Air Vehicle Design

AOE 4065 – 4066

II. Air Vehicle Design Fundamentals

Course Module A2

Understand the Problem

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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, collected and compiled the material contained herein from publicly available sources solely for educational purposes.

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)

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VIRGINIA TECH.

Aircraft CD Process: *The HOWs!*
"Top Down" – 3 Steps

1. Comprehensive Understanding of the Problem **(Initial Step)**

1.1 Analyze RFP to understand genesis and nature of customer's problem

1.2 Collect Design Requirements

(a) RFP—mission (speed, range, payload, etc), cost (acquisition, production, LCC, etc.), RM&S, and scheduling (EIS, tech freeze) requirements

(b) FAR (or CFR) and/or DoD documents—regulatory requirements & constraints

(c) ConOps—any additional requirements based on end-user perspective

1.3 Select Comparator Aircraft, Measures of Merit (MoMs), and Key Design Drivers

1.4 Identify Promising Technologies to tackle most difficult challenges

1.5 Investigate Proposal Selection Criteria

1.6 Develop Design Objectives & Strategy, and Prepare *Design Guidelines* document

2. Generation of Feasible Concepts **(Intermediate Step)**

2.1 Create multiple viable concepts—the ones you *think* could meet the need

2.2 Size all viable concepts; estimate TOGW, Wing Loading, Thrust or Power Loading

2.3 Down-select the most promising ones as a set of preferred system concepts (PSCs) using decision-making tools

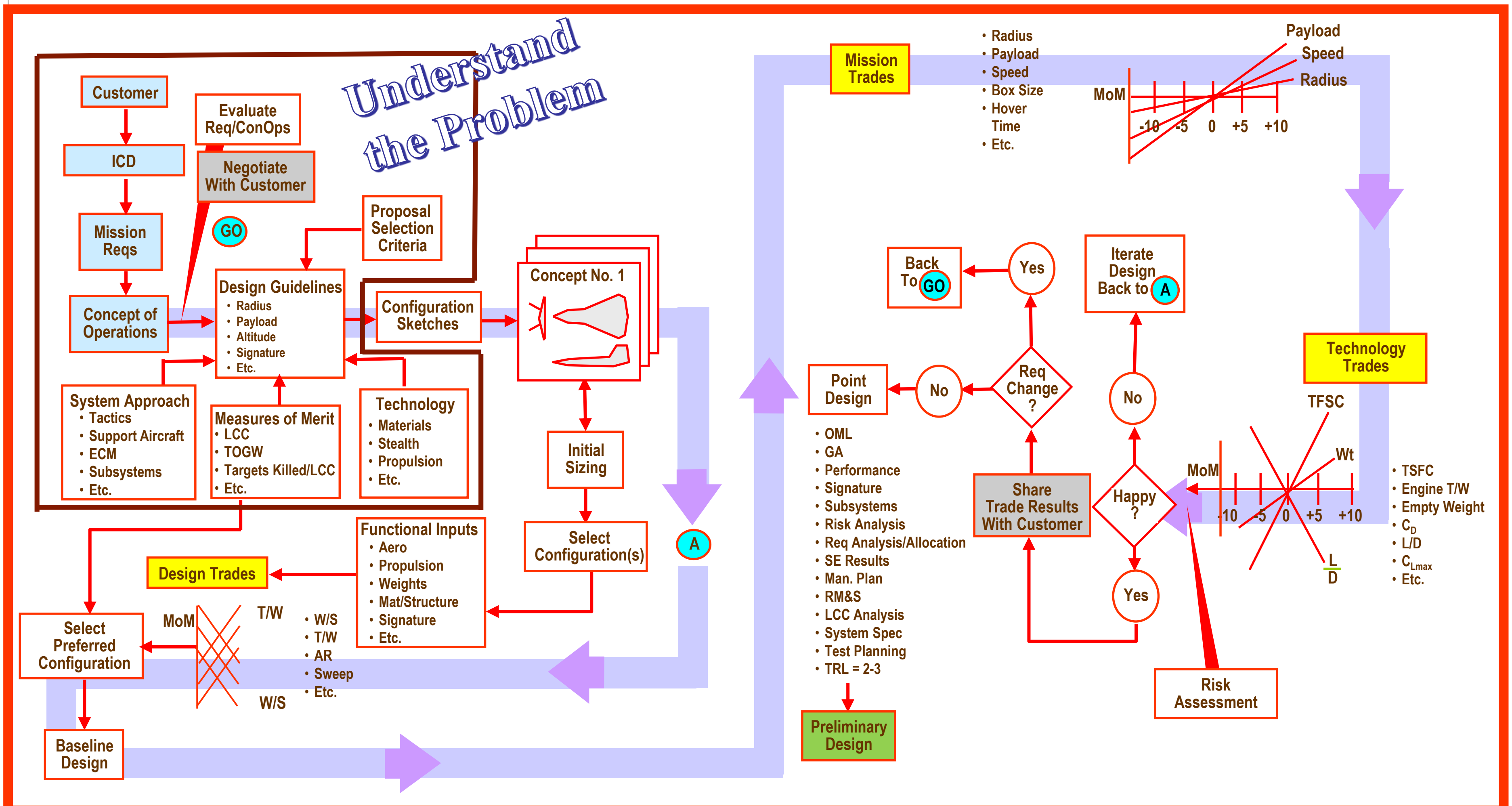
3. Selection of Best PSC as Baseline Design **(Final Step)**

3.1 Create outer mold line (OML) and interior profile of PSCs by choosing and integrating fuselage; wing; high-lift system; empennage; subsystems; C.G.; etc.

3.2 Conduct Design Trade Studies—Mission and Technology, if possible

3.3 Compare *feasible* configurations using MoMs and select "best" design!

Aircraft Conceptual Design (CD) Process



Comprehensive Understanding of the Problem Requires A Holistic Approach!

Adapted from Dr. Lee Nicolai's lecture slides

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Aircraft CD Process—Initial Step

1. Comprehensive Understanding of the Problem (6 Elements)

Questions to ask for each element

1.1 Genesis and Nature of Need

- Why did the customer issue the RFP?
- What mission does the customer need to perform that they are currently unable to?
- Is any existing system capable of meeting customer's needs?
- If an existing system is capable of meeting the need, does it have any capability gaps? In what aspect(s) does it fall short--performance, cost, readiness,…?

1.2 Design Requirements

- What requirements must be met to successfully perform the mission?
- Does the RFP spell out any cost, maintenance, support, or scheduling requirements?
- What regulatory requirements must be met by the design?
- Considering the end-user perspective for typical operational scenario(s), what additional aspects should be considered for designing the system?

1.3 Comparator Aircraft, Key Design Drivers and Measures of Merit

- Which existing system(s) come closest to meeting the need? (Comparator aircraft)
- What factors will have a major effect on the solution to the problem? Could it be speed (like Mach 3+ for SR-71)? Or fuel efficiency (high L/D for BWB)? Or stealth (B-2)? (Key Design Drivers)
- What does the customer really *want* but has not explicitly quantitatively specified in the RFP? Could it be cost, reliability, survivability,…? (Measure of Merits)
- How would we know that our design is actually delivering what the customer wants? To make an assessment, shouldn't we assign target numerical values to each MoM?

Aircraft CD Process—Initial Step

1. Comprehensive Understanding of the Problem (contd.)

Questions to ask for each element

1.4 Promising Technologies

- What design challenges (e.g., maneuverability, noise, emissions, fuel efficiency, cost, schedule, etc.) we cannot meet with currently available mature technologies, and therefore need to explore emerging technologies and assess their potential promise of solving the design challenges?
- When might the new technologies be mature enough for incorporation into the design? Will it be by the technology freeze date (based on scheduling constraints)?
- Will the risk and cost implications of incorporating new technologies be acceptable?

1.5 Proposal Selection Criteria

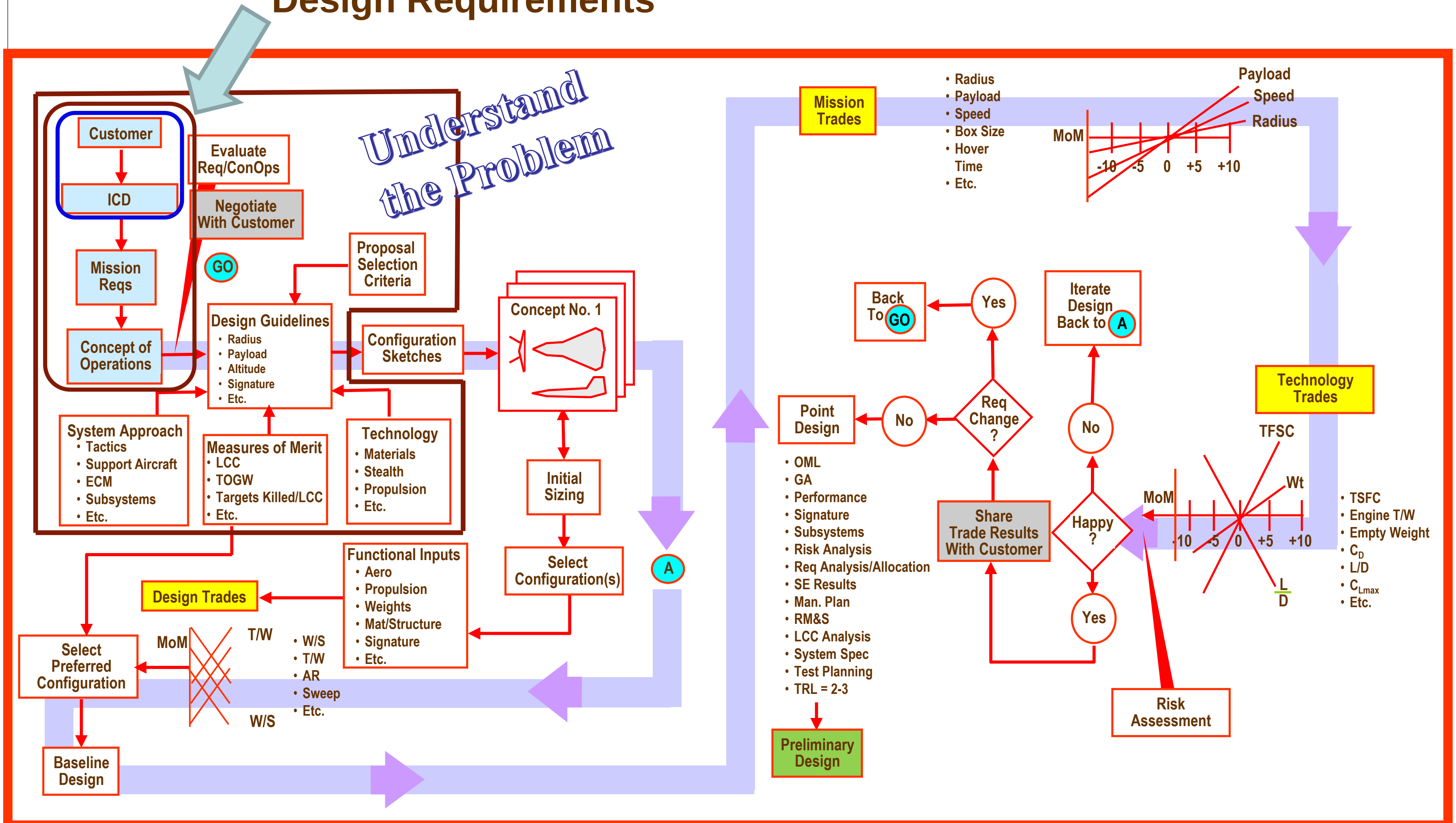
- What criteria will the customer use to evaluate the competing proposals and select a winner?

1.6 Design Objectives & Strategy, and Design Guidelines Document

- What is the customer expecting us to accomplish in the project? (Objectives)
- How do we accomplish the objectives to meet customer expectations? What should be the overall direction? (Strategy)
- How do we flow down the requirements to the design groups? (Guidelines document)

Aircraft Conceptual Design (CD) Process

Design Requirements



Adapted from Dr. Lee Nicolai's lecture slides

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It all starts with a Customer!

- **Design is (should be) a collaborative effort between you and your customer**
  - Be Passionate!
  - The customer must be involved with the design
- **Design is a Compromise**
  - Never a Right Answer…Always a Best Answer (Today)
  - Balance between competing customer pressures

Technical	Performance
Signature	Survivability
Appearance	Aesthetics
Economic	Cost
Political	Policy, Payback, Risk, etc.
Schedule	*Need it yesterday!*
Environmental	Energy Source & Pollution

Schedule driven 143 days!

- **Design is *Driven by Requirements*…**

  But *Evaluated by MoMs* (Measures of Merit)

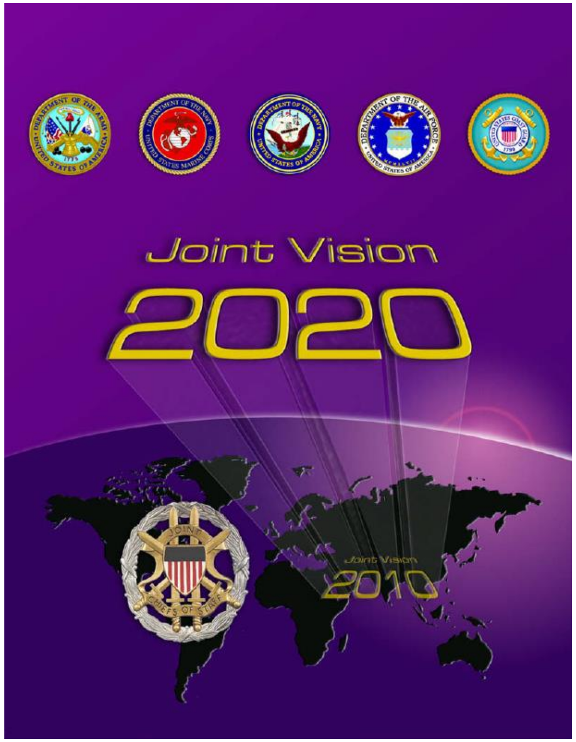
Design is the Creation of Something that Never Was!

What is an ICD?

- **ICD: Initial Capabilities Document**
  - **Identifies capability gap(s) that needs to be filled**
  - Typically a Military document, which is published by the customer
  - Called a “Requirements Pull”

- **ICD: A product of the JCIDS* Process of the US DoD (*Department of Defense*)**

  **Joint Capabilities Integration and Development System*

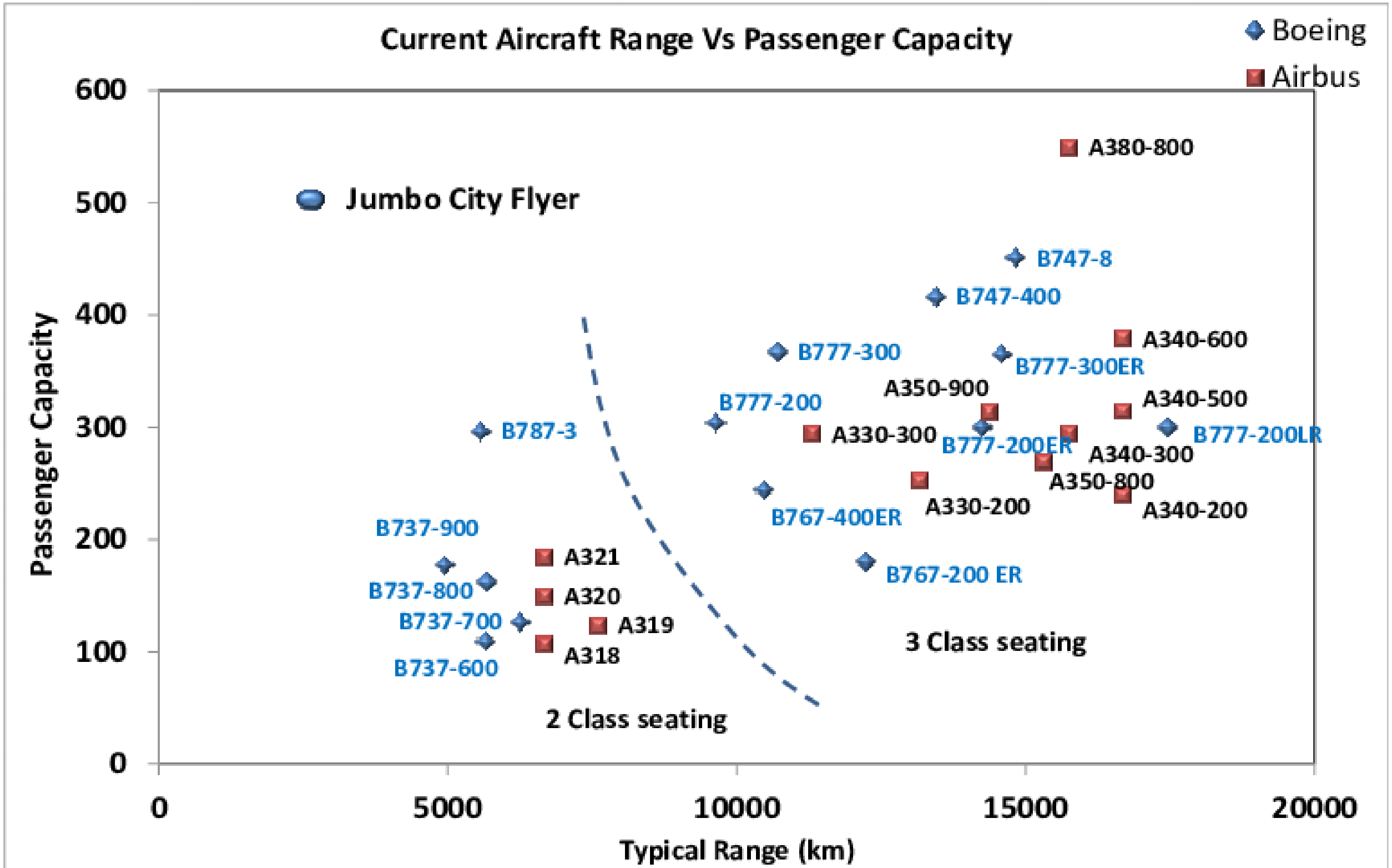


- **JCIDS seeks to**
  - Prioritize *joint* warfighting needs
  - Enhance methodology to identify and ***describe capabilities gaps*** and redundancies
  - Engage the acquisition community *early*
  - Improve *collaboration* across DoD

Note: ICD is also an acronym for *Interface Control Document*; beware of the context!

Capability Gaps Example

Commercial Aircraft



Source: https://www.researchgate.net/profile/Arvind-Gangoli-Rao/publication/281933127/figure/fig1/AS:667787223658515@1536224289886/Passenger-capacity-Vs-range-for-widely-used-civil-aircraft_W640.jpg

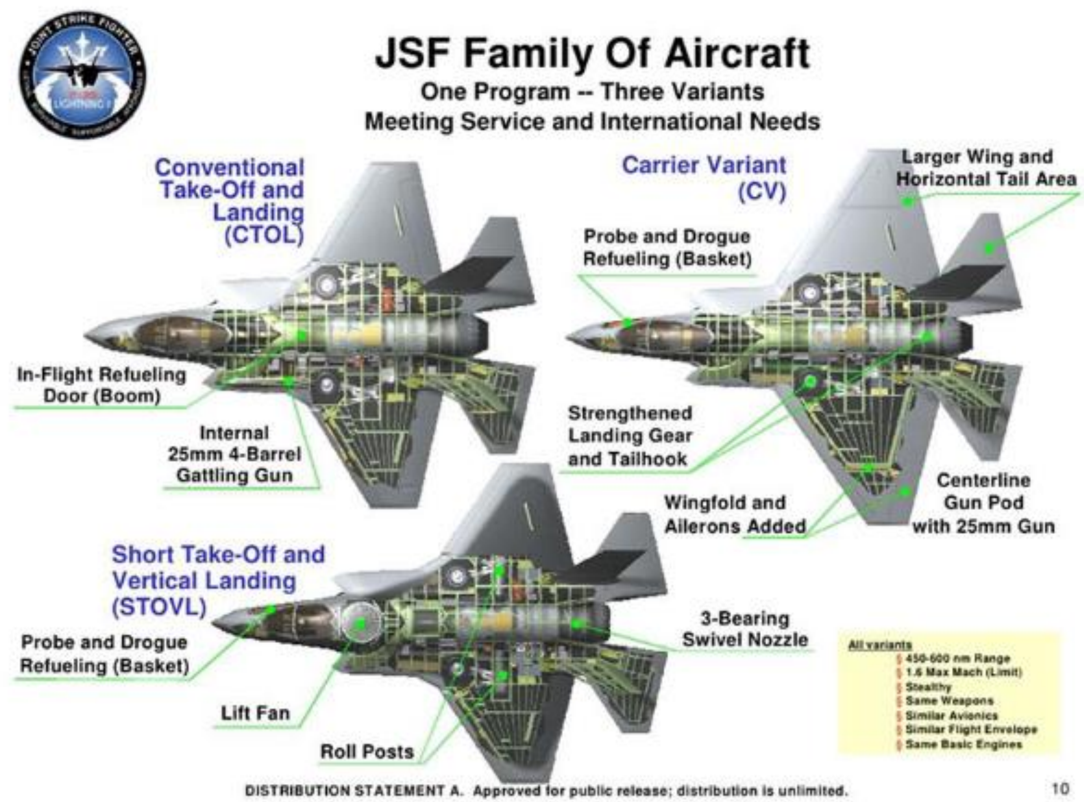
Capability Gaps Essentially Define System Requirements

Capability Gaps Example
Joint Strike Fighter (JSF)

ICD Outlined Capability Gaps

- We don’t have, i.e., we **need** fifth-generation fighter jet: *a combination of Very Low Observable (VLO) stealth, advanced sensors, information fusion and network connectivity–all packaged into a supersonic, long range, highly maneuverable fighter*
- We need *a single aircraft* that combines air-to-air, strike, and ground attack capabilities for use by *multiple branches of the U.S. military and its NATO and other allies*
- We need to reinforce air superiority of coalition nations while containing fleet development costs by channeling efforts into one highly advanced design and sharing costs across the program’s member nations

ICD helped define JSF Requirements to provide the needed capability



IOC and FOC: DoD Formal Definitions

Context: EIS (Entry into Service) usually specified in RFP

The **Initial Operational Capability (IOC)** is achieved during the Production & Deployment (PD) Phase ***when a system can provide the minimum operational (Threshold and Objective) capabilities for a user's stated need.***

- The operational capability consists of support, training, logistics, and system interoperability within the Department of Defense (DoD) operational environment.
- IOC is a good gauging point to see if there are any refinements needed before proceeding to Full Operational Capability (FOC).

The **Full Operational Capability (FOC)** is achieved when a system is delivered to a user *and* they have the *ability to fully employ and maintain* it to meet an operational need.

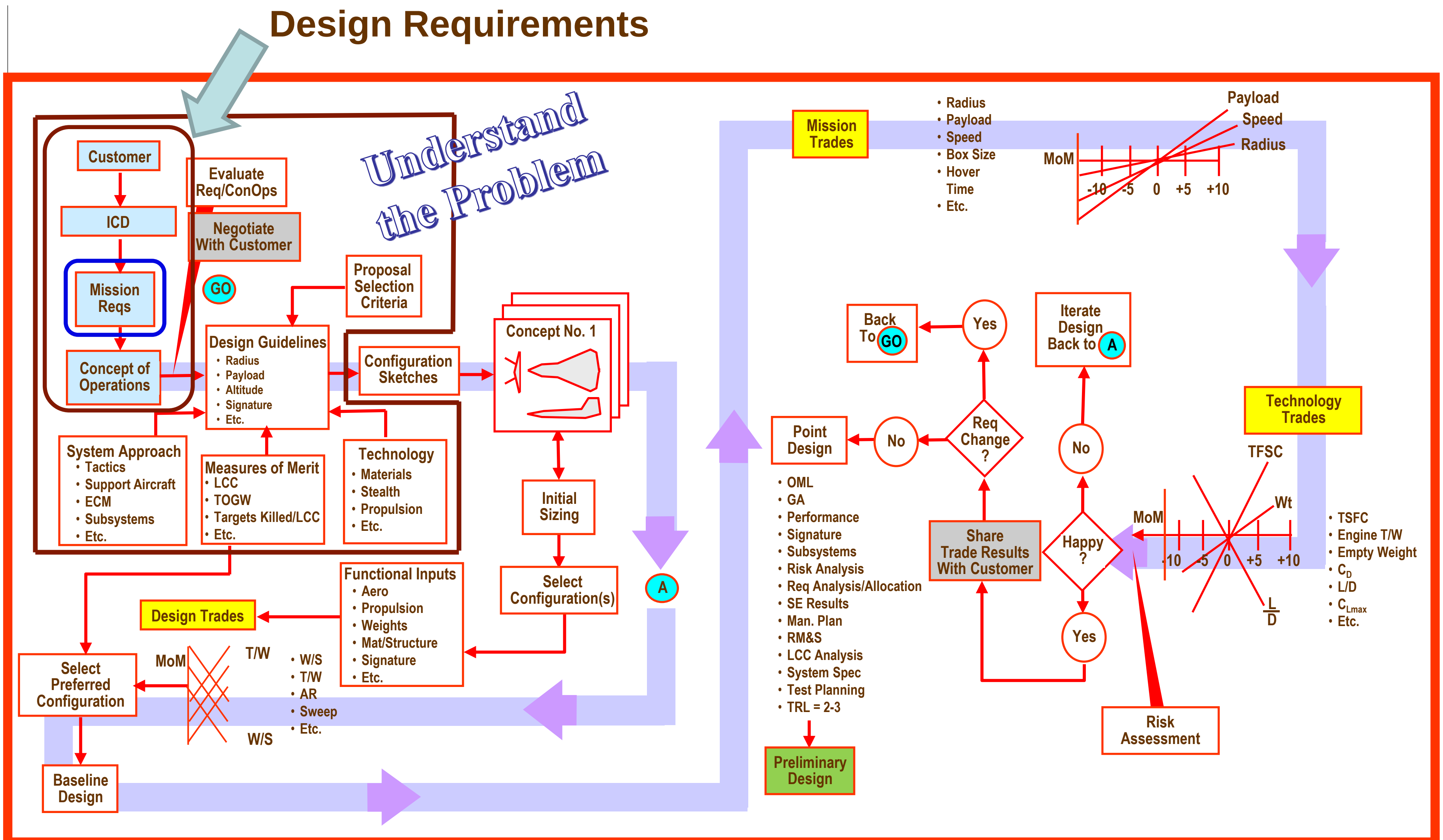
What question should you ask first?

How is the customer currently meeting their need?

The answer will tell you *why* the customer is asking for a new aircraft system, and why they need the desired capability. (*Genesis of the need*)

- **How do you go about answering the question?**
  - ✓ Conduct research to answer this question
  - ✓ Analyze the RFP to understand what the new system must do (target capabilities). How well? Under what conditions? *(Nature of the need)*
  - ✓ Is any *existing system* capable of meeting the desired capabilities?
- **Will the existing systems fully meet the customer's need?**
  - ✓ No! If they did, why would the customer want a new one?
  - ✓ Gather information about the performance and other specifications of the existing systems

Aircraft Conceptual Design (CD) Process



Adapted from Dr. Lee Nicolai's lecture slides

Mission Requirements

- **Mission Requirements are driven by the need to fill capability gaps**
  - Typically called a "Requirements Pull"
- **Usually two levels of mission requirements**
  - **1. Threshold**: Just Enough to Meet The Need
  - **2. Objective** (or Goal): "Kick Butt"
  - It's hard to justify designing for the Objective level when cost is capped
- **Not all requirements are created equal!**
  - **KPP** *(Key Performance Parameters):* ***Must have*** *– Key capabilities for a system to meet its operational goals…Failure may lead to program reevaluation or modification*
    - Better meet KPP or else program dies! Sacred, a **"Show Stopper"**
  - **SPP** *(Significant Performance Parameters)*: ***Should have*** – Tradeable for Cost
  - **DPP** *(Desired Performance Parameters):* ***Nice to have*** – Tradeable for Cost
- **Sometimes driven by new technology**
  - Called a "Technology Push"
  - Technology Offers A New Capability
  - Example: Stealth →F-117, HEL→YAL-1

Adapted from Dr. Lee Nicolai's lecture slides

F-35 KPPs

Table A-1. F-35 Key Performance Parameters (KPPs)

Source of KPP	KPP	F-35A Air Force CTOL version	F-35B Marine Corps STOVL version	F-35C Navy carrier-suitable version
Joint	Radio frequency signature	Very low observable	Very low observable	Very low observable
	Combat radius	590 nm Air Force mission profile	450 nm Marine Corps mission profile	600 nm Navy mission profile
	Sortie generation	3 surge / 2 sustained	4 surge / 3 sustained	3 surge / 2 sustained
	Logistics footprint	< 8 C-17 equivalent loads (24 PAA)	< 8 C-17 equivalent loads (20 PAA)	< 46,000 cubic feet, 243 short tons
	Mission reliability	93%	95%	95%
	Interoperability	Meet 100% of critical, top-level information exchange requirements; secure voice and data		
Marine Corps	STOVL mission performance – short-takeoff distance	n/a	550 feet	n/a
	STOVL mission performance – vertical lift bring-back	n/a	2 x 1K JDAM, 2 x AIM-120, with reserve fuel	n/a
Navy	Maximum approach speed	n/a	n/a	145 knots

Source: F-35 program office, October 11, 2007.

Notes: PAA is primary authorized aircraft (per squadron); vertical lift bring back is the amount of weapons with which plane can safely land.

Source: https://sgp.fas.org/crs/weapons/RL30563.pdf

Example of Mission Requirements
Student Design Project

"Researchers have been using Global Hawk-type UAVs to gather data during the hurricane season to improve their computer models. The models predict storm track with accuracy, but they are less accurate in predicting storm formation and intensification behaviors. Those types of predications require long-term observations and measurements. The Global Hawk-type aircraft are limited to 24 hours endurance. This challenge asks students to design ***a new system*** of next generation un-crewed aircraft platforms ***with much longer endurance.***"

- 2013-14 NASA ARMD University Engineering Design Challenge

	Threshold	Goal
Loiter Speed (kts)	150	250
Altitude (ft.)	60,000	70,000
Endurance (days)	7	10+
Payload (lbs.)	2000	3000
Payload Power (kW)	9	15
	KPP	**DPP**

RFPs Usually—Not Always—Provide Most of the Design Requirements

- **The Mission Requirements: Usually in RFP**
  - **Crew:** Manned or unmanned
  - **Payload:** Passengers, cargo, weapons, sensors, …
  - **Speed:** Cruise, maximum, loiter, landing, …
  - **Distance:** Range or radius
  - **Duration:** Endurance or loiter (time on station)
  - **Field Length**: Short or conventional
  - **Environmental:** Noise, emissions
- **The Scheduling Requirements: Usually in RFP**
  - **Entry into service (EIS):** Year
  - **Development, test and certification:** Targets and constraints
- **The Cost Requirements: Usually hinted at but not provided in RFP**
  - **Research, Development, Test & Evaluation (RDT&E) cost**
  - **Production cost**
  - **Engine and avionics cost**
  - **Acquisition cost**
  - **Operation & Support (O&S) cost**
  - **Direct Operating Cost + Insurance (DOC+I):** Airlines
  - **Life Cycle Cost (LCC):** "Cradle to Grave"

RFPs May Not Include ALL Requirements!

- **What are the Reliability, Maintainability and Supportability (RM&S) Requirements? *(commonly called '-ilities')* <u>May not be in the RFP</u>**
  - **Maintenance man-hours per flight hour (MMH/FH)**
  - **Readiness levels; mean time between failure**
  - **Ground Support Equipment**
  - **Maintenance Levels**
  - **Integrated logistics support plan**
  - **Contractor- or user-provided support**
- **What Specifications, Standards, and Regulations are applicable and must be incorporated? <u>May not be *specifically* spelled out in the RFP</u>**
  - **Federal Aviation Regulations (FARs)**
  - **DOD Specifications and Standards (DODSS) System; MIL-STD documents**
- **Where did the requirements come from? Evaluate and validate the Requirements**

Today's RFPs: Descriptive and Capability Focused
Past RFPs: Prescriptive and Vehicle Focused

Past RFP Example—the 1960s
C-5A Military Transport Aircraft (1 of 3)

C-5A RFP (12 Dec 1964)

Very extensive and detailed set of requirements and specifications

- PAYLOAD RANGE

PAYLOAD - LB	100,000	200,000	265,000
RANGE - NM	5,500	2,700	2,700
LIMIT L.F.	2.5 - 1.0	2.5 - 1.0	2.25 - 0.0

- TAKEOFF OVER 50 FT, S.L., 89.5^{0}F
  - AT BASIC DES. GR. WT. 2.5g —— 8,000 FT
  - AT MAX. DES. GR. WT. 2.25g —— 10,000 FT
- LANDING OVER 50 FT, S.L., 89.5^{0}F WITH 100,000 LB PAYLOAD AND FUEL TO RETURN AT MID-POINT OF 2,500 NM MISSION —— 4,000 FT
- INITIAL CRUISE ALTITUDE AT BASIC DES. GR. WT —— 30,000 FT
- LONG RANGE CRUISE SPEED —— 440 KTAS

Source: Garrard, The Lockheed C-5 Case Study in Aircraft Design

Past RFP Example—the 1960s

C-5A Military Transport Aircraft (2 of 3)

PROPULSION — 4 TURBOFANS S.L. RATING 40,000 LB

CARGO COMPT — WIDTH MIN. 17.5 FT
HEIGHT MIN. 13.5 FT
LENGTH MIN. 120 FT EXCL RAMPS
FLOOR AREA MIN. 2,300 SQ. FT. EXCL RAMPS
2,700 SQ. FT. INCL RAMPS

CARGO LOADING — FRONT FULL CROSS SECTION
REAR 13 FT WIDE 9.5 FT HIGH STRAIGHT IN
LOADING FLOOR HEIGHT 48 - 54 IN.

PASSENGERS — 15 PLUS ACCOMMODATION FOR TROOPS ABOVE CARGO

LANDING GEAR — FLOTATION 100 PASSES ON M-8 MAT ON CBR 4 WITH
200,000 LB PAYLOAD AND FUEL FOR 1,000 NM
TIRE DEFLECTION 40%

CROSS WIND $\pm 20^0$
180^0 TURN ON 150 FT WIDE RUNWAY

STABILITY AND CONTROL — MIL-F-8785 AND CAR REQ. 8^0 ROLL IN 1 SEC IN
APPR CONFIG AT 1.2 V_S AT LIGHT WEIGHT

Source: Garrard, The Lockheed C-5 Case Study in Aircraft Design

RFP Example—the 1960s

C-5A Military Transport Aircraft (3 of 3)

OPERATING WEIGHT	INCLUDE PALLETS, TROOP SEATS, CARGO RESTRAINT DEVICES
AIRFRAME LIFE	30,000 HR INCL 6% AT 300 FT AT 350 KIAS USING TERRAIN AVOIDANCE 12,000 LANDINGS 5,950 PRESSURIZATIONS
RELIABILITY	90% MUST REACH DESTINATION WITHOUT MAJOR SUB-SYSTEM FAILURE ADDITIONAL 8% NO ABORTS 87% LEVEL TO BE DEMONSTRATED DURING CATEGORY II (USAF) TESTS
MAINTAINABILITY	QUAN REQ BASED ON MIN OP AVAILABILITY OF 75%

500 Changes to RFP Received between 25 January and 25 March!

Source: Garrard, The Lockheed C-5 Case Study in Aircraft Design

B777 Commercial Transport Aircraft
Requirements Development—1980s - 1990s

- **Some commercial aircraft suppliers develop the requirements themselves. They develop the aircraft and put it on the shelf as a "Take-it or Leave-it"**
- **Boeing used "Take-it or Leave-it" strategy during the development of the 707 through the 767 with great success. Boeing had a well seasoned marketing staff and most of the market share for commercial transports**
- **During the development of the 777 (late 80's to mid 90's) they were locked in a war with Airbus (the Airliner War) and changed their strategy. They formed an advisory team of 8 airlines (called the Gang of Eight) to advise them on desired attributes**
  - The management style of the PMs (Phil Condit and Alan Mulally) was "Working Together"
  - The only Boeing requirement was two engine and beat the A340
  - The Gang of Eight wanted
    - Cabin cross-section similar to B747
    - At least 325 passengers
    - Fly-by-wire controls
    - Glass cockpit
    - 10% better seat-mile cost than A340
    - 3 hour ETOPs (Extended Twin-engine Operations) for LAX to Hawaii route

Shift from "Take-it or Leave-it" to Heavy Customer Involvement

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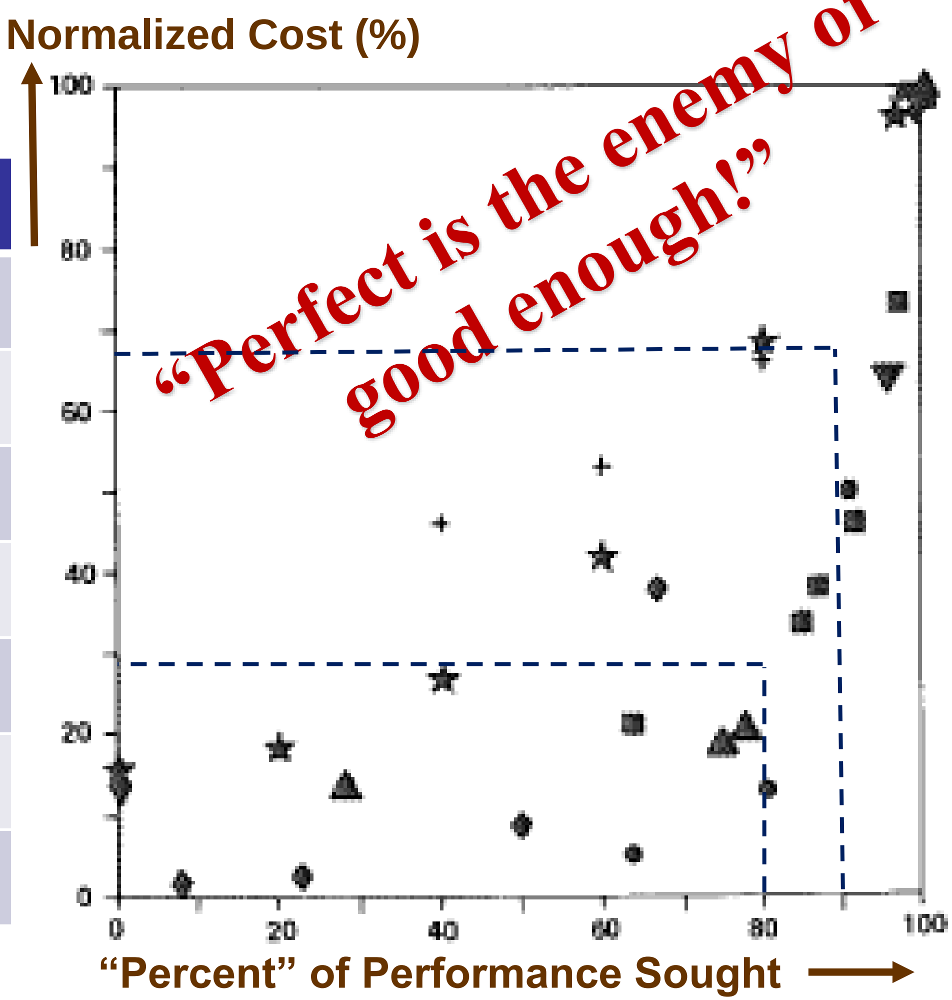
Understand Cost-Performance Coupling

Beware of the High Cost of "a Little More"

"Requirements Creep" violates the project "iron triangle"!

Symbol	Item	Measure of Performance	"100%" Performance
♦	35 mm optical lens	Focal length (f5.6) mm	600 mm
●	Baseball players	Batting average (vs. salary)	0.330
+	Machined parts	Tolerance (Logarithmic) (in.)	0.00001 in.
▲	1960's airplanes	Mach no. (vs. $/pound)	Mach 3.2
▼	Inertial references	Drift rate (MPH)	0.1 MPH
★	Diamonds	Grade (Quality) ($/kt)	$44,000/kt.
■	Radar Availability	TPQ-36 Avail. (vs. Spares Cost)	0.97



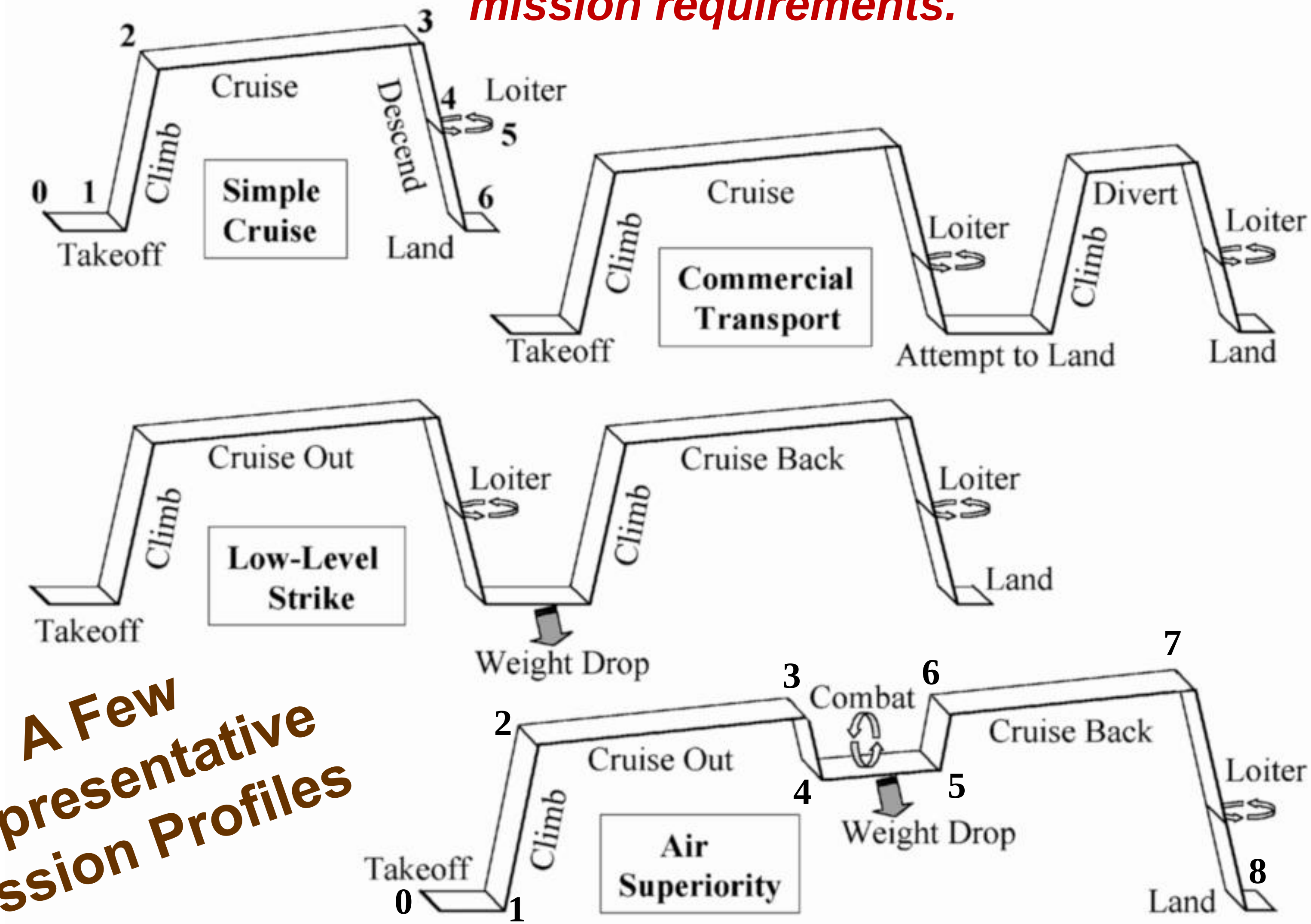
The last 10% of the performance sought generates one-third of the cost and two-thirds of the problems!

13 August 2024

Source: Augustine's Laws, 1983

Mission Profiles

Sketch of flight profile demonstrates understanding of mission requirements.

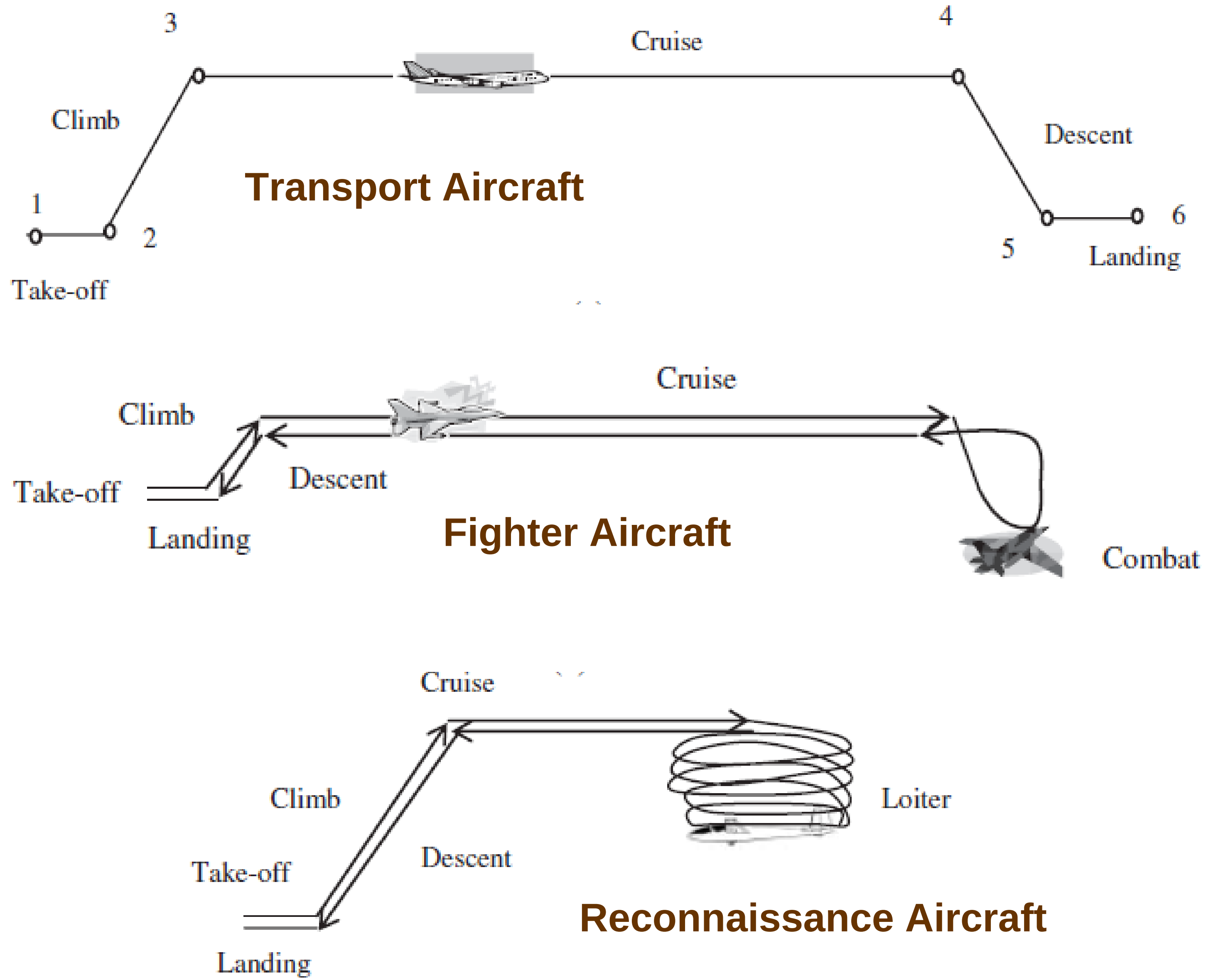


A Few Representative Mission Profiles

<u>It must be done before you begin to solve the problem.</u>

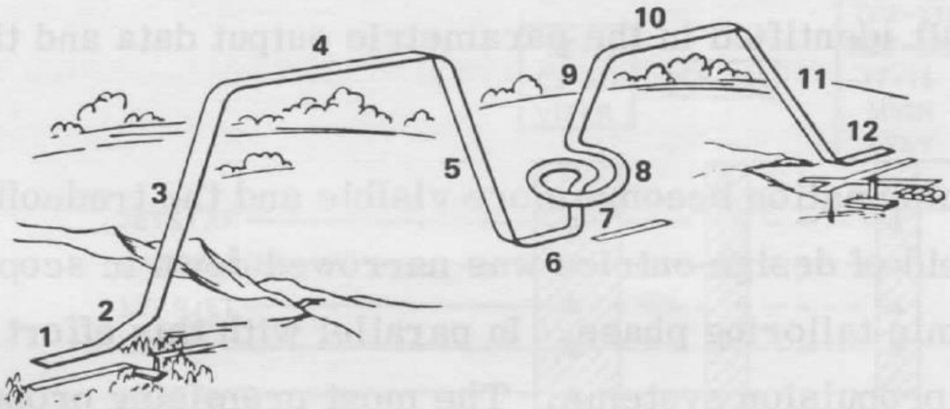
Source: Fig. 3.2, Ref. AVD 2 (Raymer)

Typical Mission Profiles



Source: Fig. 4.2, Ref. AVD 5 (Sadraey)

National Business Aircraft Association: Standard Mission Profile



1. TEN MINUTE ALLOWANCE FOR TAXI
2. ONE MINUTE ALLOWANCE AT FULL POWER FOR TAKEOFF
3. OPTIMUM RATE OF CLIMB TO ALTITUDE
4. NORMAL CRUISE AT ALTITUDE
5. DESCENT ENROUTE TO SEA LEVEL AT 3000 FEET PER MINUTE
6. STANDARD INSTRUMENT APPROACH WITH FUEL CONSUMED EQUAL TO 5 MINUTES LOITER AT 5000 FEET
7. A MISSED APPROACH FOLLOWED BY CLIMB-OUT TO 5000 FEET
8. HOLDING AT LOITER POWER AT 5000 FEET FOR 5 MINUTES AWAITING CLEARANCE
9. CLIMB ENROUTE TO CRUISE ALTITUDE
10. ECONOMY CRUISE TO AN ALTERNATE
11. DESCENT ENROUTE TO SEA LEVEL AT 3000 FEET PER MINUTE AND LAND (ITEMS 9, 10 & 11 TOTAL 200 N MI)
12. FUEL RESERVE AFTER LANDING AT ALTERNATE EQUAL TO 30 MINUTES LOITER AT 5000 FEET

0685-108B

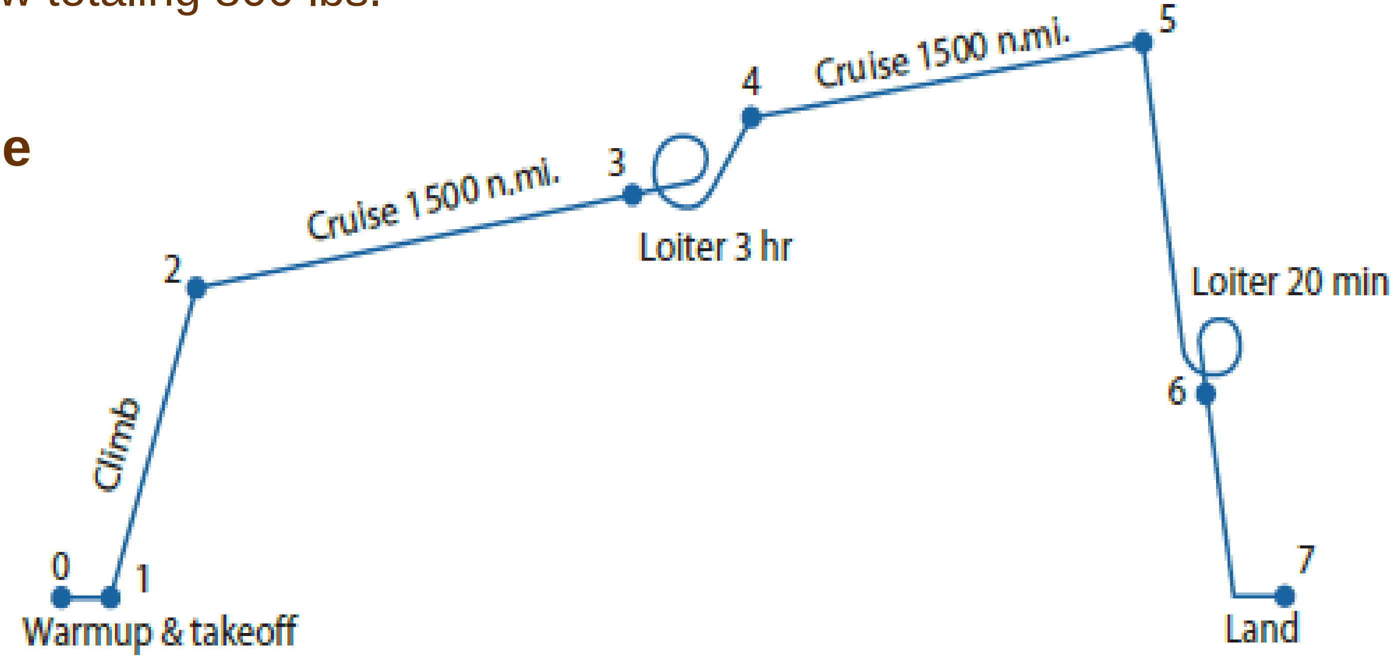
Mission Profile

Hypothetical ASW Aircraft

Requirements

- Loiter for three hours at 1500 nm from takeoff point, then return to base
- Cruise Mach number: 0.6
- Equipment weight: 10,000 lbs.
- Four-man crew totaling 800 lbs.

Mission Profile



Source: Ch. 3.6.4 , Ref. AVD 2 (Raymer)

Specifications, Standards and Regulations *(May not be in the RFP)*

- **U.S. Federal Aviation Administration (FAA) has prescribed a large number of Federal Aviation Regulations (FARs) to promote safety of aviation and to address environmental concerns.**
  - FAR examples: Engine-out minimum performance; Reserve Fuel Requirements; Emergency Exits on Airliners; Community noise
  - All civil aircraft designs must comply with applicable FARs.
    - Select the applicable FAR documents which describe specific rules in detail.
    - Use the slides in the course module as a starting point
  - https://www.faa.gov/regulations_policies/faa_regulations/
- **Department of Defense (DoD) has created an even larger number of Military Specifications and Standards (MIL-SPECs or MIL-STDs).**
  - All military aircraft must be designed to meet (or exceed) the specifications and standards
  - https://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title14/14tab_02.tpl

Use the tables in this module as a guide for selecting the applicable documents which describe specifications & regulations in detail.

Federal Air Regulations (FARs)

CHARACTERISTICS

Category	Various*	Normal	Transport
Max. take-off weight, lb	≤ 12,500	≥ 12,500	-
Number of engines	One or more	Two or more	Two or more
Type of engine	All	Propeller engines only	All
Minimum crew Flight crew Cabin attendants	 One or more None	 Two < 20 pass.: None ≥ 20 pass.: One	 Two or more < 10 pass., none ≥ 10 pass.: One or more
Max. number of occupants	10	11-23	Not restricted
Max. operating altitude, ft.	25,000	25,000	Not restricted

*normal as well as utility, aerobatic, and agricultural.

Source: Table F.1, Ref. AVD 2 (Raymer)

Federal Air Regulations (FARs)

APPLICABILITY

Category	Various*	Normal	Transport
Airworthiness standards – airplanes	Part 23	Part 23	Part 25
Airworthiness standards - engines	Part 33	Part 33	Part 33
Airworthiness standards - propellers	Part 35	Part 35	Part 35
Noise standards	Part 36: Prop-Driven, Appendix F		Part 36
General operating and flight rules	Part 91	Part 91	Part 91
Operations			
Domestic, flag and supplemental commuter operations of large aircraft	—	—	Part 121
Air travel clubs using large aircraft	—	—	Part 123
Air taxi and commuter operations	—	Part 135	—
Agricultural aircraft	Part 137	—	—

*normal as well as utility, aerobatic, and agricultural.

Source: Table F.1, Ref. AVD 2 (Raymer)

Military Specs & Standards--Aircraft Design

A Partial List

Document Number	Title
MIL-HDBK-1797	Flying Qualities of Piloted Airplanes (replaced MIL-F-8785C)
MIL-F-83300	Flying Qualities of Piloted V/STOL Aircraft
MIL-F-9490	Flight Control Sys-Design, Installation and Test of Piloted Aircraft
MIL-S-8369	Stall/Post-Stall/Spin Flight Test Demonstration Reqs for Airplanes
MIL-C-18244	Control and Stabilization Systems: Automatic, Piloted Aircraft
MIL-D-8708	Demonstration Requirements for Airplanes
MIL-A-8860-64, 70	Airplane Strength and Rigidity
MIL-I-8700	Installation and Test of Electronics Equipment in Aircraft
MIL-P-26366	Propellers, Type Test of
MIL-S-18471	Seat System, Ejectable, Aircraft
MIL-W-25140	Weight and Balance Control Data
MIL-STD-850	Aircrew Station Vision Req. for Military Aircraft
MIL-STD-757	Reliability Evaluation from Demonstration Data
MIL-C-5011	Charts; Standard Aircraft Characteristics and Performance
MIL-STD-881	Work Breakdown Structure (WBS)
MIL-STD-499B	Systems Engineering
MIL-HDBK-516B	Airworthiness Certification—U.S. Tri-Service

Source: Table 1.4, Ref. AVD 1 (Nicolai and Carichner)

Summary of *Takeoff Regulations* MIL and FAR

Conventional Takeoff & Landing (CTOL) Aircraft

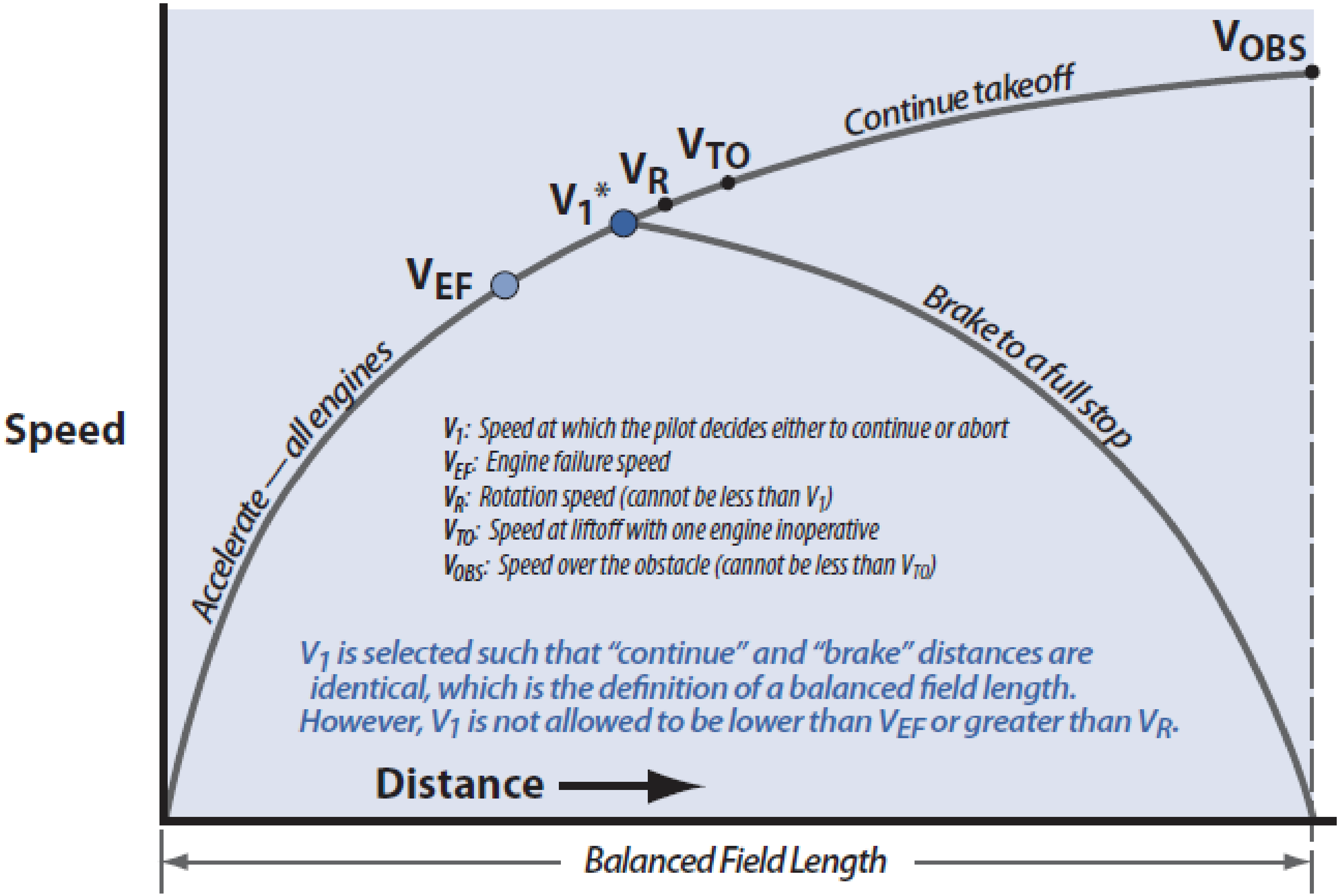
Item	MIL-C-5011C (Military)	FAR Part 23 (Civil)	FAR Part 25 (Commercial)
Speeds	$V_{TO} \geq 1.1\ V_S$ $V_{CL} \geq 1.2\ V_S$	$V_{TO} \geq 1.1\ V_S$ $V_{CL} \geq 1.1\ V_S$	$V_{TO} \geq 1.1\ V_S$ $V_{CL} \geq 1.2\ V_S$
Climb gradient	Gear up: 500 fpm at SL (AEO) 100 fpm at SL (OEI)	Gear up: 300 fpm at SL (AEO)	Gear up: 3% at V_{CL} (OEI) Gear down: 0.5% at V_{TO} (AEO)
Rolling Coefficient	μ = 0.025	Not specified	Not specified
Field Length Definition	Takeoff distance over 50 ft.	Takeoff distance over 50 ft.	115% of takeoff distance over 35 ft. <u>or</u> critical field length

SL = seal level; AEO = All Engine Operating; OEI = One Engine Inoperative

See next slide

Source: Table 10.1, Ref. AVD 1 (Nicolai and Carichner)

Critical Field Length
(aka Balanced Field Length)



Source: Fig. 10.13, Ref. AVD 1 (Nicolai and Carichner)

Summary of *Landing Regulations* MIL and FAR

Conventional Takeoff & Landing (CTOL) Aircraft

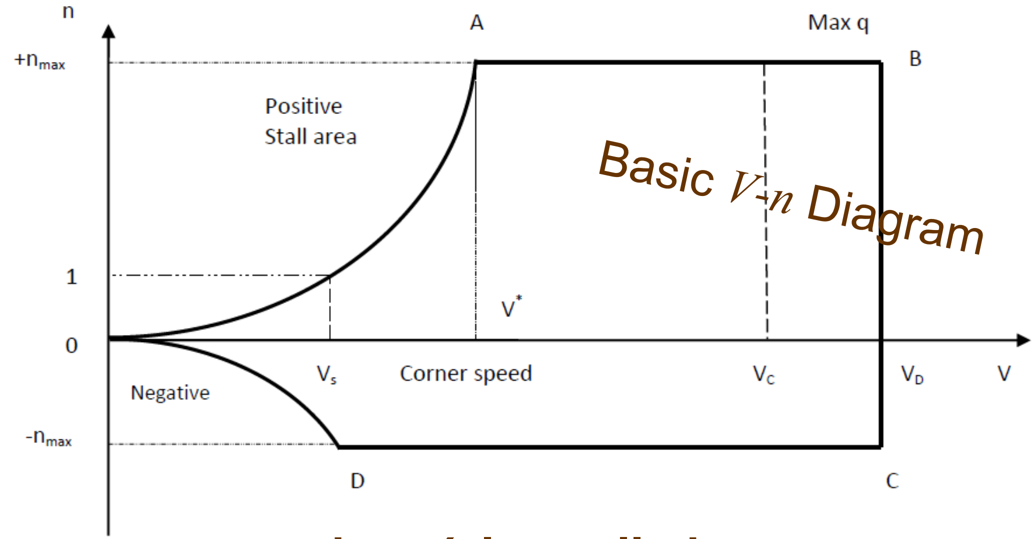
Item	MIL-C-5011C (Military)	FAR Part 23 (Civil)	FAR Part 25 (Commercial)
Speeds	$V_{50} \geq 1.2\ V_S$ $V_{TD} \geq 1.1\ V_S$	$V_{50} \geq 1.3\ V_S$ $V_{TD} \geq 1.15\ V_S$	$V_{50} \geq 1.3\ V_S$ $V_{TD} \geq 1.15\ V_S$
Braking Coefficient	0.3	Not specified	Not specified
Field Length Definition	Landing distance over 50 ft. obstacle	Landing distance over 50 ft. obstacle	Landing distance over 50 ft. obstacle divided by 0.6

See Appendix F, Ref. AVD 2 (Raymer), for OEI minimum climb gradient FAR requirements for CTOL take-off and landing

Source: Table 10.2, Ref. AVD 1 (Nicolai and Carichner)

FAR for Structural Design

- V-n **diagram provides maximum load factor,** $n = L/W$**, for structural design**
  - **If load factor is more than an allowable value, the structure will not be safe**
- **FAA regulates** $+n_{max}$ **and** $-n_{max}$ **to ensure safety of flight**



- **For a given stall speed of** V_S**, the corner speed,** V^* **(also called maneuvering speed,** V_A**), is given by**

$$V^* = V_A = \sqrt{n_{max}}\ V_S$$

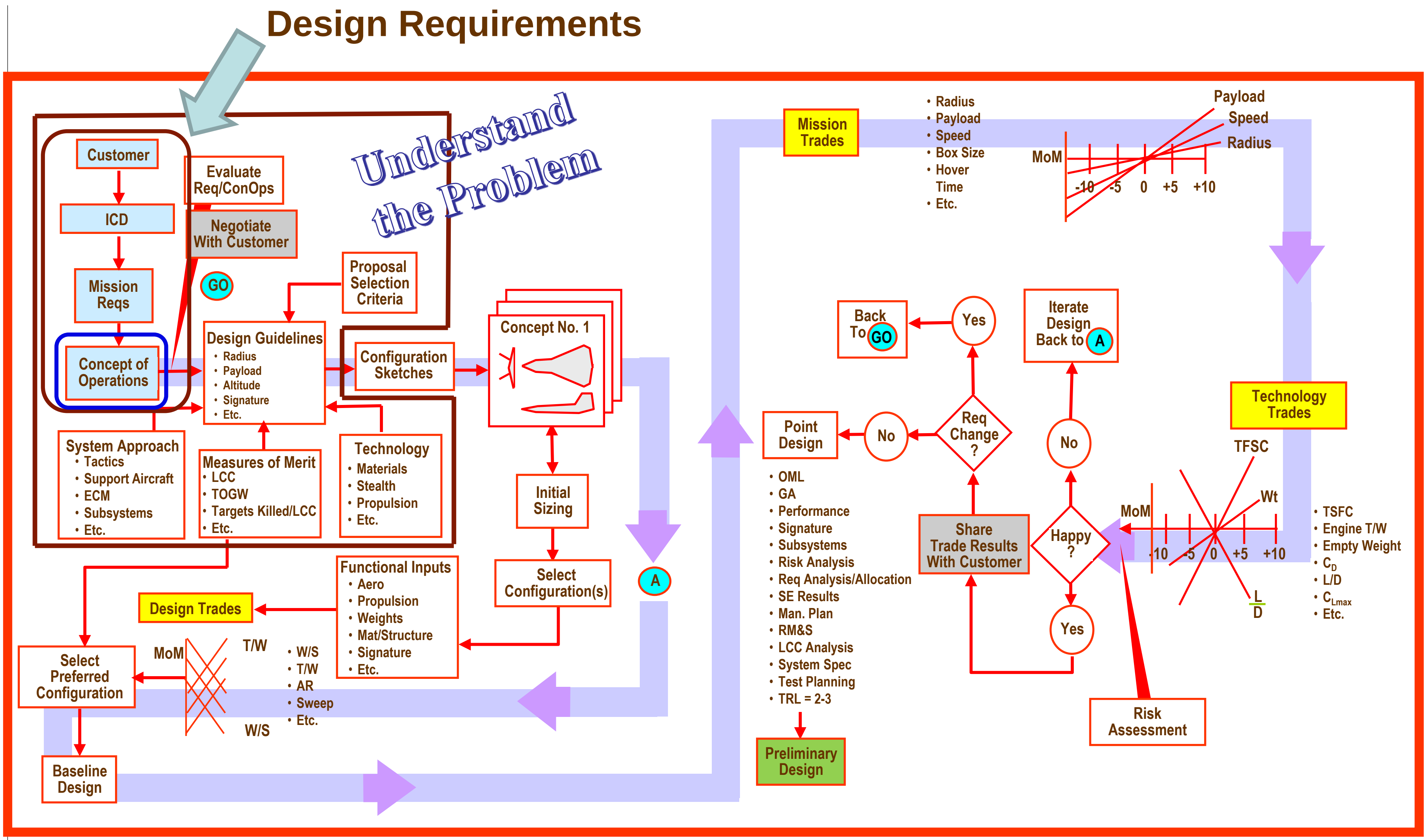
- **Regulations relate dive speed,** V_D**, to cruise speed,** V_C
  - **For example, FAR Part 23 stipulates**

$$V_D \geq 1.4 V_C \qquad \text{(Normal aircraft)}$$
$$V_D \geq 1.5 V_C \qquad \text{(Utility aircraft)}$$
$$V_D \geq 1.55 V_C \qquad \text{(Acrobatic aircraft)}$$

- **At speeds higher than dive speed,** V_D**, high dynamic pressure,** q**, can cause aileron reversal, flutter, or wing divergence; it's usually higher than** V_{max}

Source: Ref. AVD 5 (Sadraey)

Aircraft Conceptual Design (CD) Process



Adapted from Dr. Lee Nicolai's lecture slides

Concept of Operations (ConOps)

ConOps *"describes the proposed system to end users in terms of the needs it will fulfill, its relationship to existing systems, and the ways the system will be operated by its users—not in terms of its physical features since no design exists at this early stage."*

- **The ConOps document describes how the ICD will be executed**
  - Defines how the mission will be conducted
  - Describes interaction with other assets (i.e., C4ISR, jammers, tankers)
  - Defines survivability strategy (i.e., low signature, onboard ECM, decoys, low/high altitude, roll back defenses, SEAD)
  - Describes basing and logistics
- **Mission Requirements usually come with ConOps document**
- **If ConOps document not available**
  - Make one up!
  - Document assumptions
  - Useful for justifying design decisions

- **Study and evaluate the ConOps**
  - If ConOps is not credible then the resulting design will be wrong
  - This information is critical in the flow-down of the requirements into the design guidelines

Adapted from Dr. Lee Nicolai's lecture slides

Concept of Operations (ConOps)

- **A ConOps bridges *the gap between* the users' *operational needs* and the designer's *technical specifications* without becoming bogged down in detailed technical issues.**
- **The main objective of ConOps is to communicate with the end user of the system *during the early specifications stages* to assure the operational needs are clearly understood and incorporated into the design guidelines.**
- **A ConOps should include four critical components:**
    1. *The existing system the user wants to replace*
    2. *Justification for developing a new or modified system*
    3. *A 'description' of the proposed system (Remember: you haven't yet designed the system!)*
    4. *"Use case" scenarios highlighting use of the system in the user's environment including internal and external factors*
- **Use Best Practices in** https://www.mitre.org/publications/systems-engineering-guide/se-lifecycle-building-blocks/concept-development/concept-of-operations

Source: Adapted from http://www.mitre.org/publications/systems-engineering-guide/se-lifecycle-building-blocks/concept-development/concept-of-operations#

Concept of Operations (ConOps)

- **The ConOps is an important component in *capturing stakeholder expectations*, *requirements, and the architecture of a project*. It stimulates the development of the requirements and architecture related to *the user elements* of the system.**

- The ConOps is an important driver in the system requirements and therefore must be considered early in the system design processes. ***Thinking through the ConOps and use cases often reveals requirements and design functions that might otherwise be overlooked.***

- **A simple example to illustrate this point:**
  Adding system requirements to allow for communication during a particular phase of a mission. This may require an additional antenna in a specific location that may not be required during the nominal mission.

Source: Ref. SE 4, page 35

ConOps Reveals Requirements

All-electric Trainer Example

A Typical Training Flight Scenario:

The student and an instructor start up the airplane, taxi out, take off and proceed to, let's say, practice ground reference maneuvers before returning to the airport to do a few touch-and-goes and before calling it an hour. Afterward, the two repair to a briefing room to briefly go over the day's flight and cover the next lesson. During that 20- to 30-minute time period, the airplane is being charged. By the time the instructor is ready to take to the sky with his next student, the airplane is ready to go."

"Use Case" Scenario offers improved understanding of end-user needs

- Endurance: *one hour (maybe two)*
- Mission: *mostly out and back to base*
- Safety: good *stability and control characteristics for low-altitude flights*
- Battery charging: need *electrical systems infrastructure at trainer facility*
- Recharging time: *20 to 30 minutes*

Understanding of end-user operational needs provides insights into additional design aspects for design team to consider

ConOps Affects Design
JSF Carrier Variant

JSF ConOps "*Use Case" Scenarios* added design requirements

- Must fit into specified storage below the deck
- Must prevent potential hearing loss for ground crew from excessive noise
- Must take-off and land on very short runways (~300 ft.) of aircraft carriers

ConOps Impacts Design Features

Why some aircraft have built-in stairs, others don't?

Small Private Airplanes

Most have built-in stairs for boarding and deplaning

Large Commercial Airplanes

Use ground-based mobile stairs for boarding and deplaning

Desire to serve airports with limited modern infrastructure added ingress-egress requirements to the system designs!

Image Source: Internet

ConOps Impacts Design Features

Why USPS Mail Delivery Trucks are Right-hand Drive?

Background/Context

- Mail delivery is the Postal Service's largest operational function.
- USPS management is constantly working hard to reduce delivery costs.
- The Postal Service provides three modes of delivery for existing delivery points: (a) to the door; (b) to a mailbox on the curb, and (c) to a centralized point (neighborhood hub) that serves several addresses.
- Door-to-door delivery is the most costly mode--no longer available for new delivery points.
- For new housing developments, curbside and centralized deliveries are the only options.

One Typical "End User" Use-case Scenario

- Mailman drives a truck loaded with mail.
- He delivers to (a) neighborhood hubs and (b) mailboxes on the curb.

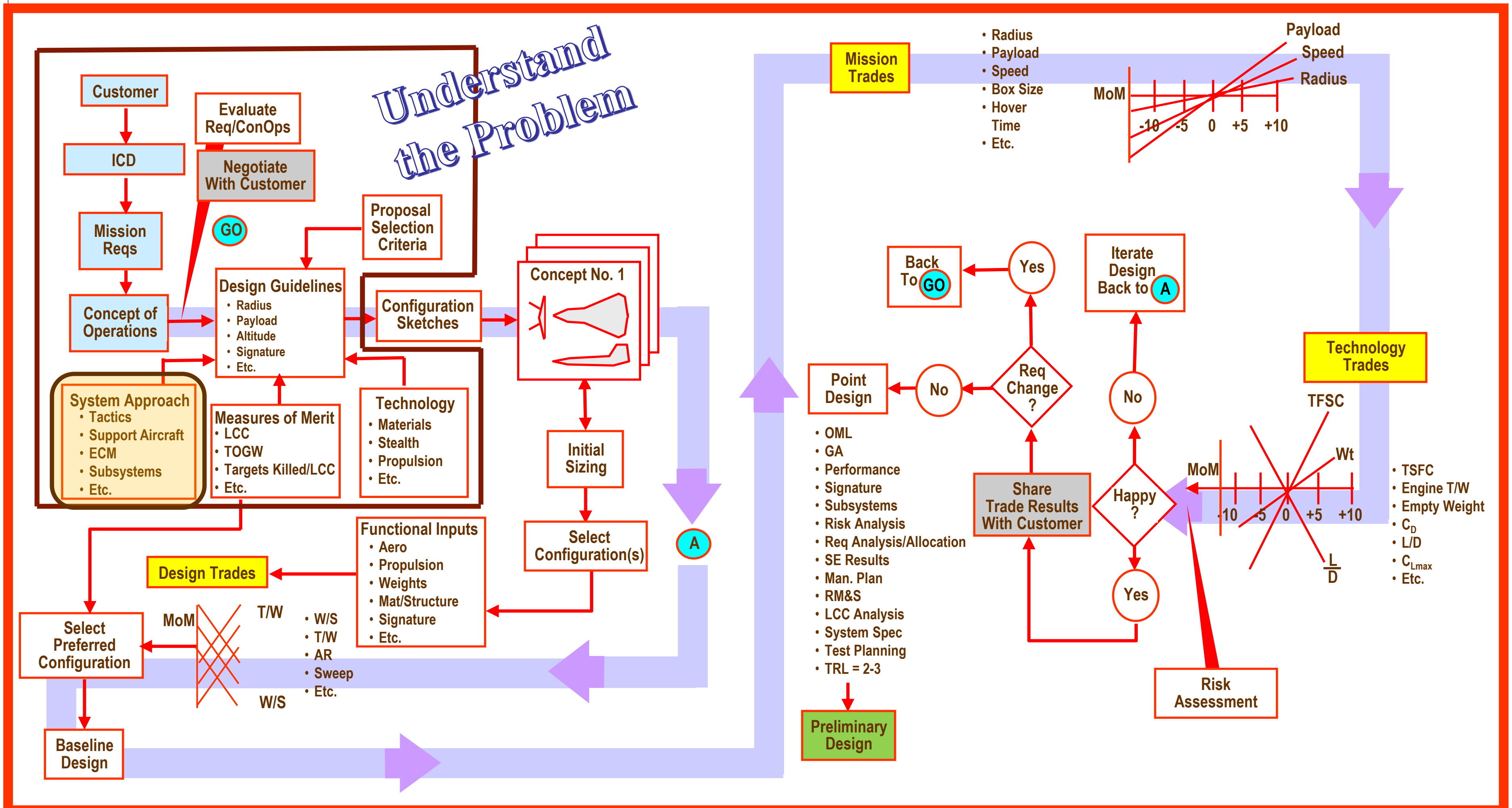
Additional Requirements from ConOps

- Need to improve safety and efficiency of mail delivery hampered by conventional driver's seat and door arrangement

Understanding of end-user operational needs led to unconventional seat and door arrangement!

Image Source: Internet

Aircraft Conceptual Design (CD) Process



Adapted from Dr. Lee Nicolai's lecture slides

Apply Systems Approach to Identify Key Design Drivers

Design Drivers are *primary factors* that will have a *major effect* on the characteristics of the final system, i.e., *these are the factors that drive the design*

Design drivers influence Design Team's decisions

Use Systems Approach to examine the customer need in the context of various 'System Environments' to identify Design Drivers

- Examples of System Environments: *Business, Project, Product, Subsystems, etc.*
- Stakeholders in different system environments have their own perspective on *what factors should drive the design!*
- Design Drivers are factors in tradeoff studies to arrive at the "best" system solution to meet *customer needs*
- **Key Design Drivers—Factors that are *essential* for meeting the most important aspects of *customer needs***

Prioritize the long list of design drivers, and select top few that are essential for meeting customer needs— These are the Key Design Drivers

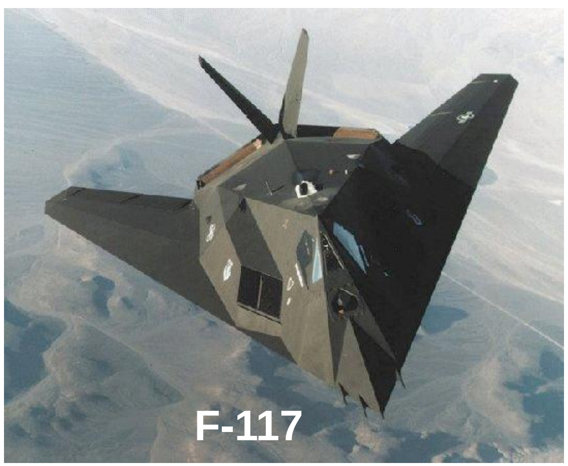
Source: Chap 4, Ref. AS 1 (Moir & Seabridge)

Some Factors Drive <u>All</u> Design Decisions…

Supersonic Speed

High Altitude & Schedule

Mach 3+ Speed



Stealth

Air Superiority

Multi-Mission Capability

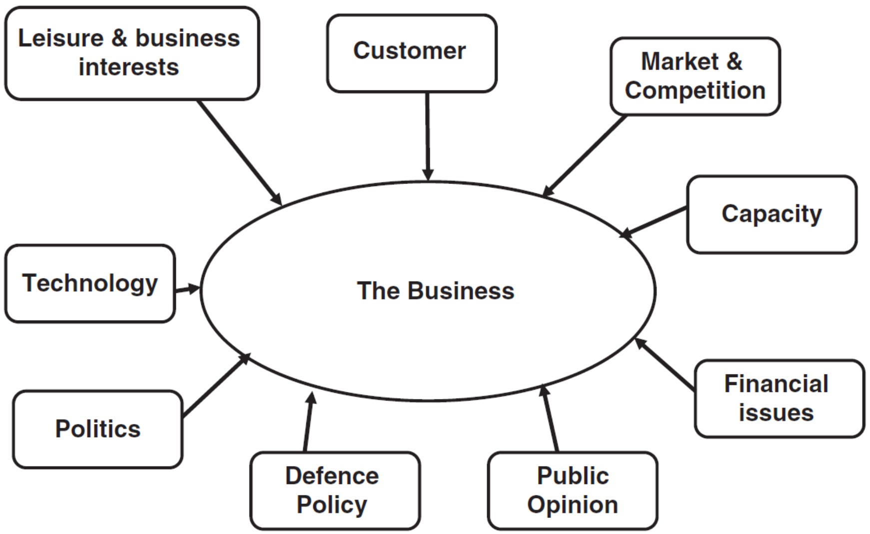
…They are the <u>Dominant</u> Design Drivers!

Image Source: Internet

Sources of Design Drivers:
Business and Project Environments

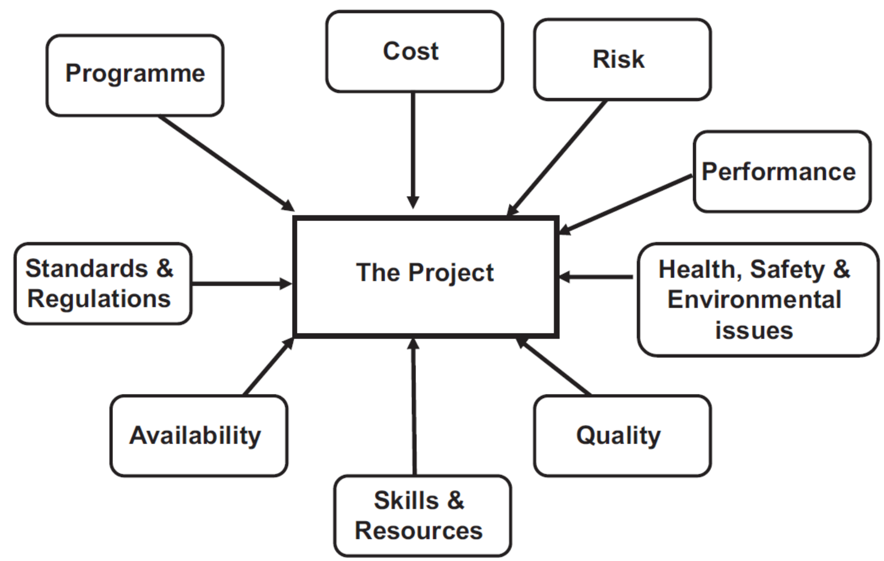
The Business Environment

- Value to the business
- Go/No-go decision to bid and win



The Project Environment

- Ensure that the project can be successfully completed



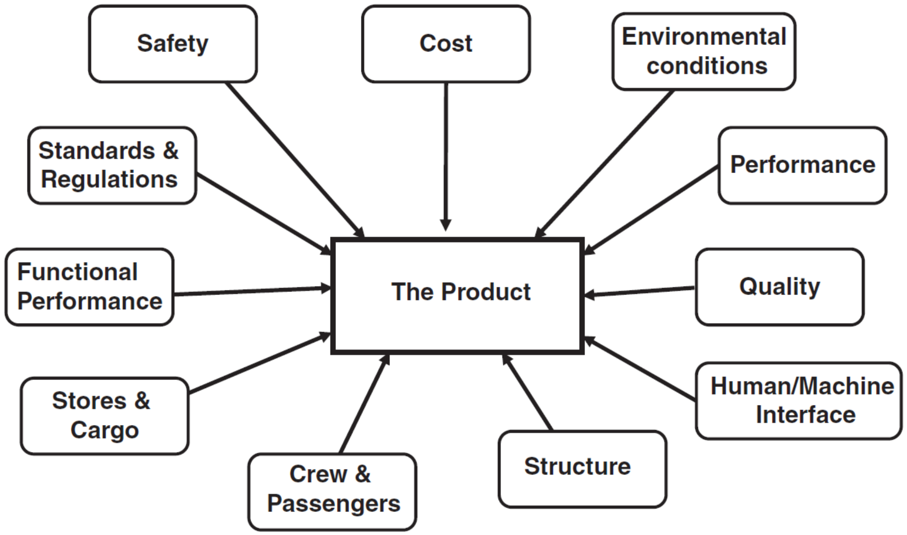
Source: Chap 4, Ref. AS 1 (Moir & Seabridge)

Sources of Design Drivers (contd.)

Product and Product Operating Environments

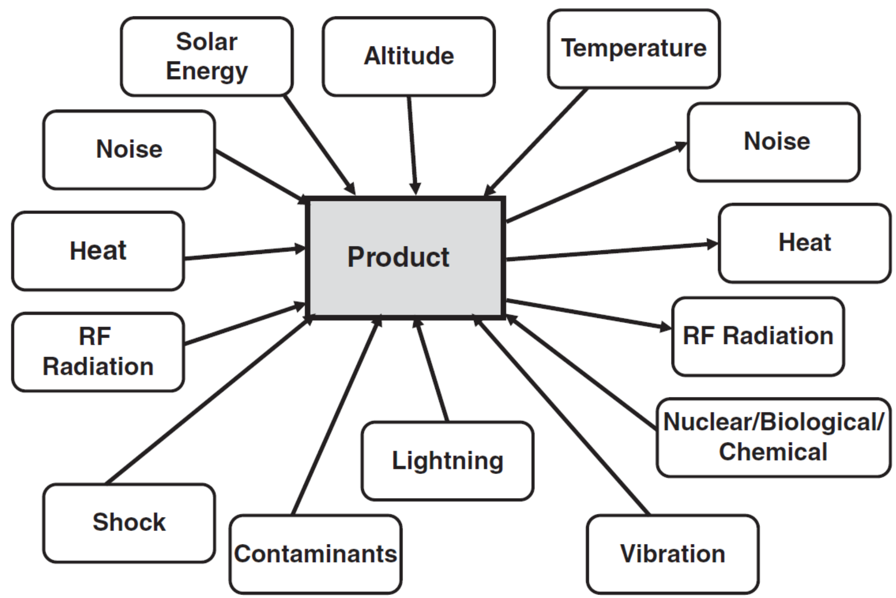
The Product Environment

- Factors affecting the design of the product itself



The Product Operating Environment

- Ensure that the product is able to operate in a defined environment for life



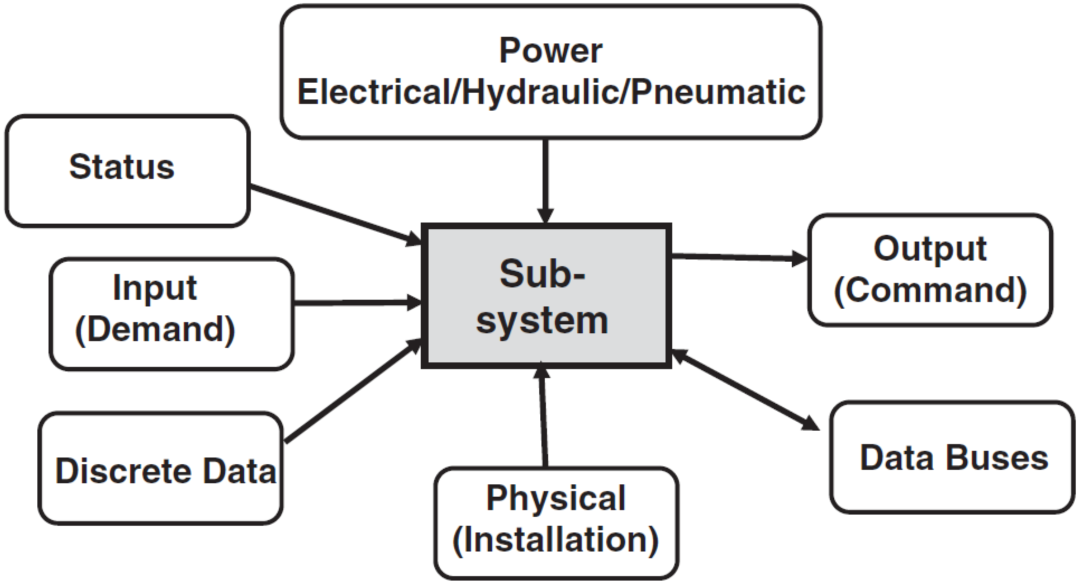
Source: Chap 4, Ref. AS 1 (Moir & Seabridge)

Sources of Design Drivers (contd.)

Subsystem Environment

The Subsystem Environment

- **Ensure that equipment-to-equipment, equipment to structure, and equipment to crew interfaces will function properly to meet all requirements**



From a long list of design drivers, select top few that are essential for meeting customer needs—
These are the Key Design Drivers

Source: Chap 4, Ref. AS 1 (Moir & Seabridge)

An Example of Design Drivers: *Commercial Transport*

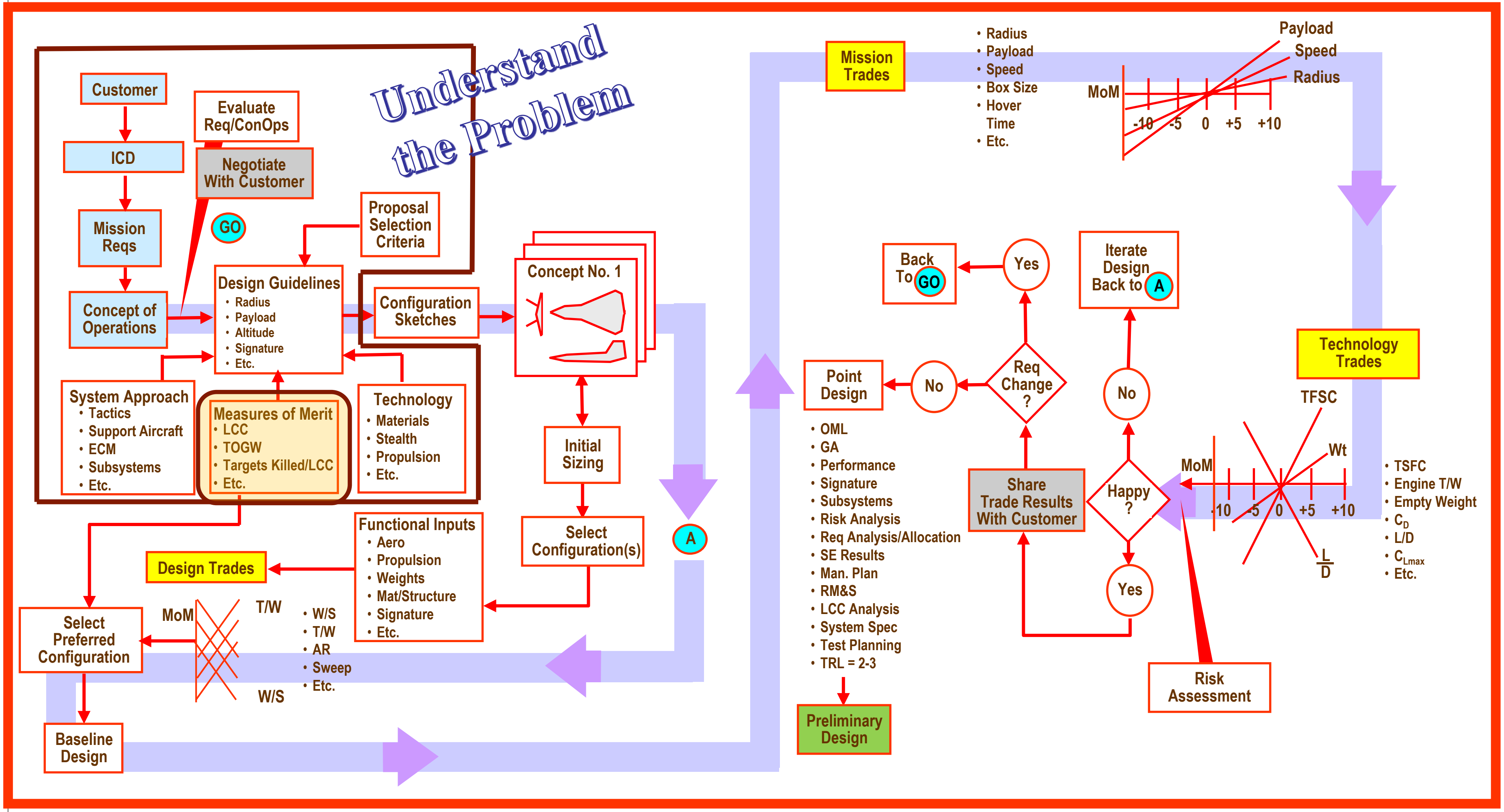
Typical Design Drivers of a Commercial Transport Aircraft

Design driver	Relevant issues
Transport function	Payload/range, design speed
Passenger cabin	Accessibility, comfort, evacuation, aesthetics
Propulsion	Engine technology, power/thrust, fuel consumption
Structure	Strength, stiffness, fatigue life, manufacturing
Systems technology	Flight control system, avionics
Flight envelope	Dynamic pressure and altitude limits
Low-speed performance	Stalling and reference speeds, field length
Airfield	Runway conditions, aircraft handling
Flight safety	Flying qualities, engine-out performance
Environment	Community noise, emissions, wake vortex clearance
Economy	Productivity, direct operating costs
Operations	Load and balance, reliability, maintainability

Not all would have major effect on your design—select the ones that are essential to meeting the needs

Source: Table 2.1, Ref. AVD 9 (Torenbeek)

Aircraft Conceptual Design (CD) Process



Adapted from Dr. Lee Nicolai's lecture slides

Measures of Merit (MoMs)

- **MoMs are characteristics that *<u>are not</u>* quantitatively specified by the customer but are generally 'hinted at' in the RFP**
- **Customers use MoMs as "Tie Breakers" in selecting winning design**
- **You can take a pretty good guess from the RFP *by reading between the lines (much like an attorney does!)***
    - Is it affordability? Is it cost? Production cost? Acquisition cost? DOC (Direct Operating Cost)? LCC (Life Cycle Cost)?
    - Is it "-ilities"? RM&S (Reliability, Maintainability and Supportability)?
    - Is it ride quality?
    - Is it capacity?
    - …

Read Section 1.3.7, Chapter 1, Nicolai & Carichner (Ref. AVD 1)

Design teams must develop quantified targets for appropriate characteristics which greatly assists teams to use MoMs to make decisions for configuration design and downselection!

What Distinguishes MoMs from Requirements

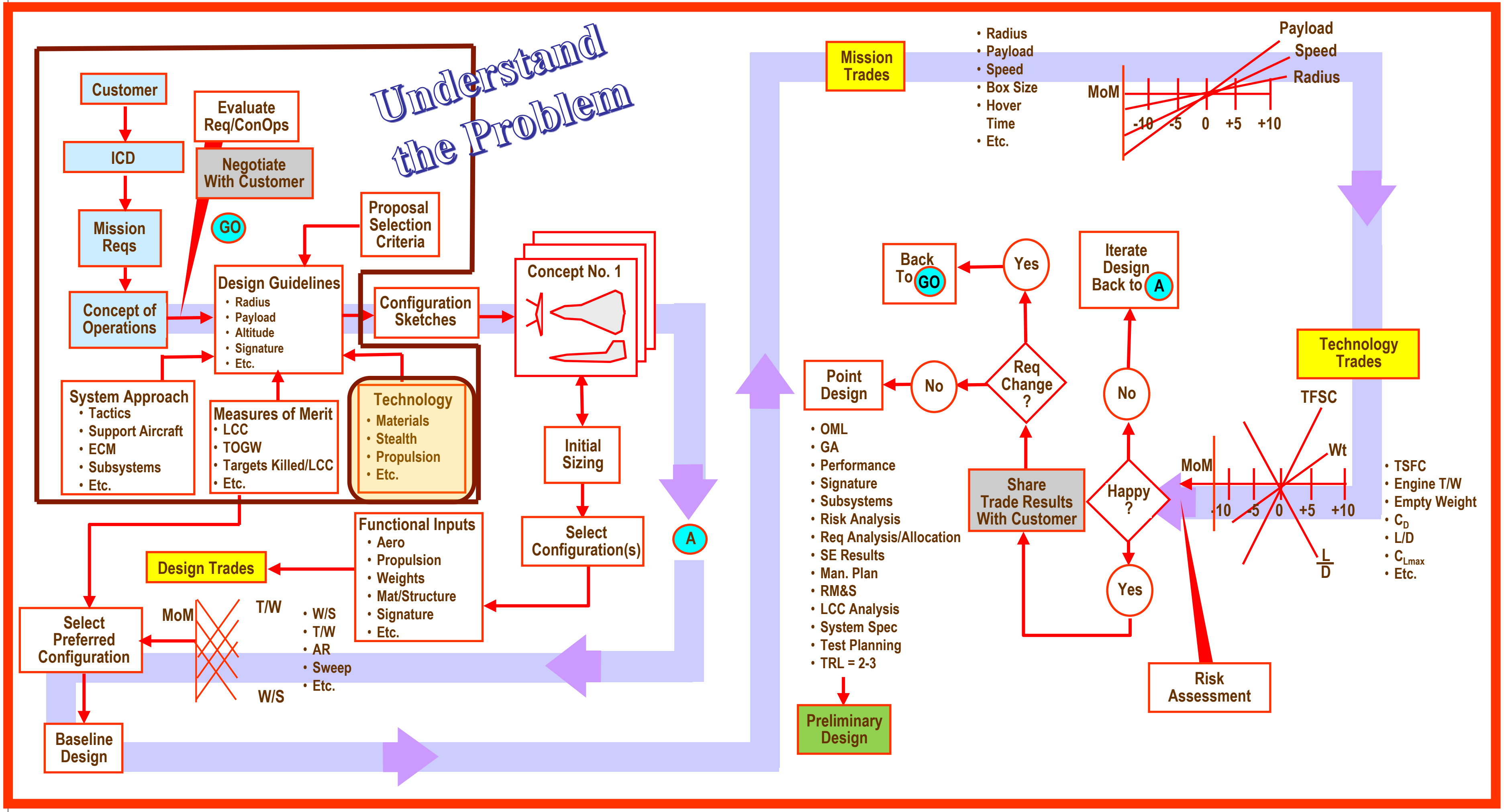
- **REQUIREMENTS: Characteristics* that *<u>are</u>* quantified by the customer prior to design, and are generally included in the RFP**
  - Driven by external influences … the <u>Needs</u> of the customer/user
  - Specified and published by the customer/user
  - Sometimes conflict with one another
  - Need to seek best balance among conflicting requirements
  - Designer has responsibility to help establish a realistic set of requirements

- **MEASURES OF MERIT (MoM): Characteristics* that *<u>are not</u>* quantified by the customer but are generally 'hinted at' in the RFP**
  - Driven by what the customer <u>Wants</u> … but is unwilling or unable to quantify
  - Usually not specified or published by the customer/user
  - They indicate what is really important to customer/user
  - Accurate identification of MoMs Requires considerable rapport with the customer/user
  - MoMs are used by the customer to define Selection Criteria to compare competing designs…could be a ***Tie Breaker***
  - MoM is sometimes called Figure of Merit (FoM)
  - Designer has responsibility of selecting MoMs and developing quantified target values for each if and when possible

Courtesy of Lee Nicolai

****Characteristics*** *include performance, signature, economic, political, schedule and environmental features*

Aircraft Conceptual Design (CD) Process



Adapted from Dr. Lee Nicolai's lecture slides

Technology Considerations

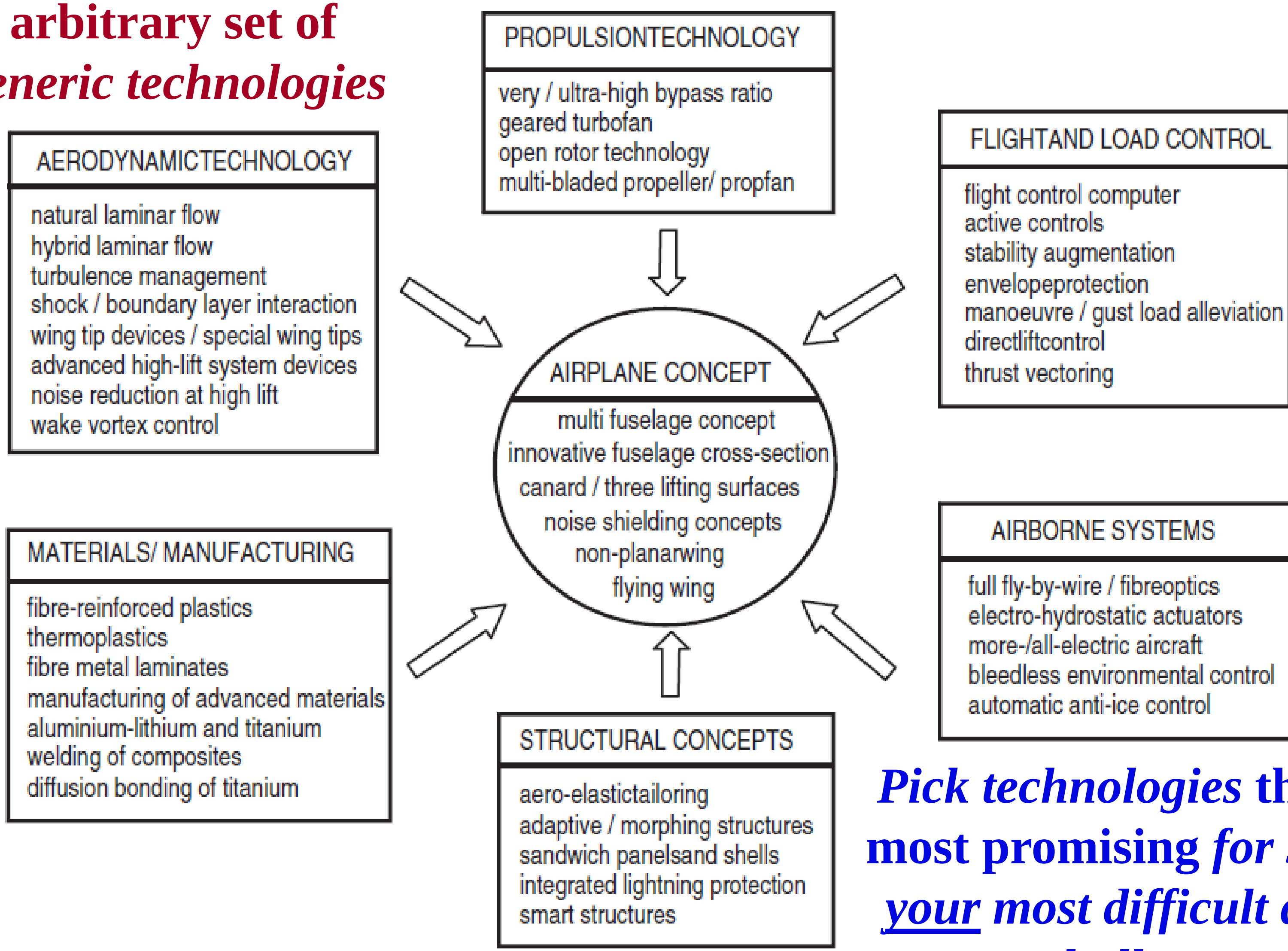
- **Why would/should designers consider advanced technologies that promise advancements in the state of the art?**
  - To tackle the most difficult challenges of the design problem
  - To improve chances of winning by delivering the most competitive solution
- **Examples include (but not limited to)**
  - Novel/ radical/ revolutionary airplane concepts for improved efficiency and lower cost, e.g., strut braced wing
  - Boundary layer control (BLC) or natural laminar flow (NLF) airfoils or winglets to reduce drag

  - Advanced high-lift systems for stringent take-off and landing requirements
  - Geared turbofan or open rotor engines for increased propulsive efficiency
  - All electric or hybrid electric propulsion system for reduced emissions and noise
  - Aeroelastic tailoring to avoid divergence or flutter
  - Fly-by-wire (FBW) or fly-by-light (FBL) flight control systems (FCS) for increased reliability and reduced weight
  - More-electric or all-electric subsystems for increased overall efficiency

Source: Fig. 1.10, Ref. AVD 9 (Torenbeek)

A List of Promising Technologies for Transport Aircraft

Don't pick **just any arbitrary set of** ***generic technologies***



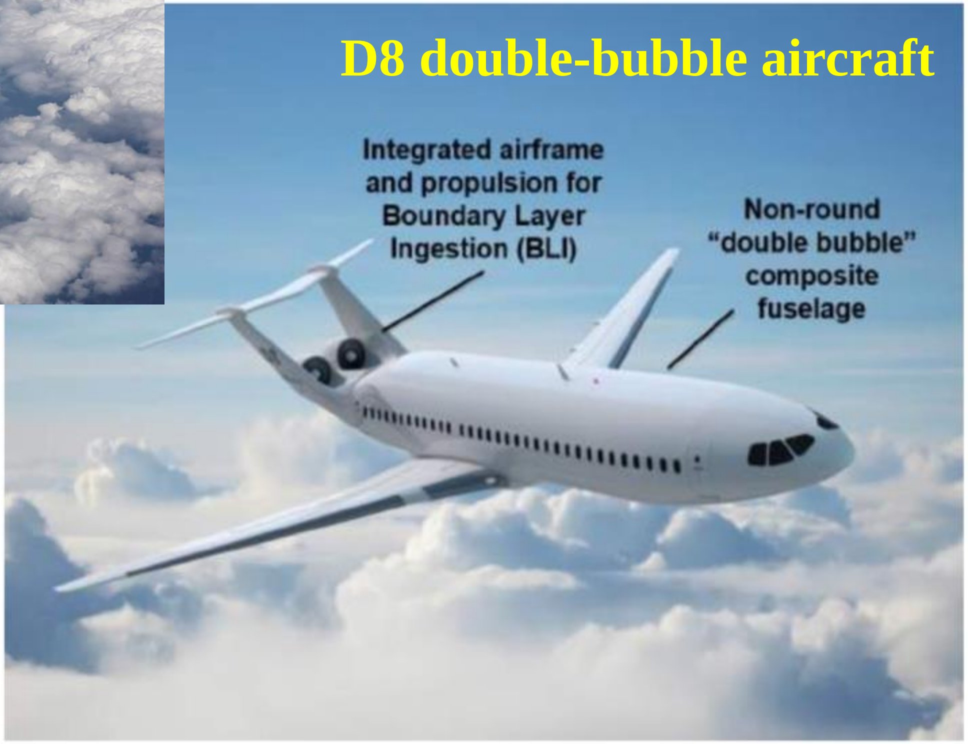
Pick technologies **that are most promising** ***for solving <u>your</u> most difficult design challenges***

Source: Fig. 1.10, Ref. AVD 9 (Torenbeek)

A Promising Technology for Improved Fuel Efficiency
Boundary Layer Ingestion (BLI) Propulsion

Source: https://sacd.larc.nasa.gov/asab/asab-projects-2/starc-abl/

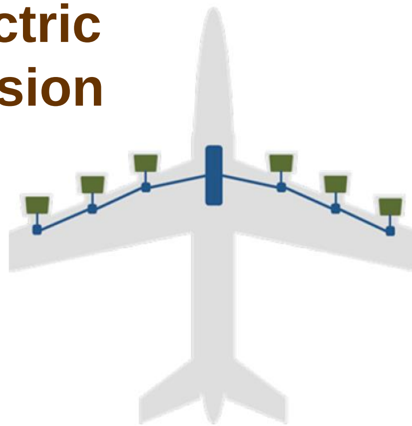
Source: Yutko et al, ICAS 2018-0875



An area of active research

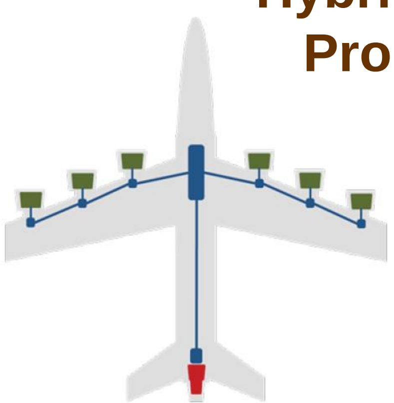
Promising Technologies to Reduce Environmental Impact of Aviation

All-electric Propulsion

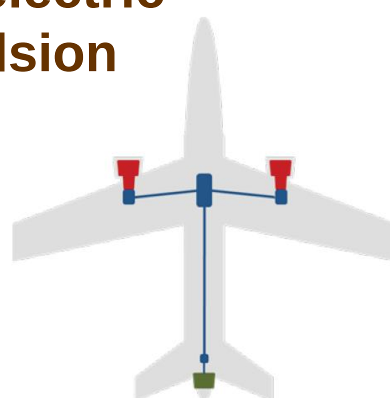


All Electric (AE)

Hybrid-electric Propulsion



Hybrid Electric (HE): Series



Hybrid Electric (HE): Parallel

Source: Electric Flight Technology: Launching The Future Of Aerospace Engineering, SAE Propulsion & Power, 2017

Technology Considerations

It's all about the advanced technologies that are *relevant* to your problem.
It's *not* about generic advanced technologies.

Key questions you must ask

- ***Could we meet (or exceed?) all design requirements without advanced technologies?***
- ***What is the risk to the project of incorporating a new technology? How mature is the technology? What is its TRL? Lower TRL, higher risk! Higher TRL, lower risk!***
- ***Does the technology "buy its way" onto the airplane?***

Stay Focused on the Requirements of Your System

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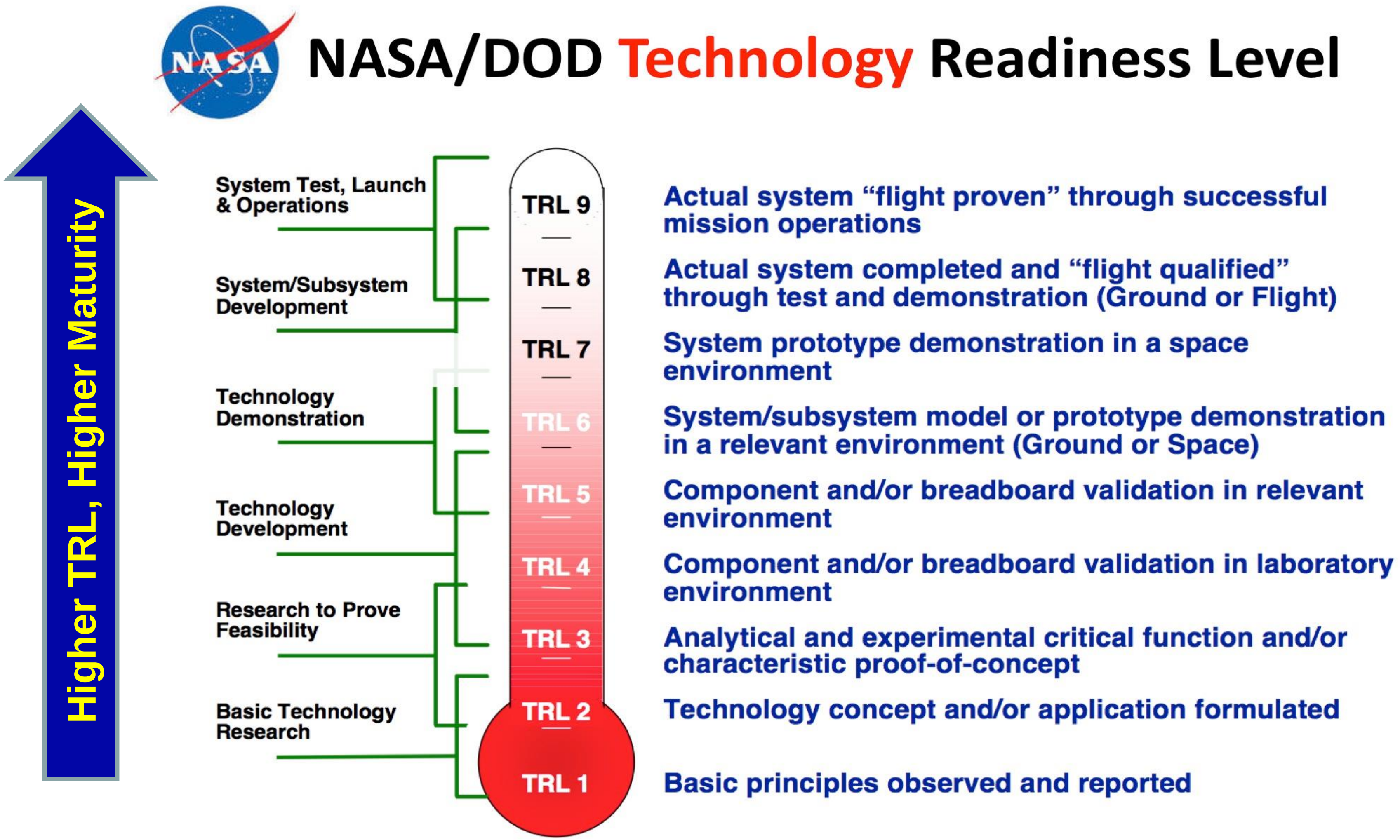
VIRGINIA TECH.

Technology Readiness Level (TRL)

A widely accepted measure of technology maturity



Higher TRL => Higher Maturity, Lower Risk

Designer's Dilemma

Technology advancements in all disciplines?

A new capability someone might pay to have?

Designer

How to exploit technology for capability?

Airplane Concept

Amazingly Tricky to Integrate Disciplinary Technological Advancements into New Concepts!

Source: Adapted from W.H. Mason's Aircraft Design Lectures

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AEROSPACE AND OCEAN ENGINEERING
VIRGINIA TECH.

An Example of Technologies for A Capstone Design Project

Technology	Perceived Benefit	Implemented in Designs
Improved Engines	Improved SFC	Yes
Hybrid Propulsion	Reduced Fuel Consumption	Yes
Electric Taxi	Improved SFC	Yes
RFP Batteries & Electric Systems	Efficient Electric Components	Yes
Fly-by-Wire	Weight Reductions	Yes
More Electric, No-Bleed Subsystems	Improved Efficiencies & Weight Reductions	Yes
Advanced Structures	Weight Reductions	Yes
Powered Battery Swap System	Faster Turn Time	No
Solid Oxide Fuel Cell APU	Improved APU Energy Efficiency	No

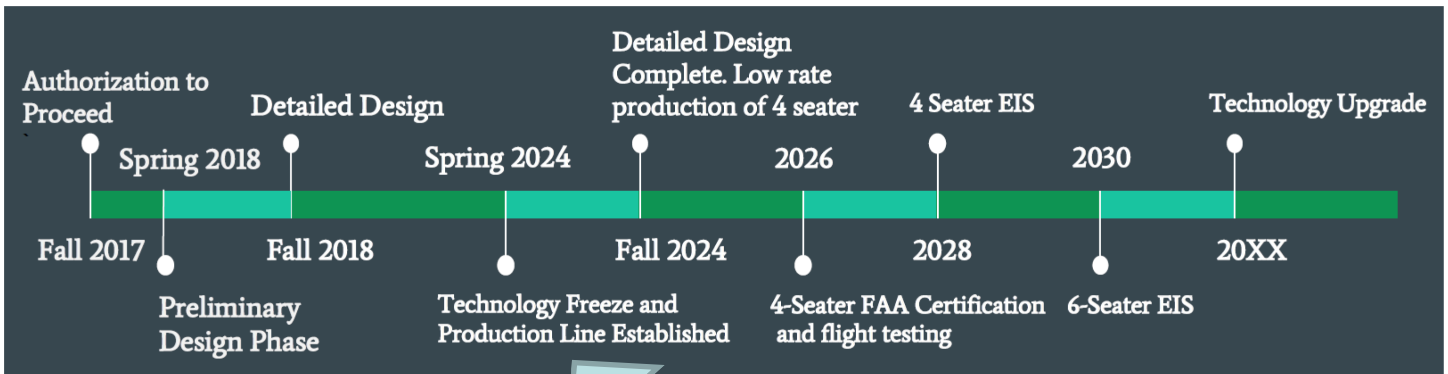
Technology Freeze Date: 2019

Technology	2013 TRL	2019 Projected TRL
Improved Engines	TRL 4	TRL 7
Hybrid Propulsion	TRL 3	TRL 6
Electric Taxi	TRL 9	TRL 9
RFP Batteries & Electric Systems	TRL 2	TRL 5
Fly-by-Wire	TRL 9	TRL 9
More Electric, No-Bleed Subsystems	TRL 9	TRL 9
Advanced Structures	TRL 9	TRL 9
Powered Battery Swap System	TRL 1	N/A
Solid Oxide Fuel Cell APU	TRL 2	TRL 4

Source: 2013 AIAA Undergrad Team Competition Winner, Cal Poly, SLO

Derive Tech Freeze Date from Project Timeline

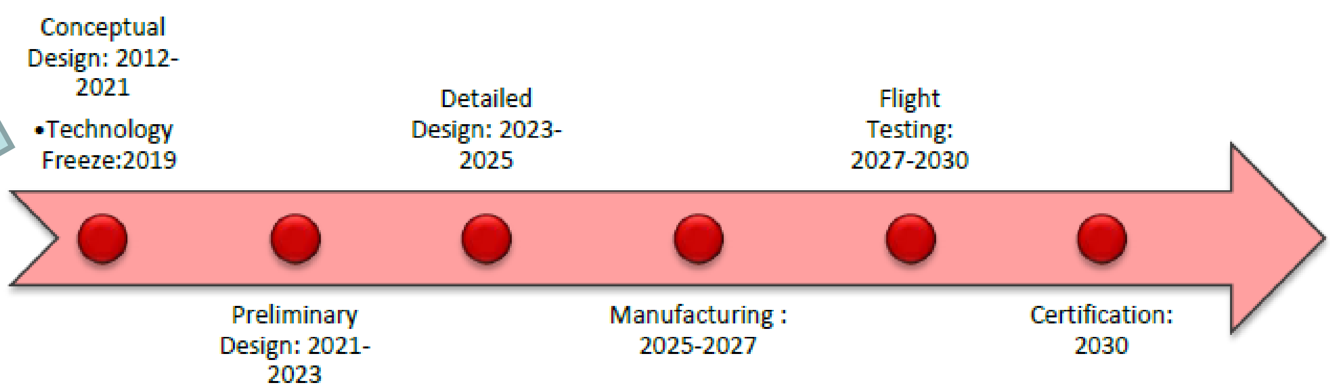
- **Project Timeline (or EIS Timeline): Typically depicts major milestones from project authorization to proceed (ATP) to product entry into service (EIS)**
- **Major Milestones: Defined using Scheduling Requirements derived from the RFP**



Too Late! ?

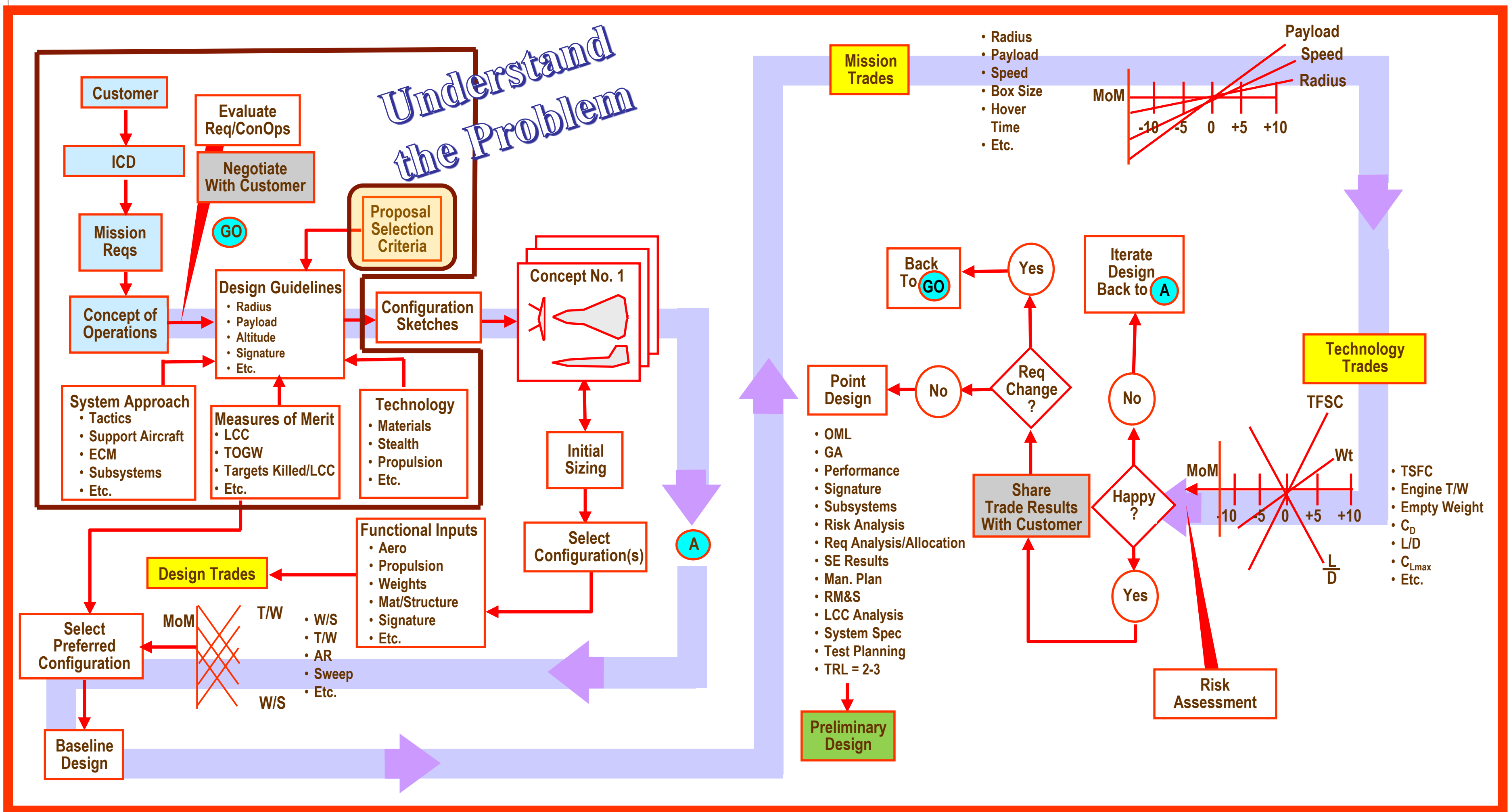
Source: 2018 AIAA Undergrad Team Competition, VT-LU project report

About Right! ?



Source: 2013 AIAA Undergrad Team Competition Winner, Cal Poly, SLO

Aircraft Conceptual Design (CD) Process



Adapted from Dr. Lee Nicolai's lecture slides

DoD Proposal "Evaluation" Criteria

Evaluation Criteria	WT. Factor (%)	Proposal A		Proposal B		Proposal C	
		Rating	Score	Rating	Score	Rating	Score
A. Technical Requirements:	25						
1. Performance Characteristics	6	4	24	5	30	5	30
2. Effectiveness Factors	4	3	12	4	16	3	12
3. Design Approach	3	2	6	3	9	1	3
4. Design Documentation	4	3	12	4	16	2	8
5. Test and Evaluation Approach	2	2	4	1	2	2	4
6. Product Support Requirements	4	2	8	3	12	2	8
B. Production Capability	20						
1. Production Layout	8	5	40	6	48	6	48
2. Manufacturing Process	5	2	10	3	15	4	20
3. Quality Control Assurance	7	5	35	6	42	4	28
C. Management	20						
1. Planning (Plans/Schedules)	6	4	24	5	30	4	24
2. Organization Structure	4	4	16	4	12	4	16
3. Available Personnel Resources	5	3	15	3	20	3	15
4. Management Controls	5	3	15	3	20	4	20
D. Total Cost	25						
1. Acquisition Price	10	7	70	5	50	6	60
2. Life Cycle Cost	15	9	135	10	150	8	120
E. Additional Factors	10						
1. Prior Experience	4	4	16	3	12	3	12
2. Past Performance	6	5	30	5	30	3	18
Grand Total	100		476		516*		450

* Select Proposal B

Source: Ref. SE 5, page 200

AIAA Proposal "Judging"

Undergraduate Team Aircraft Design

Basis of Judging

1. Technical Content (35 points)

This concerns the correctness of theory, validity of reasoning used, apparent understanding and grasp of the subject, etc. Are all major factors considered and a reasonably accurate evaluation of these factors presented?

2. Organization and Presentation (20 points)

The description of the design as an instrument of communication is a strong factor on judging. Organization of written design, clarity, and inclusion of pertinent information are major factors.

3. Originality (20 points)

The design proposal should avoid standard textbook information, and should show the independence of thinking or a fresh approach to the project. Does the method and treatment of the problem show imagination? Does the method show an adaptation or creation of automated design tools?

4. Practical Application and Feasibility (25 points)

The proposal should present conclusions or recommendations that are feasible and practical, and not merely lead the evaluators into further difficult or insolvable problems.

That's it! But it's a lot!

NASA Selection Criteria for Student Team Proposals

(US University Aeronautics Design Challenge)

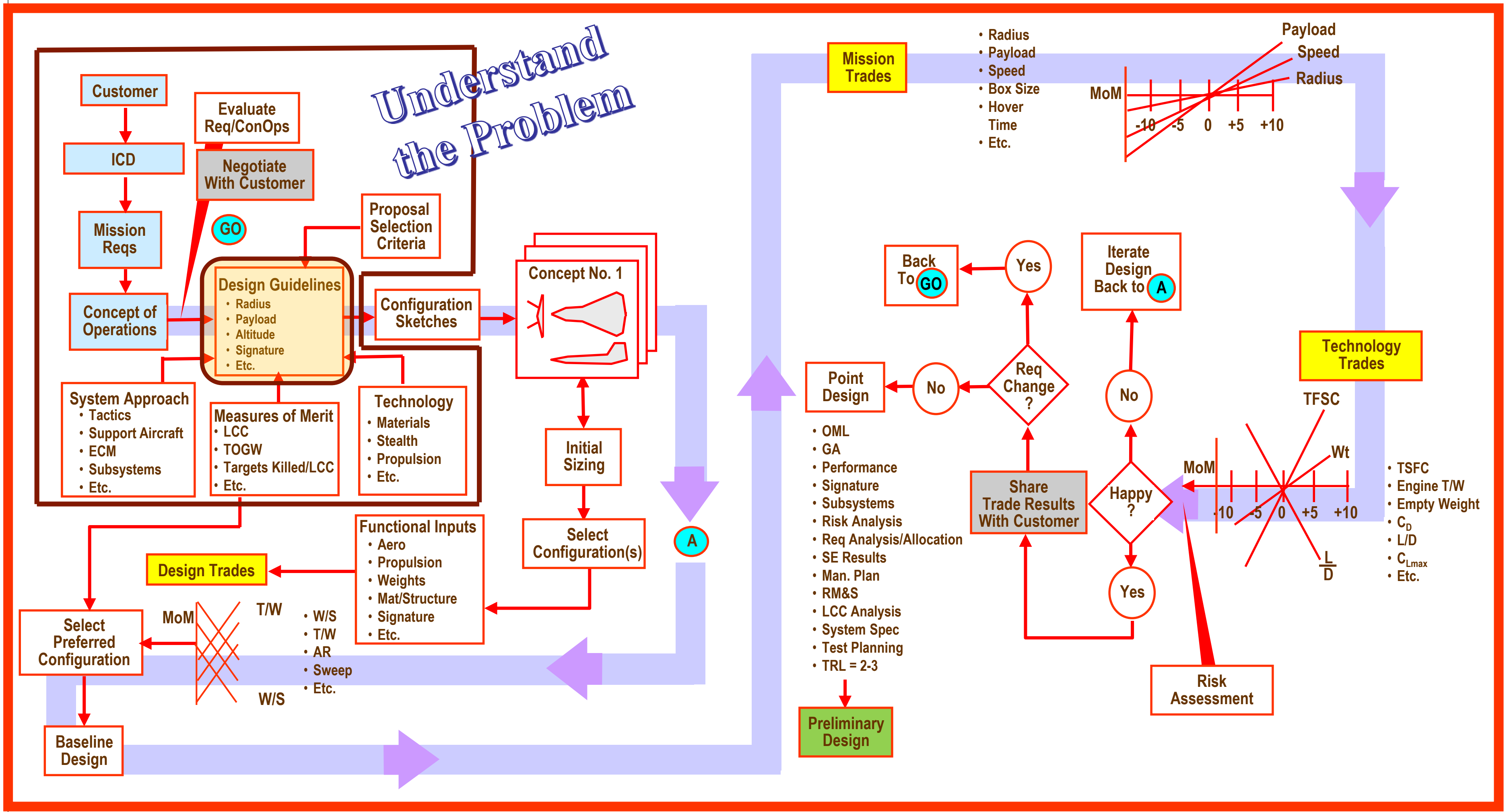
Under no circumstances should students copy the words or ideas of others without proper documentation. If students use ideas or words of others, they should give credit to their source of information using a standard reference or footnote format. Papers submitted with plagiarized material will be disqualified.

Entries will be scored on how well they have focused their paper and how well they have addressed all aspects of the problem they chose to address. A panel of NASA reviewers with expertise in the area of the challenge will read and score each entry. The panel will then do a second review and discussion of top scoring papers before a final ranking is determined.

Scores will be assigned for each of the criteria (not listed in order of point value): writing and organization, literature review, innovation/creativity; discussion of feasibility; baseline comparison with relevant current technology, system, or design; point by point detailed discussion of their design.

Award level entries will be well written, well organized, thorough and concise.

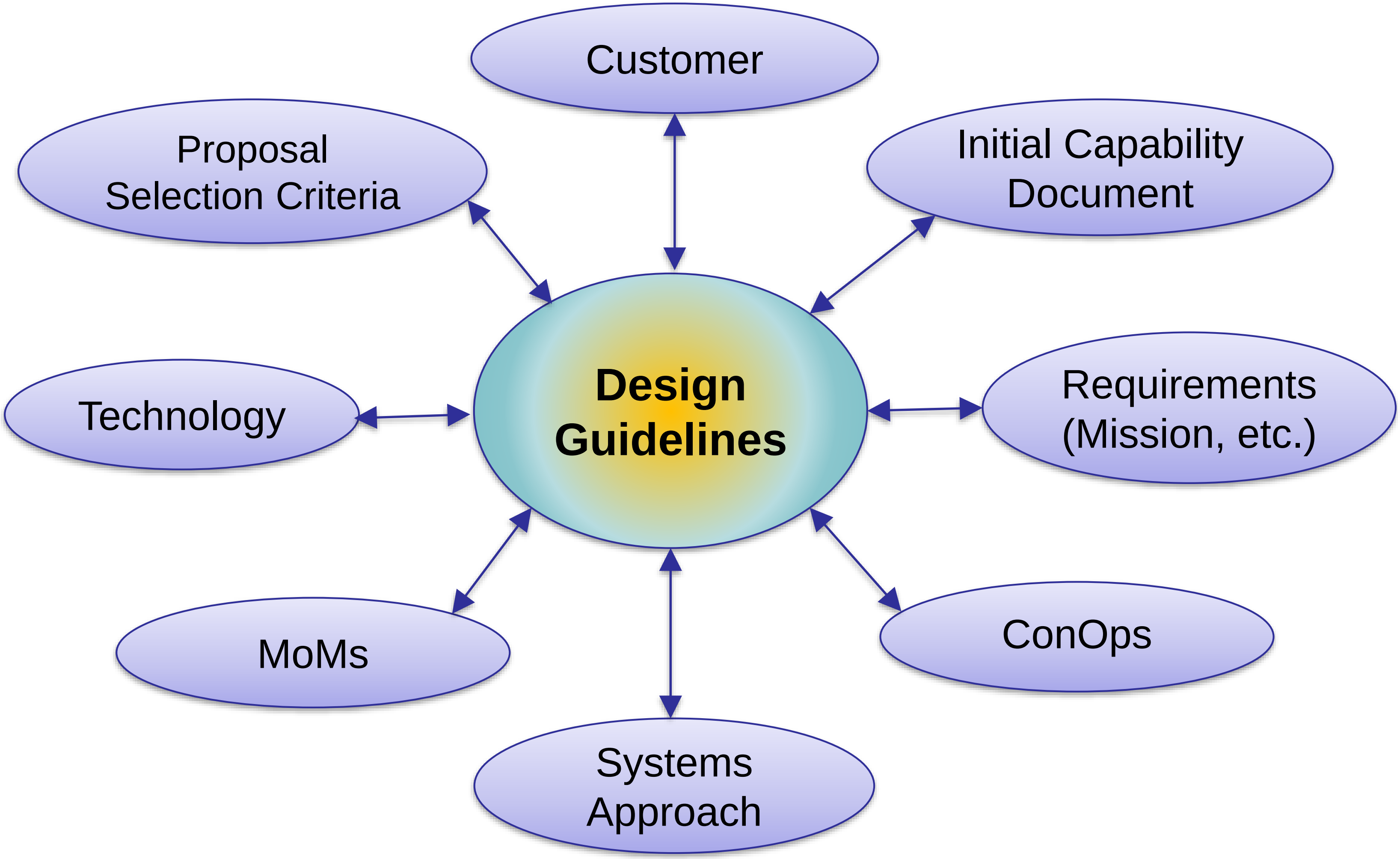
Aircraft Conceptual Design (CD) Process



Adapted from Dr. Lee Nicolai's lecture slides

Aircraft Conceptual Design Process

Design Guidelines are the Outcome of the Initial Step



A Holistic Integration of Various Inputs

Design Guidelines

- **Contractor interpretation and amplification of ICD and CONOPS**
- **Formal study document**
  - Agreed upon at start of design effort
  - Represents contractor acceptance of ICD
  - Sometimes called Design Requirements or Derived Requirements
- **Reveals contractor strategy**
  - Value Proposition – Why us?
  - Threshold vs. Objective
  - Cost Strategy
  - Measures of Merit
  - Technologies
  - …

Design Team Works to the Design Guidelines

Represents Requirements "Flow Down" to Engineering Teams

Design Guidelines Example

Civil Aircraft

Reflects Requirements Flow Down

- **Airworthiness**
  - Range of xxx nm with full payload of yy lbs.
  - Airframe and Engine(s) to meet all applicable FARs xx, yy, …
  - Capable of Cat II landing
  - Flight operations to comply with applicable FARs xx, yy, …
  - Ice protection to be provided for engines, wing, and stabilizer
  - Cabin pressurization system to automatically control pressure at xx psi
  - Aircraft shall function satisfactorily for ground ambient temperatures of -xx^{o}F to +yyy^{o}F
  - …
- **Accommodations**
  - Design shall allow different interior arrangements for passengers, crew and cargo
  - …
- **x% less cost and y% more fuel efficiency than comparator aircraft**
- **On and on for other areas such as reliability, maintenance, etc.**

A Living Document!

Epilogue

Key Takeaways

- ***Comprehensive Understanding of the Problem* requires**
  - Considering a large number of stakeholders/ sources
  - Asking the right questions about each stakeholder (customer, end user, operator, etc.)
    - *Examples:*
      - ✓ *Customer: What do they need? Why do they need new/different capability? How do they meet their need now? Etc.*
      - ✓ *End User: What features should the design have to best serve the needs of the end users?*
  - Critically evaluating all information and data (“be devil’s advocate”)
  - Connecting all dots (i.e., information and data) to develop a thorough and complete understanding of the problem
- **All team members should contribute to, and use, one single Design Guidelines document**
- **Beware of “Group Think” – Don’t Let One Group Dominate**

If One Group Dominates…

In many ways a completed airplane is a compromise of the knowledge, experience, and desires of engineers from the various design and production groups.

Engineers in these various groups tend to feel that their part in the design of an airplane is most important and that design difficulties are due to the requirements of less important groups.

This cartoon "Dream Airplanes" by Mr. C.W. Miller, indicates what might happen if each design or production group were allowed to take itself too seriously.

Source: Fig. 1.1, Ref. AVD 1 (Nicolai & Carichner)

Image Source: https://www.linkedin.com/pulse/dream-aeroplanes-samuel-merry/

…You Would End Up With One of the "Dream Airplanes"

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

Recommended Readings

Ref. No.	Chapter	Author(s)	Title
AVD 1	**Chapter 1**	Nicolai, L.M. and Carichner, G.E.	***Fundamentals of Aircraft and Airship Design*, *Volume I—Aircraft Design*,** AIAA Education Series, AIAA, Reston, VA, 2010.
AVD 2	**Chapter 2**	Raymer, D.P.	***Aircraft Design* : *A Conceptual Approach*,** AIAA Education Series, AIAA, Reston, VA, 2012.
AVD 5	**Chapter 3**	Sadrey, M.H.	***Aircraft Design: A Systems Engineering Approach*,** John Wiley & Sons, Inc., 2013.
AVD 8	**Chapter 1 & 2**	Kundu, A.K.	***Aircraft Design*,** Cambridge University Press, 2010.
AVD 9	**Chapter 1**	Torenbeek, E.	***Advanced Aircraft Design: Conceptual Design, Analysis and Optimization of Subsonic Civil Airplanes*,** John Wiley and Sons, Ltd., June 2013.
AS 1	**Chapter 4**	Moir, I., and Seabridge, A.	***Design and Development of Aircraft Systems,*** John Wiley and Sons, Ltd., 2nd ed., November 2012.

NOTE: See Appendix in Overview CM