Large wing area, High lift airfoil, Low drag, Low weight
  - Landing distance
    - Large wing area, High lift airfoil, Low weight
- **Cruise Altitude**
  - Climb rate and ceiling
  - High power, Low drag, Low weight

Military Design Specifications

1) Functional rqmnt's; air-to-air, air-to-ground, bomber, aerial re-fueling tankers, transport

2) Performance rqmnts: payload, range, cruise speed, etc.

3) Design rqmnts: engineers specifies configuration to meet performance goals

4) verification rqmnts:

   a) inspection

   b) analysis

   c) demonstration (normal operating functions)

   d) flight test

   e) lifetime ?

Performance (old paradigm)

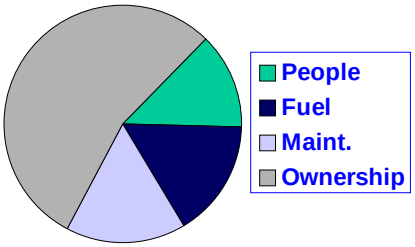
- Lift to Drag ratio ("L over D")
- Power to Weight ratio
- Wing Loading (TOGW / wing area)
- Weight

New Paradigm

- Cost
  - Development / Engineering
  - Retail price
  - Lifetime maintenance
  - Fuel consumption
    - $Fuel ↑ Speed ↓

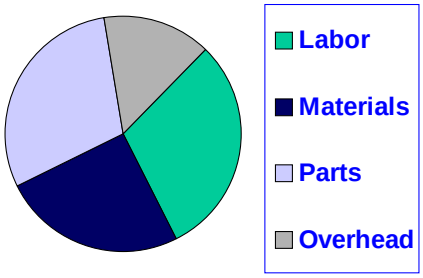
Costs

sample only



Airline costs

Manufacturing costs



Labor

- Do we have the:
  - Engineers ?
  - Machinists ?
  - Support network ?

Competition

- Airbus / Boeing
- Existing airplanes
- Interchangeable parts
- International agreements

Competition

- Late 1960's:
  - Lockheed L-1011
  - McDonnell-Douglas DC-10
- DC-10 / L-1011 direct competition
- Lockheed bowed out of commercial business

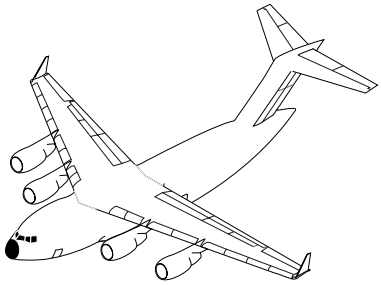
FAA Regulations

- Federal Aviation Administration
  - Responsible for safety regulation of civil aircraft
- Part 23: Airworthiness Standards
  - Come from crash investigations
  - Normal, Utility, and Acrobatic Category (< 12,500 lb TOGW)
- Part 25: Airworthiness Standards
  - Transport Category Airplanes (> 12,500 lb TOGW)
- Part 103: Ultralights

Design Steps

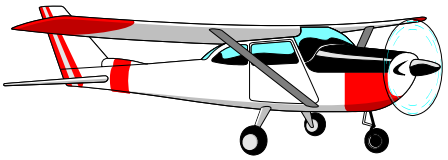
- Conceptual Design
  - Basic characteristics considered
- Preliminary Design
  - Aerodynamics, final configuration, performance details
  - Formal review, CEO involved
- Detailed Design
  - Structural design
  - Actual hardware and parts are drawn

Conceptual Design

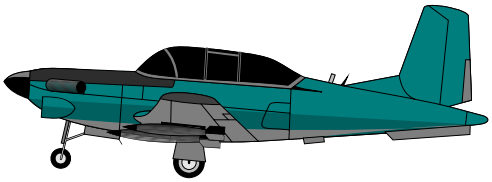


Jet engine powered

Or, propeller ?

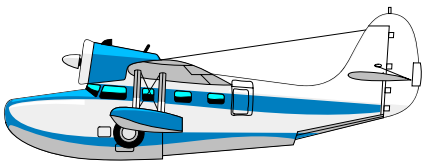


Conceptual Design



Land based

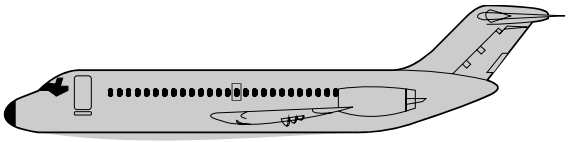
Or, amphibian ?



Conceptual Design

Wing mounted Engines
(707, 737-787)

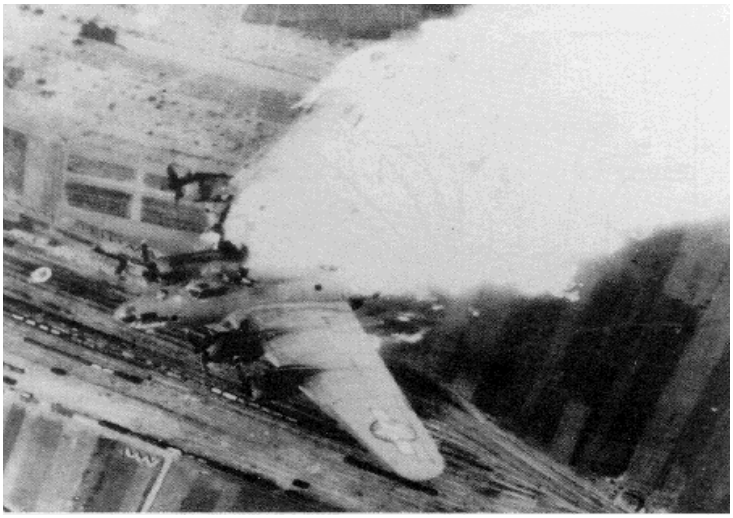
Or, tail Mounted ?
(DC9, 717, 727)



Engine Location

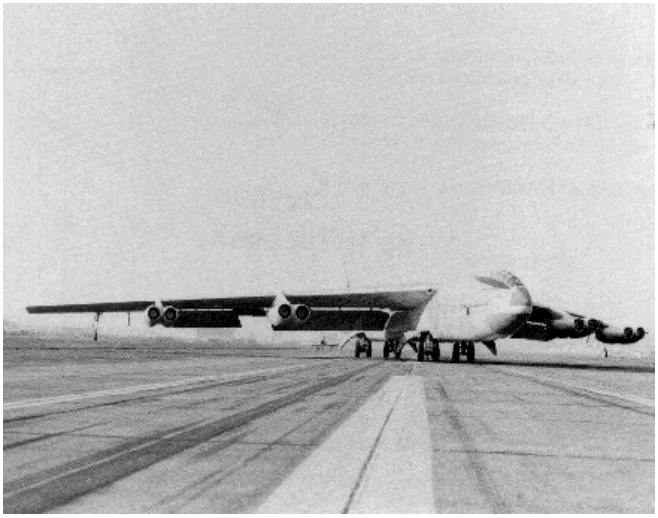
B-17

Engine Location - Fire



B-17

Engine Location - Landing Gear



B-52

Engine Location - Stealth Capability

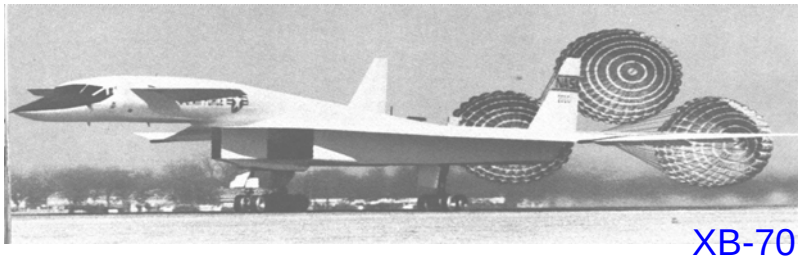
F-117A Retired 2008

(Prototype named "Have Blue" 60% scale)

Engine Location - Stealth Capability

Tacit Blue - 1996

Engine Location - Compression Lift



XB-70 Valkyrie

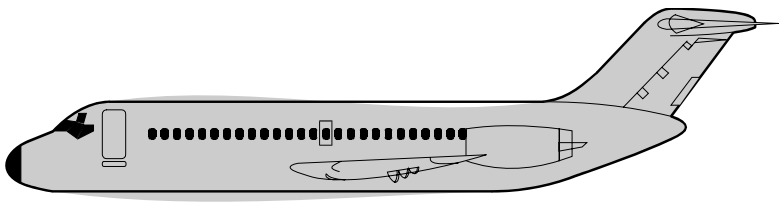
Conceptual Design

- Most fun part: but few jobs
- AA101 airplane example
  - 100 passenger commuter jet
  - land-based
  - tail mounted engines
  - short fields (3,500 ft runways)

Conceptual Design Goals
(AA101 Design Project)

- What requirements drive design ?
- What does it look like ?
- What trade-offs should be considered ?
- What should it cost ?
- Initial weight estimate ?

Preliminary Design

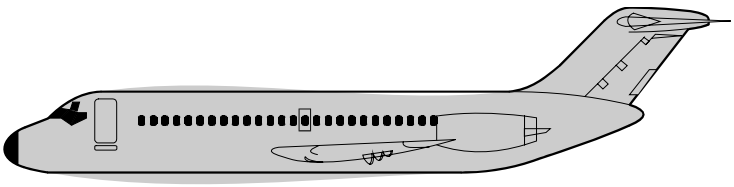


What do we do next ?

Preliminary Design

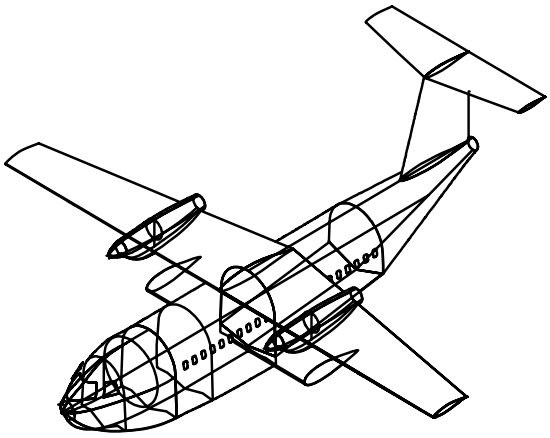
- Expensive phase
- “Freeze configuration”
  - Aerodynamics
- Develop lofting
  - Detailed drawings
- Develop test and analytical base
  - Wind tunnel
- Design major items
- Develop actual cost estimates
  - Weight and performance estimates advertised

Freeze Configuration

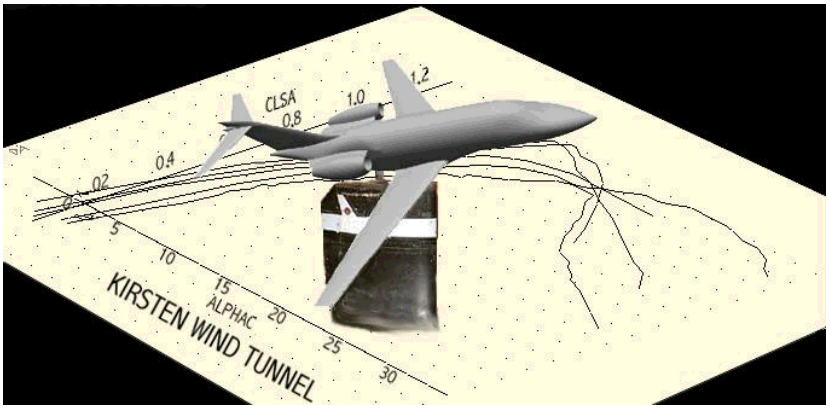


- Basic layout done
- Engines selected

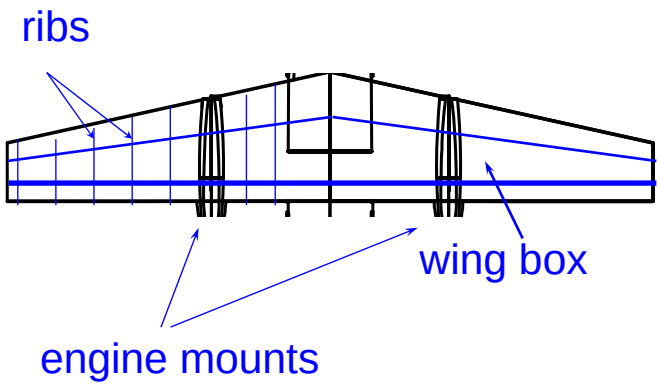
Develop Lofting



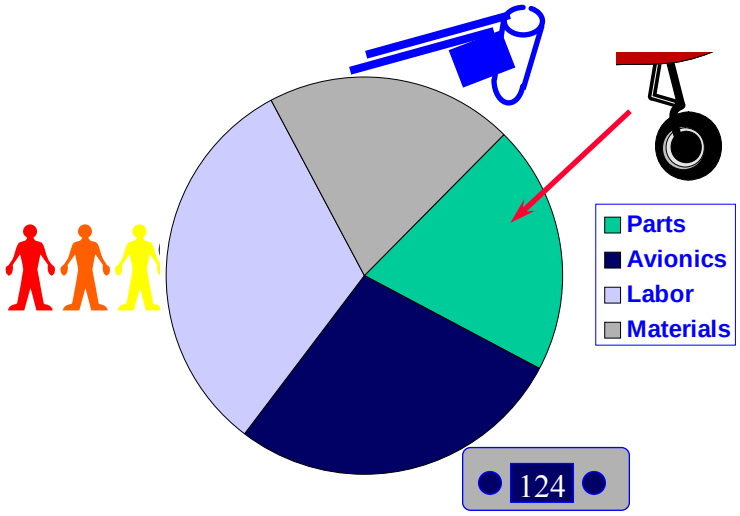
Develop Test & Analytical Base



Design Major Items



Develop Actual Cost Estimate



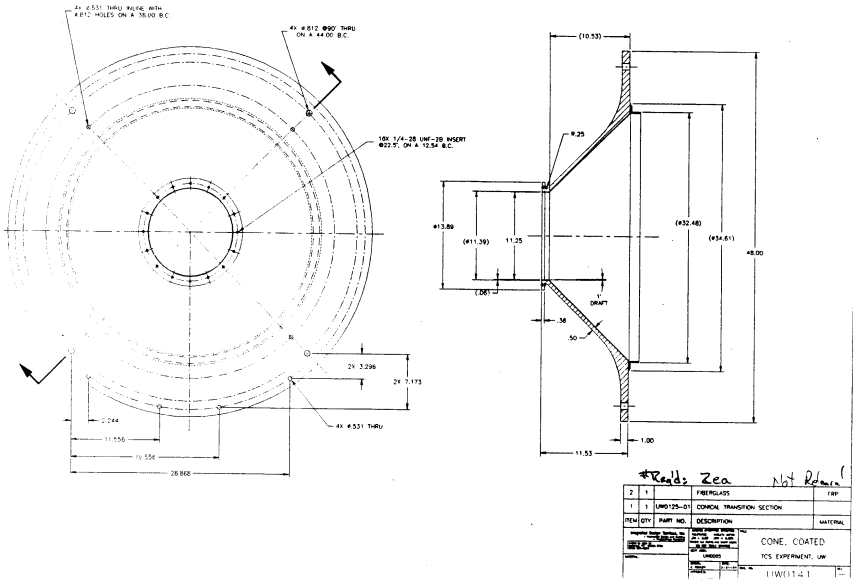
Preliminary Design

- More engineers required
- Many airplanes at this stage still do not get built
- Many challenges

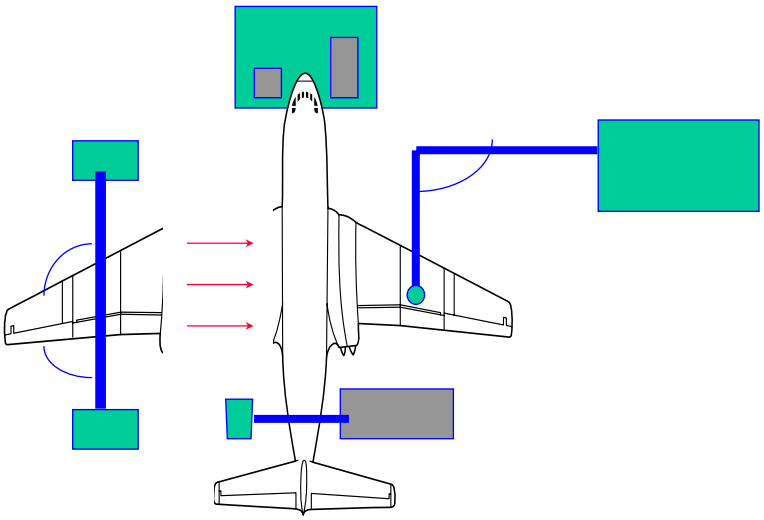
Detailed Design

- Design actual pieces to be built
- Design tooling and fabrication
- Test major items - structure, landing gear, etc.
- Finalize weight and performance estimates

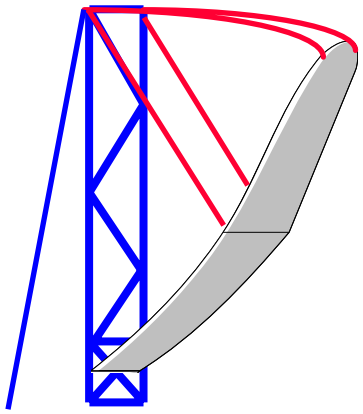
Parts Design



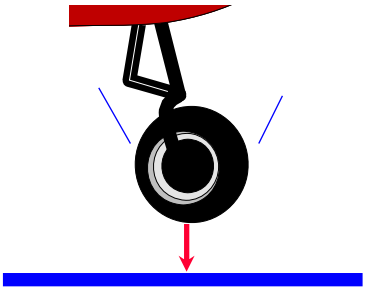
Design Tooling & Fabrication Process



Parts Testing



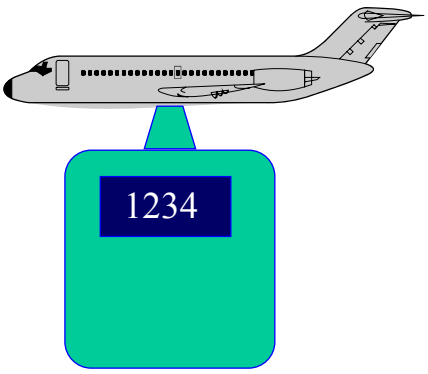
wing ultimate load test



landing gear drop test

Finalize Weight & Performance Estimates

?

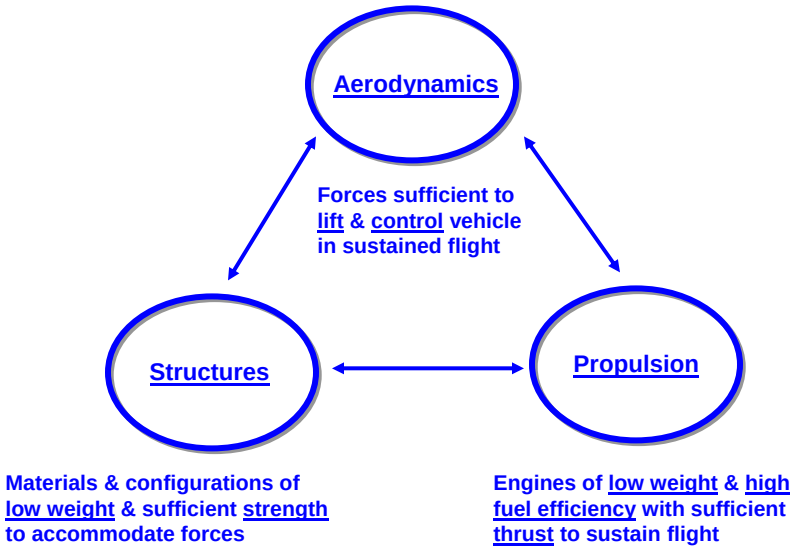


- Range
- Endurance
- Payload
- Takeoff Weight

Detailed Design

- Most of design labor is here
- Many engineers involved
- Can be less than exciting
  - Individuals work in their specialized fields
- Failures still possible
  - 1st commercial jet => British comet
  - 2 major crashes
  - Failures due to fatigue at windows

Primary Design Elements of Feasible Flight Vehicle



AA101 Conceptual Design

- 100 passenger commuter jet
- 3,000 mile range
- tail mounted engines
- short fields (3,500 ft runways)
- made out of aluminum

Take-off Weight Buildup

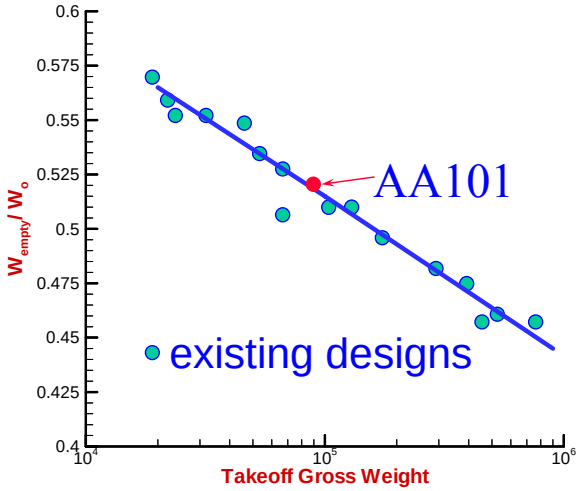
$$W_o = W_{crew} + W_{payload} + W_{fuel} + W_{empty}$$

W_o is Design Takeoff Gross Weight

W_{empty} is dry weight of airplane, i.e., unloaded & unfueled

To start, assume W_o = 100,000 lb

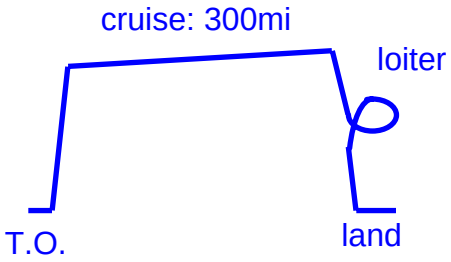
Empty Weight Estimation (W_{empty})



W_{empty} ~ 0.52 x W_o = 52,000 lb

Fuel Estimation

Mission



Fuel Consumption

T.O.	0.03
Climb	0.02
Cruise	0.16
Loiter	0.04
Landing	0.005

Reserve Fuel ?

Fuel Fraction = 0.255

W_{fuel} = 0.255 x W_0 = 25,500 lb

Crew and Payload Weight

- Crew: 175 lb + 30 lb of baggage
  - 205 lb per crew member
- Passengers: 175 lb + 35 lb bags
  - 210 lb per passenger

5 crew * 205 lb + 100 passengers * 210 lb

=> $W_{crew} + W_{payload} = 22{,}025$ lb

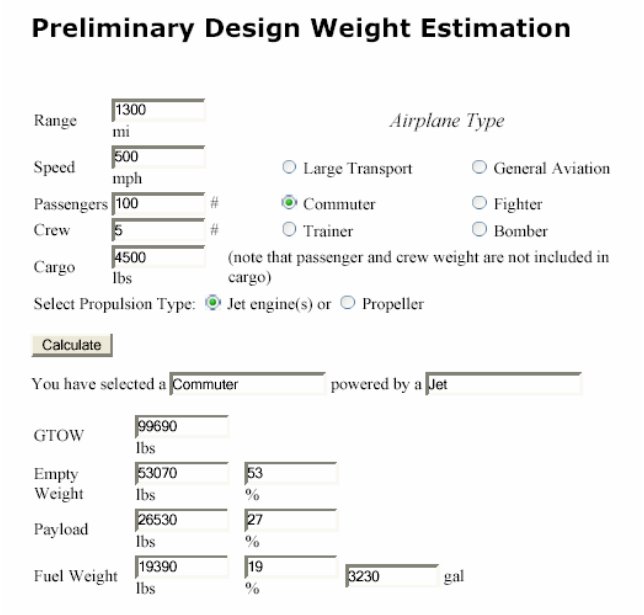
Takeoff Weight Calculation

- $W_{crew} + W_{payload} = 22{,}025$ lb
- $W_{empty} = 52{,}000$ lb
- $W_{fuel} = 25{,}500$ lb

Result: TOGW = $W_0 = 99{,}525$ lb

If not close, then re-iterate; i.e., adjust payload, fuel, and/or initial mass and determine impact on range…

Weight Estimation Tool



Summary

- Design steps
- Conceptual design
- Preliminary design
- Detailed design
- Weight estimation

Airbus A380

2007

W_0 = 1,300,000 lb

$325 M

525 - 850 passengers

Boeing 747-800

W_0 = 970,000 lb

$300 M

470 passengers

2008

Sonic Cruiser

Mach 0.95

Cancelled 2002

Some features incorporated in New Boeing 787

New Fuel Efficient Concepts