COLLEGE OF ENGINEERING
KEVIN T. CROFTON DEPARTMENT OF
AEROSPACE AND OCEAN ENGINEERING
VIRGINIA TECH.

Air Vehicle Design

AOE 4065 – 4066

II. Air Vehicle Design Fundamentals

Course Module A7A

Configuration Layout: *Drawings & Loft*

Kevin T. Crofton Department of Aerospace and Ocean Engineering
Blacksburg, VA

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AOE 4065-4066:
Capstone Air Vehicle Design (AVD) Course Modules (CMs)

Overview of AVD Courses

I. Foundational Elements

F1. Design: *An Engineering Discipline*

F2. Systems and Systems Thinking

F3. Basics of Systems Engineering

F4. Decision Making with Ethics and Integrity

II. Air Vehicle Design Fundamentals

A1. Purpose & Process

Conceptual Design

A2. Understand the Problem

A3. Solve the Problem

A4. Initial Sizing: *Takeoff Weight Estimation*

A5. Initial Sizing: *Wing Loading and Thrust Loading Estimation*

A6. Cost Considerations

A7. Concept to Configuration: *Key Considerations*

A7A. Configuration Layout: *Drawings & Loft*

Conceptual & Preliminary Design

A8. Trade Studies

A9. Use of Software Tools

A10. Preliminary Design: *Baseline Design Refinement & Validation*

III. Project Management Topics

P1. Basics of Project Management and Project Planning

P2. Project Organization

P3. Roles & Responsibilities of Team Members

P4. Project Execution: *Teamwork for Success*

P5. Project Risk Management

P6. Delivering Effective Oral Presentations

P7. Writing Effective Design Reports

Disclaimer

Prof. Pradeep Raj, Aerospace and Ocean Engineering, Virginia Tech, excerpted and compiled the material contained herein solely for educational purposes from publicly available presentation slides of Prof. Wm. Michael Butler's lecture to the Air Vehicle Design class in the fall of 2021.

Although a good-faith attempt is made to cite all sources of material, we regret any inadvertent omissions.

CRUCIALLY IMPORTANT

CMs only introduce key topics and highlight some important concepts and ideas…but without sufficient detail.

We must use lots of Reference Material* to add the necessary details!

(*see Appendix in the Overview CM)

Outline

A7A. Configuration Layout: *Drawings & Loft*

A7A.1 Computer Aided Design (CAD) Systems

A7A.2 Configuration Layout and CAD Drawings

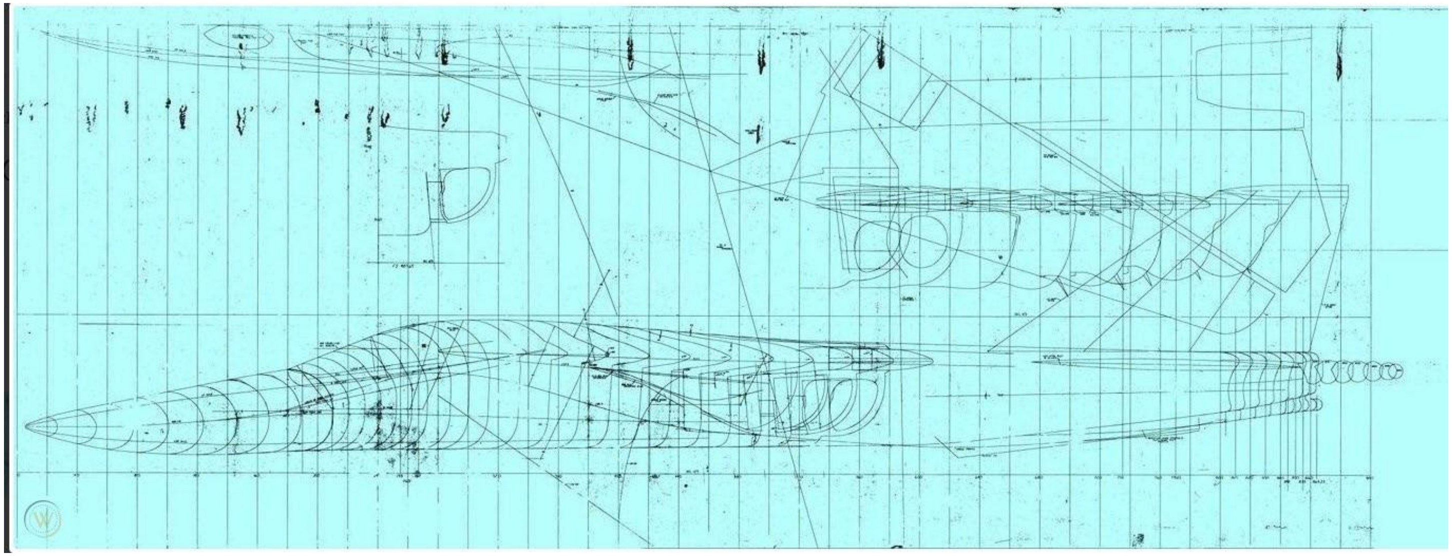
A7A.3 Basics of Conic Lofting

A7A.4 Lofting in Solidworks*

*Excerpt of notes from Greg Marien - San Diego State University

Pre-computer Based Design (1960s)

F-111
GENERAL DYNAMICS



2D drawings lead to the 3D entity

Image Source: https://www.worthpoint.com/worthopedia/111-general-dynamics-ardvark-jet-1779162262, CCBySA

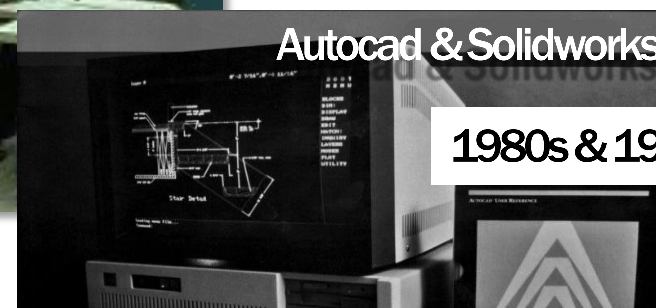
CAD Progression: *1960s through the 1990s*

DAC-1 (Design Automated by Computer) developed by **GM & IBM**

1960s

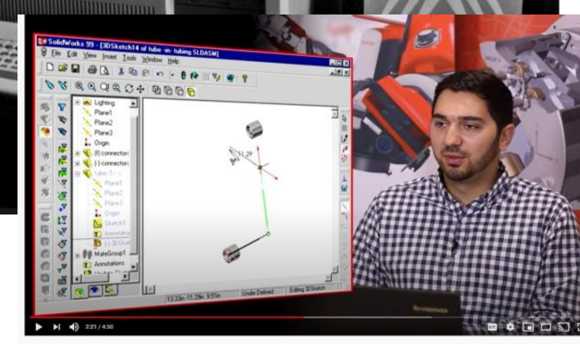
CADAM

1970s



Autocad & Solidworks

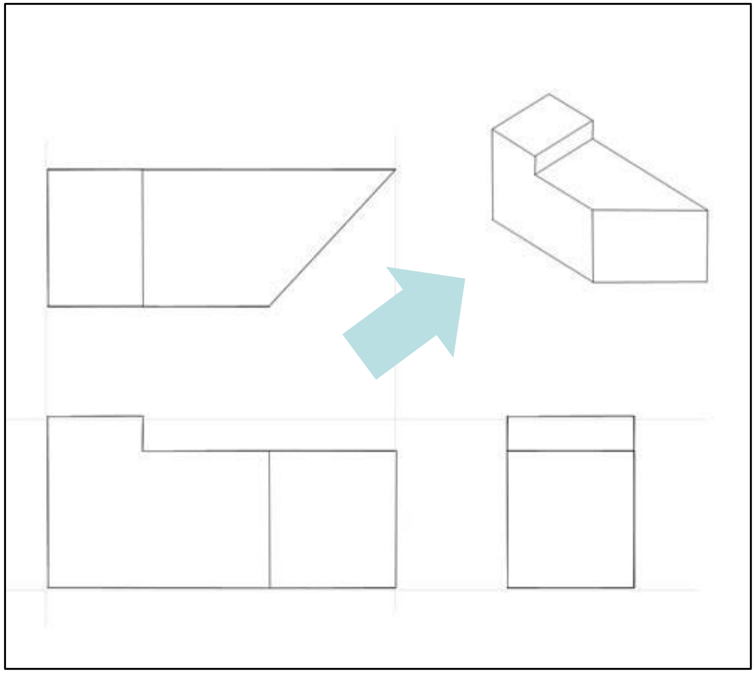
1980s & 1990s



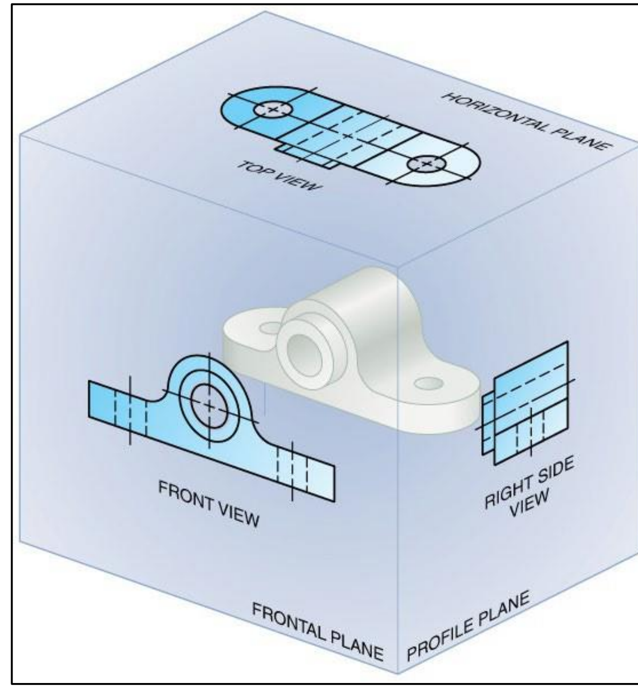
Initial CAD programs were computerized versions of traditional drafting

Computing advances directly impacted the growth of CAD and CAD capabilities

Engineering Graphics and CAD



Early CAD:
Using 2D to make 3D

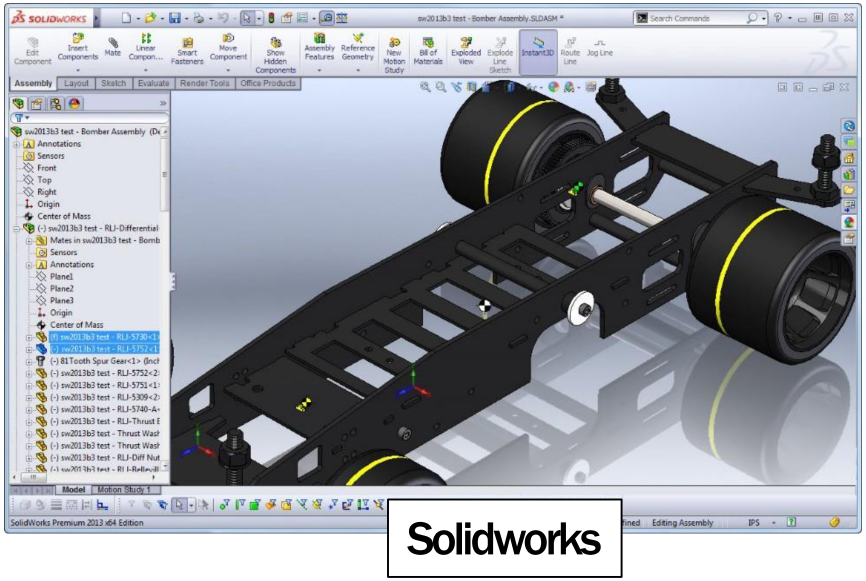


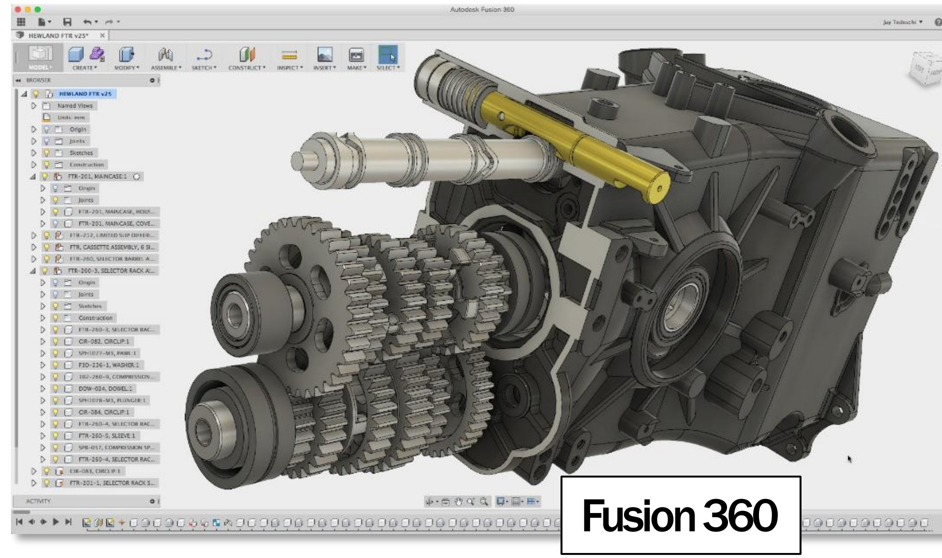
Today's CAD:
Using 3D to make 2D as needed

Remember: **CAD is a tool**

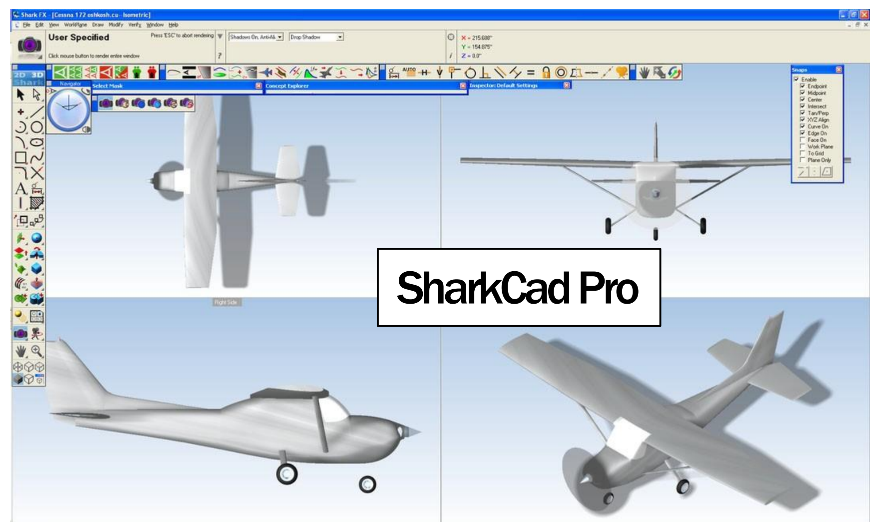
Technical drawing principles are still at the core of modern CAD

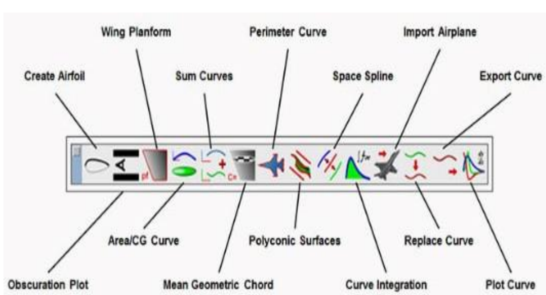
CAD Systems:
Solidworks, Fusion 360, & Others – *"Low Soln"*





- Many alternatives out there and they all have their strengths and weaknesses.
- Parametric modeling tends to be norm.





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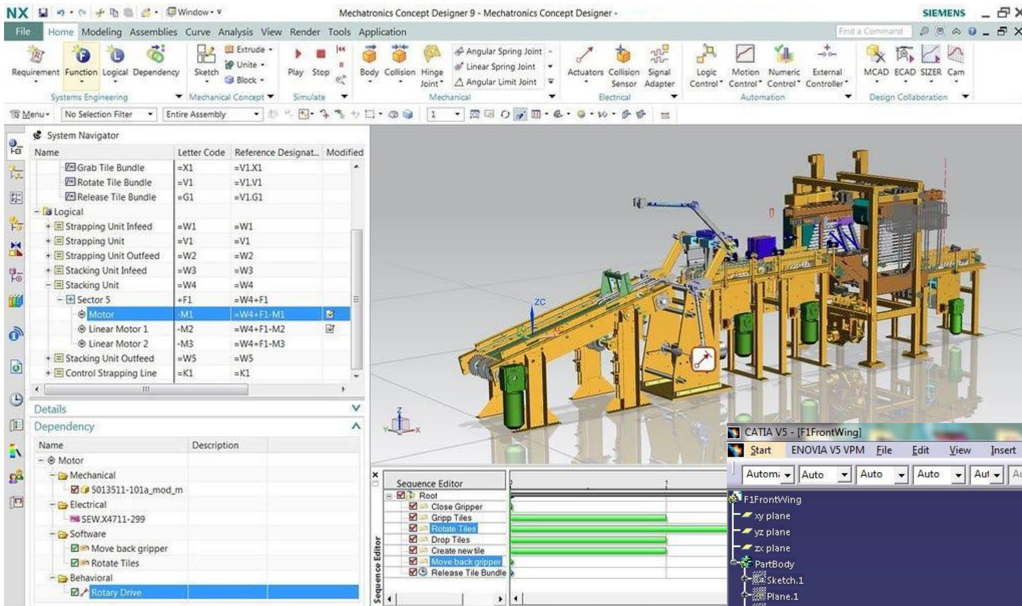
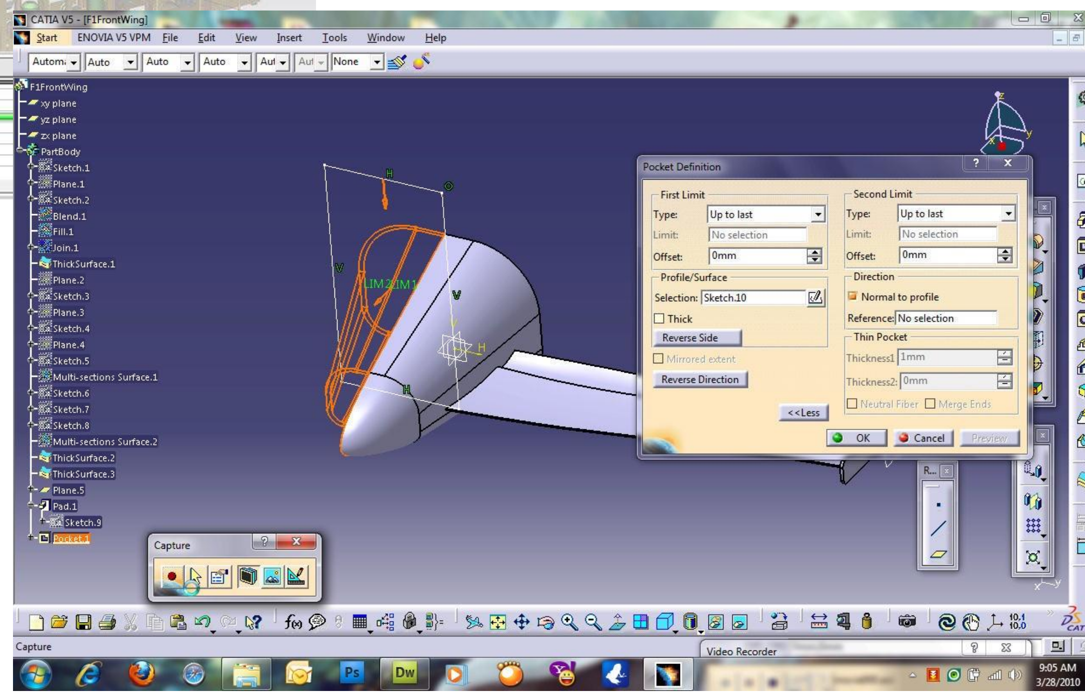
Production Level CAD Systems – "*High Soln*"



NX by Siemens

CATIA by Dassault



Very powerful software but takes time to learn.

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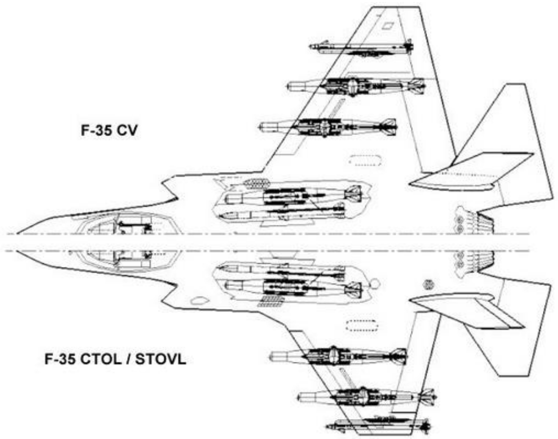
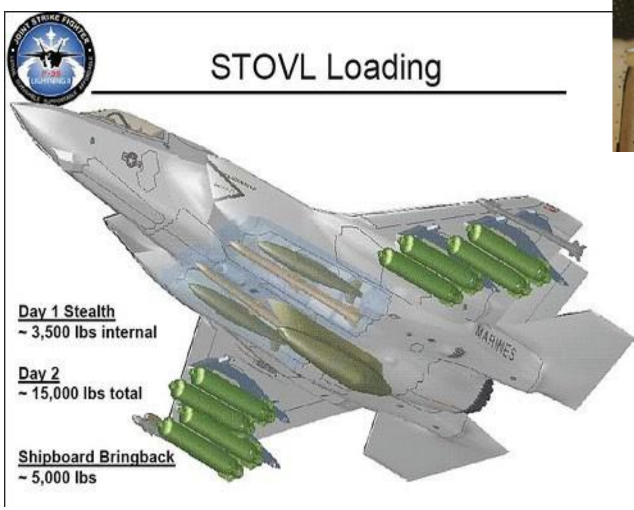
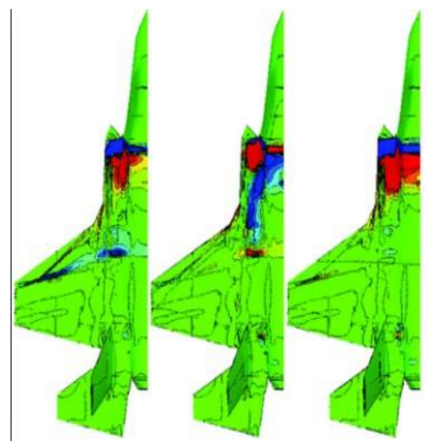
Design Today with CAD

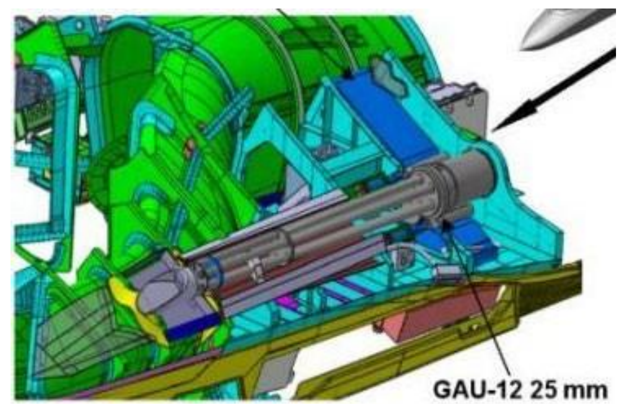


F-35

LOCKHEED MARTIN







3D virtual models lead to drawings and physical models

Source:http://www.cobaltcfd.com, gupta9665.wordpress.com

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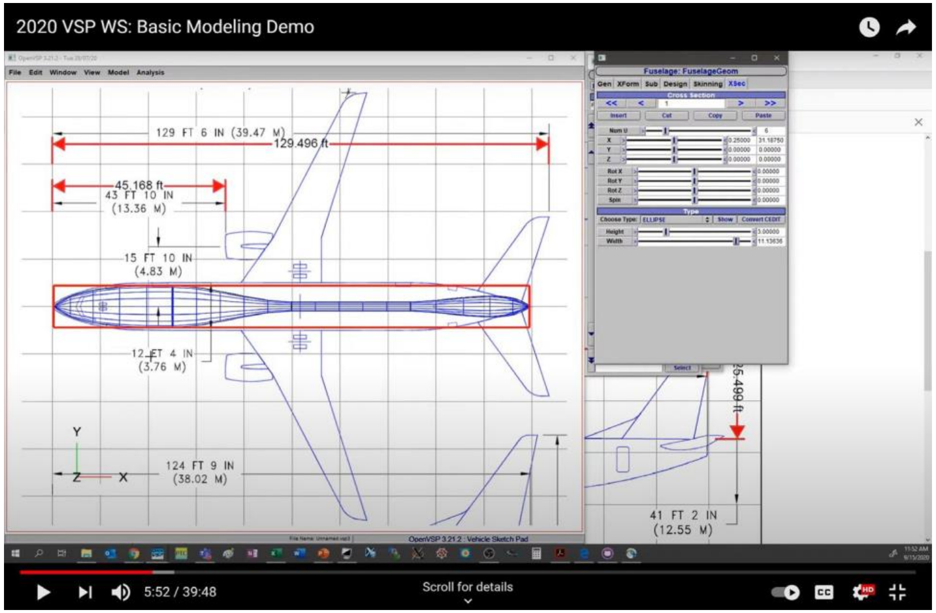
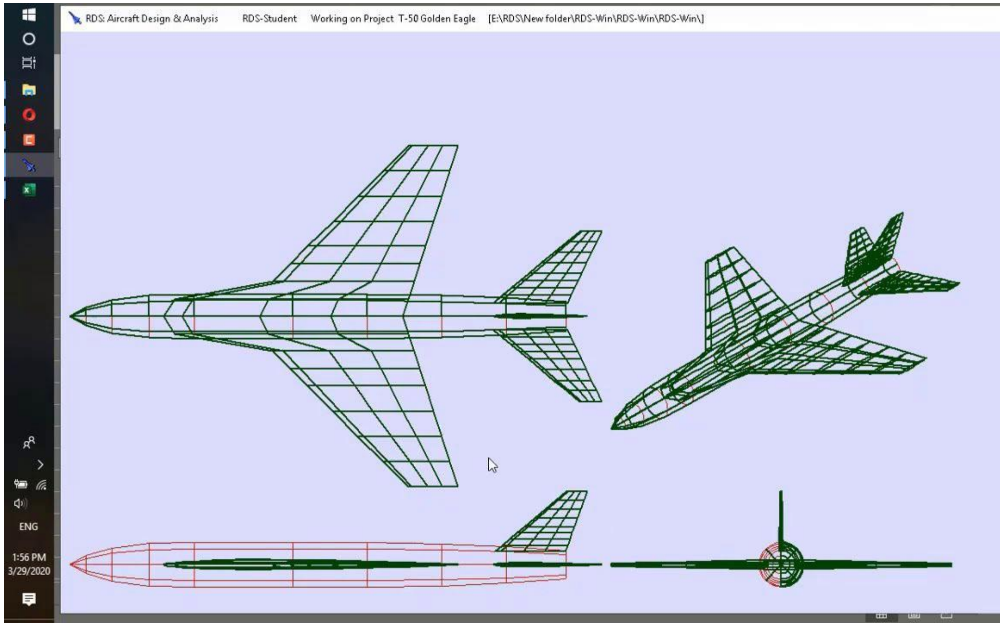
OpenVSP & RDS Student Type Tools

OpenVSP

Allows you to use your sketch directly to create a 3D model





RDS

Creates a parametric model that is highly conducive to being used in various analysis programs – air vehicle synthesis

A Recommended Approach

- **Generate and support two models of the main concepts you want to further develop**
  - *CAD Model*
  - *VSP or "VSP-like" model*

Why?

- **Answer: These models serve two different purposes**
  - *CAD Model – This is the final geometry (internal and external) used in drawings, making physical models, etc.*
  - *VSP or "VSP-like" model – This is the model most conducive to use in various analysis tools available to you – analysis quick trade study model.*

You should have, and maintain, both models – I would start with the CAD model

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*Excerpt of notes from Greg Marien - San Diego State University

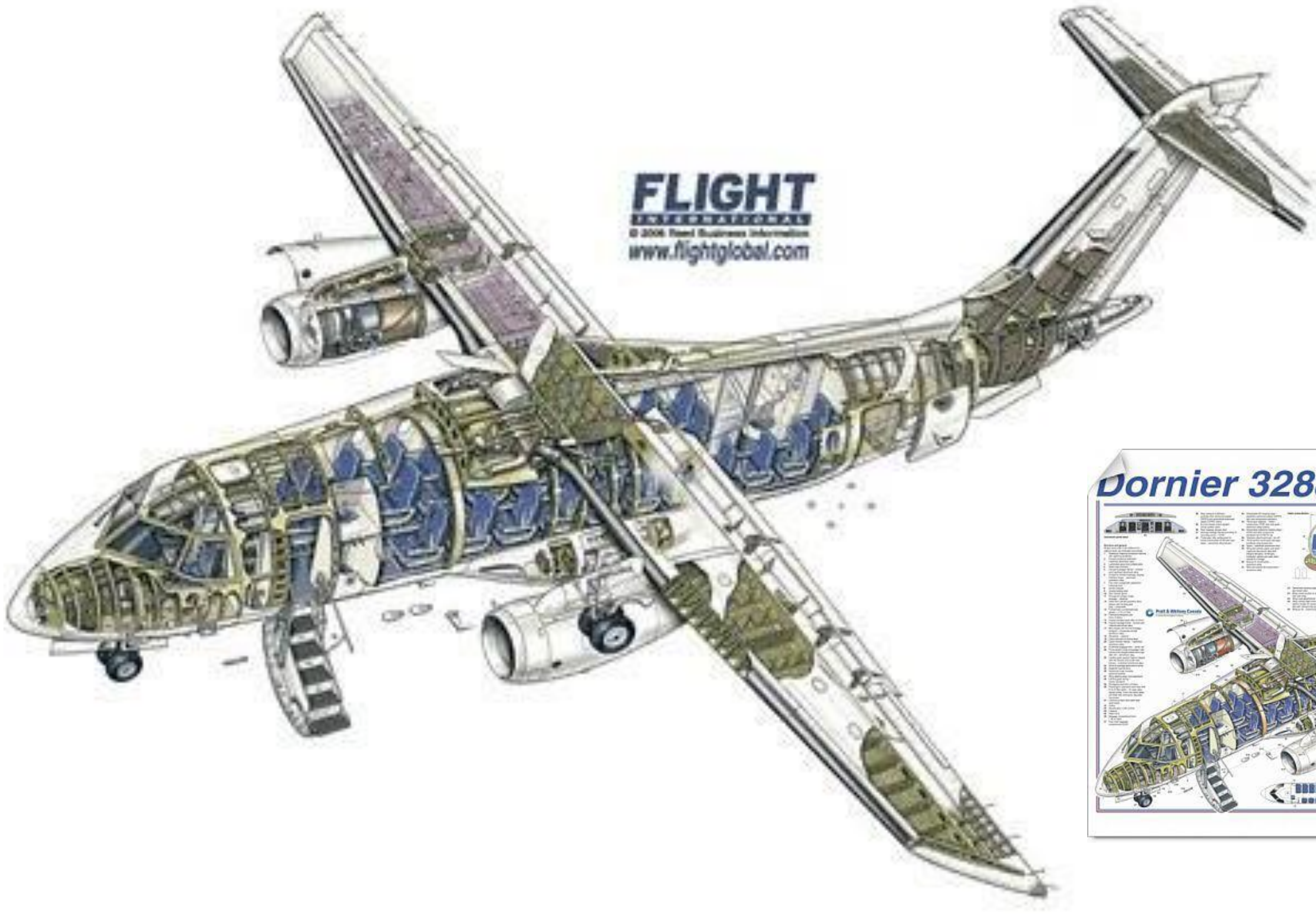
First Select Specific Design Features
(see CM A7)

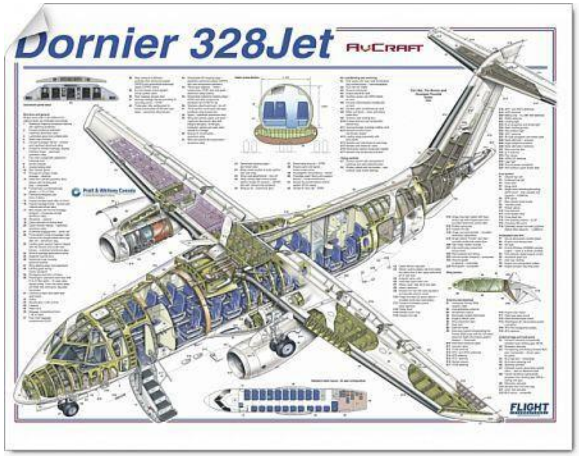
- **Fuselage size and shape** (fineness ratio, cross-sectional area distribution, basic structural layout, etc.)
- **Wing size, shape and location** (span, sweep, *AR*, taper ratio, basic structural layout, etc.)
- **High-lift devices** (mechanical vs. powered)
- **Empennage type and size** (aft tail, canard, tailless, etc.)
- **Static stability level** (degree of static margin, SM, in %MAC)
- **Propulsion system** (turboprop, turbofan, turbojet, number of engines, bypass ratio, podded or buried, etc.)
- **Inlet and nozzle** (location, type)
- **Landing gear type & location** (tricycle, bicycle, tail dragger, etc.)
- **Subsystems** (avionics, ECS, FCS, etc.)
- **Materials** (metals or composites or both)
- **Etc.**

Many, many Decisions!

Use Selected Features to Generate Configuration Layouts!

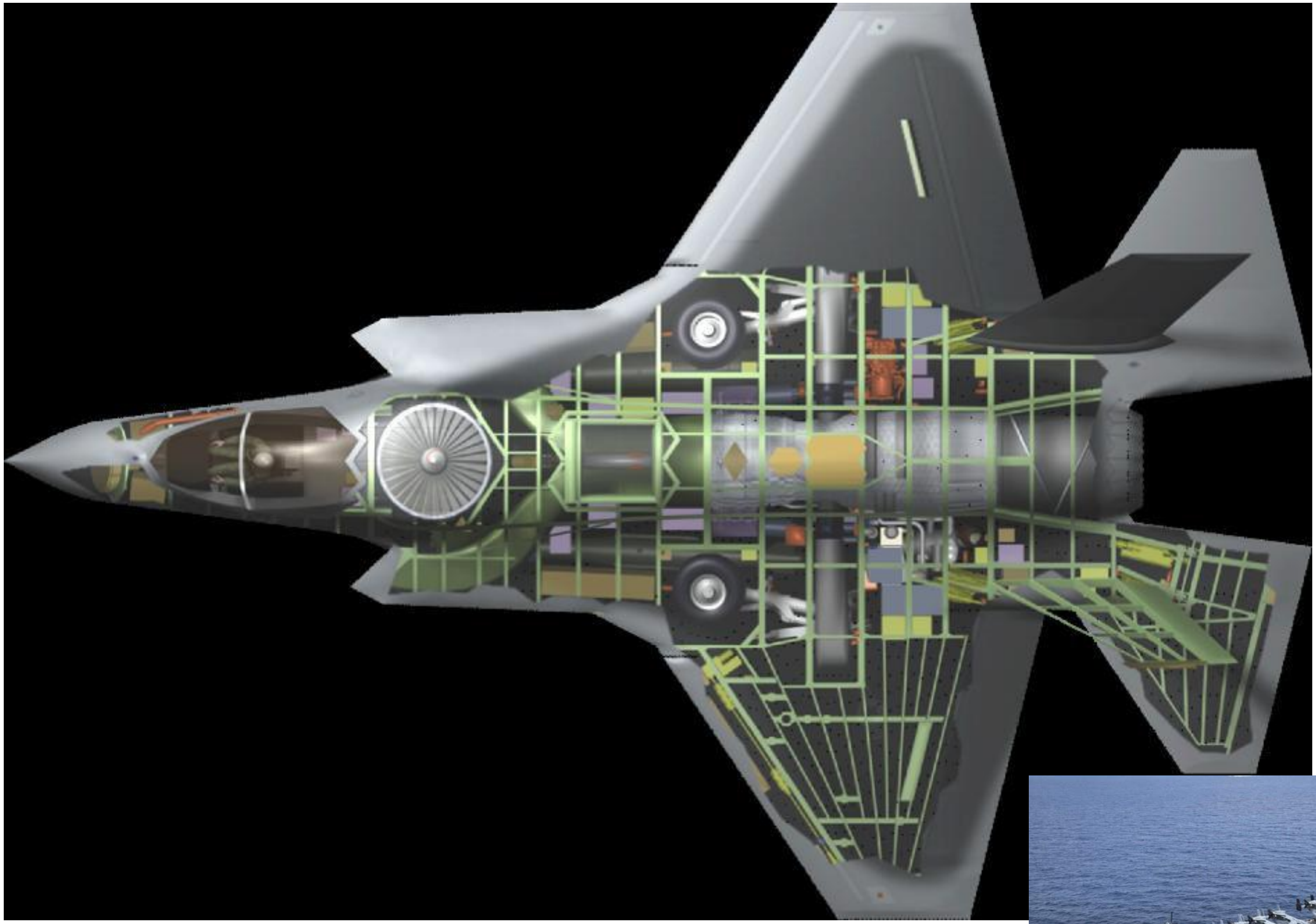
What are some key physical features of the Dornier 328 Jet that drive its fuselage design?





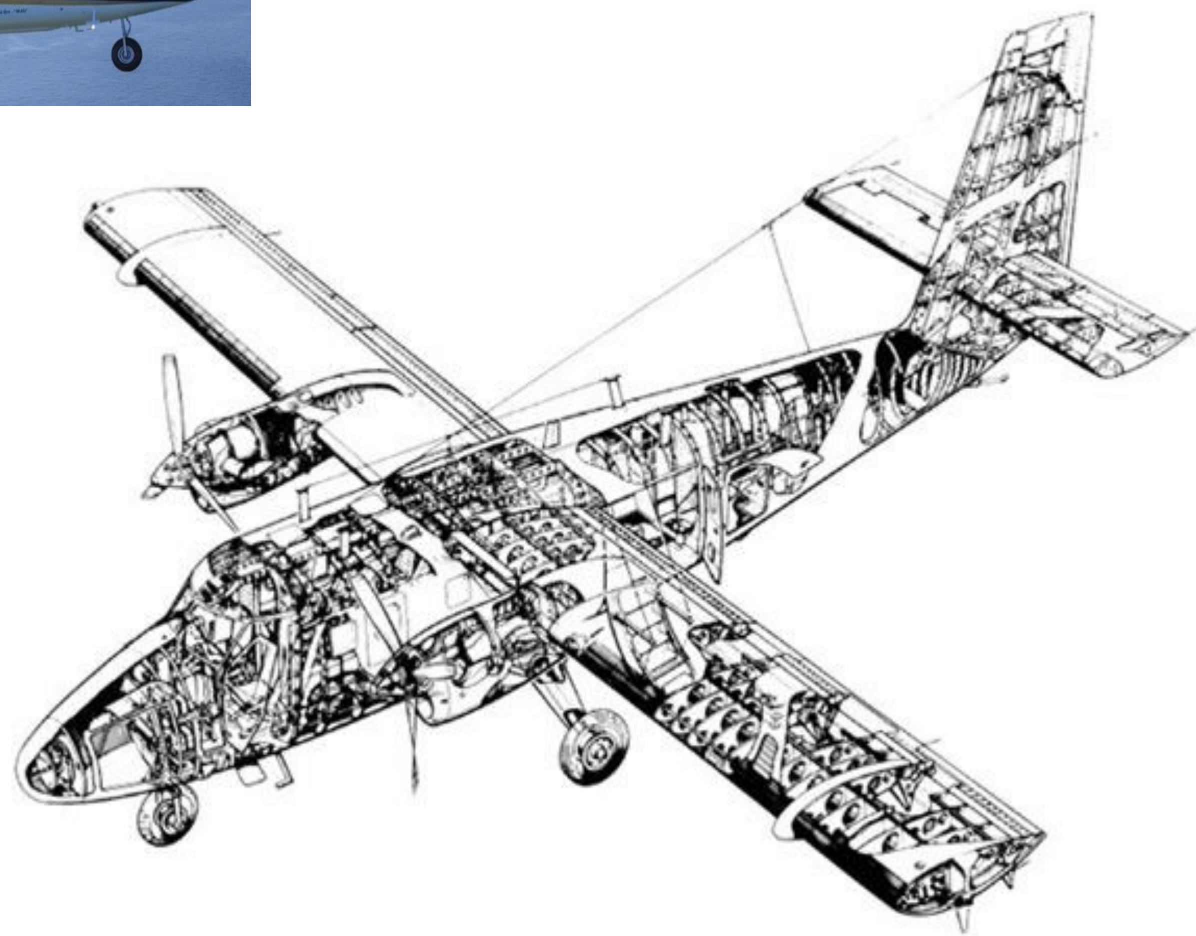
Source: Flight International

F-35B Cutaway



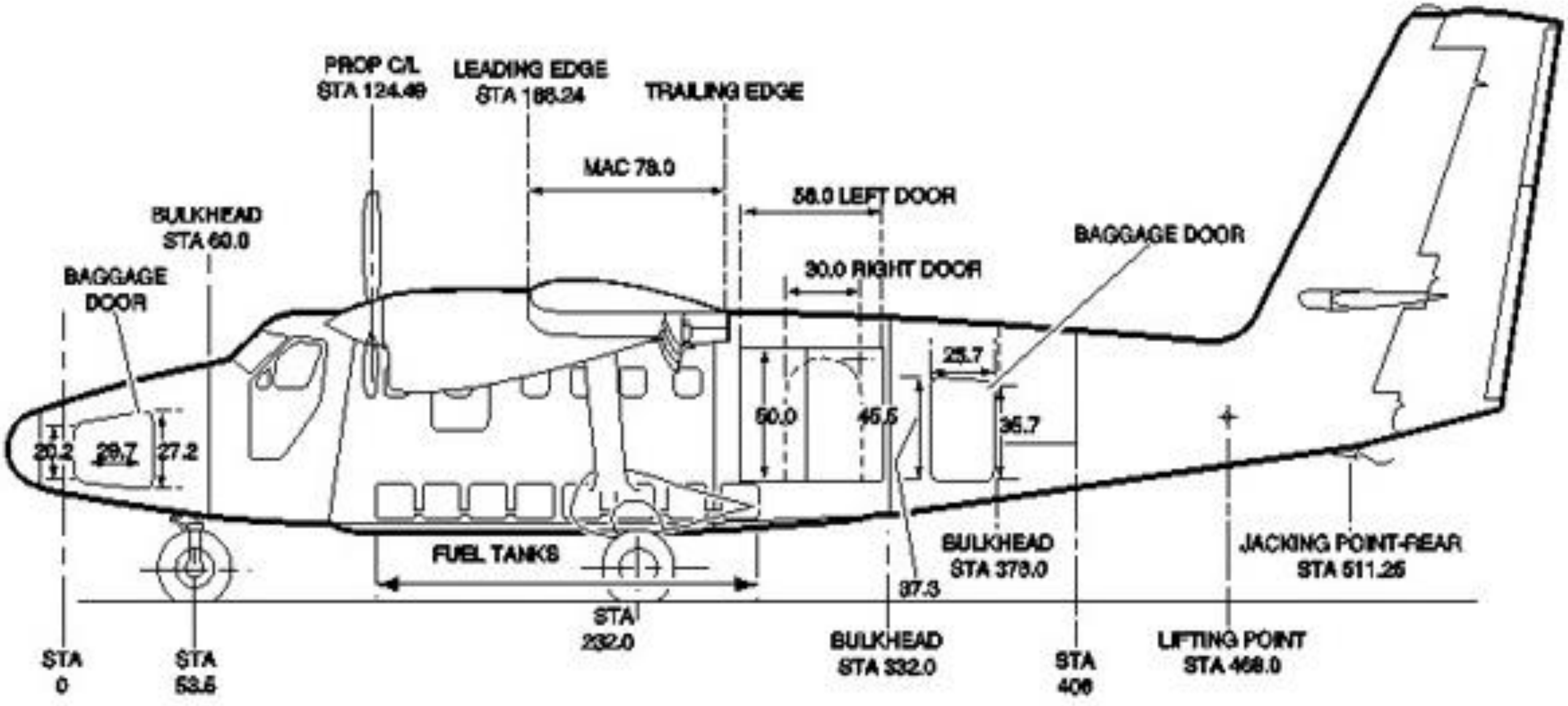
Propulsion integration (lift fan and engine), weapons payload, stealth, and integration on LHAs & LHDs were some of the design drivers on the F-35B model

What are some key physical features of Twin Otter that drive its design?



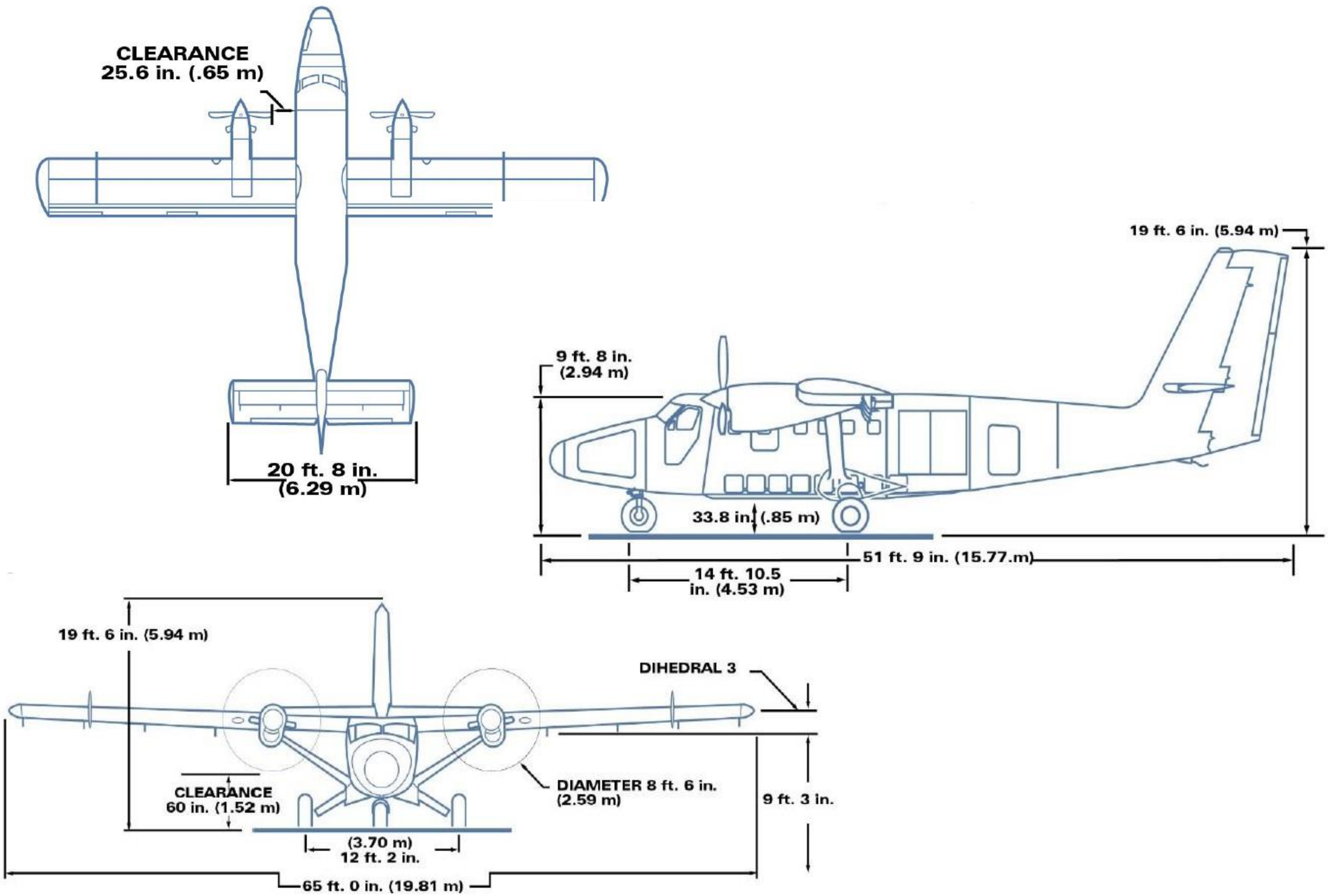
Source: https://www.vikingair.com/twin-otter-series-400/technical-description

DHC-6 Twin Otter



Source: https://www.vikingair.com/twin-otter-series-400/technical-description

DHC-6 Twin Otter



Source: https://www.vikingair.com/twin-otter-series-400/technical-description

Configuration Layout Process

- ***Where to begin?*** **No Single Answer**
  - **Kirschbaum says:**
    - Start with Crew Station
  - **Raymer says:**
    - Start with C.G.
  - **Shrock says:**
    - Just Start Somewhere!!
- ***Keep in mind:*** **the final vehicle layout might (no, would) be quite different from the concept you initially sketched**
- ***Major Components Get (Re)arranged Multiple Times!***
  - Engines, Flowpath (Inlet/Nozzle), Crew Station, Payload, Internal Fuel Tanks, Cargo Compartment, Landing Gear, etc., etc., etc.
  - Take a first cut at wing planform and type of tail surfaces, their sizes and locations

HIGHLY ITERATIVE!

Some Items to Note When Making an Air Vehicle in CAD

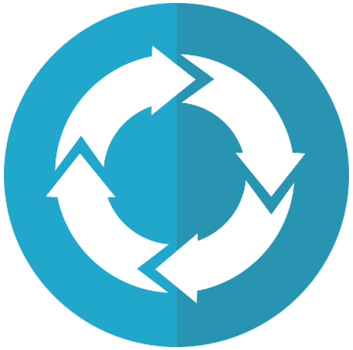
- We typically build half of the model (unless there is an asymmetric feature) – *on drawings we show both halves*
- Units – In the U.S. we would use inches and pounds and seconds
- We use some naval architecture terms when describing locations (water line, WL, buttock line, BL, & fuselage station, FS, which align with certain axes)
- Build your model with some distance away from (0,0,0) to allow for growth of the model and to avoid negative numbers.
- CAD is good for weights and CG of the overall OML (and IML if detailed enough)
    - Initial model usually does not have IML
- You will need to model or purchase various systems for the vehicle – engines, seats, actuators, assorted cockpit items, etc. (GrabCAD with caution)
- Engine manufacturer good source for propulsion details and models

Some Items to Note When Making an Air Vehicle in CAD

- **You can view creation of a 3D configuration layout and model as building a puzzle where you have some parts predefined and others you are allowed to create**

- **Think about the vehicle itself and how it fits in the larger system (*How is the end-user going to interact with it?*)**

- **You don't make the model once and that is it. Even your CAD model is part of the iteration process!**



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Three-view (or 3-vu) Drawings:

Standard for Depicting Configuration Layout

Common Standard Language of Designers for Communication with everyone

FS: Fuselage Station

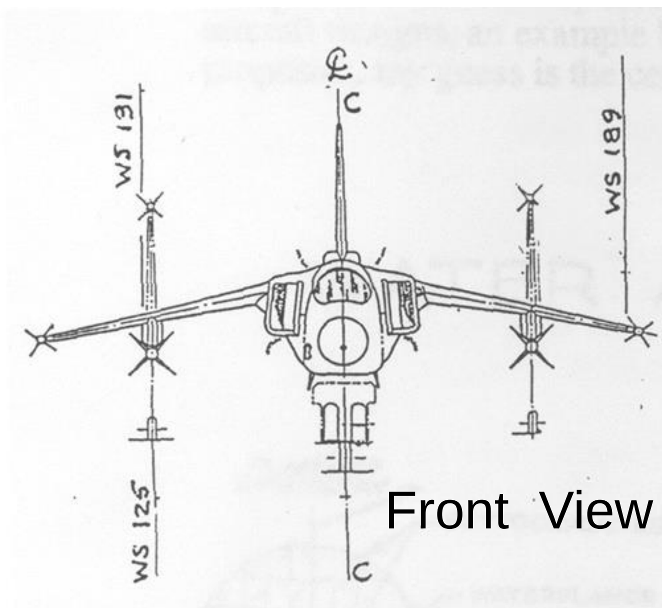
WL: Water Line

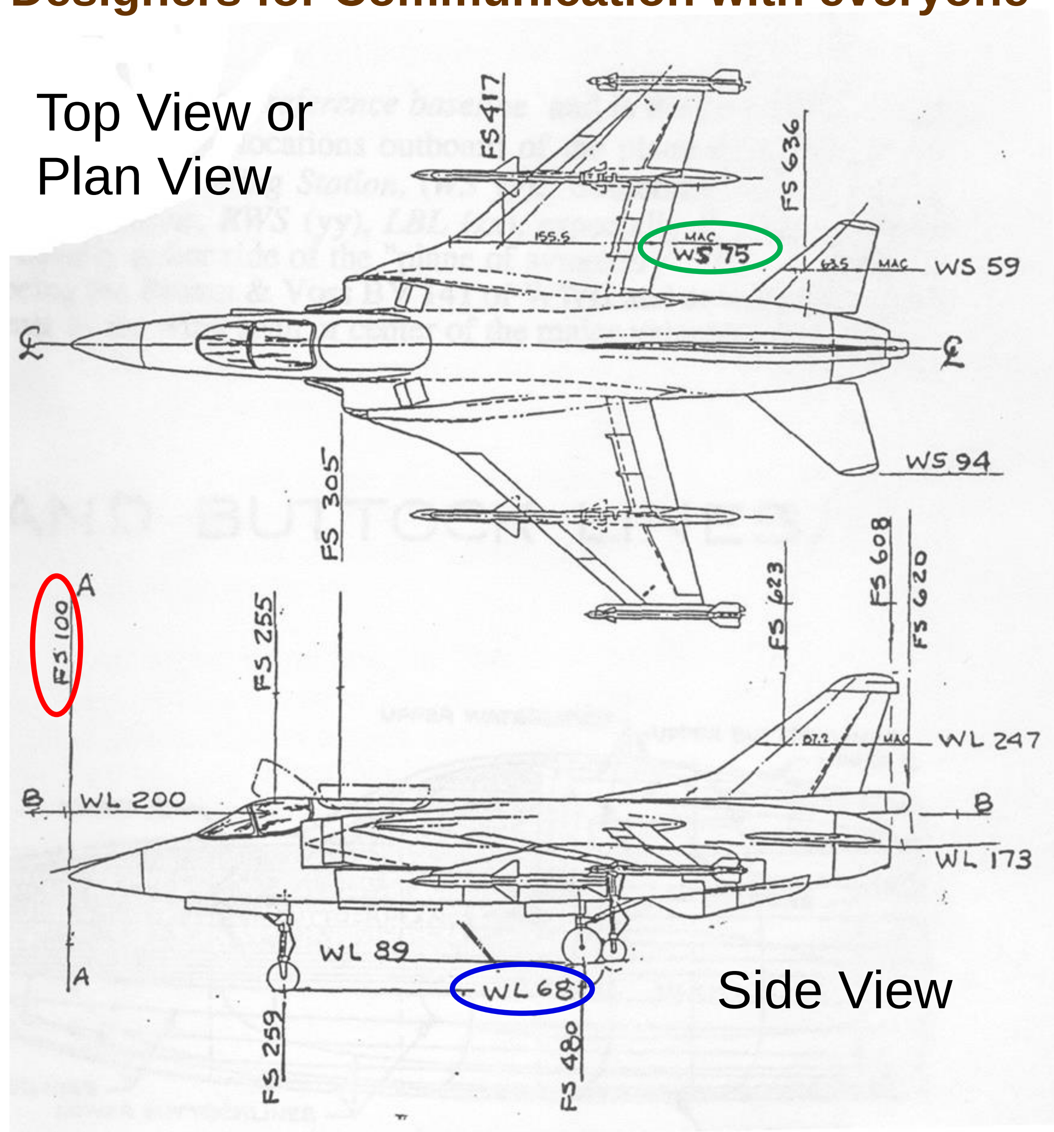
WS: Wing Station

A-A: Vertical Reference Plane

B-B: Fuselage Reference Plane

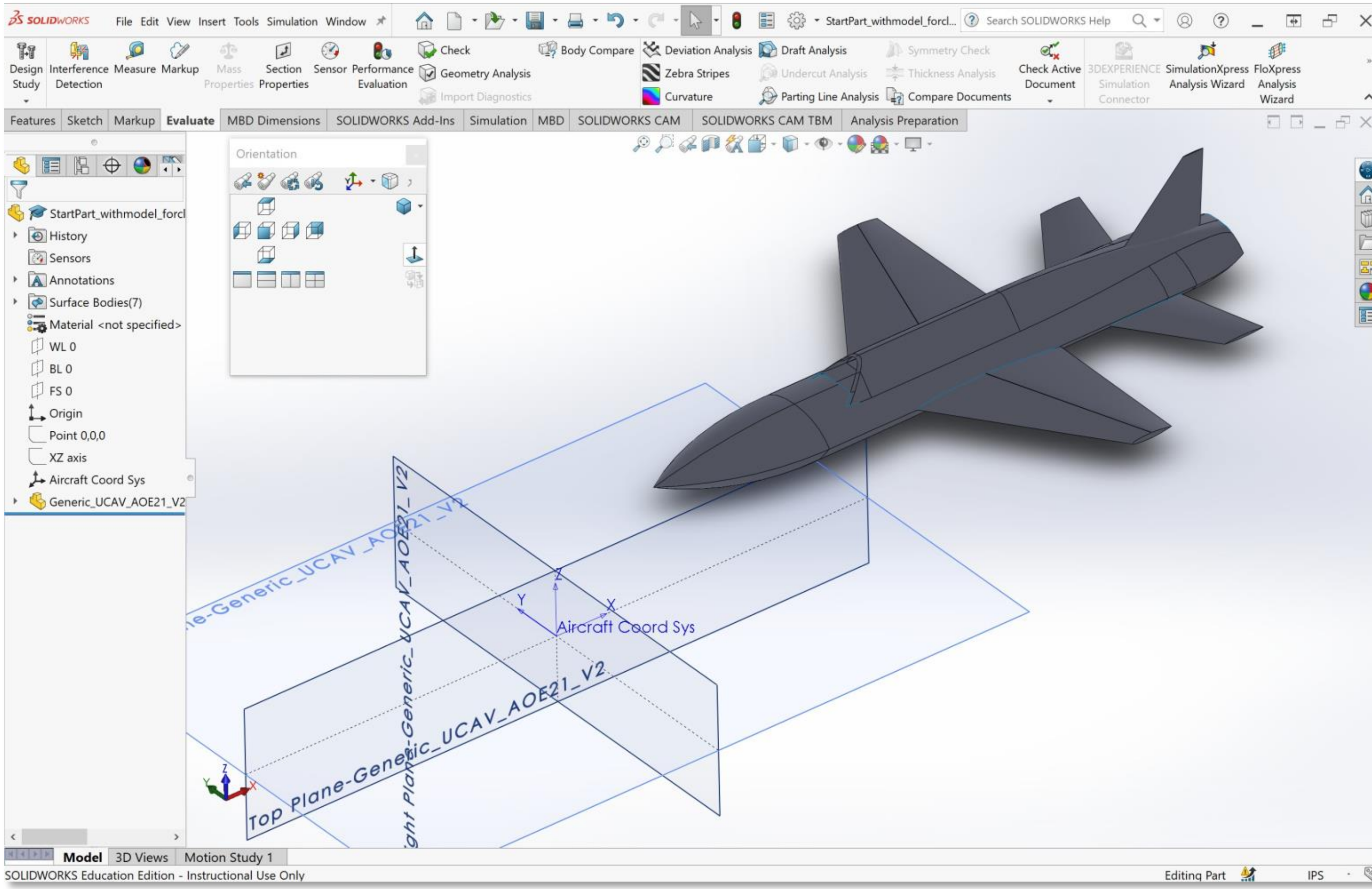
C-C: Centerline Plane of Symmetry





Source: *Figure 1-1, Ref. AVD 6 (Kirschbaum and Mason)*

Model Orientation



Solidworks Starter Part Available

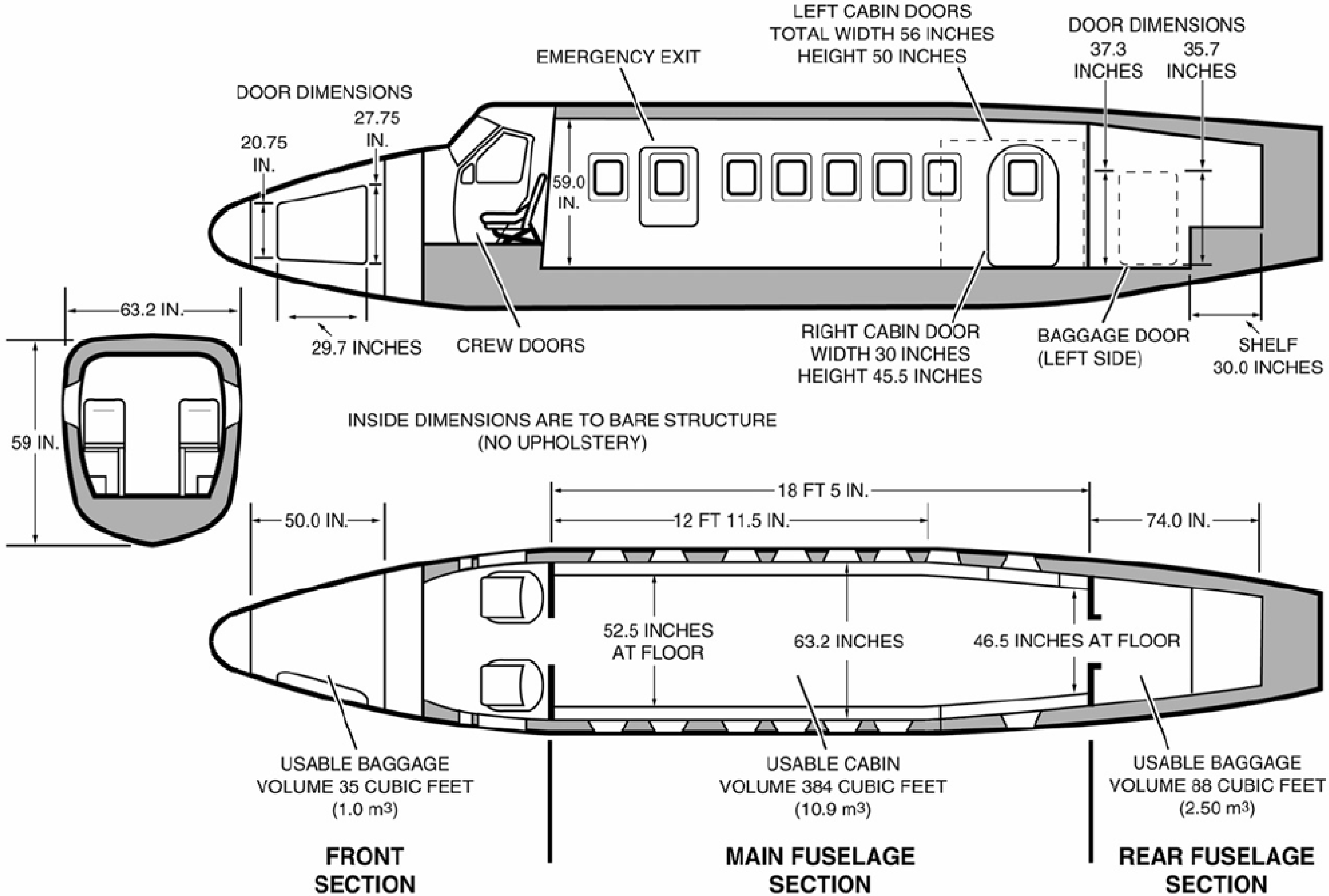
FS: Fuselage Station – *X-Axis*

BL or WS: Buttock Line or Wing Station – *Y-Axis*

WL: Water Line – *Z-Axis*

You should build models of the key components to use as guides when making the 3D model

Example of Initial Fuselage Guidance for Commercial Aircraft



Source: https://www.vikingair.com/twin-otter-series-400/technical-description

Example Cockpit & Cabin

Cockpit

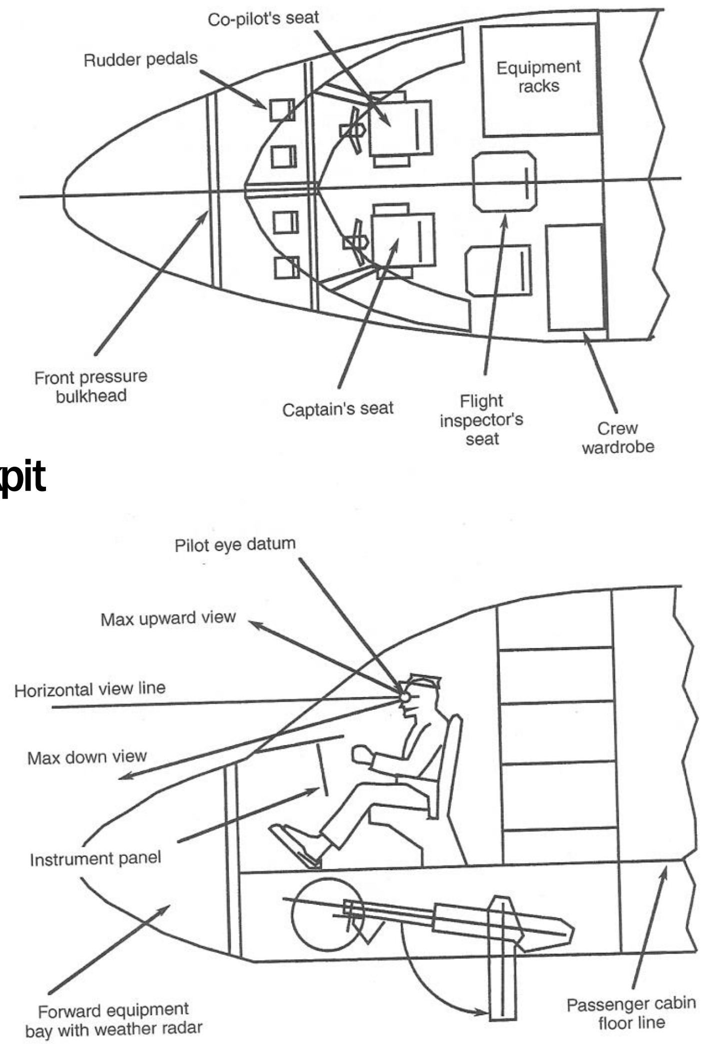
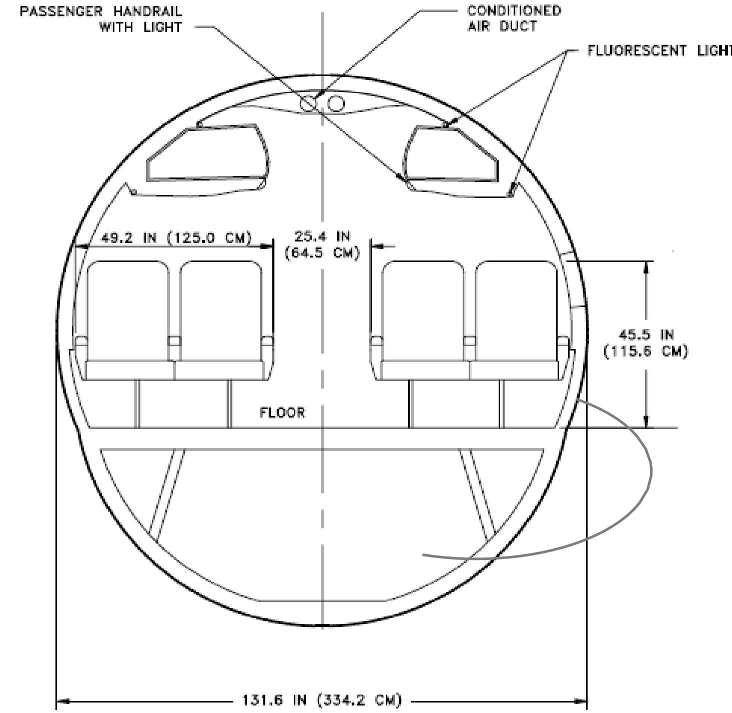


Fig. 5.16 Flight deck layout.



1st Class Cabin

2.5.2 CABIN CROSS-SECTION - FIRST CLASS SEATS
MODEL 717-200

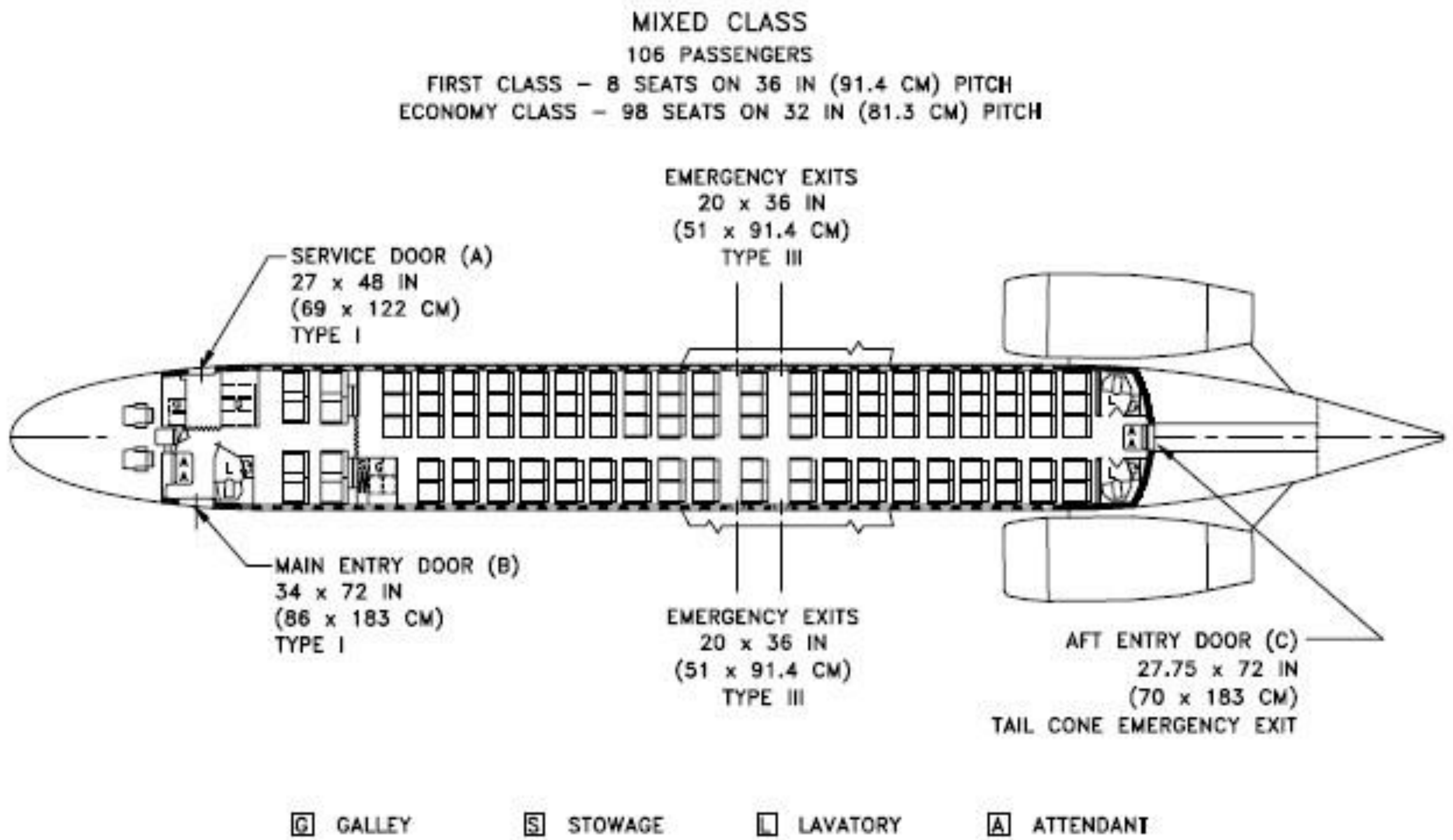
Items to consider when laying out the vehicle

Source: Civil Jet Aircraft Design by L. Jenkinson et al

Example Internal Arrangement

2.4.1 INTERIOR ARRANGEMENTS - MIXED CLASS CONFIGURATION
MODEL 717-200

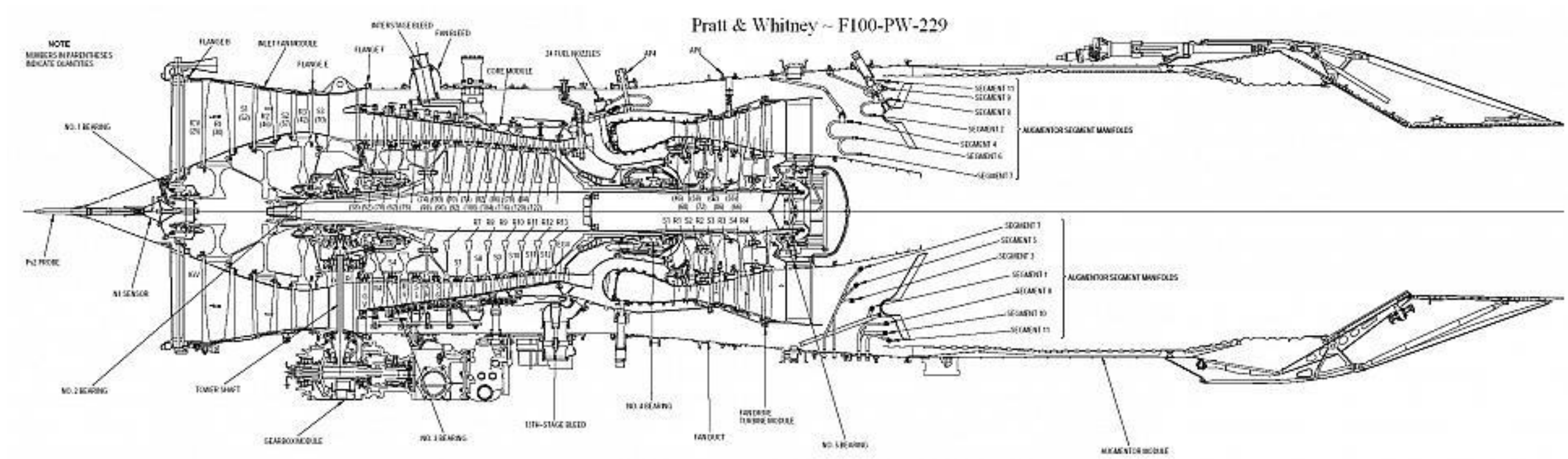
FWD



Source: 717-200: Airplane Characteristics for Airport Planning by Boeing

Propulsion

Example of Selected Propulsion System



ENGINE CHARACTERISTICS

Thrust 29,160 pounds (129.7 kN)

Weight (specification maximum) 3,826 pounds (1,735 kg)

Length 191 inches (4.85 m)

Inlet diameter 34.8 inches (0.88 m)

Maximum diameter 46.5 inches (1.18 m)

Bypass ratio 0.36

Overall pressure ratio 32 to 1

Thrust to weight 7.6

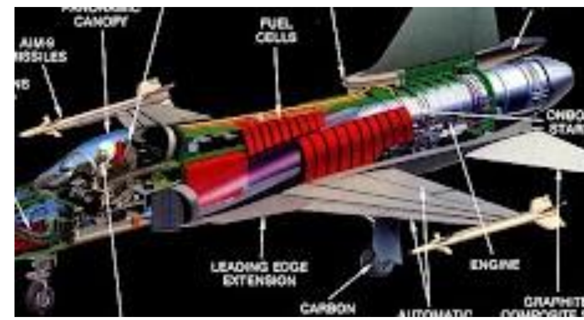
Research web, VT AOE resources or contact vendor to obtain a model or info to create a model

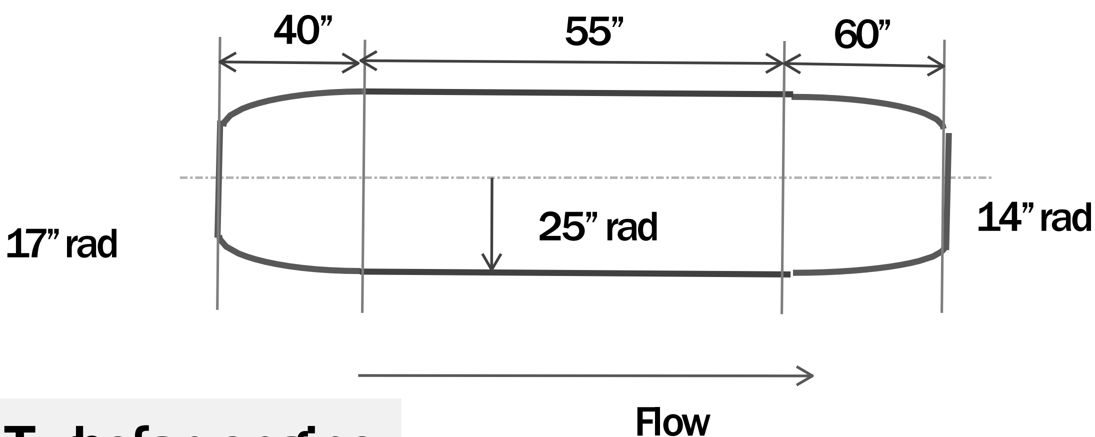
F100 – PW-229 Engine w/ afterburner

Source: F-16.net, P&W site, Diamond aviation

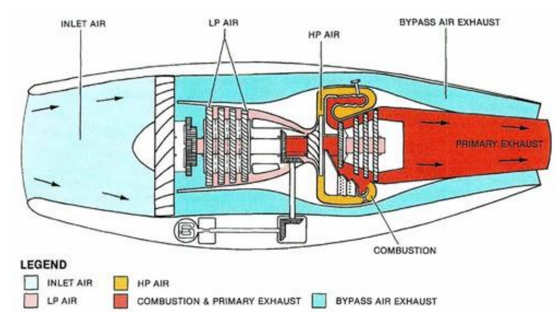
Simple Nacelle Basic Geometry

- There can a cowling around the engine itself depending upon the vehicle design
- Inlets, ducts, nozzles can drive part of the fuselage design if the engines are buried in the fuselage.
  - Be careful of where exhaust impinges
- Work with propulsion on inlet size and shape and required duct cross-sectional area profiles
- Be careful of ground clearances and provide enough structure for engine attachment



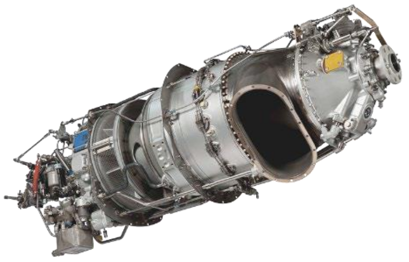


Turbofan engine

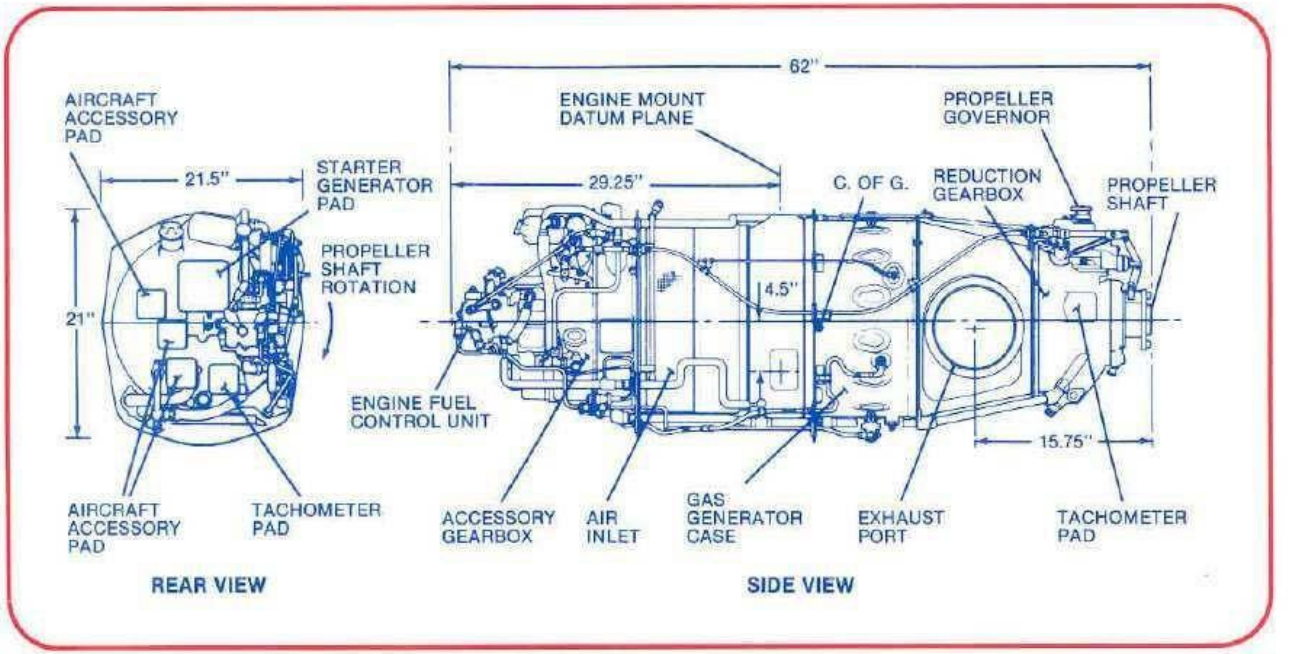


Example of Initial Propulsion System

PT6A engine



Research web, VT AOE resources
or contact vendor to obtain a model or info to create a model – maintenance manuals are also good sources of information



	Thermodynamic Power Class* (ESHP***)	Mechanical Power Class* (SHP)	Propeller Speed (Max. RPM)	Height** (Inches)	Width** (Inches)	Length** (Inches)
PT6A' Small' (A-11 to A-140)	600 to 1075	500 to 900	1,900 to 2,200	21 to 25	21.5	61.5 to 64
PT6A 'Medium' (A-41 to A-62)	1,000 to 1,400	850 to 1,050	1,700 to 2,000	22	19.5	66 to 72
PT6A 'Large' (A-64 TO A-68)	1,400 to 1,900	700 to 1,900	1,700 to 2.000	22	19.5	69 to 75.5

Source: P&W site

Example of Initial Propulsion System

Propeller for the PT6A engine

SPECIFICATIONS

Propeller Part Number	P7646314-0152
Number of Blades	4
Blade Design	Semi-elliptical
Installed Propeller & Spinner Weight	145 lbs. each (approx.)
Maximum Diameter	94 inches
Minimum Diameter	92 inches
TBO	5000 hours or 72 calendar months (whichever occurs first)
Shipping Weight	380 lbs./each 760 lbs./set (approx.)
Carton Dimensions	86″ x 84″ x 28″ each (approx.)

Source: P&W site, Pixers, internet

Subsystems

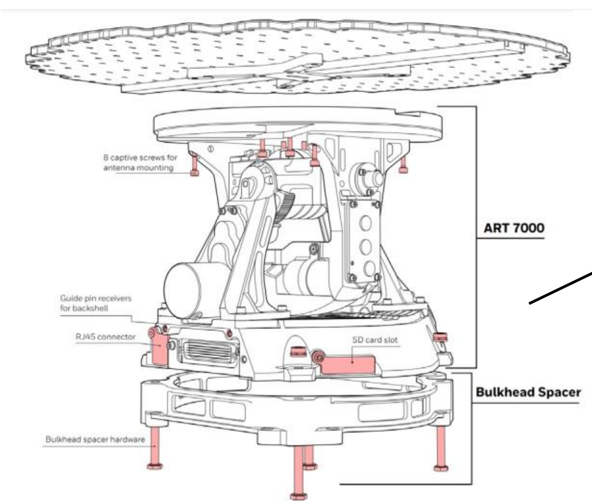
Landing Gear for the Twin Otter

Look up or select a the tire size in a tire book (example: *Good Year Aviation Data Book*)

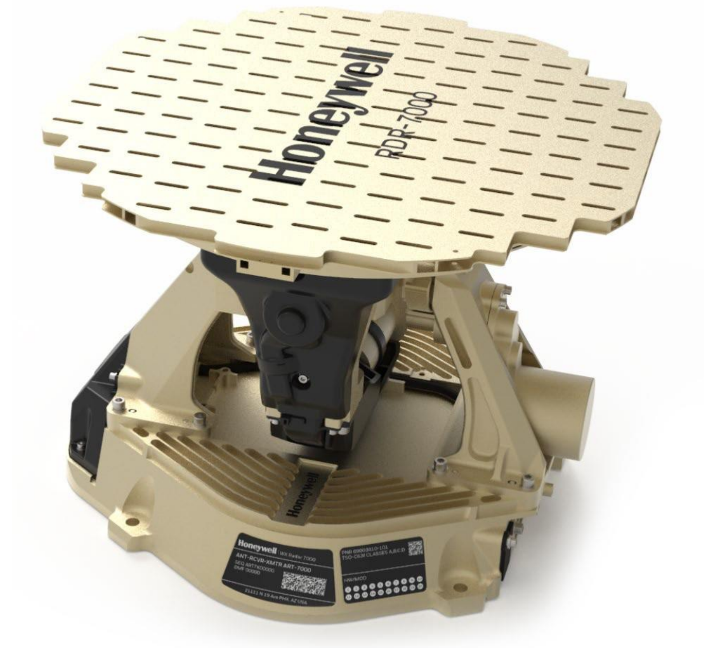
MODEL	NAME	MAIN TIRE		AUXILIARY TIRE	
		TIRE SIZE	PLY RATING	TIRE SIZE	PLY RATING
DHC-3	Otter	11.00-12	6	6.00-6	6

Source: F-16.net, P&W site

Example of Subsystems – Radar



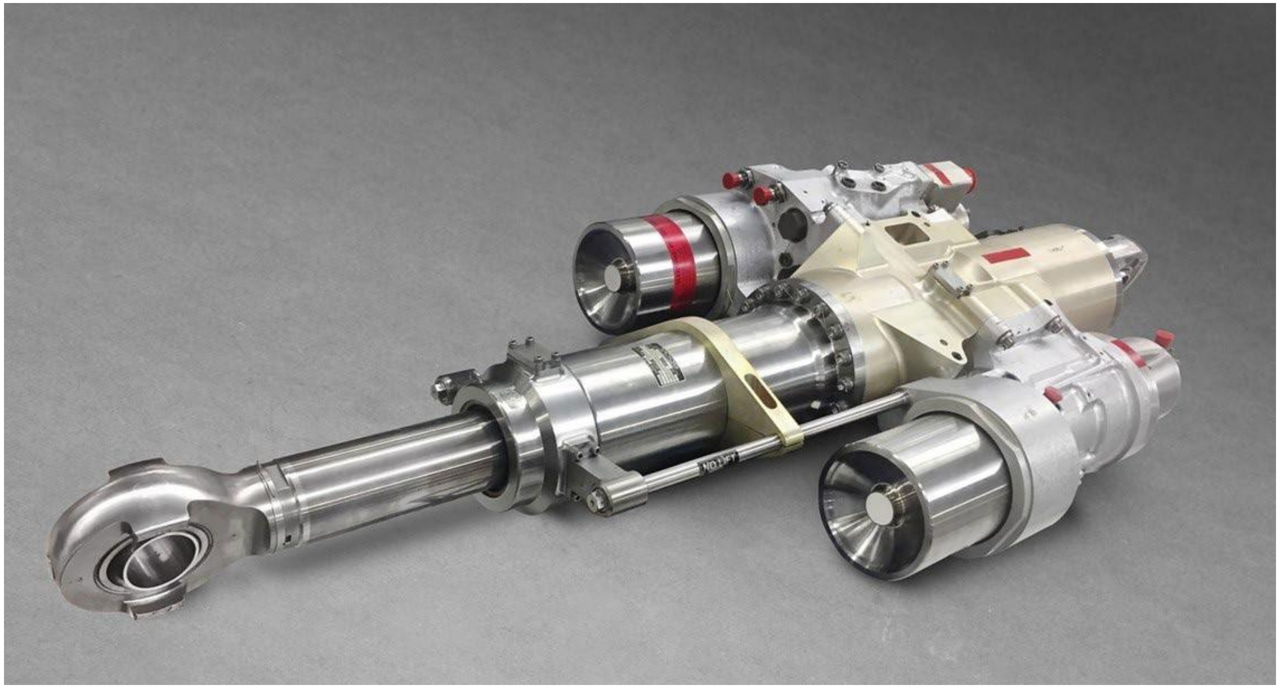
Honeywell Radar

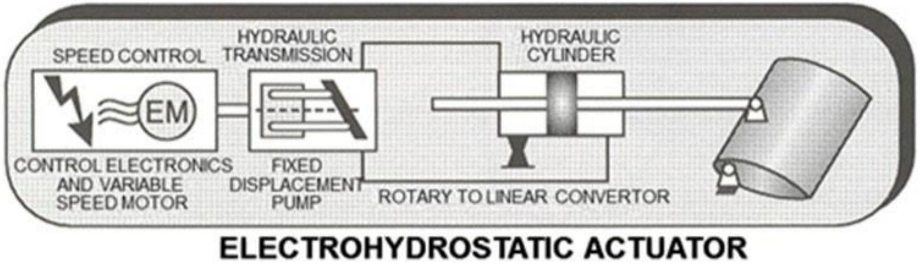


Cessna Citation Bravo

Source: F-16.net, P&W site

Example of Subsystems – Actuator

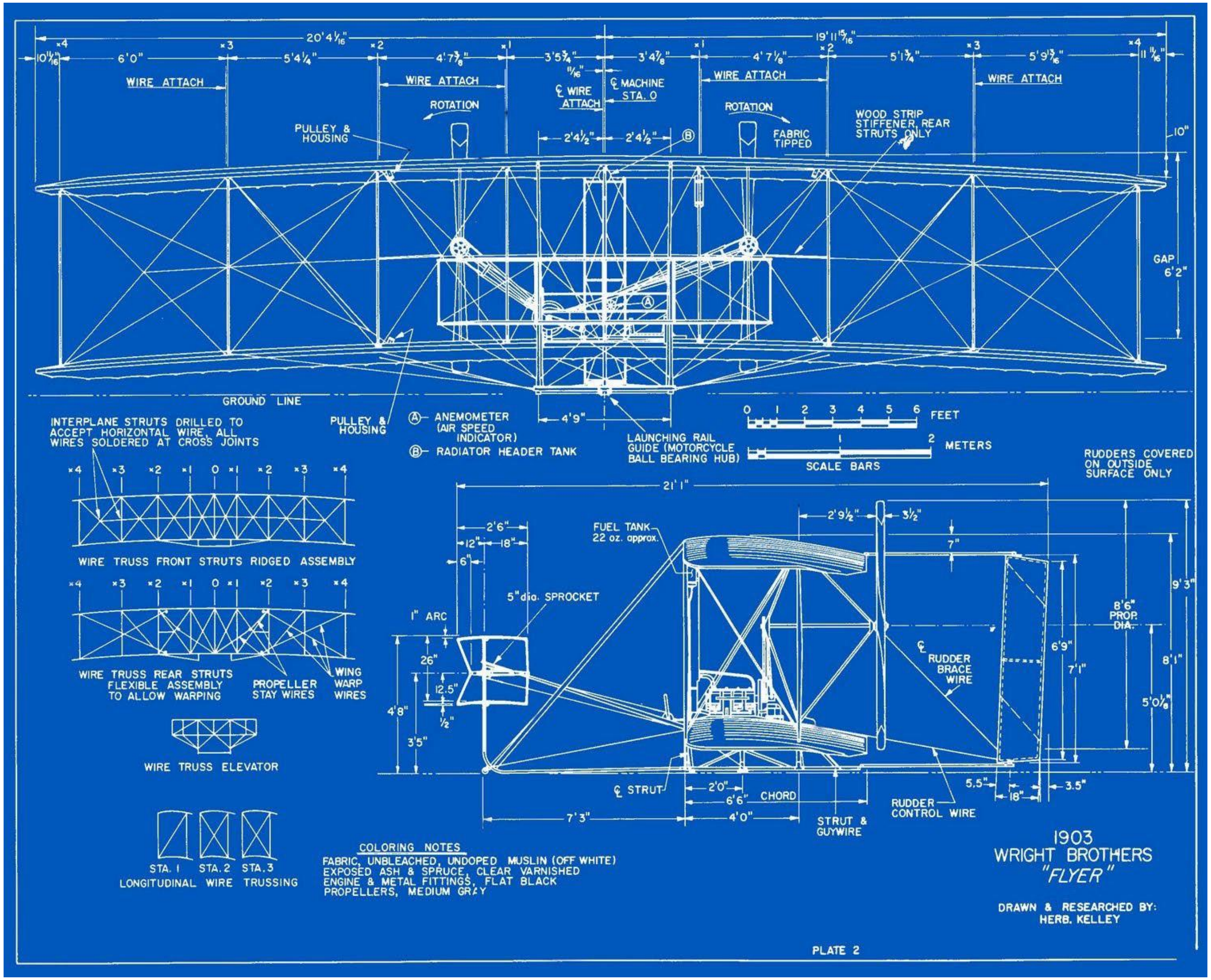




Moog Common
Electro-Hydrostatic Actuator

Source: Moog

Drawing of the Wright Flyer



Line Types

Visible (or Object) – used to show visible edges in a view

Hidden - used in multiview drawings to indicate a feature that is behind another feature in the view

Center – used to mark the center of arcs > 180 degrees (both in-plane and longitudinal). When the center line is short a single short dash is used.

Construction – light solid lines used as guidance. Should be light enough that when the sketch is held at arms length the construction line is barely visible

A General Arrangement Drawing

Provide a complete graphical description of the air vehicle

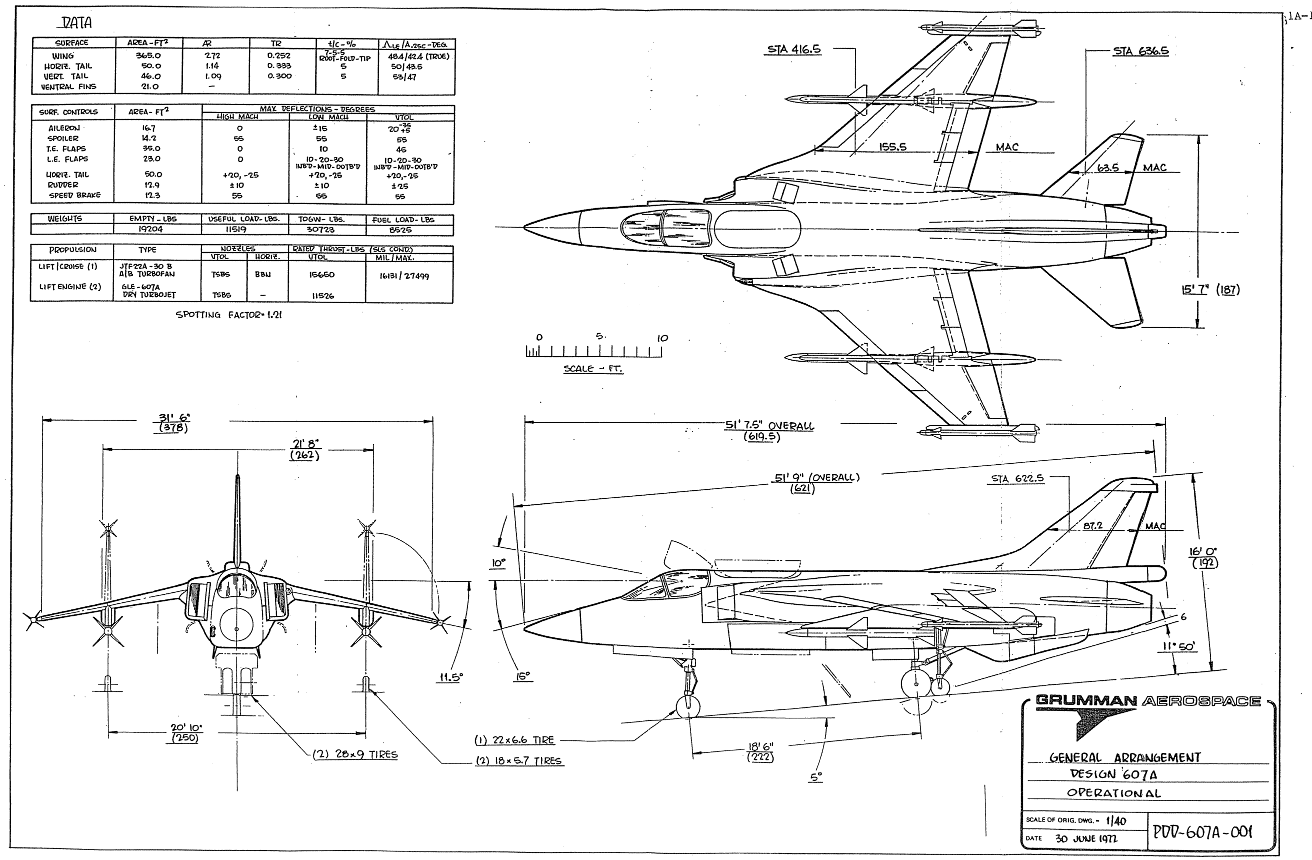
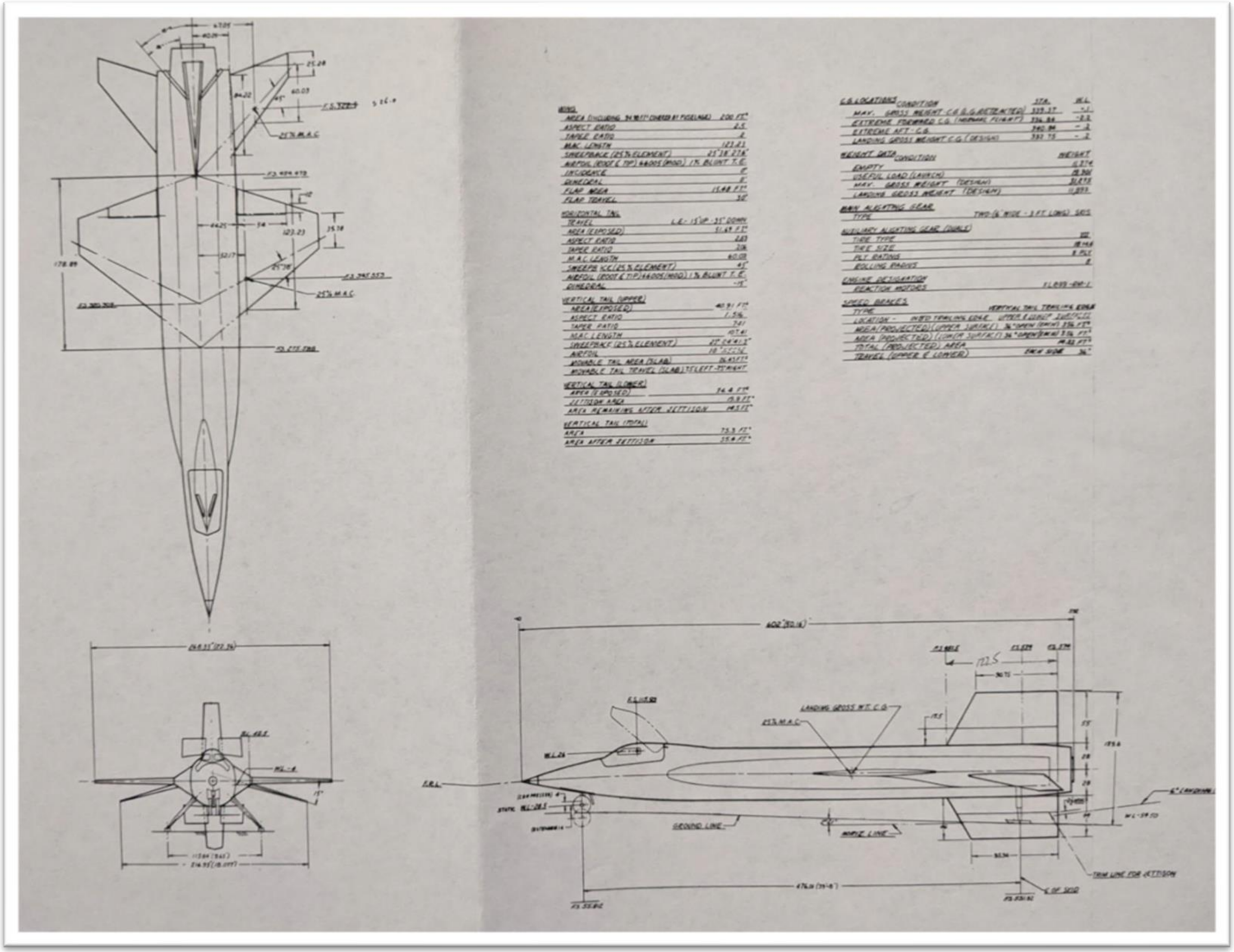


Figure 1A-1. Three View - Grumman Design 607A, Lift+Lift/Cruise VSTOL Navy Fighter

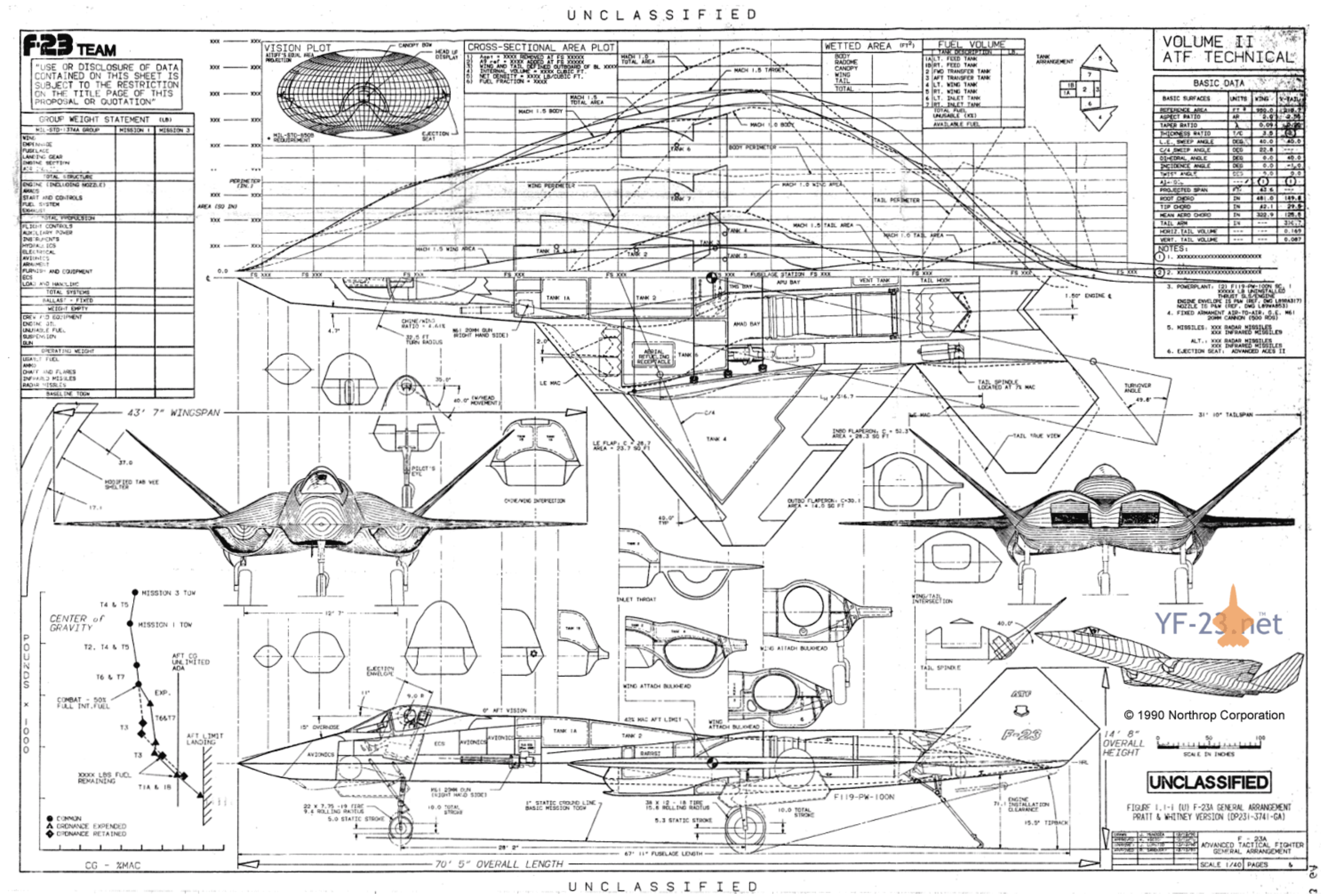
- Parallel projection and proper scale should be used
- Note the data block and dimensioning
- Note the units assumed in this drawing

A full and fairly accurate 3D model of the OML of a vehicle can be generated from a 3-view when combined with a little knowledge.

General Arrangement Drawing: X-15

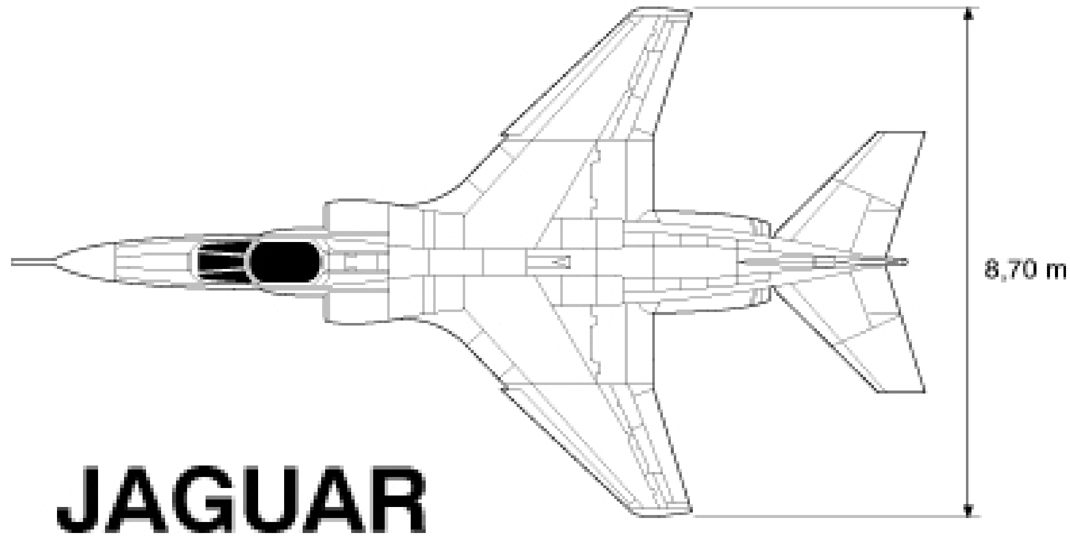


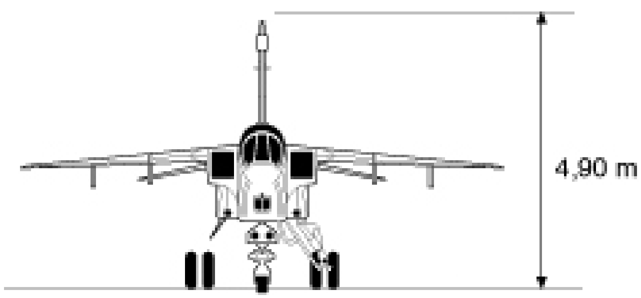
YF-23 General Arrangement - Proposal

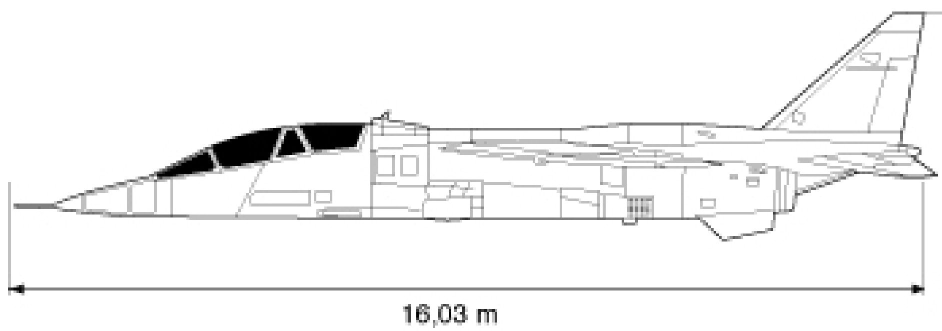


You can learn quite a bit from a good 3-view drawing!

They Provide Key Inputs for Engineering Analyses (See CM A3)



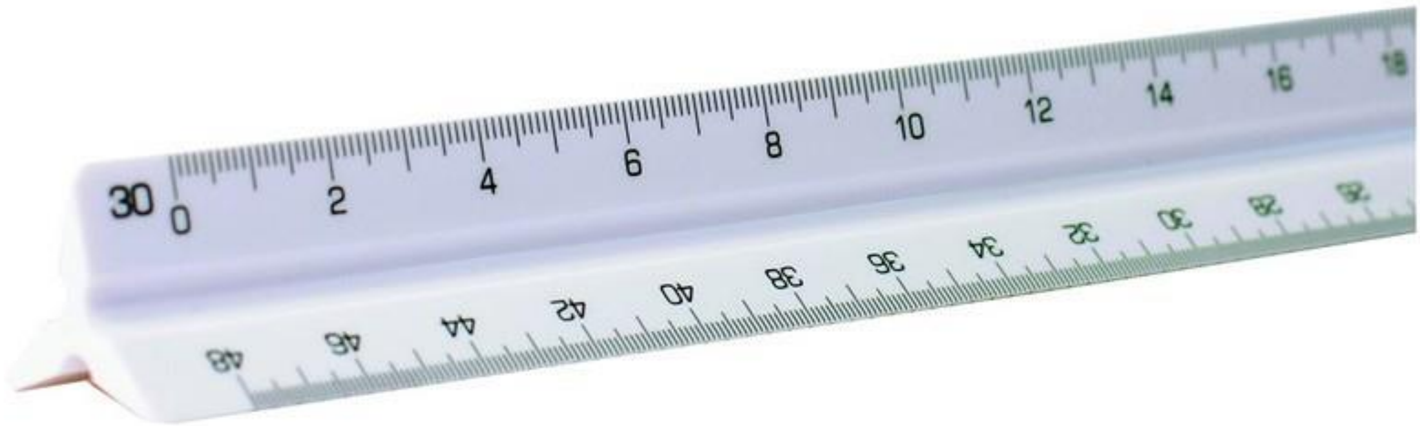




Drawing: Dimensioning and Scale

Use good scales on vehicle or large object drawings such as:

1/10, 1/20, 1/30, 1/40, 1/80 etc.



Engineer’s Scale

Remember drawings are meant to illustrate a concept and also to be useful

There are standards!

Aircraft Three-view Specs (SAE)

- **Required Views**

  The plans shall consist of a standard aeronautical three-view, using a US-standard third-order projection:

  1. Show [Right] Side view in the lower left with the nose pointing right
  2. Show Top view above the right side view also with the nose pointing right
  3. Show Front view in the lower right.

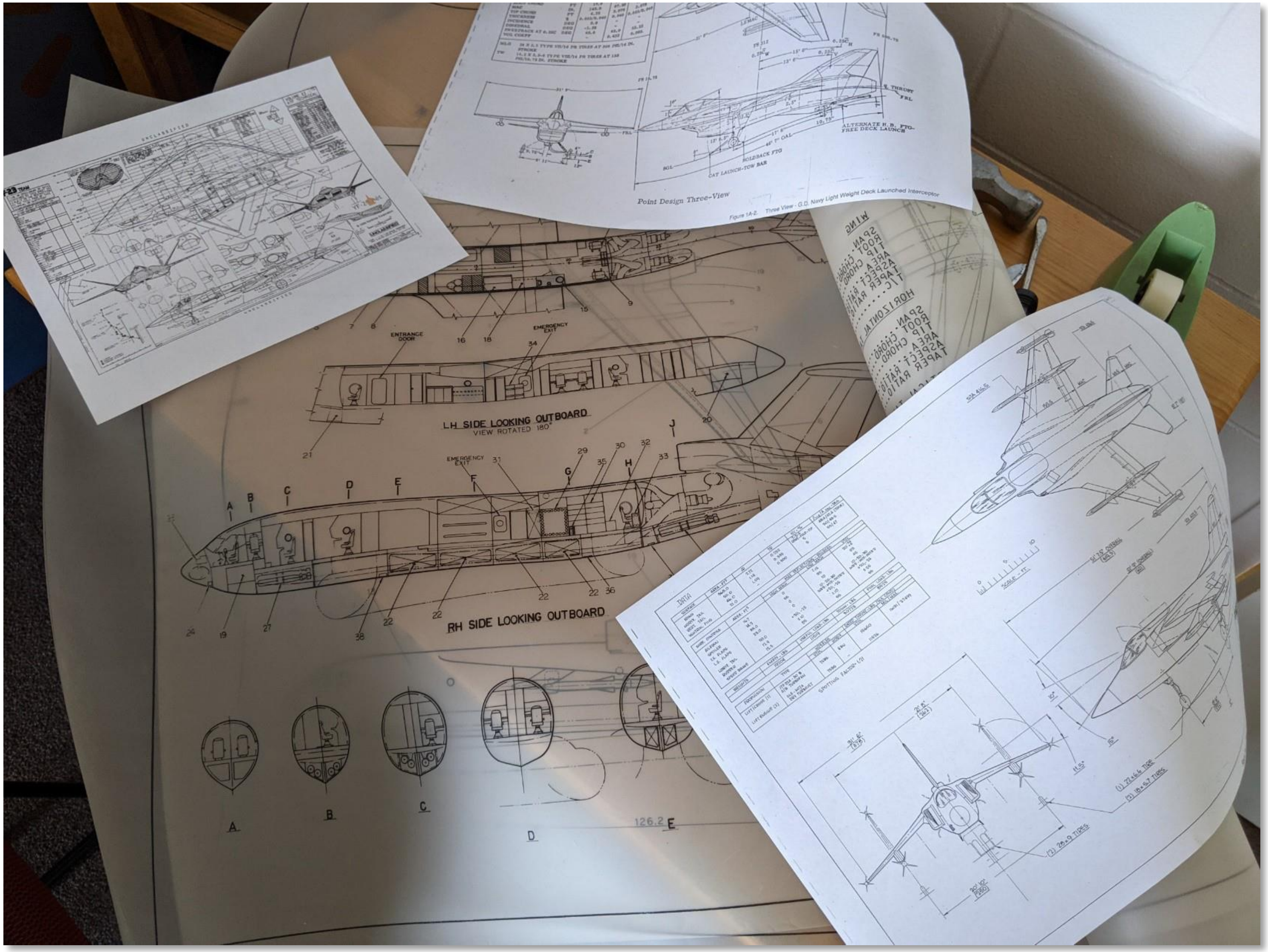
- **Dimensions**
  - At a minimum, all aircraft must have the length, width, height, and CG location clearly marked and dimensioned on the submitted engineering drawings.
  - All dimensions must be in set of units (e.g., inches and decimal inches) to an appropriate level of precision. **(*Hint: four decimal places are too many*!)**

- **Summary Data**

  Include a table with a summary of <u>pertinent</u> aircraft data such as wingspan, TOGW, empty weight, fuel weight, engine make and model, SM, etc.

We Recommend Using SAE Specs

Other General Arrangement Drawings



Internal Arrangement Drawings

Provides a complete graphical description of the interior of an air vehicle

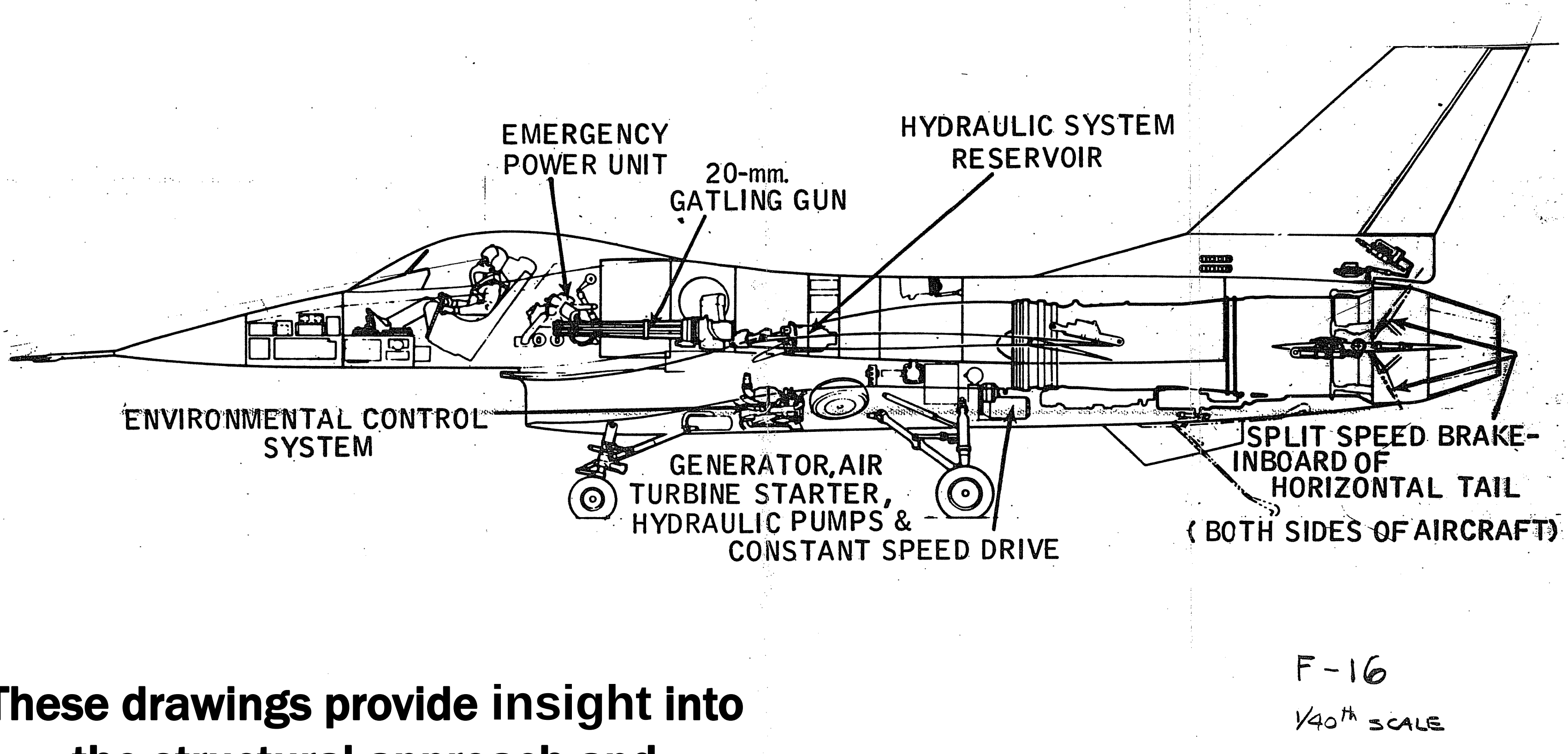
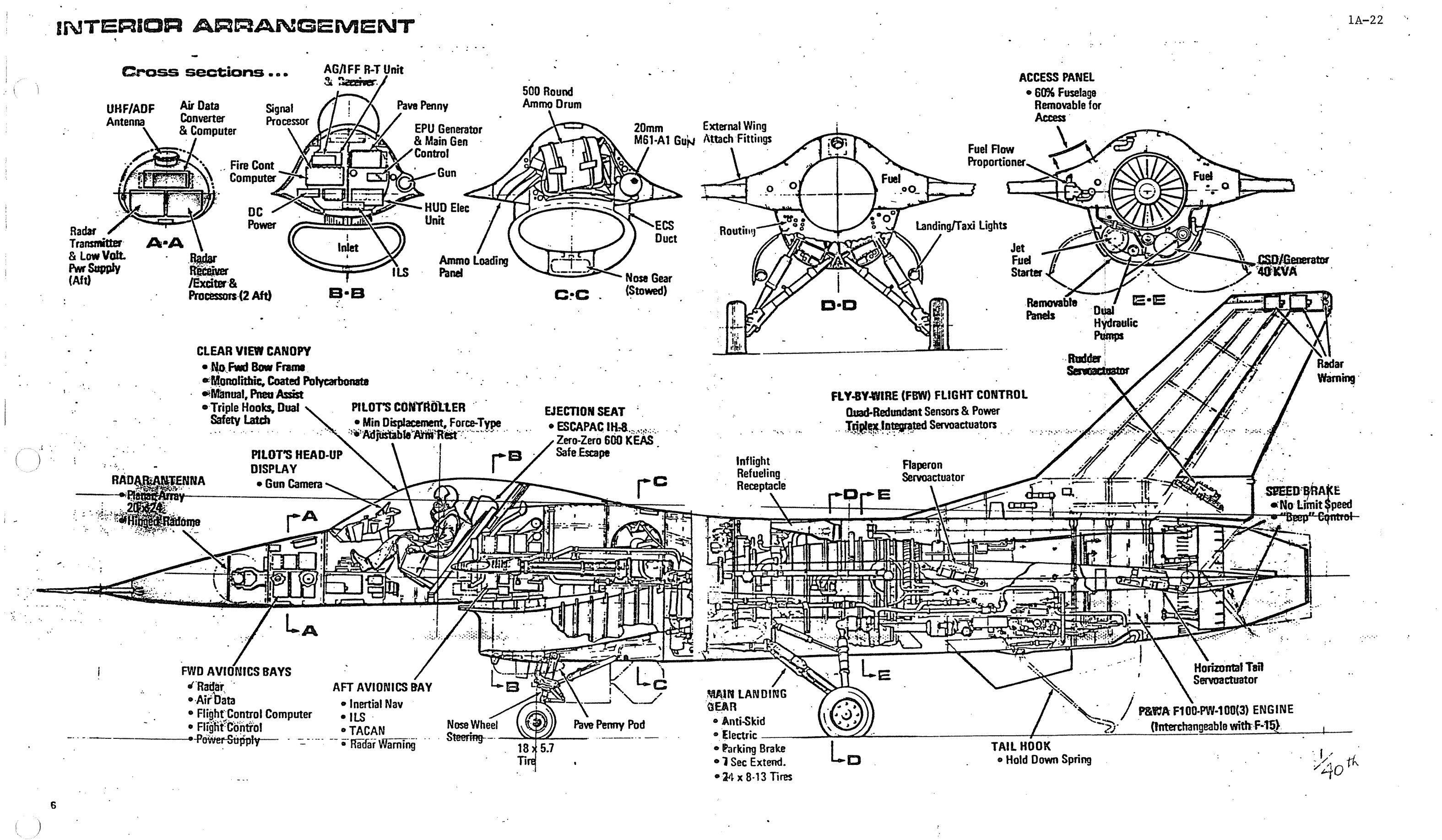


Figure 1A-10. Inboard Profile - G.D. F-16A Fighter (Executive Summary and Vu-Graph)

These drawings provide insight into the structural approach and arrangement of systems in the vehicle. Parallel projection and proper scale should be used.

Interior Profile Drawing

Provides a complete graphical description of the interior of an air vehicle

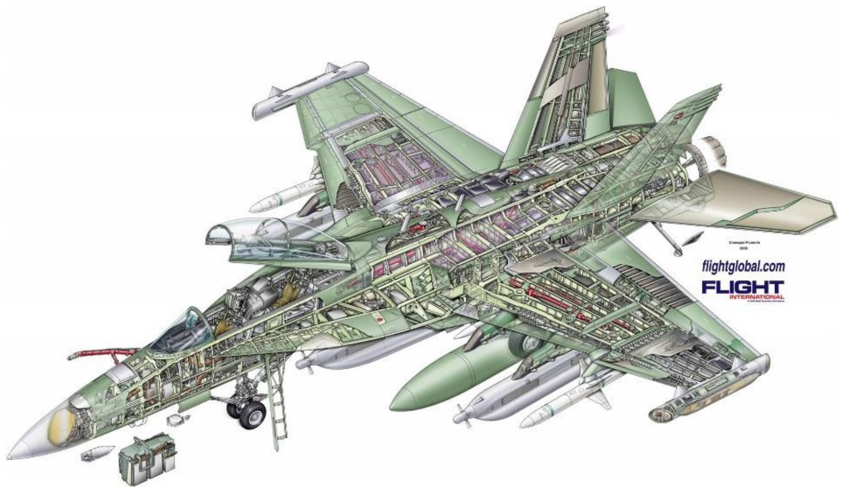


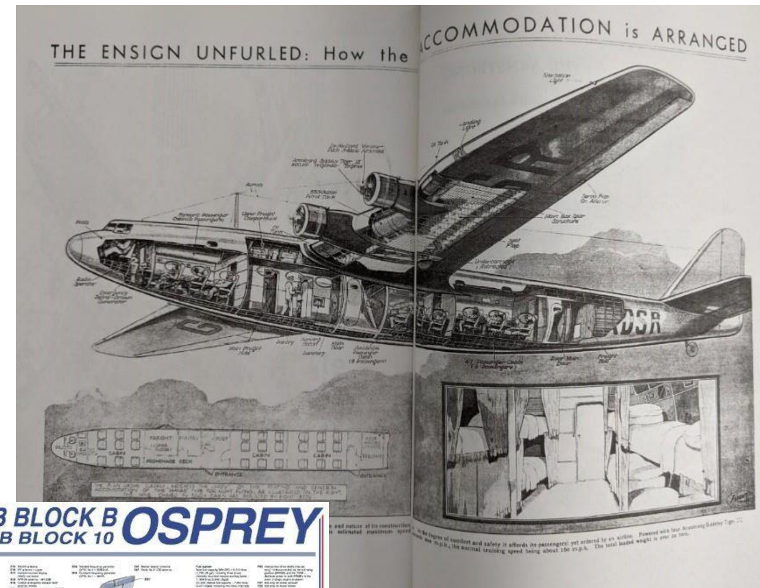
Note: key systems call-outs

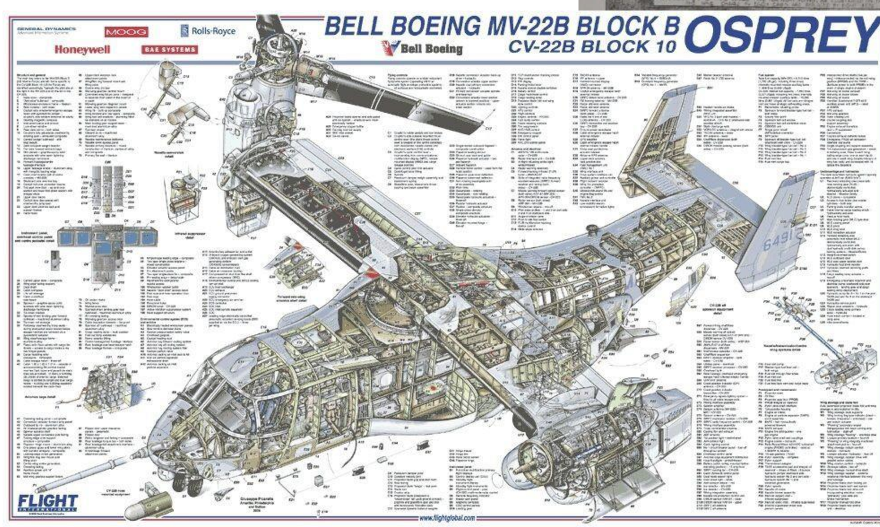
Figure 1A-11. Inboard Profile - G.D. F-16A Fighter (Presentation Vu-Graph)

These drawings provide insight into the structural approach and arrangement of systems in the vehicle. Parallel projection and proper scale should be used.

Cutaway Drawings







Flight International is a great source of vehicle cutaway illustrations

Typically are basically an inboard drawing turned 3D illustration (is done in perspective).

Cutaway Drawings

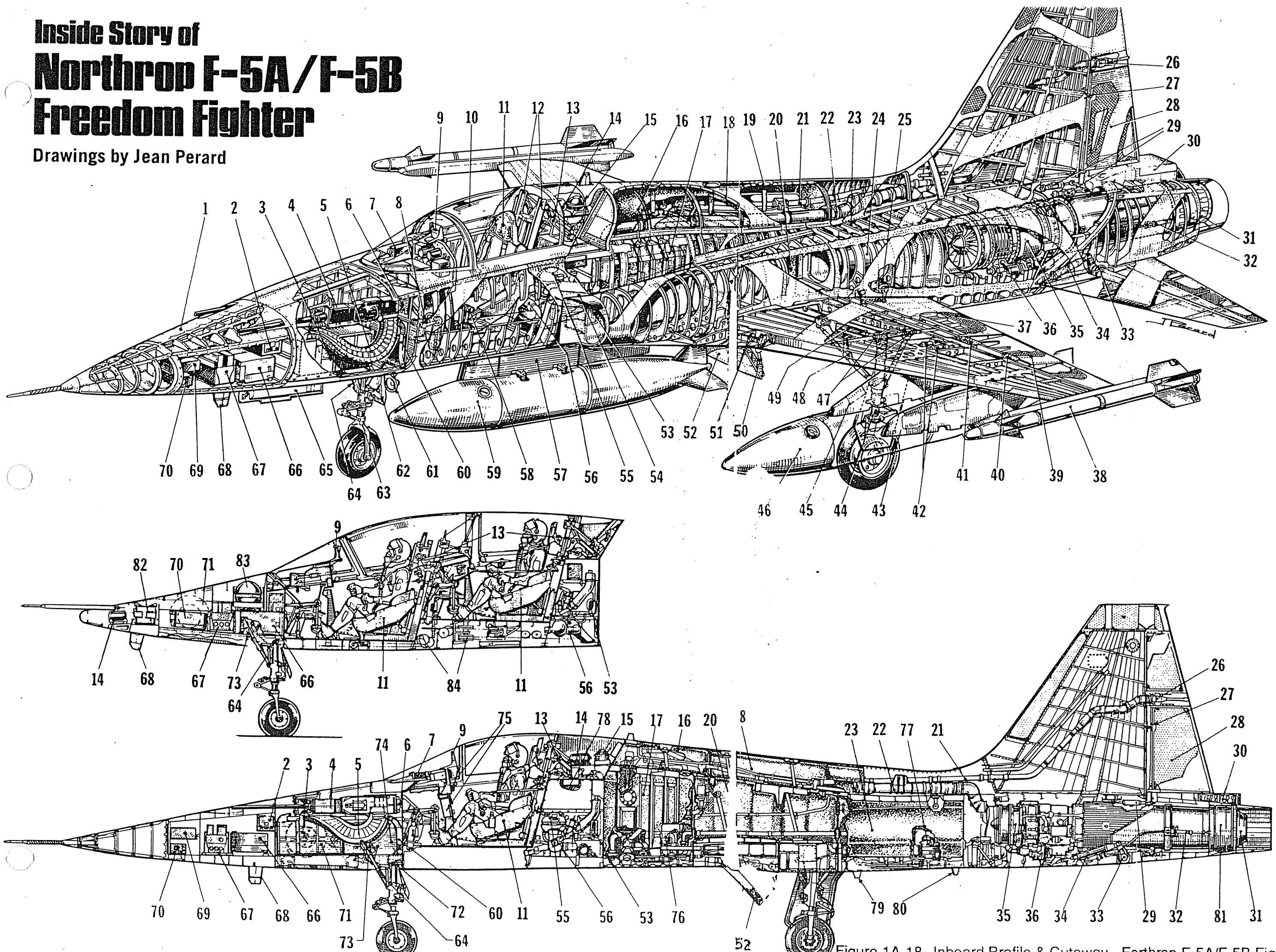


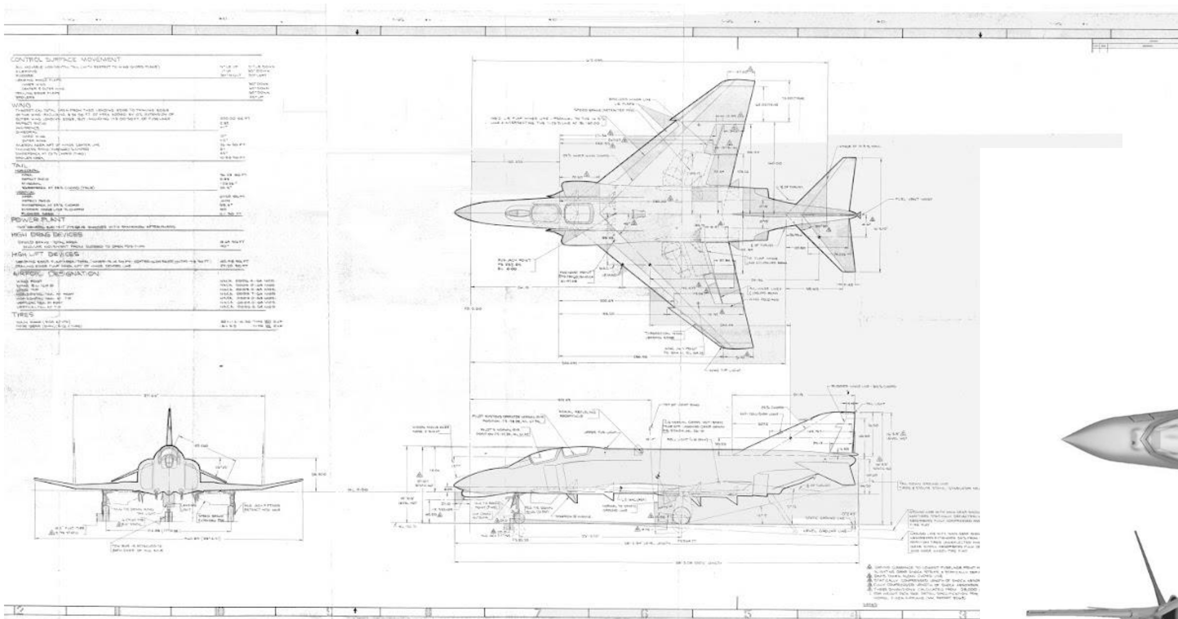
Figure 1A-18. Inboard Profile & Cutaway - Forthrop F-5A/F-5B Fighter

1A-30

Key to Cutaway Drawing and Inboard Profile Illustrations

1 Electronics compartment
2 Servo amplifier
3 Ammunition box
4 M-39 20-mm cannon
5 Ammunition feed
6 Cannon mount
7 Gun camera
8 Rudder pedals
9 Gun sight
10 Jettisonable canopy
11 Zero-zero ejection seat
12 Ejection guide rails
13 Canopy opening mechanism
14 Vertical gyro
15 Directional gyro
16 Upper forward fuel tank
17 Forward fuel tank
18 Upper aft fuel tank
19 Tank gauge
20 Center fuel tank
21 Air vent duct
22 Air conditioner bleed
23 Aft fuel tank
24 Engine air duct
25 Wing flap drive motor
26 Fuel tank air vent
27 Rudder hinge
28 Rudder
29 Rudder servo controls
30 Drag chute compartment
31 Variable area exhaust nozzle
32 Nozzle control jack
33 Elevator hinge
34 Elevator control jack
35 General Electric J 85-13 turobjet
36 Accessories relay
37 Wing flap
38 Sidewinder air-to-air missile
39 Aileron
40. Outboard aileron hinge
41 Aileron main hinge
42 Aileron control jacks
43 Outboard pod
44 Main gear
45 Inboard pod
46 Drop tank (150 gallons)
47 Main gear trunnions
48 Side strut/radius rod
49 Gear actuator jack
50 Air brake actuator
51 Leading edge slat motor
52 Belly air brake
53 Air conditioning inlet
54 Boundary layer control
55 Oxygen supply
56 Air conditioning unit
57 Belly pod
58 Thrust levers
59 Drop tank (150 gallons)
60 Gun gas exhaust
61 Landing light
62 Nose wheel door
63 Nose gear
64 Nose gear strut
65 Nose wheel door
66 TACAN T/R
67 IFF T/R
68 UHF aerial
69 Yaw damper
70 Communications radio
71 Nose wheel well
72 Nose gear trunnion
73 Nose gear actuator
74 Empty ammo casing collector box
75 Instrument panel
76 Left inverted flight circuits
77 Right inverted flight circuits
78 Static inverter
79 TACAN aerial
80 IFF aerial
81 Afterburner
82 Storage battery
83 Oxygen equipment
84 Flight controls linkage

Drawing and Illustration: *Distinct Entities*



Drawing

F-4 Phantom

Illustration

F-35B Lightning II

Each plays an important role in design as it is practiced but they are not the same thing.

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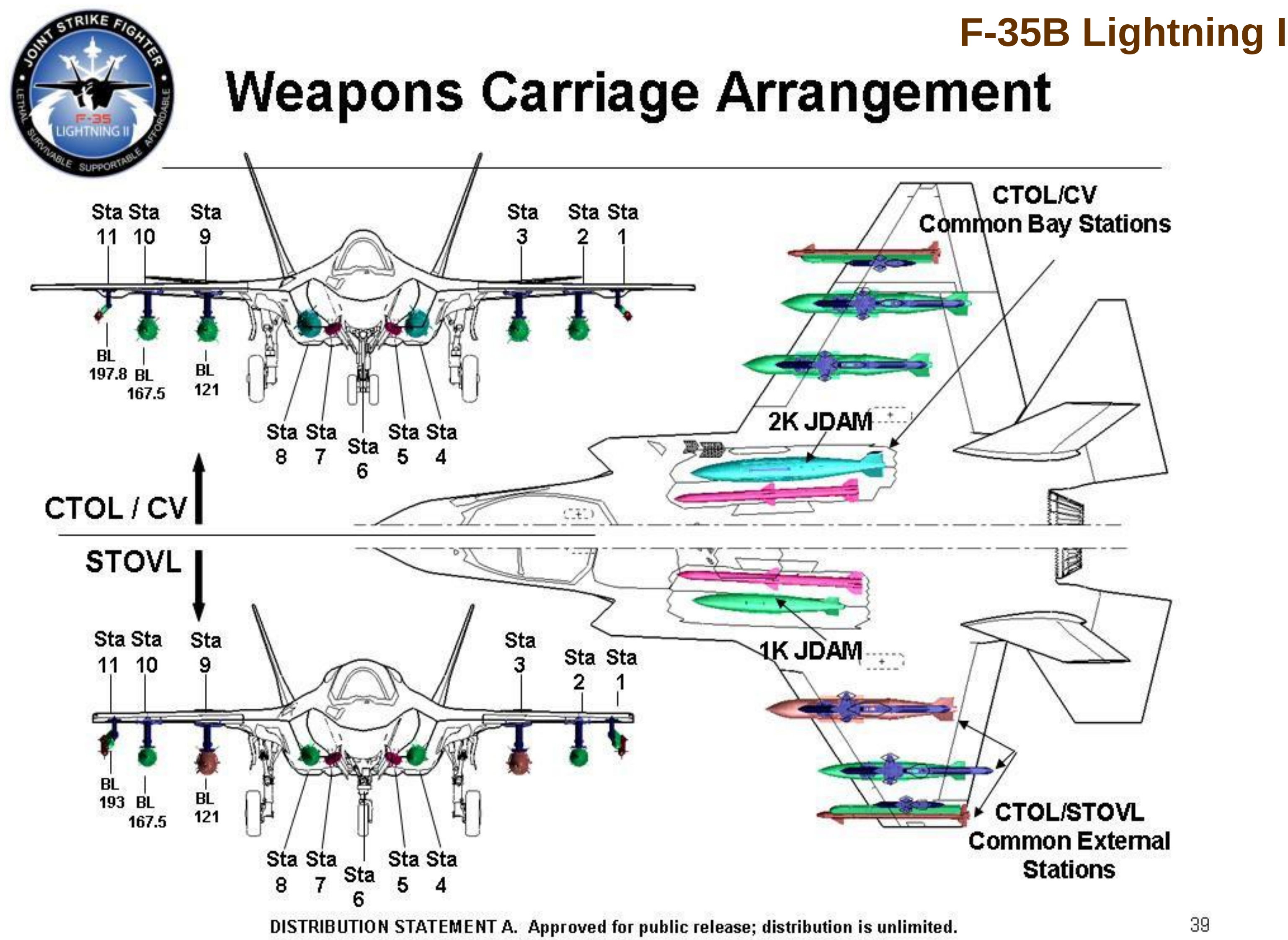
VIRGINIA TECH.

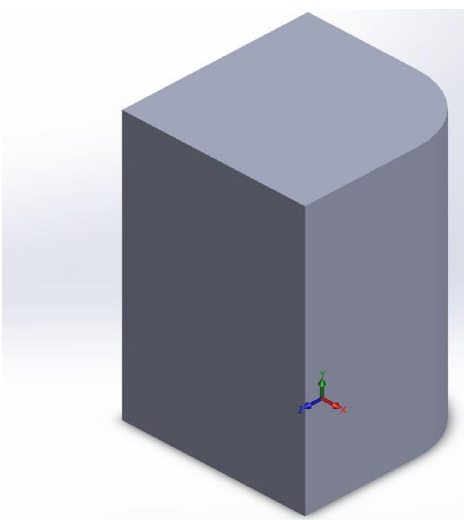
But sometimes there are hybrids…

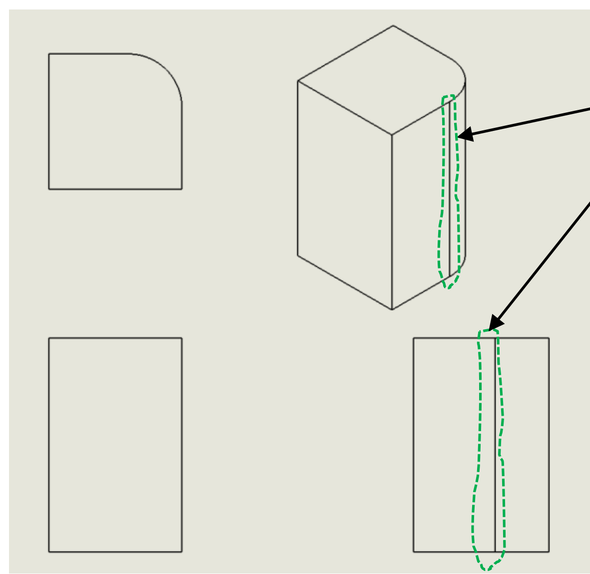


…with drawing elements adapted for an illustration

Some Things to Note About Doing Drawings in CAD

- Drawing standards still apply
- Drawings for conceptual design are different than drawings in detailed design
- Be careful about tangent edges and hidden lines in any CAD program
- Remember CAD is tool – you still need to have the understanding on how to use the tool correctly





Line showing a tangent edge that should not be visible in a drawing

Outline

A7A. Configuration Layout: *Drawings & Loft*

A7A.1 Computer Aided Design (CAD) Systems

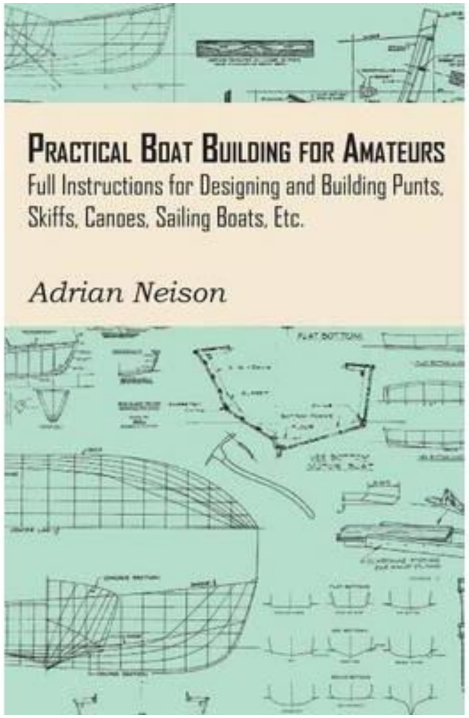
A7A.2 Configuration Layout and CAD Drawings

A7A.3 Basics of Conic Lofting

A7A.4 Lofting in Solidworks*

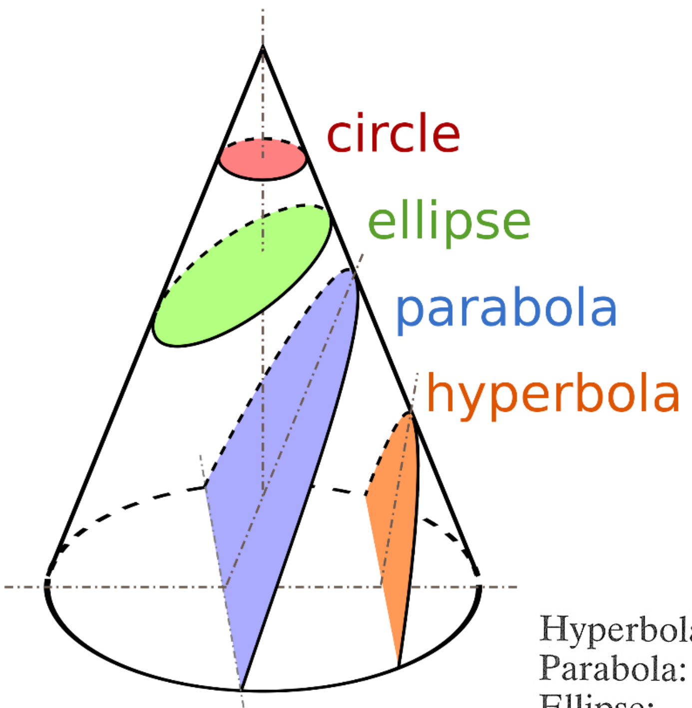
*Excerpt of notes from Greg Marien - San Diego State University

Conic Lofting



Conics

Conics defined by a rho value are a powerful tool



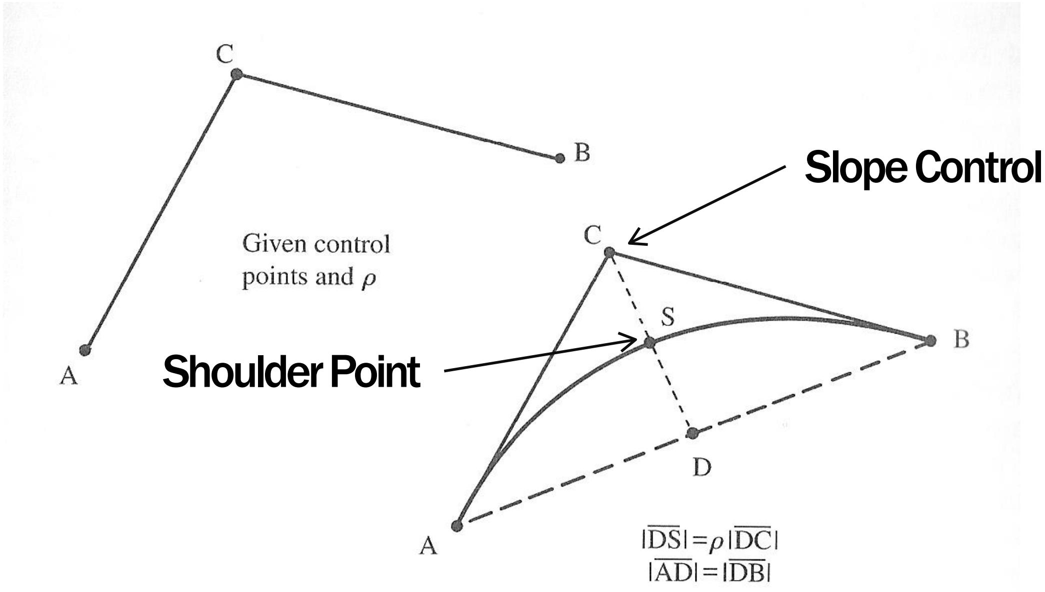


Fig. 7.16 Conic layout using ρ.

Hyperbola:	$\rho > 0.5$
Parabola:	$\rho = 0.5$
Ellipse:	$\rho < 0.5$
Circle:	$\rho = 0.4142$ and $\lvert\overline{AC}\rvert = \lvert\overline{BC}\rvert$

Source: Aircraft Design: A Conceptual Approach, 3rd Edition by D. Raymer

Conic Surfaces

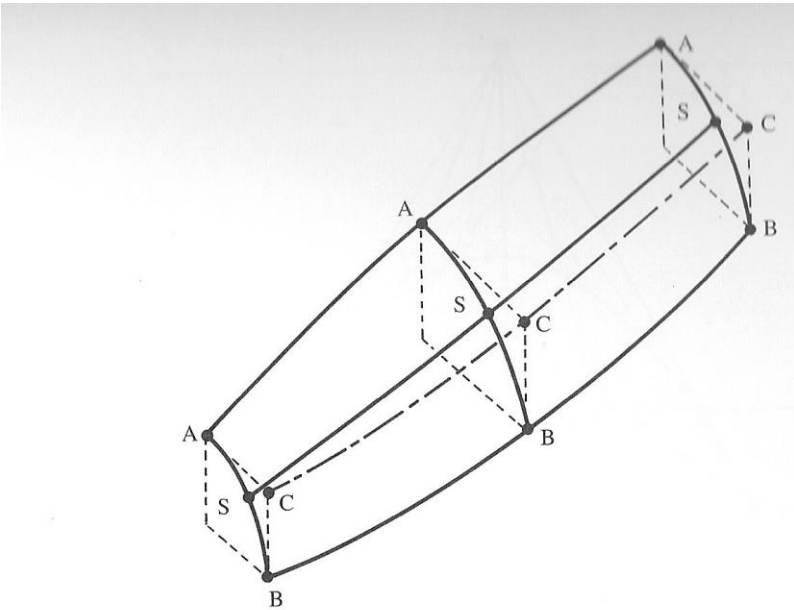


Fig. 7.13 Longitudinal control lines.

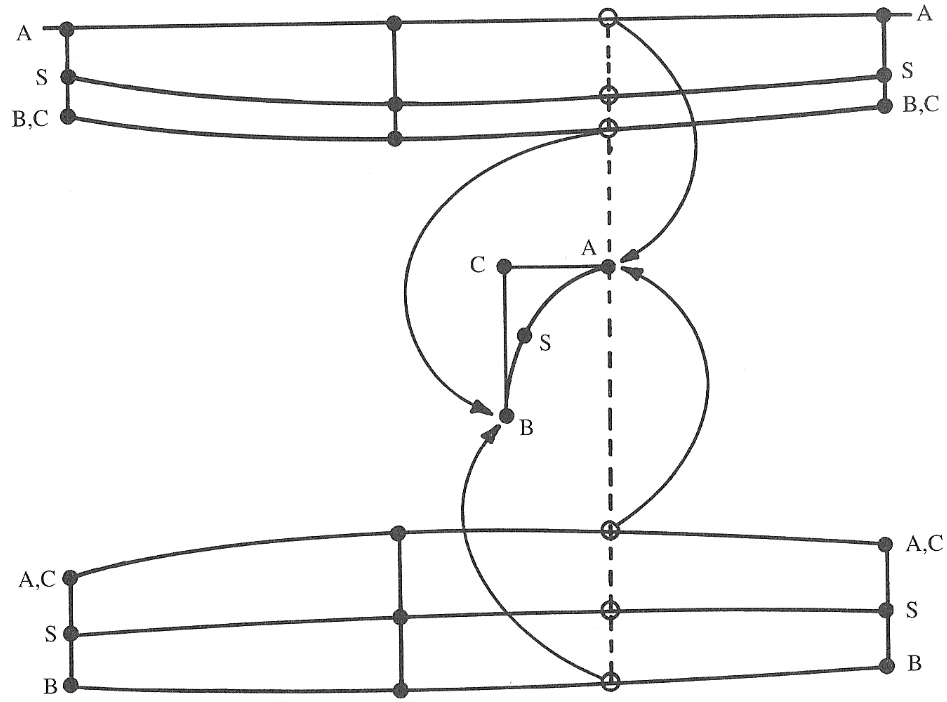


Fig. 7.14 Cross section development from longitudinal control lines.

How you go about creating these types of surfaces really depends upon the CAD system you are working in

Source: Aircraft Design: A Conceptual Approach, 3rd Edition by D. Raymer

Fuselage Creation

Conic Lofting: Fuselage Edge Curves

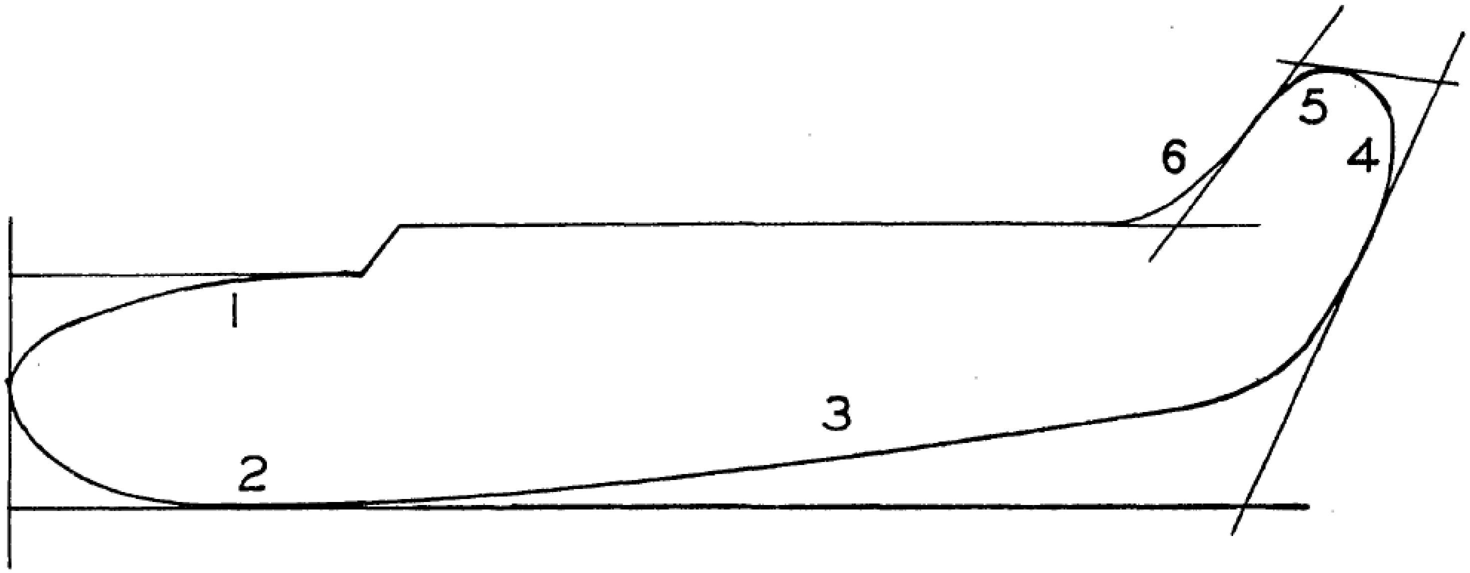


Fig. 3

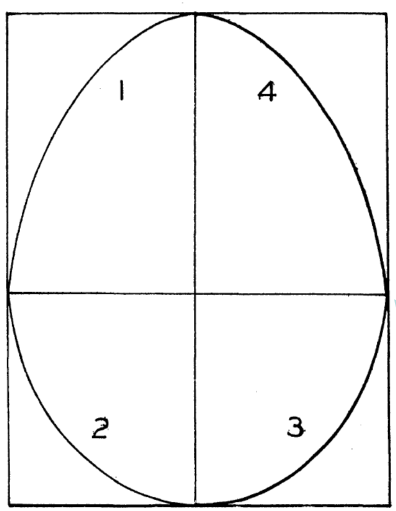


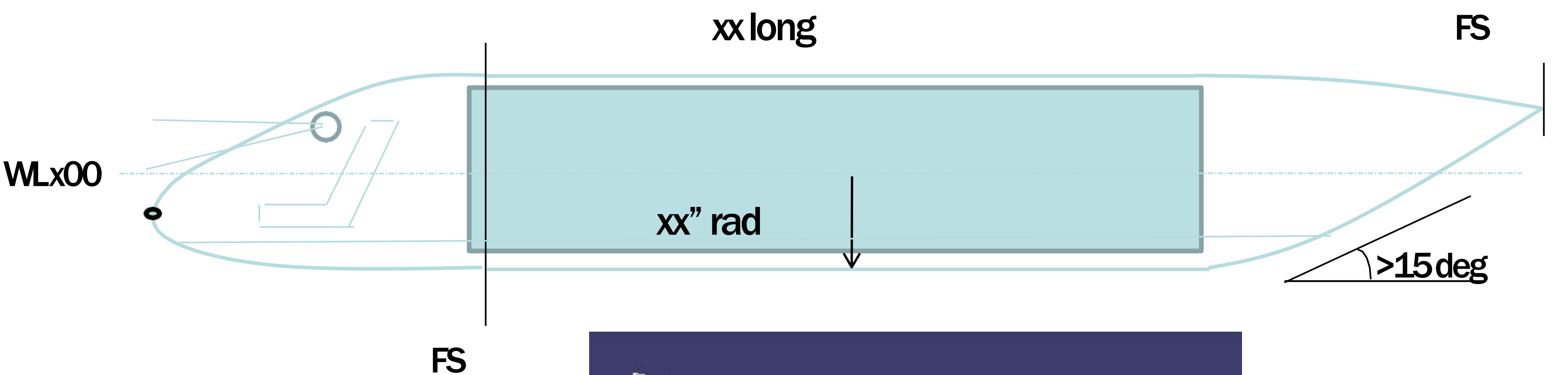
Fig. 4

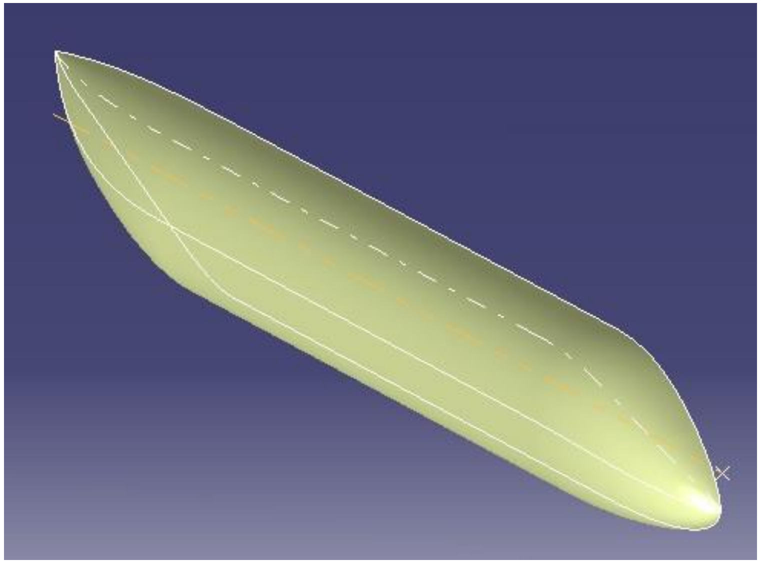
A combination of conics and lines can be used to generate control lines for the entire OML

Max Half-Breadth

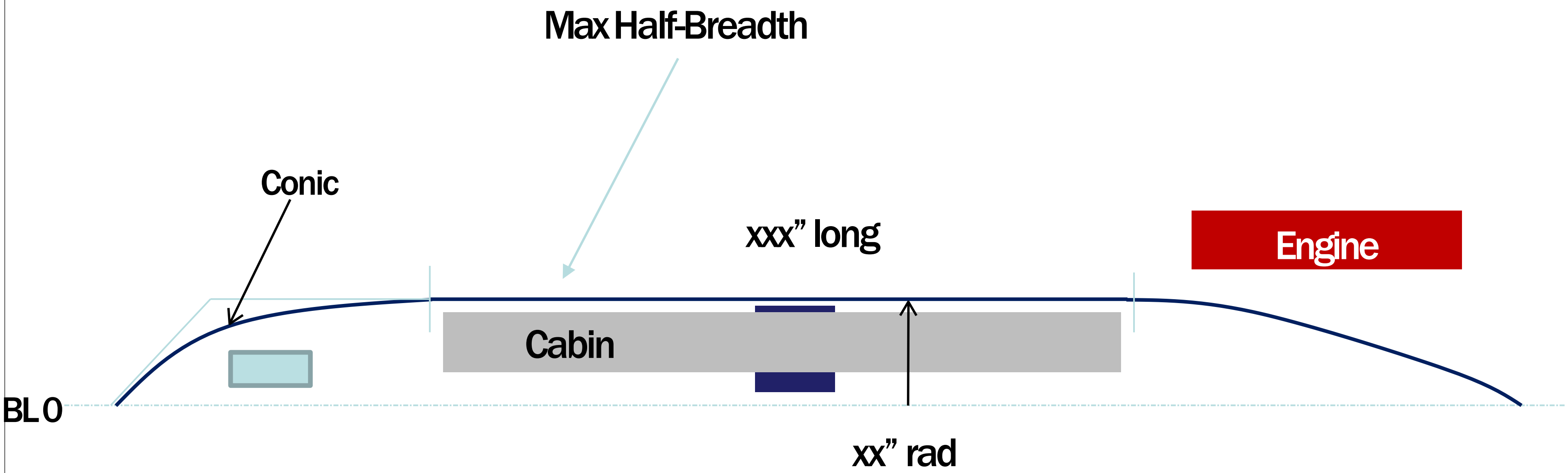
Image Source: Use of Conics in Airplane Design, L.J. Adams 1952

Set up a Fuselage Profile on a BL 0 plane





Fuselage Planview



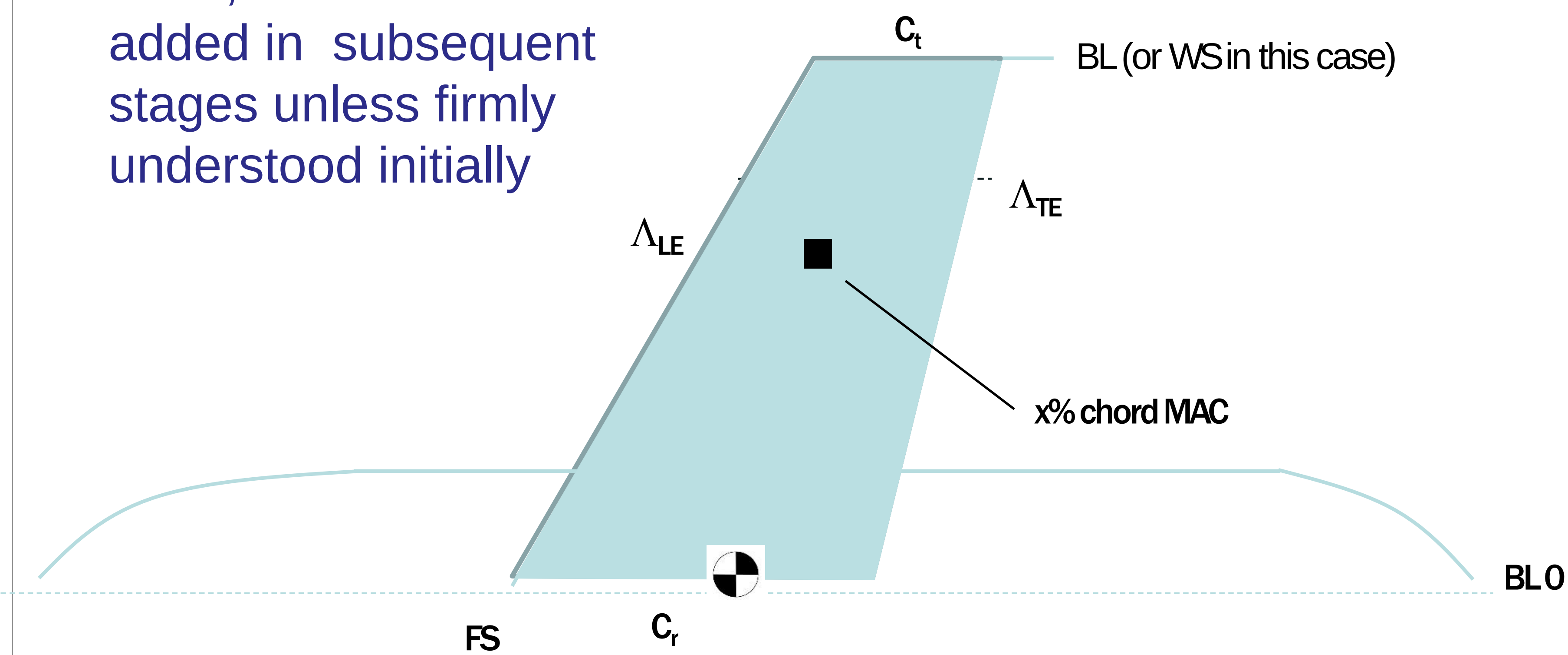
Approach is basically wrapping a clean aerodynamic shape around the required systems in the fuselage

- Attempt to minimize wetted area and cross-sectional area

Wing Creation & Placement

Wing Basic Geometry Information

- On a simple wing establish a simple wing first with airfoils initially in a single construction plane
- A good construction order is wing planform>airfoil sections> surfaces/solids
- Twist, dihedral etc. can be added in subsequent stages unless firmly understood initially



Wing MAC Calculation: *Simple Wing Geometry*

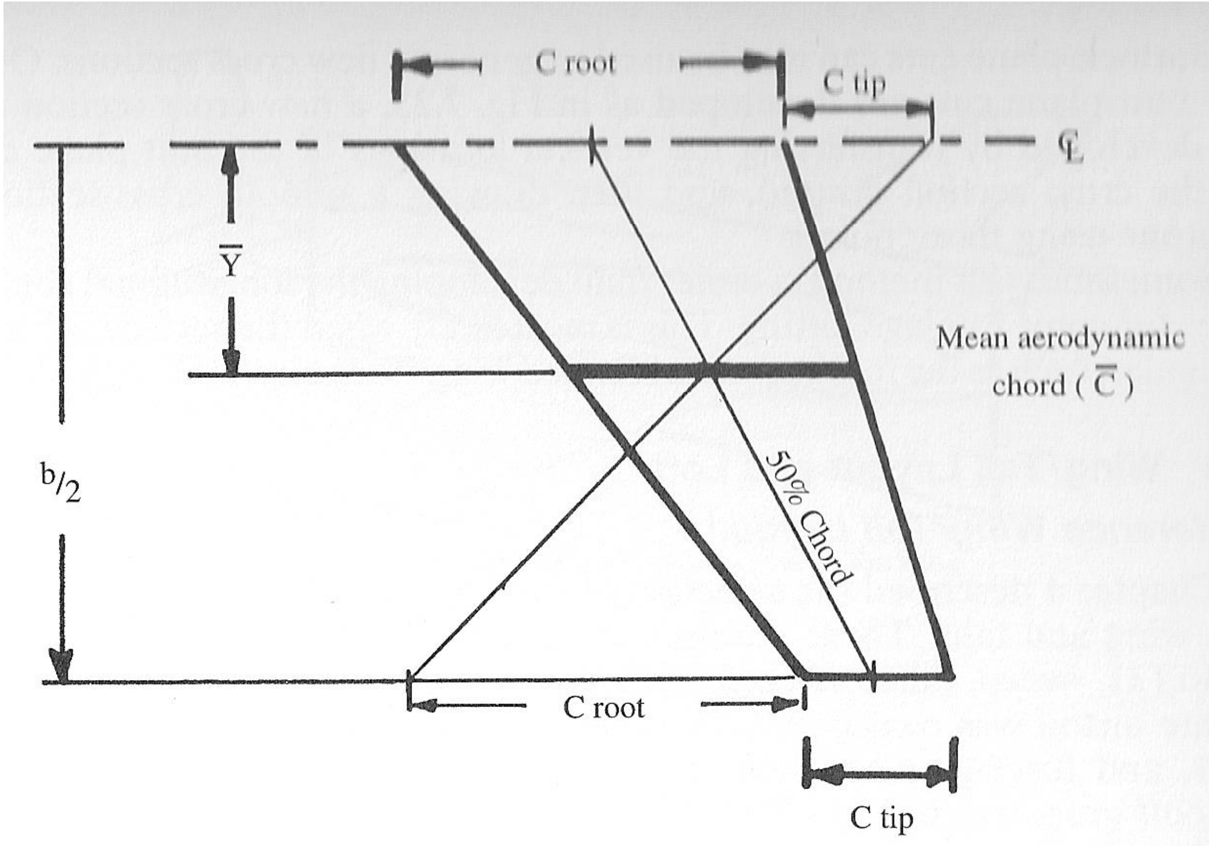
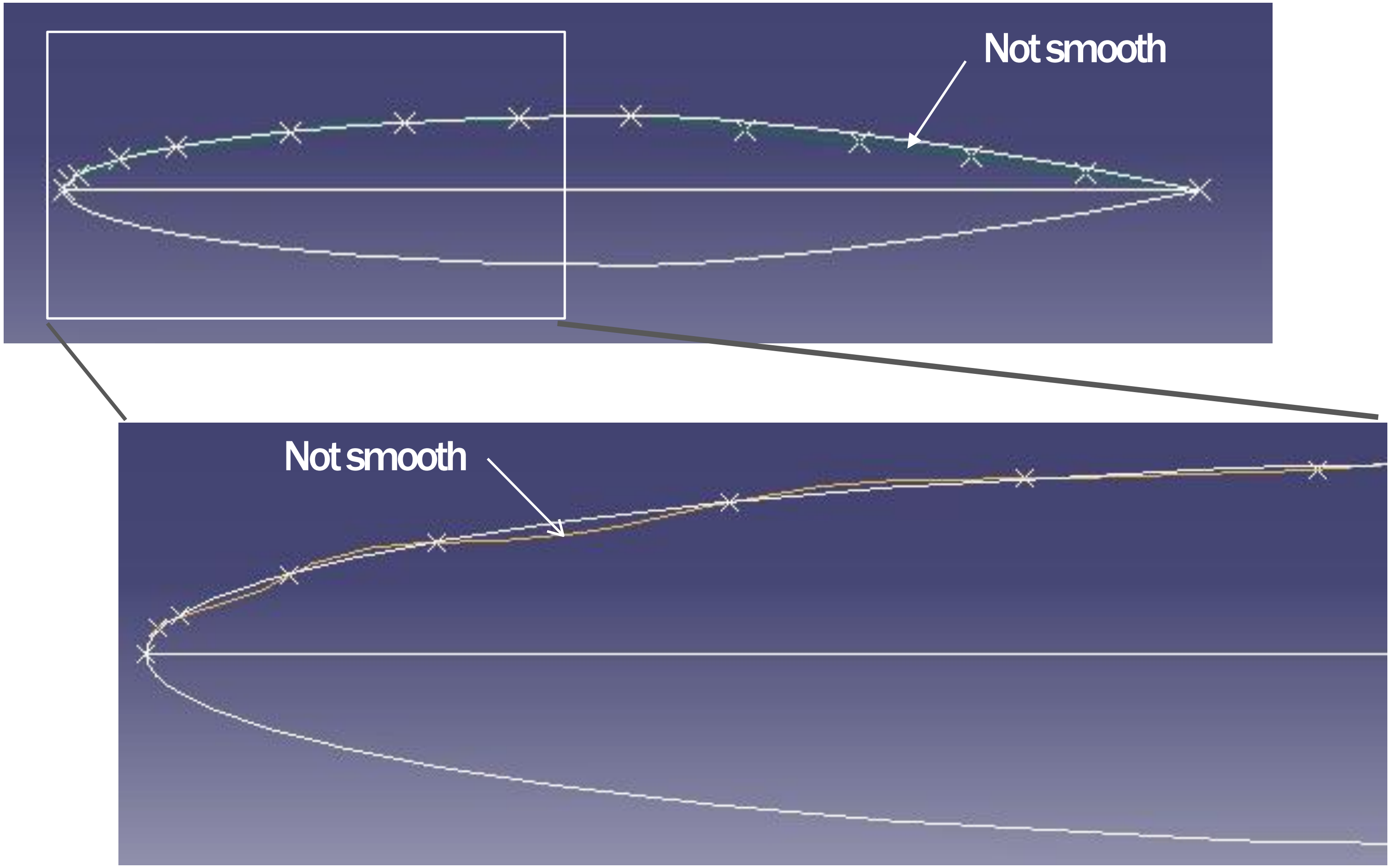


Fig. 7.24 Reference (trapezoidal) wing/tail.

Source: Aircraft Design: A Conceptual Approach, 3rd Edition by D. Raymer

Something to be careful of in CAD when creating airfoils

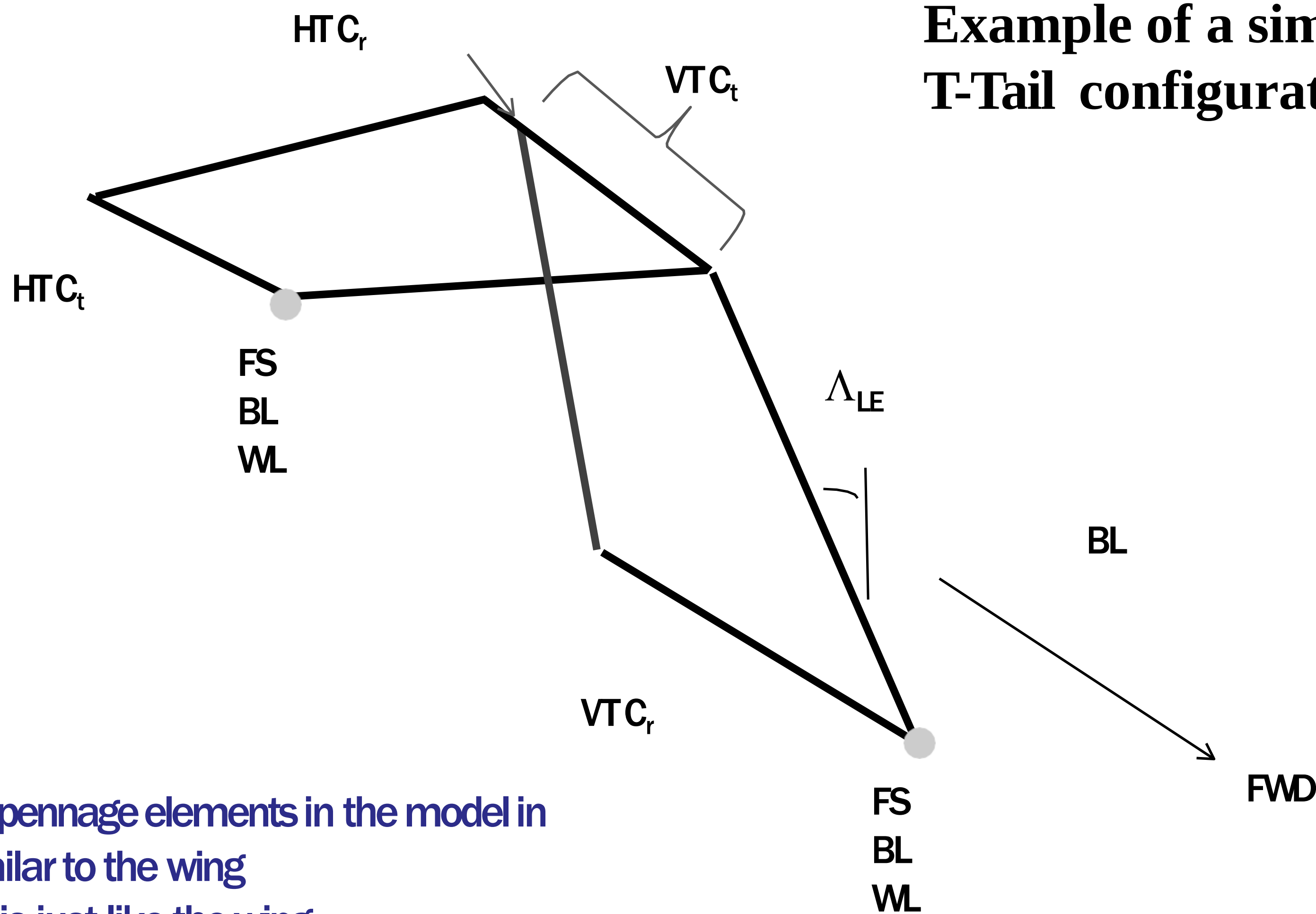


Using splines alone can yield non-smooth curves.
Combinations of conics & lines yield better results

Empennage Creation & Placement

HT & VT Basic Geometry Information

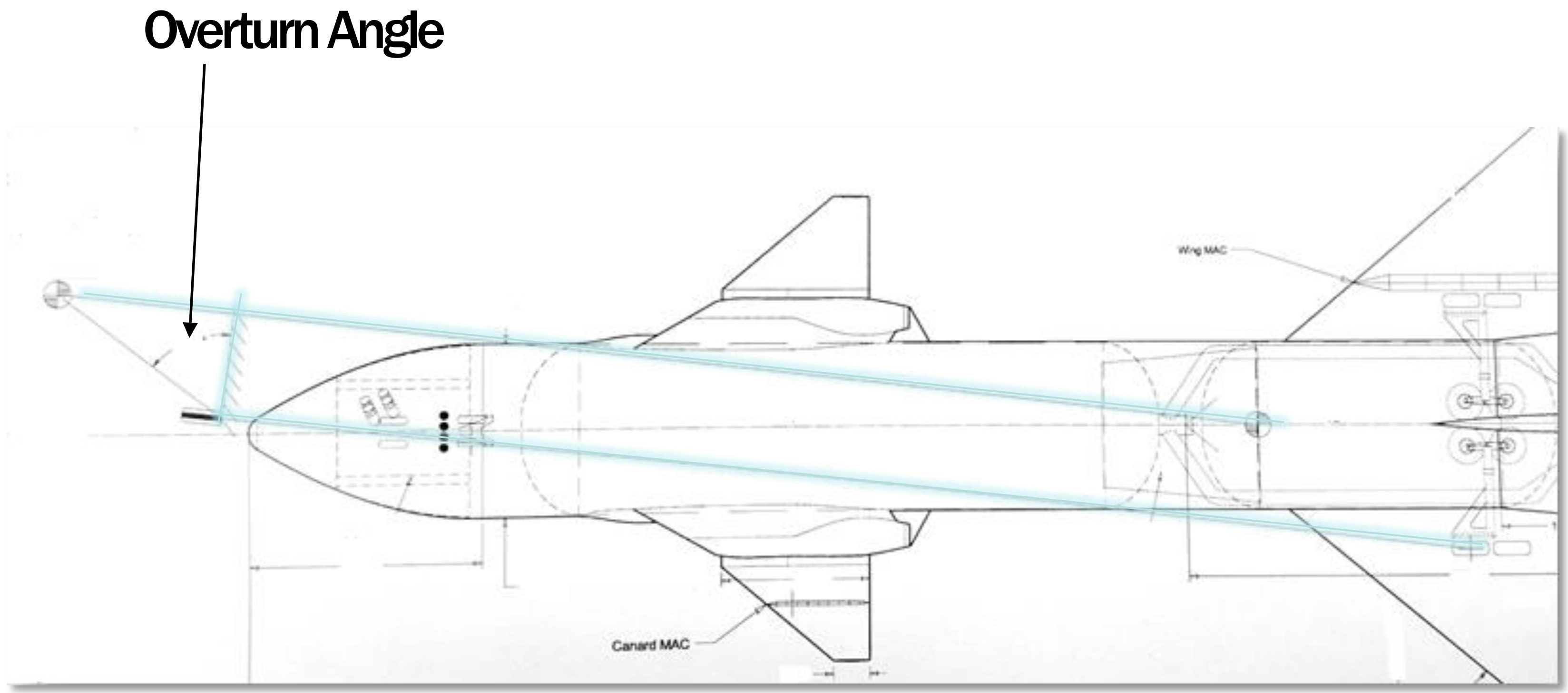
Example of a simple T-Tail configuration



Place the empennage elements in the model in a manner similar to the wing
Construction is just like the wing (planform>airfoil sections>surfaces/solids

Landing Gear Considerations

Example of Overturn Angle on Drawing



Lockheed Martin Liquid Fly-Back Booster

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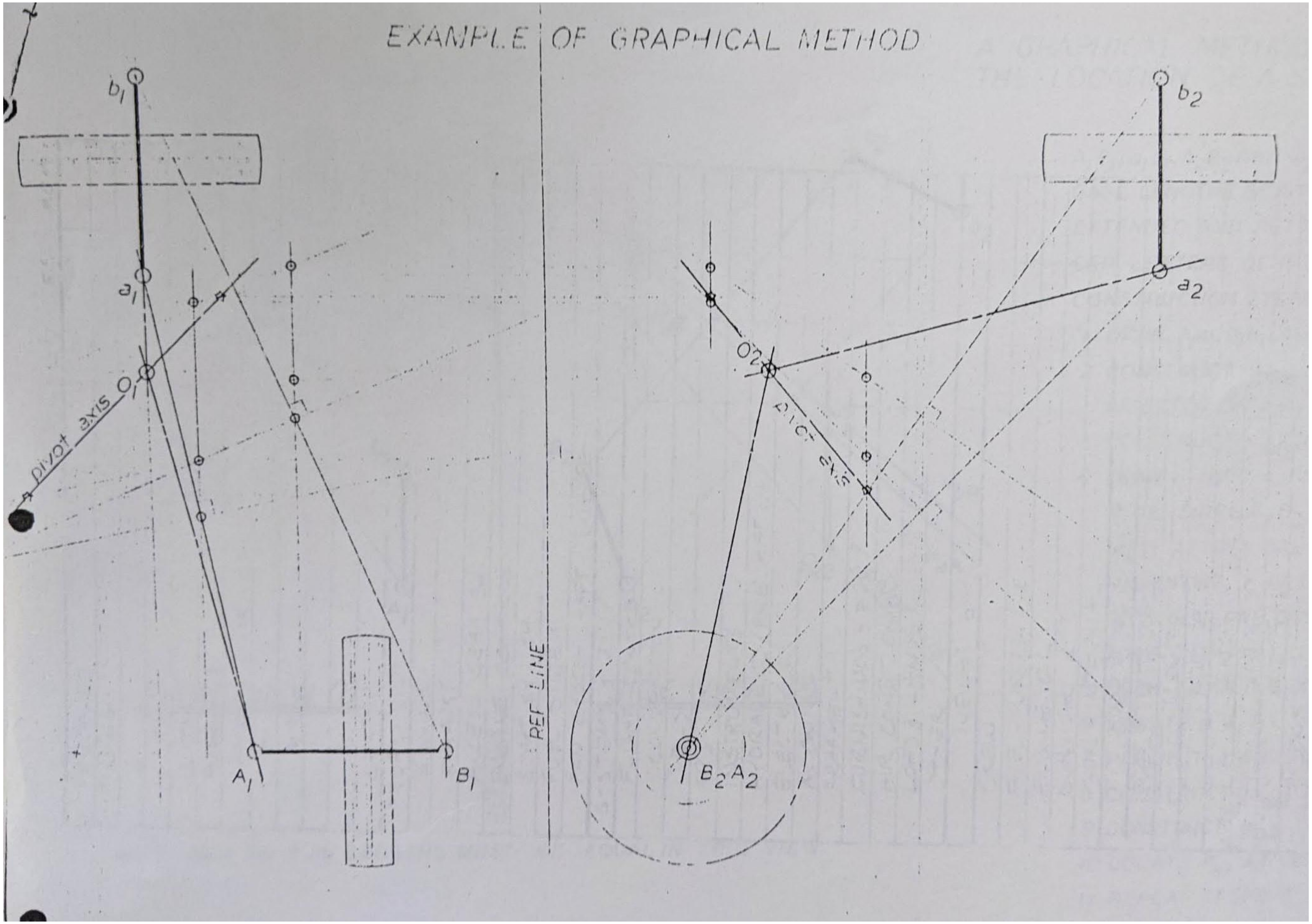
Landing Gear Layout

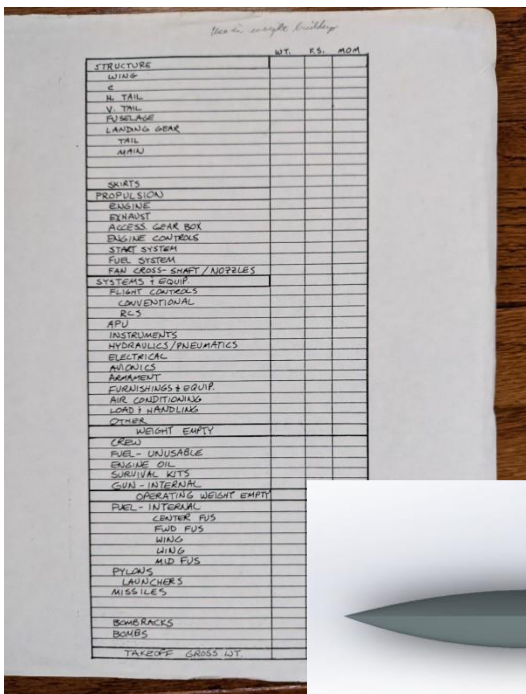


Classic Graphical Method

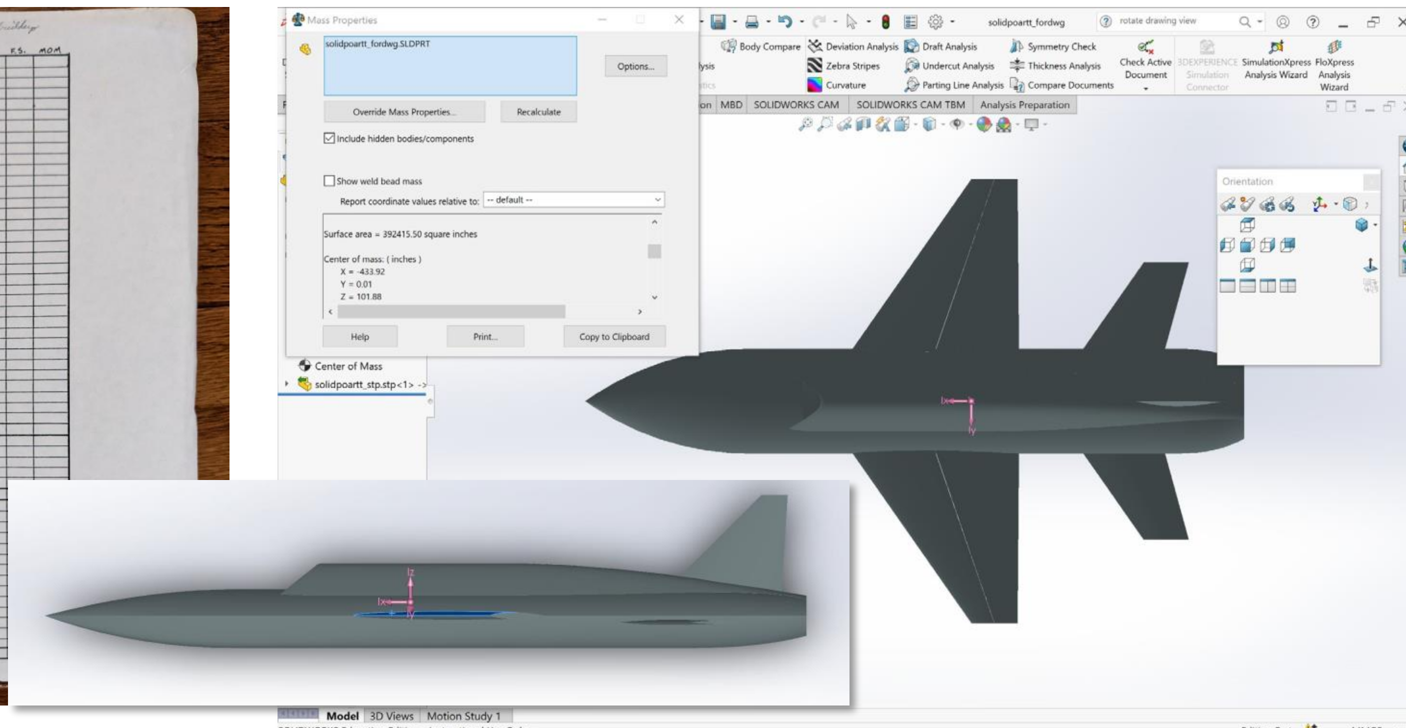
CG Location for a Starting Point

CG location is essential to balancing the design

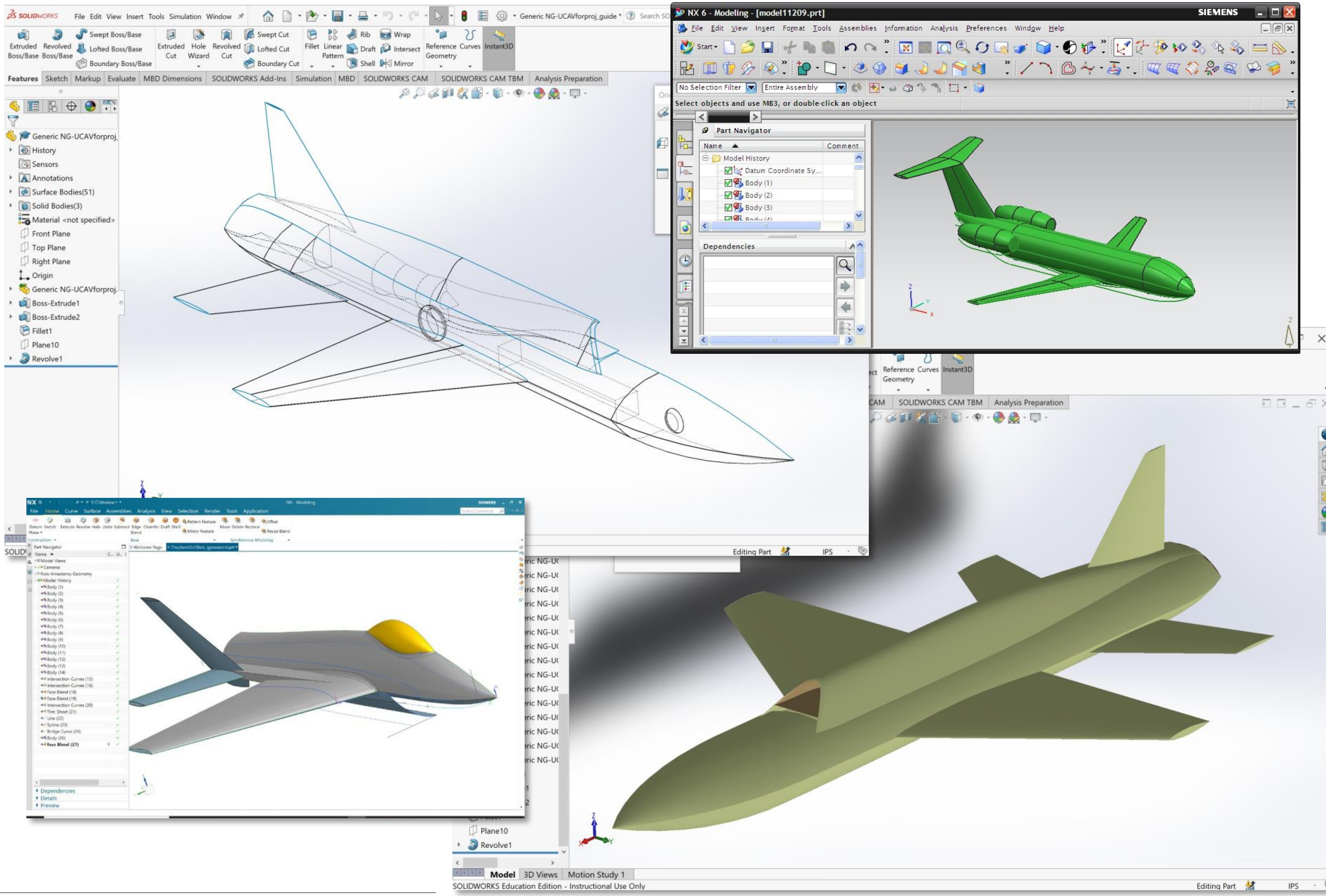
- **Get a rough CG using the major contributors to the overall weight in the empty vehicle (fuselage, wing, tails, propulsion (batteries?), and other items**
- **A mass properties spreadsheet can be good to use**
- **CAD Assemblies are best for vehicles with systems**



	WT.	F.S.	MOM
STRUCTURE			
WING			
C			
H. TAIL			
V. TAIL			
FUSELAGE			
LANDING GEAR			
TAIL			
MAIN			
SKIRTS			
PROPULSION			
ENGINE			
EXHAUST			
ACCESS. GEAR BOX			
ENGINE CONTROLS			
START SYSTEM			
FUEL SYSTEM			
FAN CROSS-SHAFT / NOZZLES			
SYSTEMS & EQUIP.			
FLIGHT CONTROLS			
CONVENTIONAL			
RCS			
APU			
INSTRUMENTS			
HYDRAULICS / PNEUMATICS			
ELECTRICAL			
AVIONICS			
ARMAMENT			
FURNISHINGS & EQUIP.			
AIR CONDITIONING			
LOAD & HANDLING			
OTHER			
WEIGHT EMPTY			
CREW			
FUEL - UNUSABLE			
ENGINE OIL			
SURVIVAL KITS			
GUN - INTERNAL			
OPERATING WEIGHT EMPTY			
FUEL - INTERNAL			
CENTER FUS			
FWD FUS			
WING			
WING			
MID FUS			
PYLONS			
LAUNCHERS			
MISSILES			
BOMBRACKS			
BOMBS			
TAKEOFF GROSS WT.			



CAD Model Examples of Lofting



Outline

A7a. Configuration Layout: *Drawings & Loft*

- A7a.1 Computer Aided Design (CAD) Systems
- A7a.2 Configuration Layout and CAD Drawings
- A7a.3 Basics of Conic Lofting
- **A7a.4 Lofting in Solidworks***

***Excerpt of notes from Greg Marien - San Diego State University**

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CAD Design Part 1

AE460

Greg Marien
Lecturer

Background/Purpose

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- CAD is the tool of choice for modern design activity, providing:
  - Accuracy of the design
  - Ease of collaboration in the design and manufacturing of a product
  - Ease of changes in the design
- This activity assumes
  - You have had a course in SolidWorks and a working knowledge of the tool
  - You will take pity on me since I only know Pro/E, CATIA, and NX
- Purpose:
  - Set you up with a working knowledge of the "rules" to designing complex assembly
  - Assist to get you started laying out your configuration

Standardization is key to maximizing the efficiency of using CAD tools.

Standardization

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- Create a **Part Template and Assembly Template** in the proper coordinate system orientation
  - Use the **Aircraft Coordinate System (ACS)** method for design
  - Use ACS for every part to ensure proper coordinate system
- Create the **Loft Surfaces** of the aircraft and "lock it down" from any changes **ASAP**
  - Loft surfaces are also known as Outer Mold Line (OML)
- Use **Loft Surfaces** to create **Layouts** of:
  - Primary Structure (load path)
  - Control Surfaces
  - Subsystems
    - Landing Gear, Cockpit, Passenger compartment, Fuel Volumes/Tanks, LRUs, Payloads, etc.
  - Make models as parametric as possible (I will show you how)
- The **Layout** is then used in design discussions for:
  - **Configuration Design** during **conceptual** and **preliminary** design phases
  - **Design fesibility** - Does it address all the requirements?
  - Weight and Mass Balance Analysis
  - Lift, Drag, Performance Analysis
  - Cost Analysis
  - Trade Studies
  - Comparisions of existing or competing aircraft

Use **General Arrangement** and **Inboard Profile** drawings to foster real-time design discussions in your teams

Part/Assembly Template for SolidWorks

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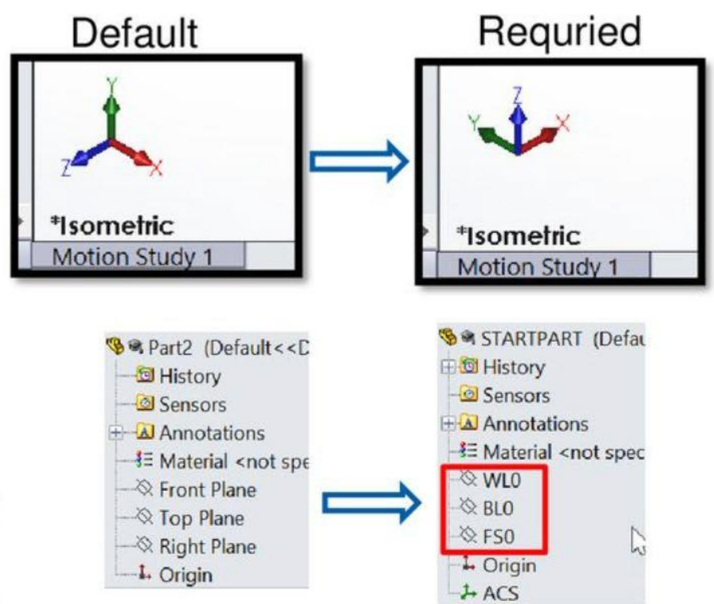
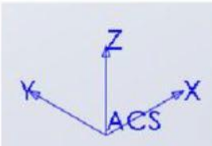
- Use **STARTPART.SLDPRT** and **STARTASSY.SLDASM** downloaded from class website
- Open the file in SW and do a **SAVE AS**, then "**Save as type**".prtdot and .asmdot for part and assemblies, respectively. This allows you to have the template available when doing file->new.
- **Why do this?**
  - Note the Default Global Coordinate System has Z axis on the horizontal plane. Also notice standard names for the planes: Front, Top and Right.
  - This is not an aircraft design convention, therefore use the template I provide.





VT AOE NOTE: A start part has been added to the class Canvas site under
AOE_4065 > Files > Supplemental Reference Material
Aircraft OML Modeling_Lofting > Aircraft_Solidworks_StartPart.SLDPRT

Example

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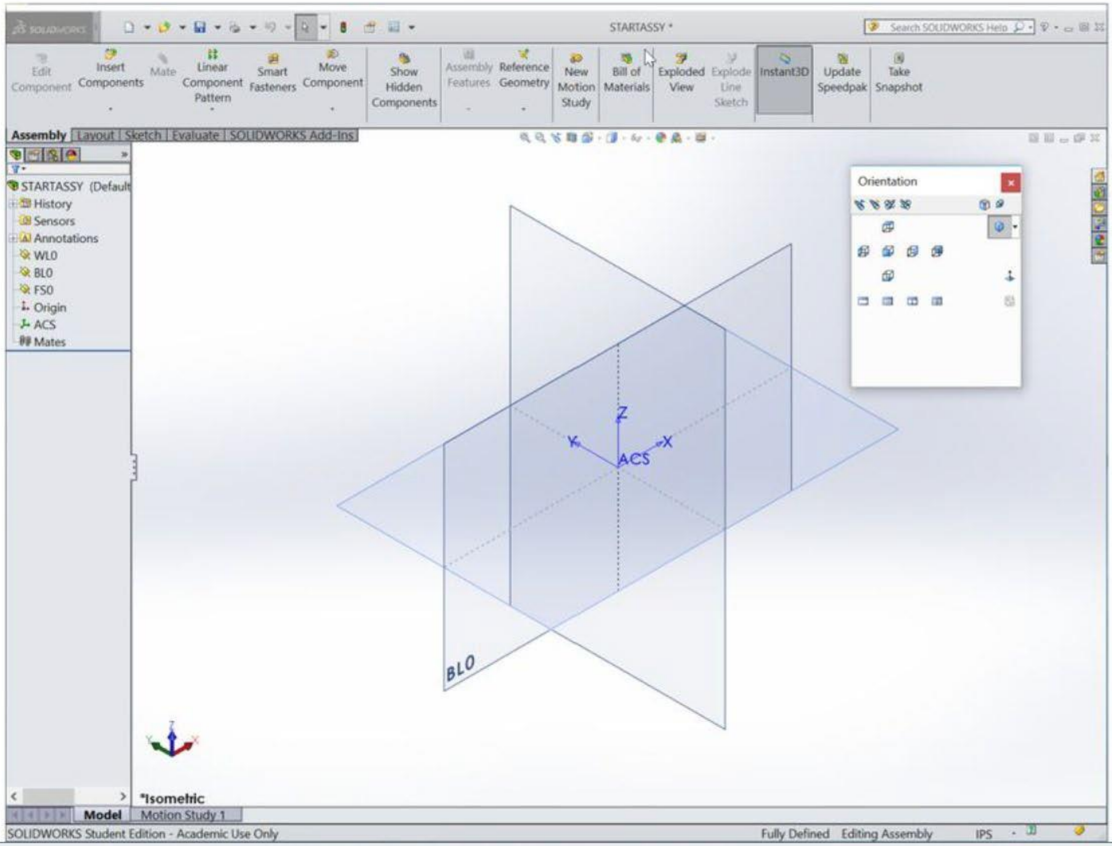

5

Creating a "STARTPART" template

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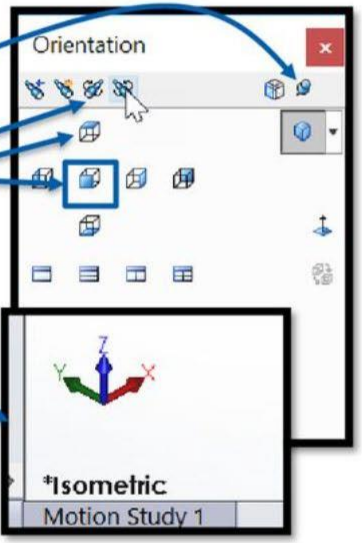
1. Create a new part
2. In the isometric view, note the Z axis is in the horizontal plane (TOP Plane)
3. Press the spacebar, bringing up the **Orientation** window then "Pin" Orientation pallet, just for ease of use.
4. Click on **FRONT** view, making it normal and pointing to you.
5. In the **Orientation** window click on **Update Standard Views**
6. In the **Orientation** window click on the **Top View**
7. You will receive a warning about the change, click **Yes**
8. Click on Iso-view, which now shows the correct orientation
9. Rename plane names to Water Line, Frame/Fuselage Station and Butt Line "zeros" as follows:
    1. Front Plane to WL0
    2. Top Plane to FS0
    3. Right Plane to BL0
10. Add a **Coordinate System (CS)** to the part and rename the **CS** to "**ACS"** (May need to "Rebuild" to have the name show up properly)
11. Save part as a **Part Template**: call it **STARTPART**
12. **Use the STARTPART for all your parts that are to be in one location only, i.e. loft, primary structural parts and control surface parts. Payloads, LRUs, etc, may be modeled at 0, 0, 0 and assembled into ACS.**



"STARTASSY" was also created in this way

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Lofting

AE460

Greg Marien
Lecturer

Background

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- Ship design history
- Surfaces with CAD
  - Lofting method is independant of CAD system (Solidworks, Creo, NX, etc.)
  - Loft is also know as the Outer Mold Line (OML)
  - Innner Mold Line (IML) is the OML minus the thickness of the skin
  - Loft is the anchor and form factor of the primary structure, i.e skins, frames bulkheads, spars, ribs, stringers, longerons, etc.
- Lofting uses a combination of:
  - Conics,
  - Splines,
  - Spines,
  - Swepted Blends Surfaces,
  - Multi-Section Surfaces

Warning: Lofting is an art, and coordination with aero is required to get the smoothness and accuracy for the loft.

Where to Begin?

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- Start with knowns
  - Wing Planform
  - Tail planform (Vertical and Horiztonal)
  - Airfoils
  - Payloads
  - Avionics
  - Radar
  - Engines
  - Fuel volume
  - Landing Gear/Tire sizing
  - Tip back criteria
- Create a scale planform and side views sketch and create a “lofting plan”
  - Use Reference Aircraft Coordinate System (ACS) (0, 0, 0)
  - Ensure every “known” from above fits
- Obtain approximate x, y, z (FS, BL, WL) locations from the lofting plan then go to town!
  - Result is the first 3-view

FS = Frame or Fuselage Station
BL = Butt Line
WL = Water Line

Scale Sketch

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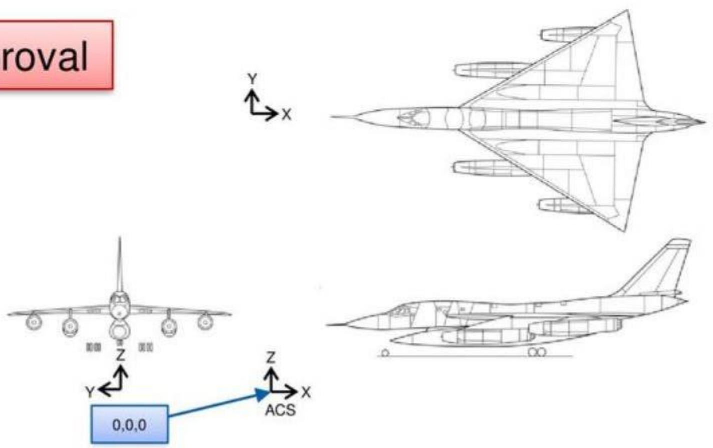
- Sketch in ACS
- Obtain X, Y, Z Locations for loft
- Don't forget to account for all payloads and systems in the sizing!

Submit Sketch(s) for Approval



Wing Loft

Wing Layout

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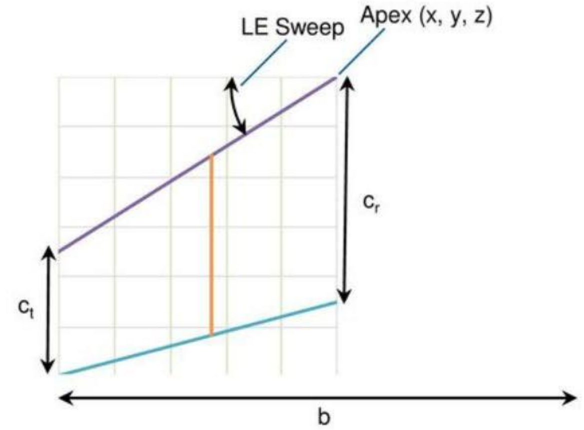
- Inputs
  - Planform
    - Wing Apex Location (x, y, z)
    - Tip and Root Chords
    - Span
    - LE Sweep
  - Other
    - Dihedral
    - Incidence Angle
    - Twist (wash-out, wash-in)
    - Airfoil Choices

- Outputs
  - Wing Loft



Wing Layout Setup in CAD

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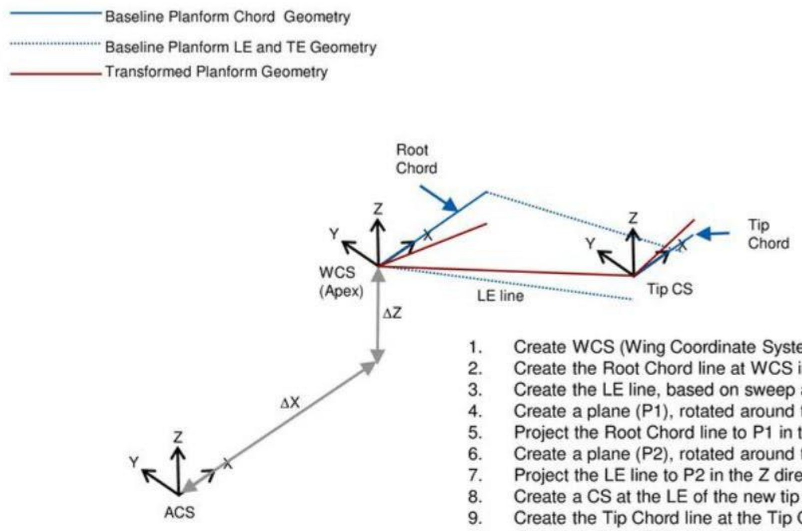

1. Create WCS (Wing Coordinate System) at the Apex
2. Create the Root Chord line at WCS in X direction
3. Create the LE line, based on sweep angle and half span on WCS X-Y plane
4. Create a plane (P1), rotated around the WCS Y-axis using the wing incidence angle
5. Project the Root Chord line to P1 in the Z direction
6. Create a plane (P2), rotated around the WCS X-Axis using the dihedral angle
7. Project the LE line to P2 in the Z direction
8. Create a CS at the LE of the new tip chord
9. Create the Tip Chord line at the Tip CS in the X direction
10. Create a plane (P3), rotated around the Tip CS Y-axis using the tip incidence angle
11. Project the Tip Chord line to P3 in the Z direction

Important Notes:
1. Projected chord lines are longer than the original chord. The projected chord length is used to scale the airfoil points in order to maintain the original planform area. The little bit of angle and length change will not matter much aerodynamically, but it is a bookkeeping exercise in maintaining the original planform reference area (S).

2. When designing uniform trailing edge thicknesses for manufacturing and aerodynamic purposes, scaling the airfoil may be needed to add or subtract from the airfoil trailing edge, or modification of the airfoil's trailing edge as required.

Wing Layout Example (CATIA)

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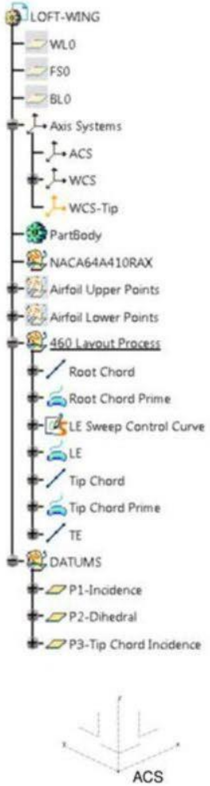

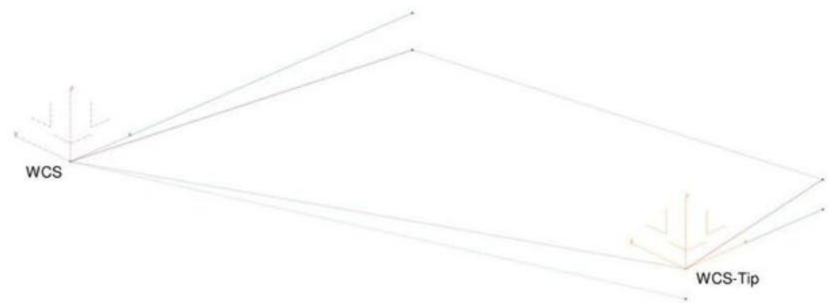

Airfoil Points

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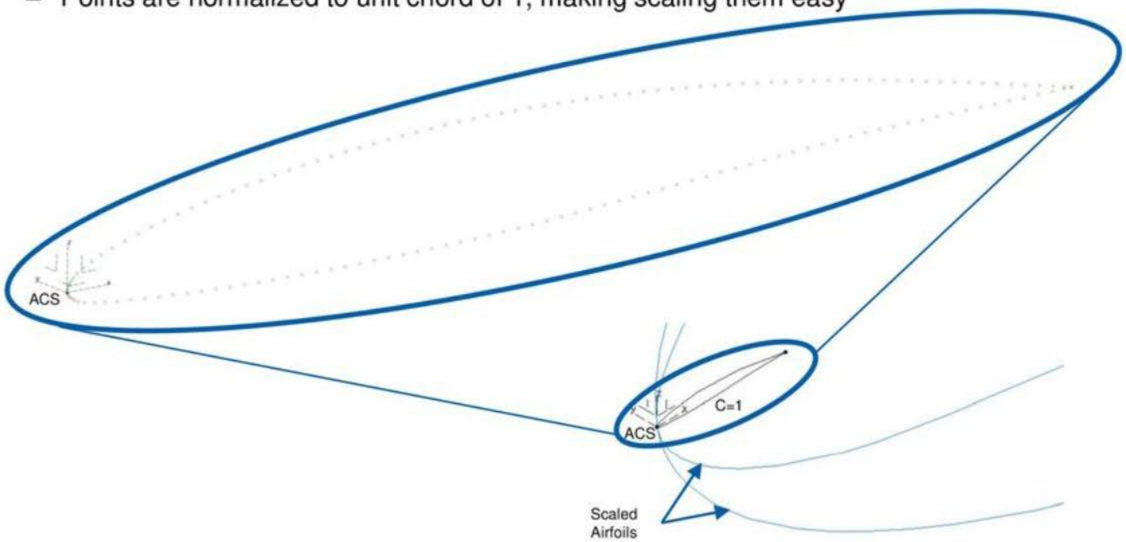
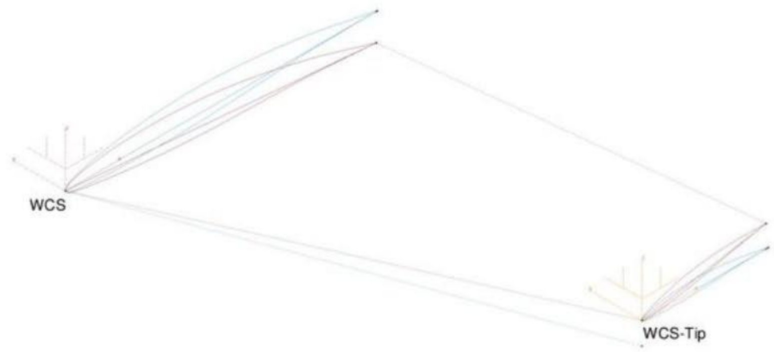
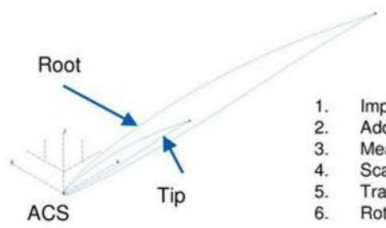
- Airfoil databases
  - Contain NACA and other special purpose/custom airfoil data
  - Points are normalized to unit chord of 1, making scaling them easy



Warning Reminder: Lofting is an art, and coordination with aero is required to get the smoothness and accuracy for the loft.

Scaling, Translating, and Rotating Airfoil Points





1. Import unit (c=1) airfoil points to ACS at 0,0,0 (LE to be at 0,0,0)
2. Add a spline to the points (do not connect the TE upper and lower points)
3. Measure the projected chords for root and tip.
4. Scale the unit chord with the projected chords for root and tip
5. Translate the airfoils from ACS to their respective CS
6. Rotate the airfoils around the respective y axis of the local CS, matching the required incidence angle

Add Multi-Section Surfaces

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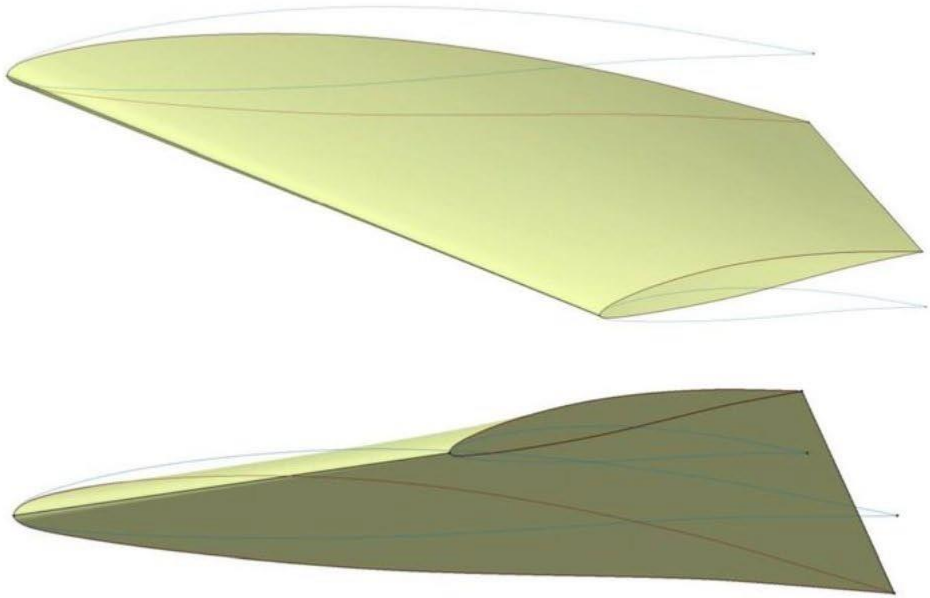

Why not just use one curve, and one surface, vs. splitting it in an upper and lower surface?

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Body Lofting, i.e. Fuselage

Example of a Sketch

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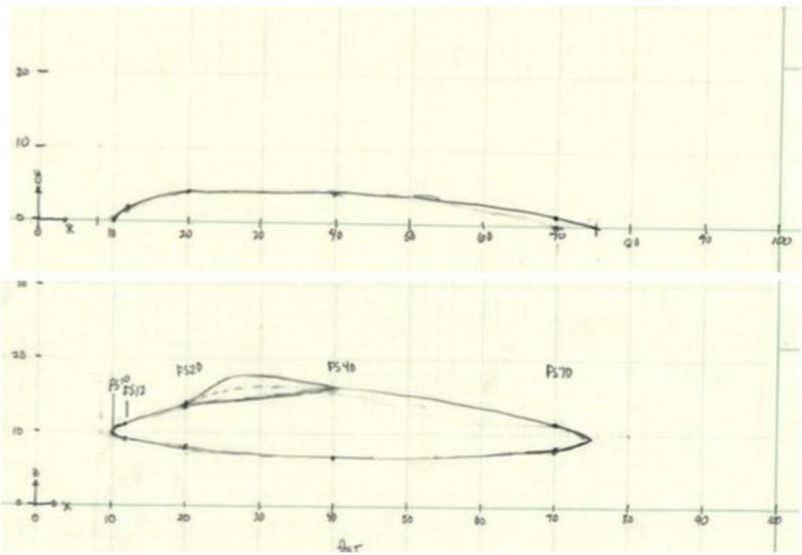
- Inputs
  - Scale sketches (planform and side view) with FS, BL, WL locations
- Output
  - Fuselage or Body Loft in CAD



Splines and Conics Background

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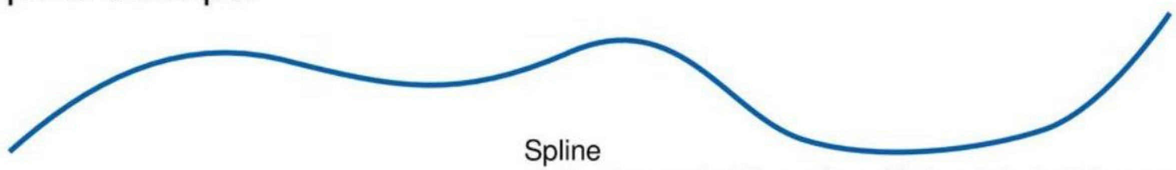
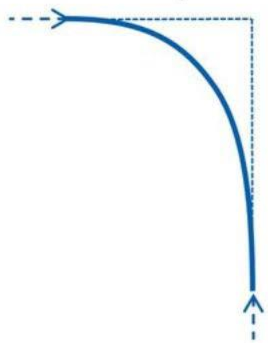
Spline example



Spline
- Can be routed through multiple points in 3-D space
- Each point's curvature can be controlled
- Allows for tangency and curvature constraints

Conic example



Conics
- Feature is required to be on a single plane
- Tangent lines need to intersect

Process for a Body Loft

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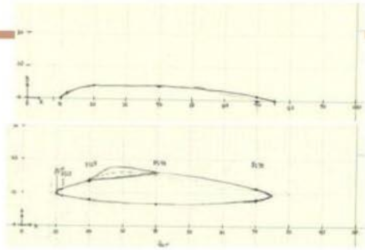
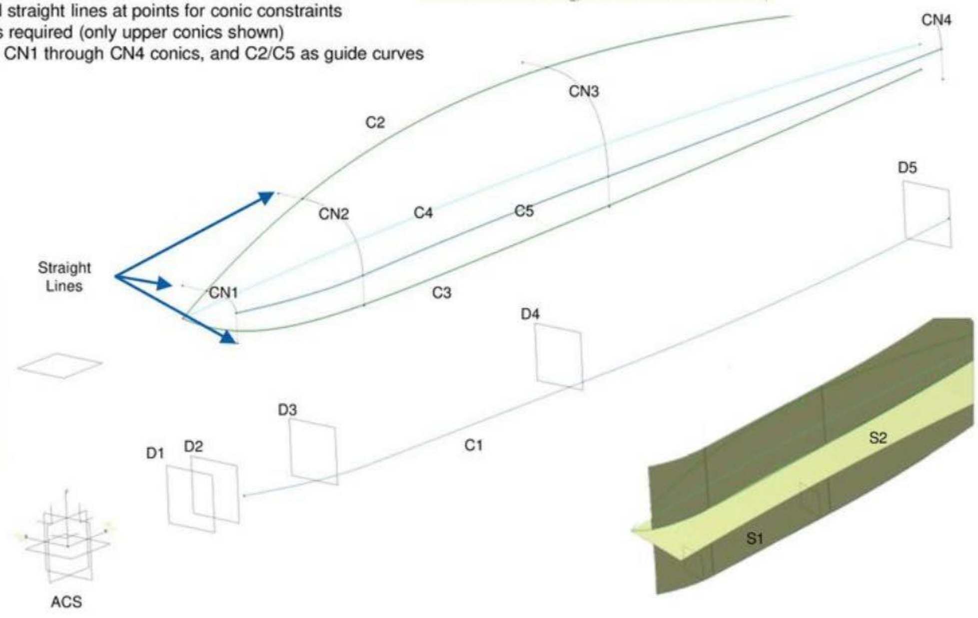
1. Create Datums (D1 thru DX) as required to constrain FS and WL curve locations
2. Create planform curve (C1) on WL0
3. Create Upper Curve (C2) on BL0
4. Create Lower Curve (C3) on BL0
5. Create HMBL construction curve (C4) on BL0
6. Extrude surface (S1) from C1 in +Z direction
7. Extrude surface (S2) from C4 in –Y directions
8. Create HMBL curve (C5) using the intersection of S1 and S2
9. Create intersection points between FS datums and C2, C3, C5
10. Optional (may not be need) – add straight lines at points for conic constraints
11. Create Conics (CN1 thru CNX) as required (only upper conics shown)
12. Add a multi-section surface using CN1 through CN4 conics, and C2/C5 as guide curves

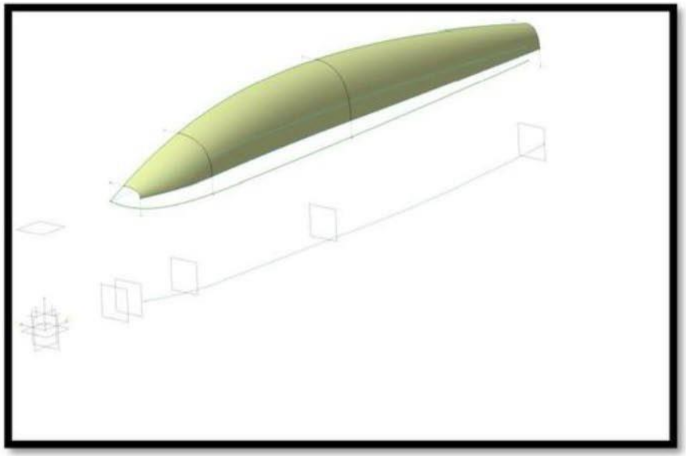




DATUMS should be renamed in the CAD system, and should be FSXXX, BLXXX, WLXXX where XXX is the distance from ACS, i.e. FS100

Nose Loft Shaping

- Notice the nose and rear surfaces are missing - Do this task last
- Construction curve development depends on if you want a bulbous nose, or a sharp nose.
- Use conics, splines, fills as required to complete the task
- Exercise is left to you



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Advanced Topic

Alternate Method using Angled Datums

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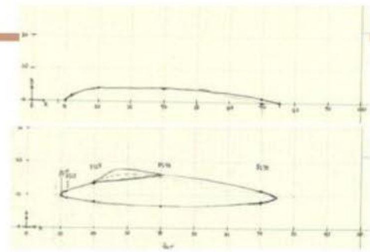
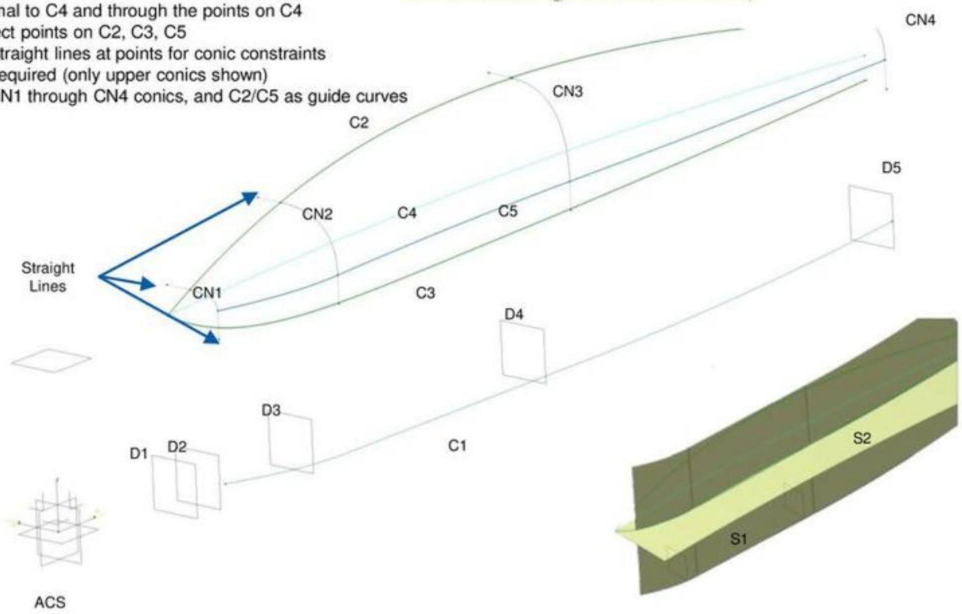
1. Create Datums (D1 thru DX) as required to constrain FS and WL curve locations
2. Create planform curve (C1) on WL0
3. Create Upper Curve (C2) on BL0
4. Create Lower Curve (C3) on BL0
5. Create HMBL construction curve (C4) on BL0
6. Extrude surface (S1) from C1 in +Z direction
7. Extrude surface (S2) from C4 in –Y directions
8. Create HMBL curve (C5) using the intersection of S1 and S2
9. Using Datums D1 thru DX, create intersect points on C4
10. Create DD1 thru DDX, datums normal to C4 and through the points on C4
11. Using DD1 thru DDX, create intersect points on C2, C3, C5
12. Optional (may not be need) – add straight lines at points for conic constraints
13. Create Conics (CN1 thru CNX) as required (only upper conics shown)
14. Add a multi-section surface using CN1 through CN4 conics, and C2/C5 as guide curves



DATUMS should be renamed in the CAD system, and should be FSXXX, BLXXX, WLXXX where XXX is the distance from ACS, i.e. FS100



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Good Vehicle Layout & Lofting References

Please look beyond the stated chapters in the following list – there is plenty of useful information there

- ***Design of Rocket and Space Launch Vehicles*** **by D. Edberg & W. Costa – AIAA 2020 publication →Chapters 7, 8**
- ***Aircraft Design of WW II: A Sketchbook*** **by Lockheed Aircraft Corp – Dover Publications 2017**
- ***Civil Jet Aircraft Design*** **by L.R. Jenkinson, P. Simpkin, & D. Rhodes– AIAA 1999 publication →Chapters 3,5,6,7,9,12,15**
- ***The Design of the Airplane*** **by D. Stinton– AIAA 2001 publication →Chapters 4,5,7,8,9,10,12,14**
- ***General Aviation Aircraft Design: Applied Methods and Procedures*** **by S. Gudmundsson– Elsevier Publications 2014 → Chapters 4,5,7,9,10,11,12,13,14**
- ***Aircraft Design Handbook: Aircraft Design Aid and Layout Guide*** **by N. Kirschbaum – VT AOE internal publication**
- ***Designing Unmanned Aircraft Systems: A Comprehensive Approach*****, 2nd Ed. by J. Gundlach– AIAA 2014 publication →Chapters 4,6,7,8,10,11,12**
- ***Fundamentals of Aircraft and Airship Volume I – Aircraft Design*** **by L.M. Nicolai,**
- **G.E. Carichner – AIAA 2010 publication →Chapters 8,9,11,14,15,16,17,18,19,23**
- **Aircraft Design: A Conceptual Approach, 6th Ed. by D. Raymer– AIAA 2018 publication →Chapters 8,9,11,14,15,16,17,18,19,23**