Introduction to Aircraft Design

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What is Aircraft Design ?

- Arriving at layout and configuration that :-
  - Meets customer specs. and Airworthiness reqmts.
  - Less expensive and easy to produce in large quantities
- Customer specifications
  - Market and operational requirements
  - Forecasts of the economic situation in future
  - Technological developments
- Airworthiness requirements
  - Based on previous experience
  - To ensure safety of operation
  - Lead to uniformity & standardization in reporting data

Preliminary Comments on Design

- There are no unique solutions in design
  - *There are as many ways to design an airplane as there are airplane designers*
- It is an iterative process
  - *It stops when money, time, or patience runs out !*
- It is a team effort
  - *There are no individual heroes, only villains !*
- It has to be cost-effective
  - *Or else its not worth the paper its drawn on !*

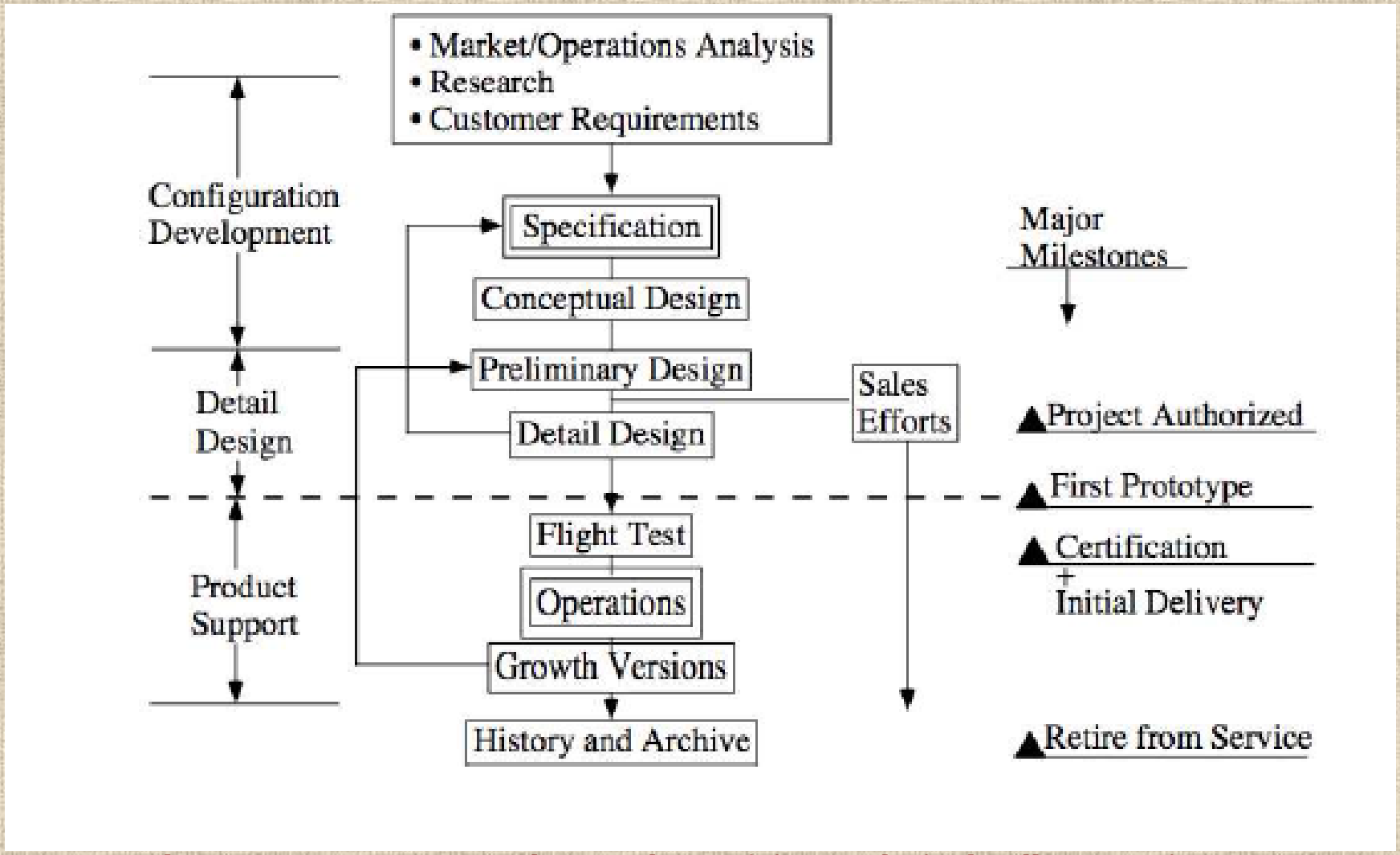
Phases in Aircraft Design

- CONCEPTUAL (*Method*)
  - Establish concept feasibility
  - Identify the requirements that drive the design
  - Carry out initial sizing & layout
  - Estimate component masses, performance, and cost
- PRELIMINARY (*Numbers*)
  - Freeze the configuration
  - Ensure design practicality
  - Develop mechanical & structural concepts
  - Develop test and analytical base
- DETAIL (*Nuts & Bolts*)
  - Design various components
  - Develop tooling and fabrication process
  - Test major items
  - Finalize weight and performance estimates
  - Source: Raymer &

Design Stages

- Conceptual Design (1 %)
  - Competing Concepts Evaluated — *What drives the design*
  - Performance Goals Established — *Will it work ?*
  - Preferred Concepts Selected — *What will it look like ?*
- Preliminary Design (9%)
  - Refined Sizing — *Optimization*
  - Examination & Verification — *Wind Tunnel Tests*
  - Modifications & Amendments — *Cost Estimates*
- Detailed Design (90%)
  - Drawings / CAD — *Flight Controls*
  - Detailed Performance Estimation — *Component/Systems checks*
  - Only minor changes — *Certification*

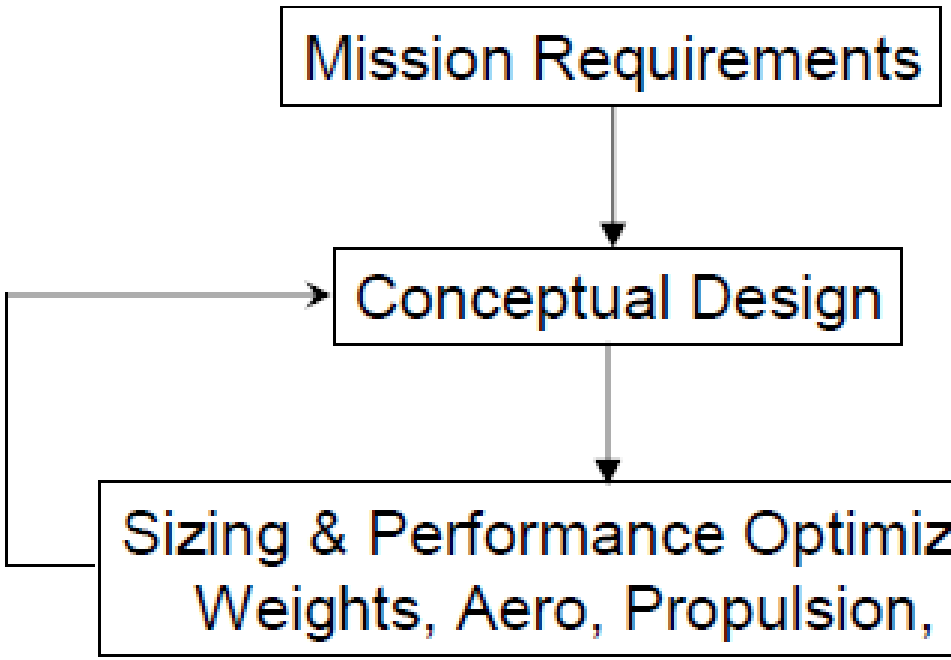
Civil Aircraft Process



Dr. John McMasters, Research Aerodynamicist, Technical Fellow, Boeing 1996

Outstanding Aerospace Engineer, School of Aeronautics & Astronautics, Purdue Univ., 2002

Mission Focused Aircraft Design



What does it need to do?

What do we think it will look like?

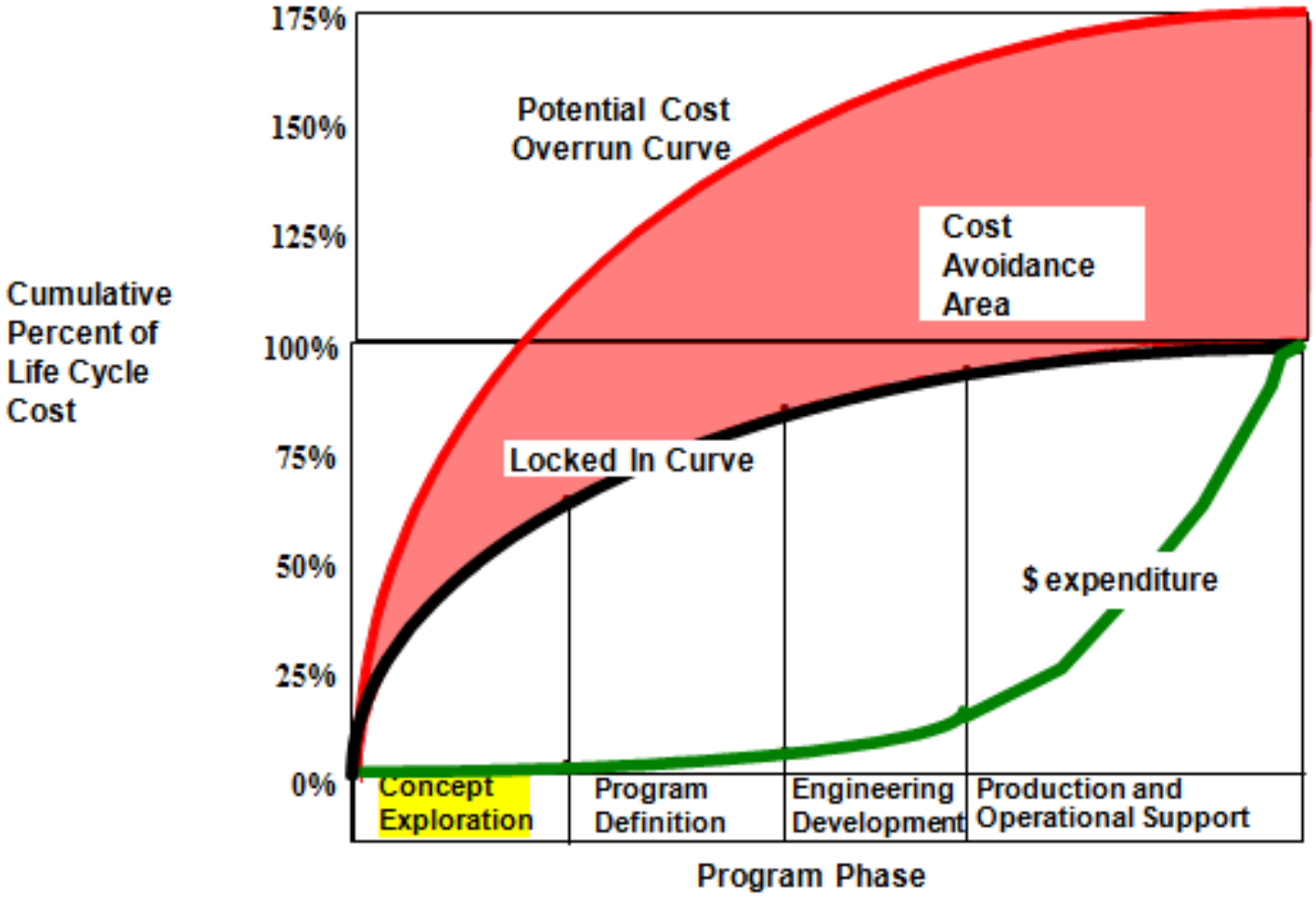
What do the equations tell us?

Usually, there are many aircraft designs that can fulfill the mission requirements - thus, there is not a one way to design an aircraft, but some will be better than others.

TODAY, COST IS THE MAIN DESIGN DRIVER !

Life Cycle Cost –

Airplane Design Like Aerodynamics is an "Initial Value Problem"



Initial Decisions Affect the Slope of the Locked In Curve

Source: Prof. Scott Eberhardt

Cost is the Key !

- Needs to be established very early in design
- Paradigm shift in Aircraft Design

  'Performance at any cost' 1940

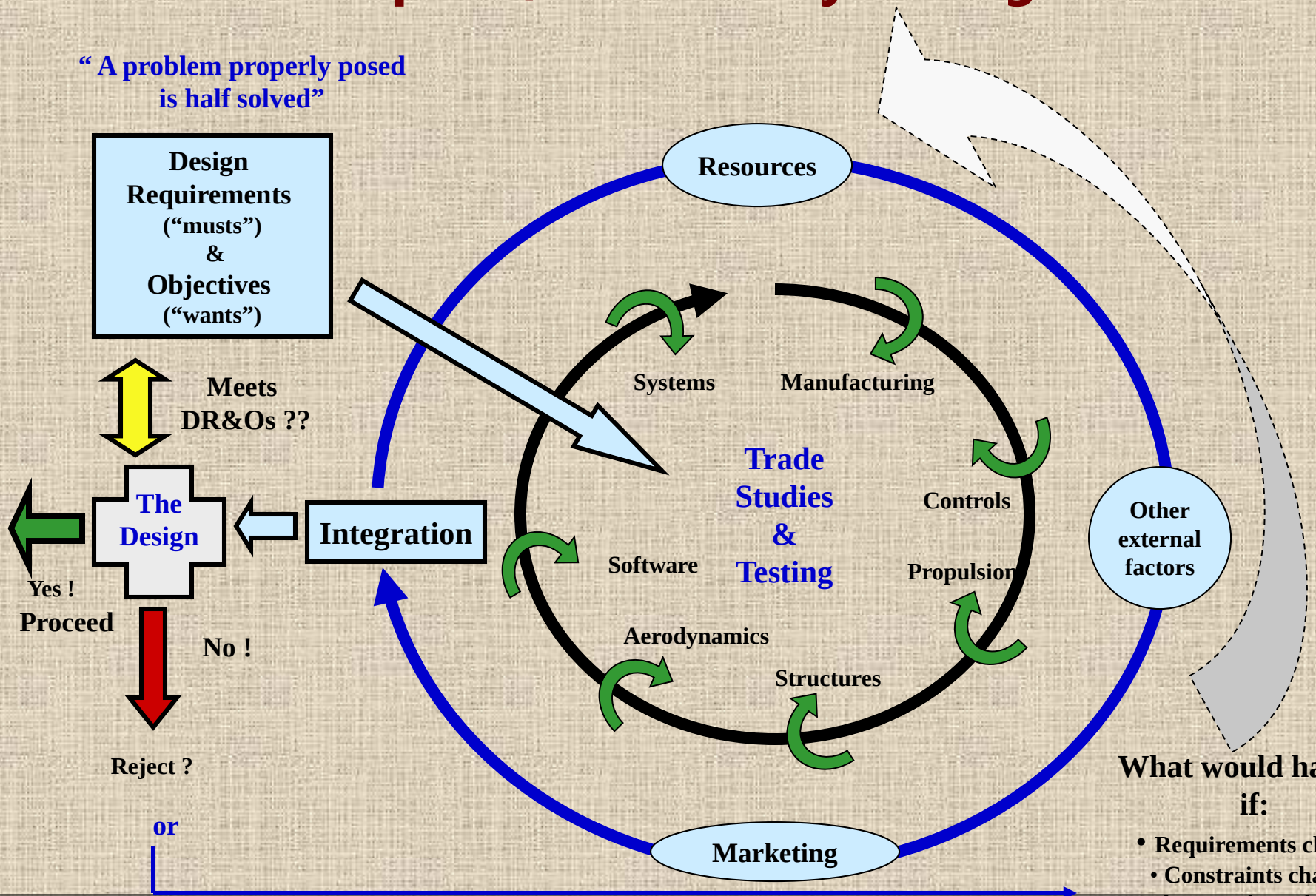
  'Design-to-cost' 1970

  'Design-to-LCC' 2000

- Requirements drive cost
  - Requirements always *creep* → Costs increase
  - Classic examples: B-2, F 22, F-35, ….

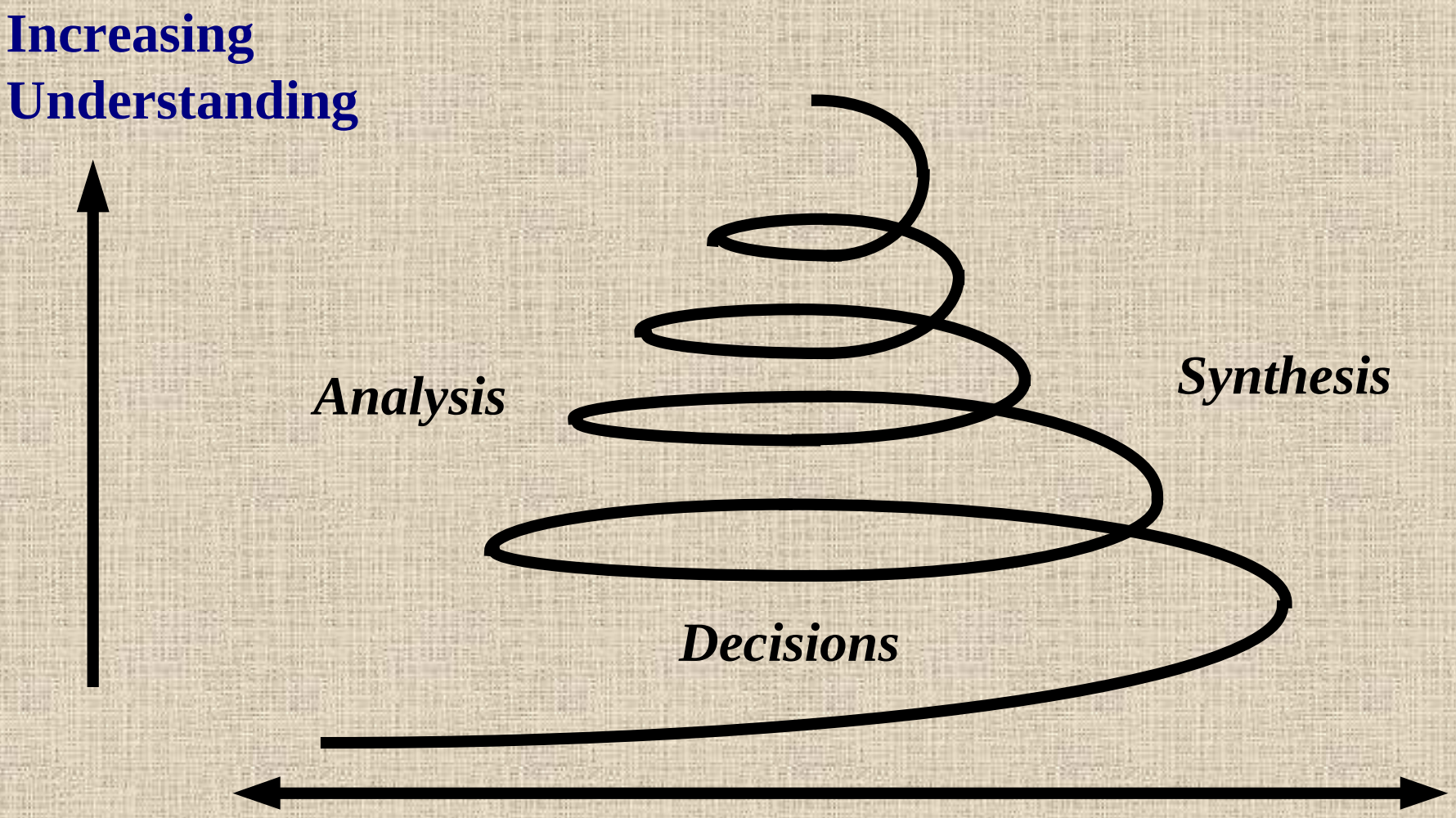
The Conceptual/Preliminary "Design Process"

"A problem properly posed is half solved"



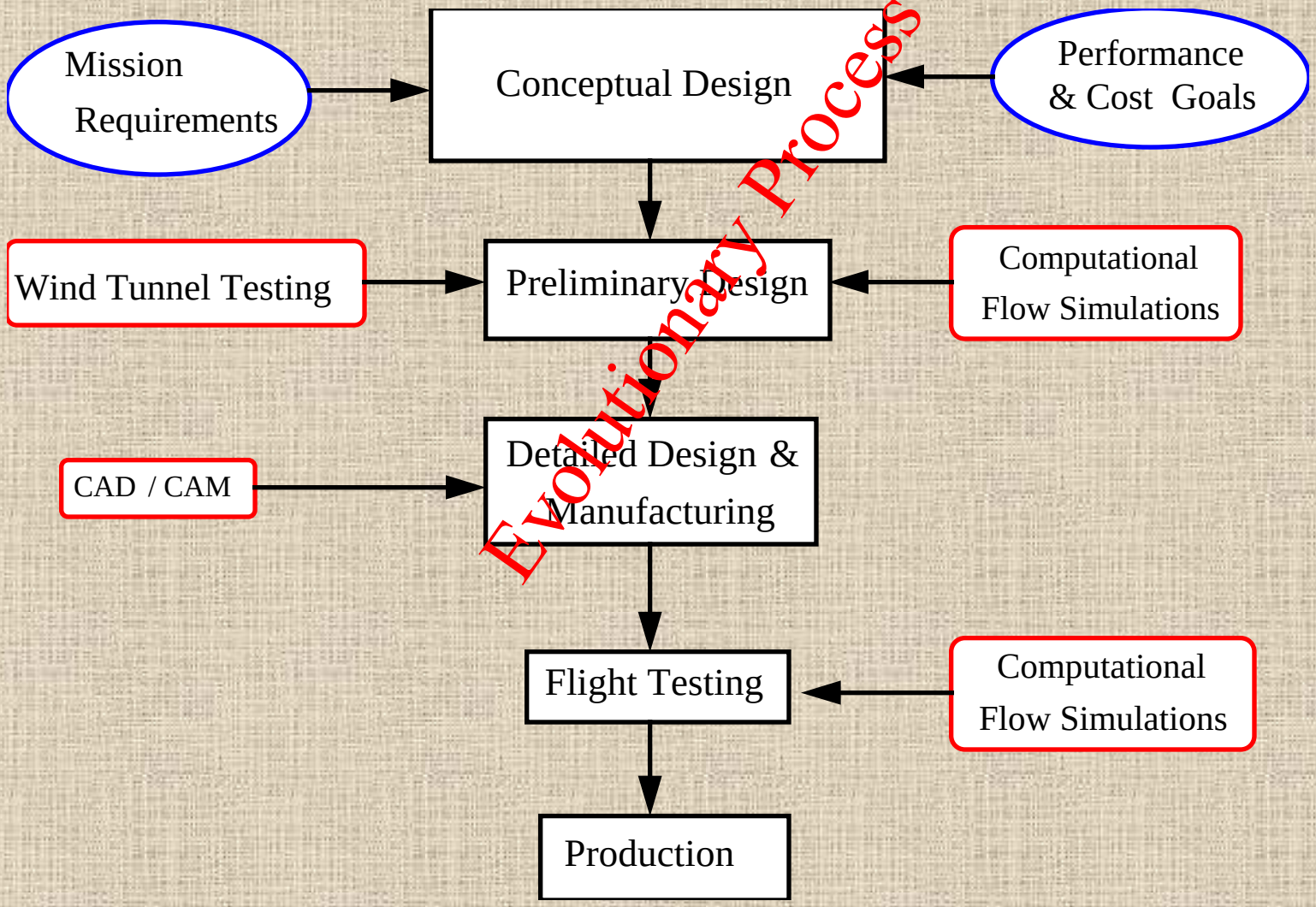
Source: Prof. Scott Eberhardt

The Design Spiral

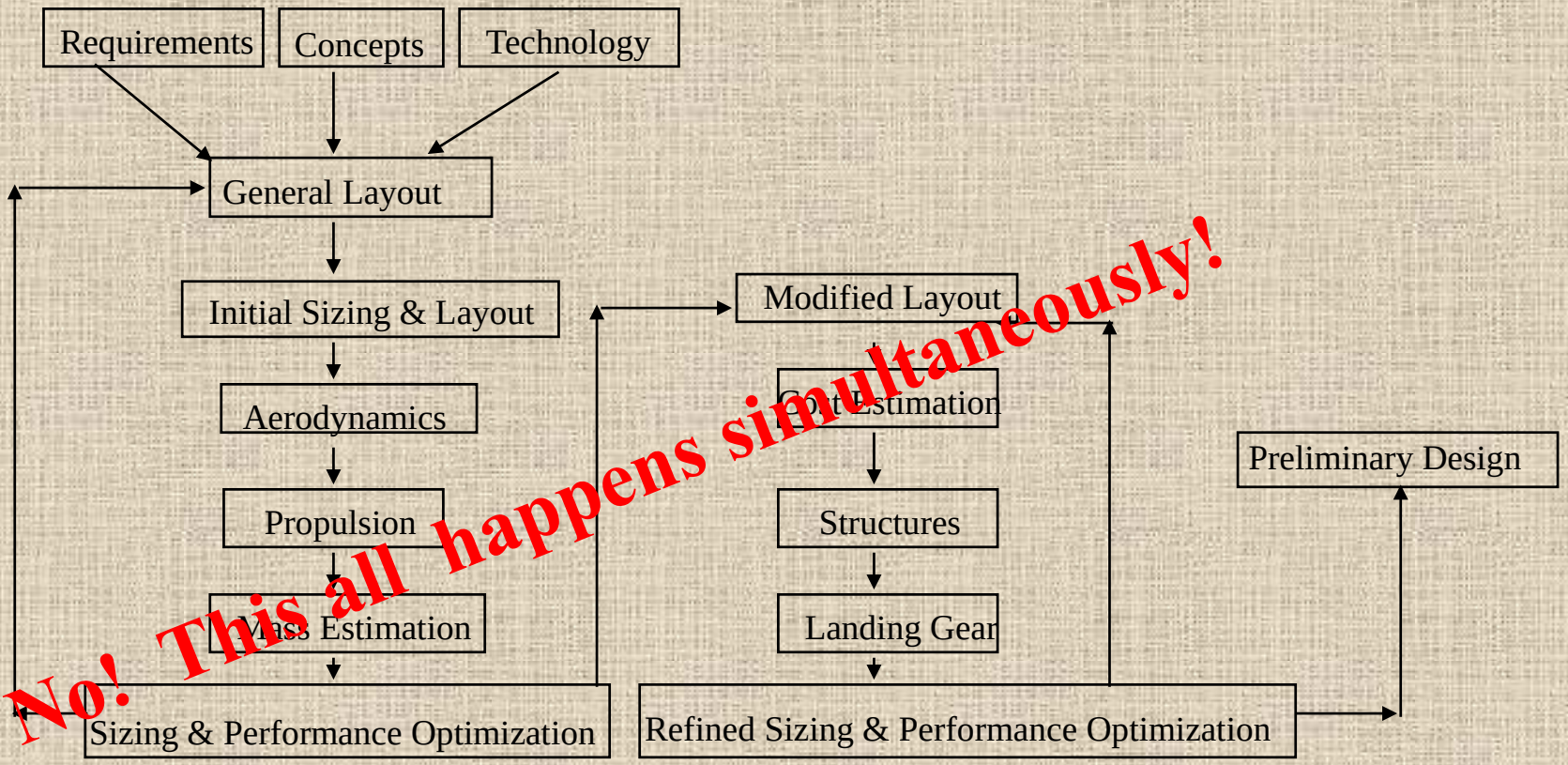


Source: *Introduction to Aeronautics: A Design Perspective*, Brandt, Stiles, Bertin, Whitford, 2nd ed., AIAA Education Series, 2004

Aircraft Development Process

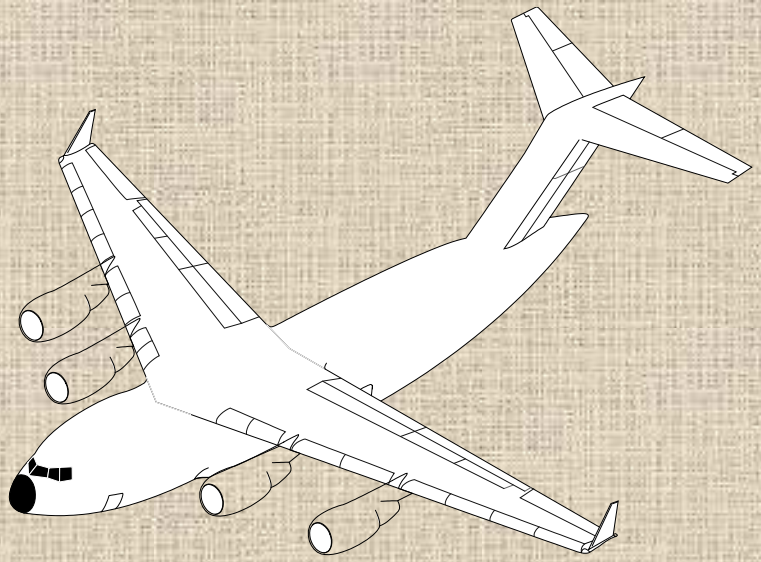


Aircraft Conceptual Design Process



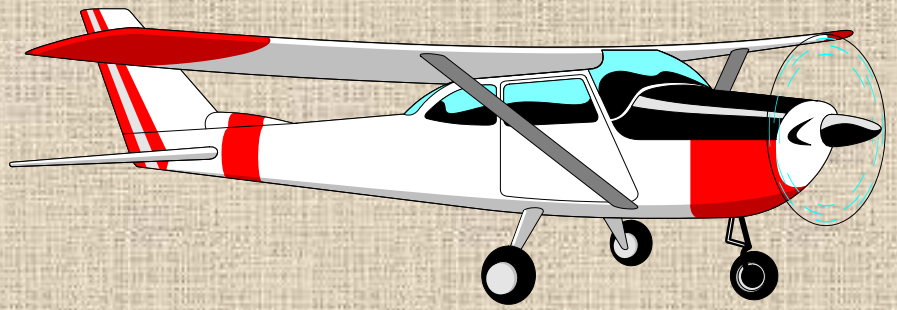
Source: *Aircraft Design, A Conceptual Approach*, Dan Raymer, 4th Ed. AIAA Education Series, 2006

Beginning Conceptual Design



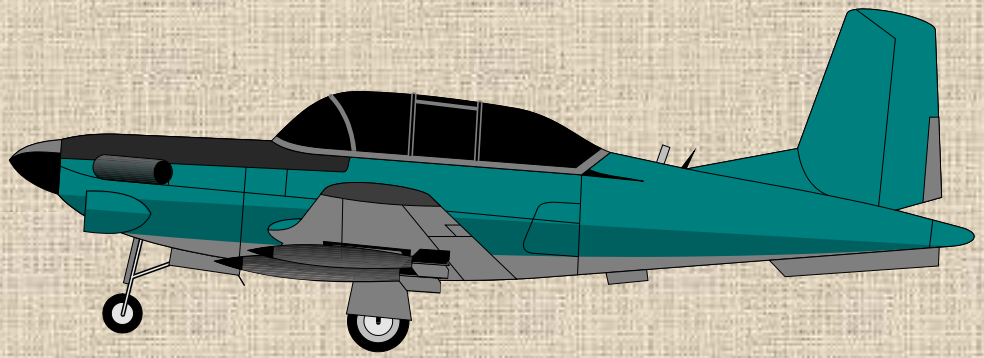
Jet engine powered

Or, propeller?



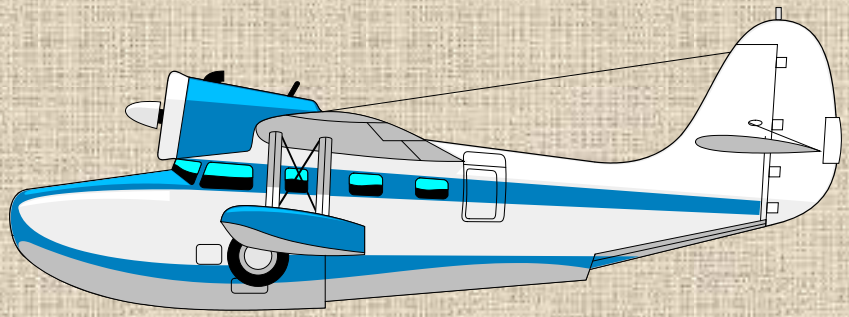
Source: Prof. Scott Eberhardt

Conceptual Design



Land based

Or, amphibian?



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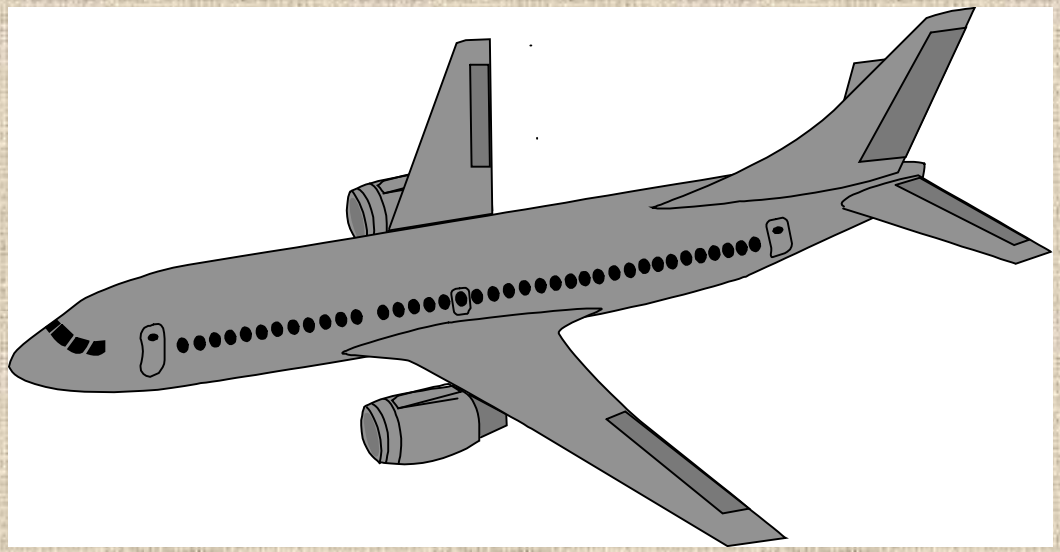
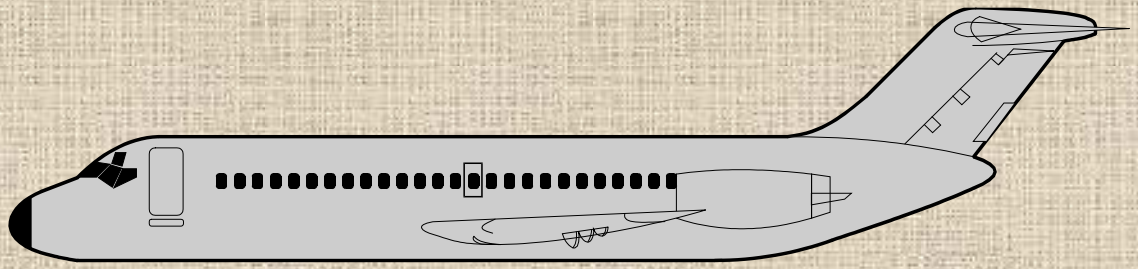
Conceptual Design



Wing mounted engines

Or, tail mounted?



Source: Prof. Scott Eberhardt

Requirements Capture

What is Requirements Capture ?

- Understanding exactly what the Customer wants
- Understanding the priorities of Customer's needs
- Identifying the features in the design that will
  - help in meeting these needs
  - result in highest customer satisfaction
- Comparative analysis of competitor's designs
  - identifying areas where they are better/superior
  - identifying areas of superiority & leadership
  - identifying areas offering scope for improvement

Part of First US Military Airplane Specifications

SIGNAL CORPS SPECIFICATION, NO. 486.

ADVERTISEMENT AND SPECIFICATION FOR A HEAVIER-THAN-AIR FLYING MACHINE.

To The Public:

Sealed proposals, in duplicate, will be received at this office until 12 o'clock noon on February 1, 1908, on behalf of the Board of Ordnance and Fortification for furnishing the Signal Corps with a heavier-than-air flying machine. All proposals received will be turned over to the Board of Ordnance and Fortification at its first meeting after February 1 for its official action.

Persons wishing to submit proposals under this specification can obtain the necessary forms and envelopes by application to the Chief Signal Officer, United States Army, War Department, Washington, D. C. The United States reserves the right to reject any and all proposals.

Unless the bidders are also the manufacturers of the flying machine they must state the name and place of the maker.

Preliminary. – This specification covers the construction of a flying machine supported entirely by the dynamic reaction of the atmosphere and having no gas bag.

Acceptance. – The flying machine will be accepted only after a successful trial flight, during which it will comply with all requirements of this specification. No payments on account will be made until after the trial flight and acceptance.

Inspection. – The Government reserves the right to inspect any and all processes of manufacture.

The general dimensions of the flying machine will be determined by the manufacturer, subject to the following conditions:

1. Bidders must submit with their proposals the following:
   - *(a)* Drawings to scale showing the general dimensions and shape of the flying machine which they propose to build under this specification.
   - *(b)* Statement of the speed for which it is designed.
   - *(c)* Statement of the total surface area of the supporting planes.
   - *(d)* Statement of the total weight.
   - *(e)* Description of the engine which will be used for motive power.
   - *(f)* The material of which the frame, planes, and propellers will be constructed. Plans received will not be shown to other bidders.

2. It is desirable that the flying machine should be designed so that it may be quickly and easily assembled and taken apart and packed for transportation in army wagons. It should be capable of being assembled and put in operating condition in about one hour.

3. The flying machine must be designed to carry two persons having a combined weight of about 350 pounds, also sufficient fuel for a flight of 125 miles.

4. The flying machine should be designed to have a speed of at least forty miles per hour in still air, but bidders must submit quotations in their proposals for cost depending upon the speed attained during the trial flight, according to the following scale:

40 miles per hour, 100 per cent.
39 miles per hour, 90 per cent.
38 miles per hour, 80 per cent.
37 miles per hour, 70 per cent.
36 miles per hour, 60 per cent.
Less than 36 miles per hour rejected.
41 miles per hour, 110 per cent.
42 miles per hour, 120 per cent.
43 miles per hour, 130 per cent.
44 miles per hour, 140 per cent.

Source: Prof. Scott Eberhardt

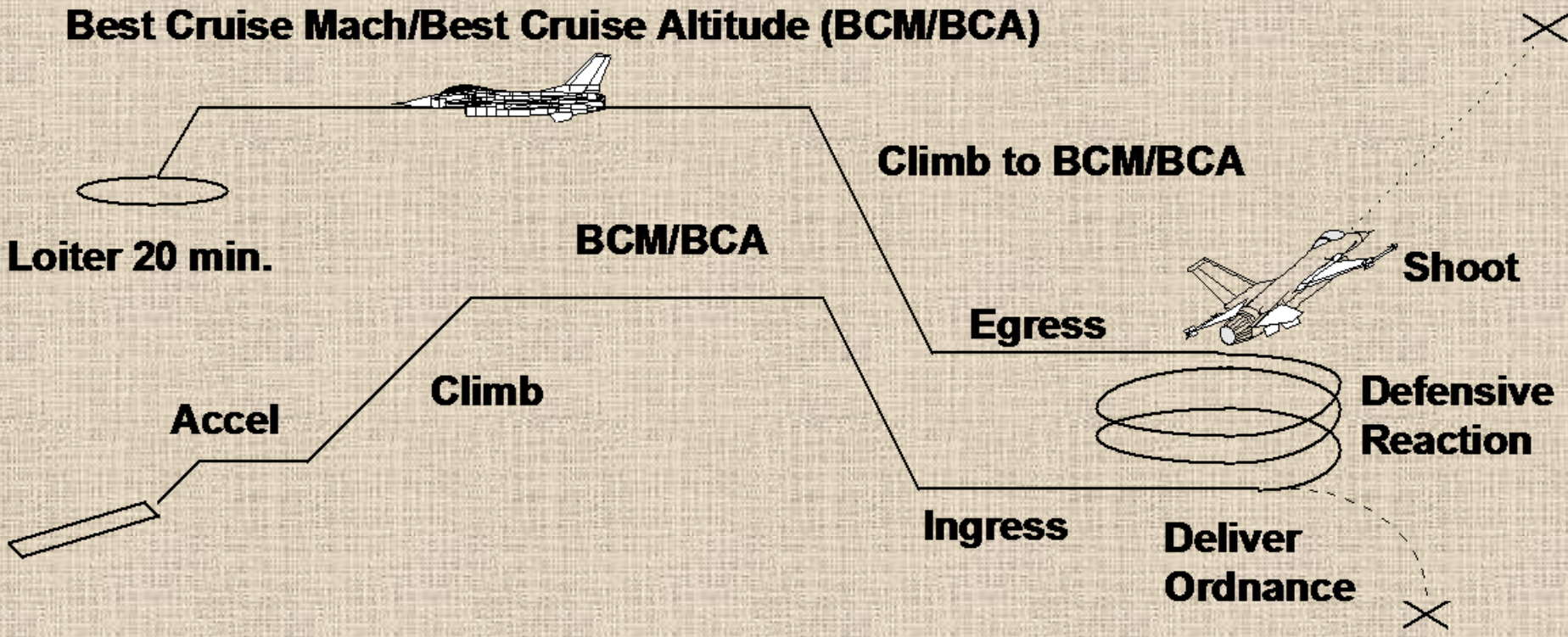
Typical Design Requirements : MJF

PARAMETER	REQUIREMENT
Combat Mission Radius	400 nm
Weapons Payload	2 AIM-120, 4 x 2000 lb MK-84
	600 rounds 20 mm ammunition
Takeoff Distance	2,000 ft
Landing Distance	2,000 ft
Max Mach Number	M = 1.8 at optimum altitude at Wman[a]
Instantaneous Turn Rate	18 deg/sec at M = 0.9, 20,000 ft MSL[b] at Wman
P_s	800 ft/sec, M = 0.9, 5,000 ft MSL at Wman
Sustained g	4-g at M = 1.2, 20,000 ft MSL at Wman
	9-g at M = 0.9, 5,000 ft MSL at Wman

a. The maneuver weight (Wman) is the aircraft weight with 50% internal fuel, two AIM-120 AMRAAM missiles, and full cannon ammunition, but no air-to-ground weapons.

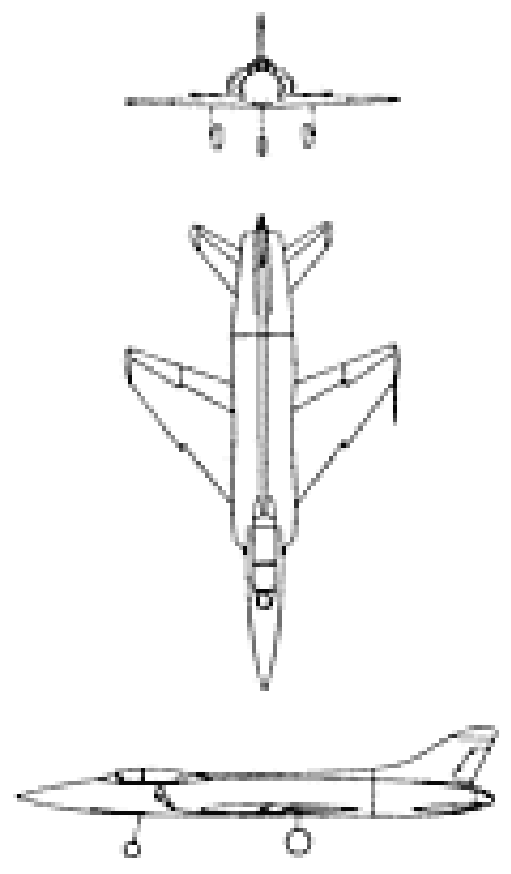
b. The abbreviation MSL signifies altitude above mean sea level, the average elevation of the Earth's oceans

Typical Mission Profile: MJF



Multirole Jet Fighter Aircraft

Aircraft Design



MODEL	"Marut" Mk.1	
CREW	1	
ENGINE	2 x HAL/Rolls-Royce Orpheus Mk 703, 21.6kN	
Take-off weight	10908 kg	24048 lb
Empty weight	6195 kg	13658 lb
Wingspan	9.0 m	30 ft 6 in
Length	15.87 m	52 ft 1 in
Height	3.6 m	12 ft 10 in
Wing area	28.0 m^2	301.39 sq ft
Max. speed	1070 km/h	665 mph
Ceiling	12000 m	39350 ft
Range	800 km	497 miles
ARMAMENT	4 x 30mm cannon, 50 x 68mm missiles	

Quality Function Deployment

Tool for Requirements Capture

Quality Function Deployment (QFD)

- Originated in 1972 @Mitsubishi's Kobe Shipyard
- Developed by Toyota and its suppliers
- Adopted worldwide by mid-eighties
- Also called House of Quality Chart (HOQ)

What is QFD ?

- Conceptual map or Set of routines for
  - Planning & Communication
- Focusing & Co-ordinating in-house skills in
  - Design
  - Manufacture
  - Marketing
- Foundation of QFD
  - *Products should be designed to reflect customer's designs and tastes, so all departments should work closely together from the time a product is conceived*

Steps in QFD

- What do the customers want ?
- How can we change the product ?
- How can engineers influence product qualities ?
- How does one engineering change affect the other characteristics ?

Identifying Customer Attributes (CAs)

- What is a CA ?
  - Phrases that customers use to describe products and their characteristics
  - Typical CAs for a passenger car
    - Low Fuel Consumption
    - Spacious boot
    - Good road grip
    - Good Acceleration
    - Good Looks

Customer Attributes for a Car Door

- Good Operation & Use
  - Easy to Open & Close
  - Isolation
  - Arm rest
    - Soft and Comfortable
    - Correct position
- Good Appearance
  - Interior Trim
    - Material does not fade
    - Attractive (non-plastic) lock
  - Clean
    - Easy to clean
    - No grease from door
  - Fit
    - Uniform gaps between matching panels

Easy to Open & Close

- Easy to open from outside
- Easy to close from outside
- Easy to open from inside
- Easy to close from inside
- Stays open on a hill
- Does not kick back

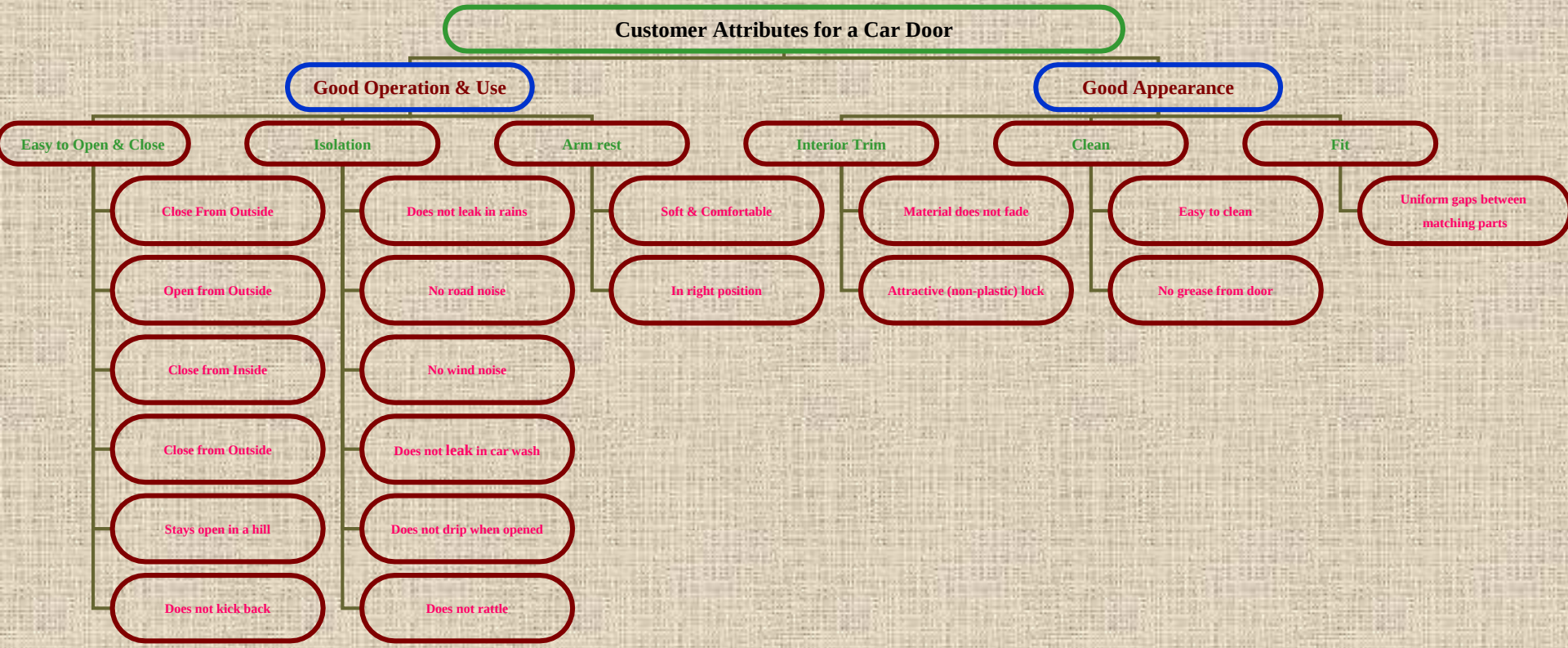
Isolation

- Does not leak in rains
- No road noise
- Does not leak during car wash
- No wind noise
- Does not drip water or snow when opened
- Does not rattle

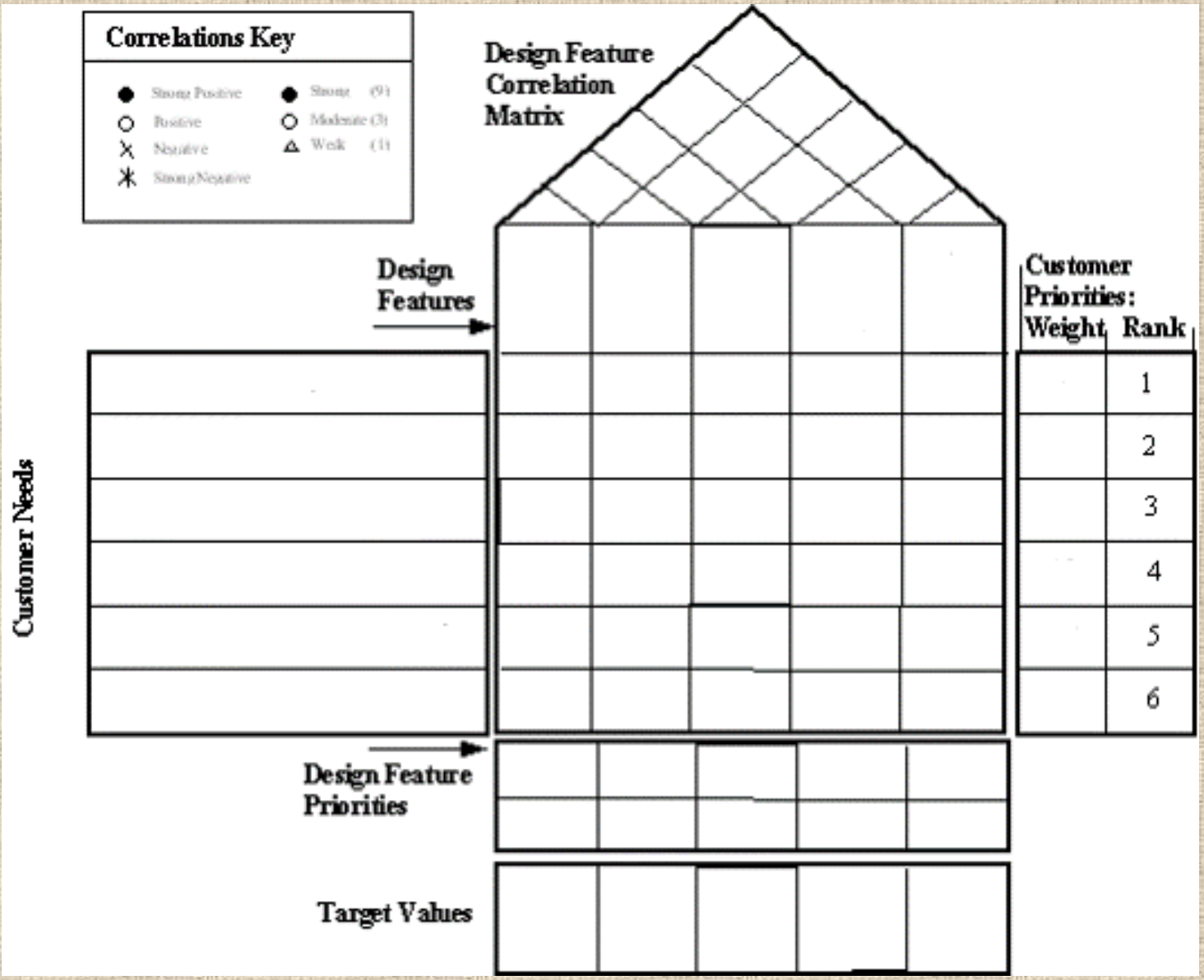
Good Appearance

- Interior Trim
  - Material does not fade
  - Attractive (non-plastic) lock
- Clean
  - Easy to clean
  - No grease from door
- Fit
  - Uniform gaps between matching panels

Primary, Secondary & Tertiary Requirements



House of Quality (HoQ) Chart



Steps in making a HOQ

- List down Customer needs
- Assign Priorities to the needs
- Decide Design Features to be provided
  - Indicate Target Values, if possible
- Fill In Design Features Matrix
- Calculate Design Feature Priorities
- Rank the Design Features
- Repeat
  - Using Design Features as Customer Needs

Illustration of HOQ for a General Aviation Aircraft

ZODIAC CH 640 *Details:www.zenair.com*

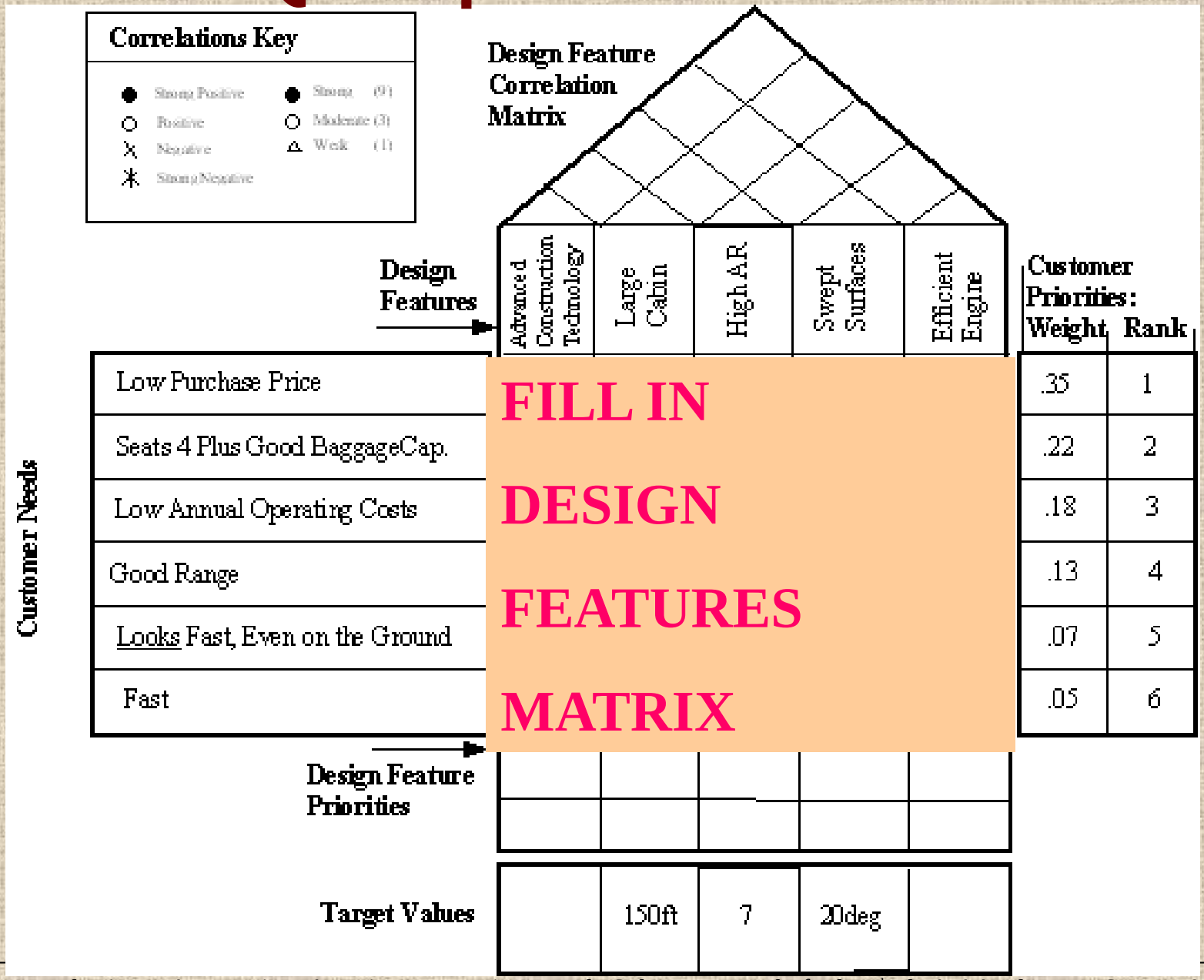
Customer Needs & Priorities

Low Purchase price	0.35
4 seats +baggage	0.22
Low Annual Operating Costs	0.18
Good Range	0.13
Looks Fast, even on Ground	0.07
High Speed capability	0.05

Proposed Design Features

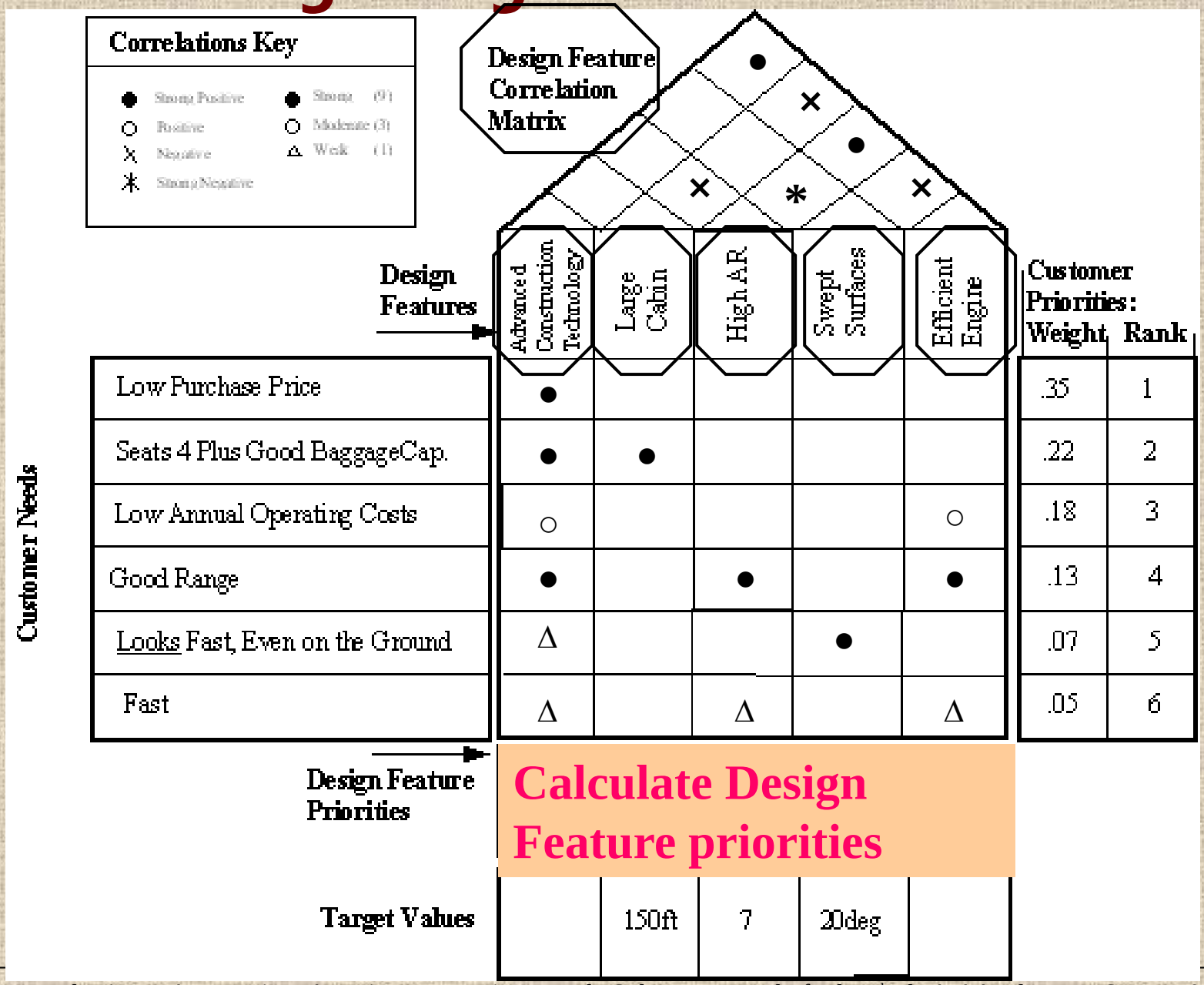
- Advanced Construction Technology
- Large Cabin
- High Aspect Ratio
- Swept Surfaces
- Efficient Engines

HOQ Template for GA Aircraft



Source: *Introduction to Aeronautics: A Design Perspective*, Brandt, Stiles, Bertin, Whitford, 2nd ed., AIAA Education Series, 2004

Filling Design Features matrix



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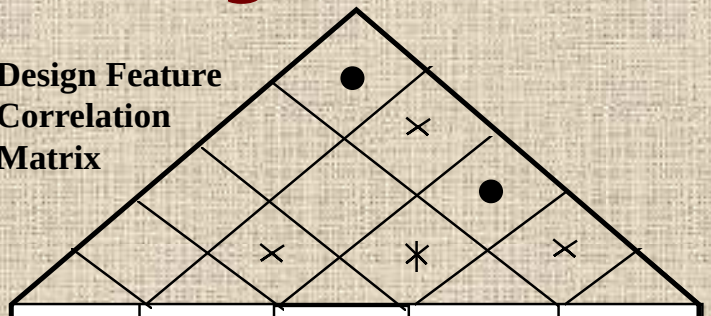
Calculation of Design Feature Priorities

Correlations Key

●	Strong Positive	●	Strong (9)
○	Positive	○	Moderate (3)
×	Negative	△	Weak (1)
✳	Strong Negative		

Design Feature Correlation Matrix



Customer Needs

Customer Needs	Advanced Construction Technology	Large Cabin	High AR	Swept Surfaces	Efficient Engine	Customer Priorities: Weight	Rank
Low Purchase Price	●					.35	1
Seats 4 Plus Good BaggageCap.	●	●				.22	2
Low Annual Operating Costs	○				○	.18	3
Good Range	●		●		●	.13	4
Looks Fast, Even on the Ground	△			●		.07	5
Fast	△		△		△	.05	6
Design Feature Priorities	**6.96**	**1.98**	**1.22**	**0.63**	**1.76**		
Rank	**1**	**2**	**4**	**5**	**3**		
Target Values		150ft	7	20deg			

Source: *Introduction to Aeronautics: A Design Perspective*, Brandt, Stiles, Bertin, Whitford, 2nd ed., AIAA Education Series, 2004

Higher Levels of HOQ

- Use Design Features as Needs
- Assign priorities based on ranking
- Identify second level features
- Repeat
- Example of HOQ sequence
  - Customer Attributes
  - Engineering Characteristics
  - Parts Characteristics
  - Key Process Operations
  - Production requirements

Different for different types of aircraft

DESIGN CONSIDERATIONS