# Air Vehicle Design

## AOE 4065 – 4066

***III. Project Management Topics***

## Course Module P3

## Roles & Responsibilities of Team Members

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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.*

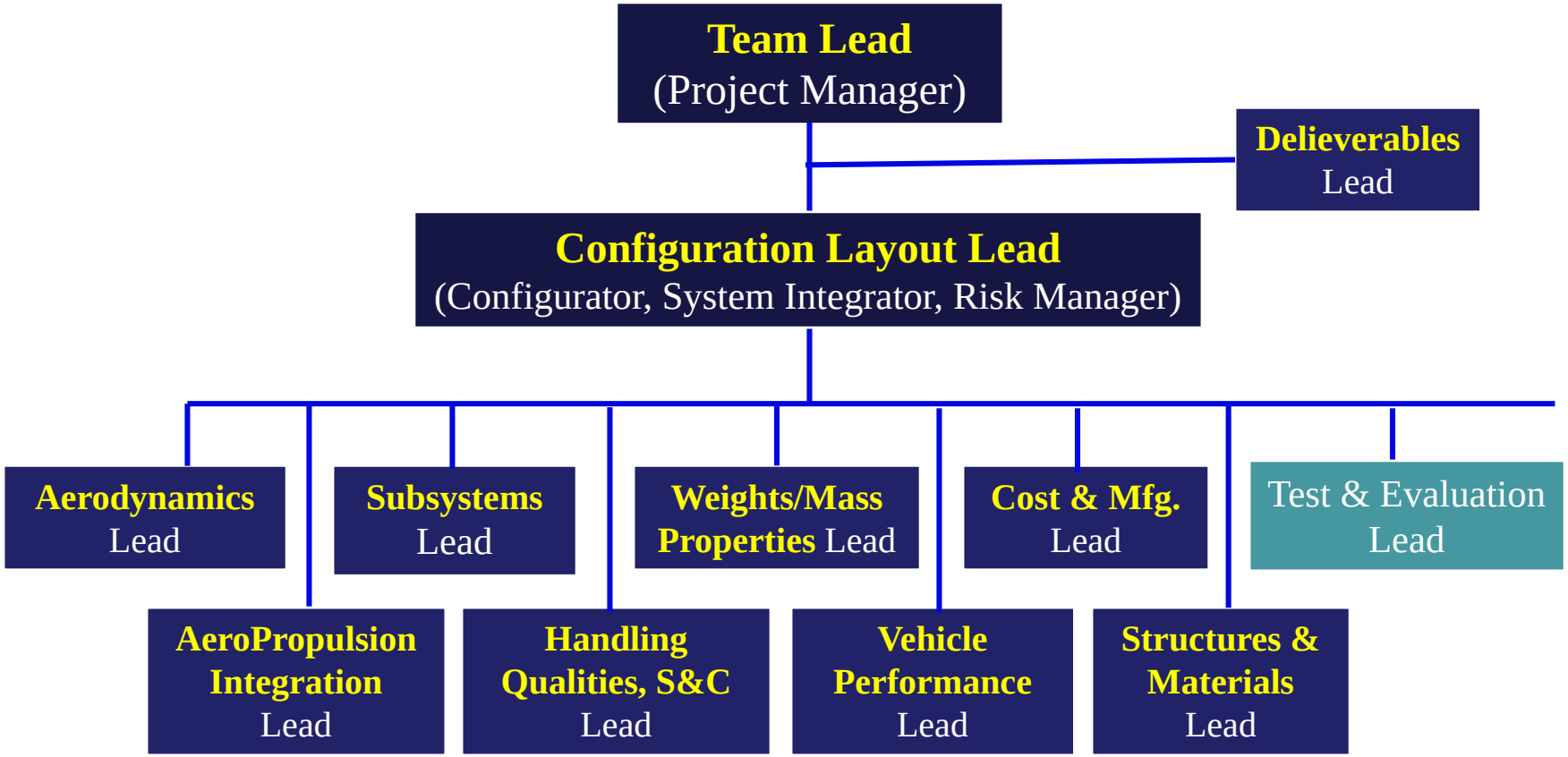
***CRUCIALLY IMPORTANT***

***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)***

# Typical "Organization Chart" of a Capstone Student Design Project




**Complete the Org Chart by adding names of the Leads (and of the Other Members, if any) to the respective boxes**

***This CM Highlights R&Rs of Team and Subteam Leads***

# What Distinguishes a 'Team' from a 'Group' of individuals?

- A **group** is a collection of individuals who coordinate their individual efforts.

- A **team** is a special group of individuals who share a *common purpose* and a number of *challenging goals*. Members of the team are *mutually committed to the goals and to each other*.

*Source: Adapted from AOE-3564 lectures by Dr. Kim Carlson, VT Management School*

# What Distinguishes Your 'Role' from Your 'Responsibility'?

- **Role is what you 'do.'**
- **Responsibility is what you 'decide.'**

**In This CM:**

- **For each of the lead positions:**
  - ***A top-level summary of the R&Rs is provided. R&Rs adapted from Dr. Mason's Aircraft Design lectures.***
  - ***This is augmented by a "Recommended Reading" list.***
- ***We strongly encourage team lead and subteam leads to spend the time to read the recommended reading material in order to better understand the nature and scope of their own R&Rs.***

# Team Lead

***Being a leader is like being a lady.***
***If you have to go around telling people you are one, you aren't.***

**-- Lady Margaret Thatcher**

Britain's First Female Prime Minister, 1979-1990

# ‘Leader’ and ‘Manager’ Aren’t Synonymous

## Each exhibits very different traits and behaviors

- Managers give answers, leaders ask questions.
- Managers criticize mistakes, leaders call attention to mistakes indirectly.
- Managers forget to praise, leaders reward even the smallest improvement.
- Managers focus on the bad, leaders emphasize the good.
- Managers want credit, leaders credit their teams.

***“My way or the highway” approach isn’t going to encourage or motivate anyone to help you in your problem solving endeavors.***

*Source: The Difference Between Managers and Leaders (Ilya Pozin), 2013*

# Team Lead R&Rs

- **Coordinate everything**: the person who needs help gets it, and good communications exist among all team member.
- Set schedules and meet deadlines.
- Work with the configuration layout lead and the entire team to establish the "*vision*" of the concept.
- Work with team members to define the decision-making process for each part of the design process:

  *What do we need to decide, how will we make decisions?*

  - trade study pro/cons data
  - carpet plots
  - *etc*., etc.
- Keep the scorecard: *Are you meeting the requirements*?

# Team Lead R&Rs (contd.)

- Have the team define the risks, and risk mitigation, relative to technology choices as an absolute minimum.
- Keep the design notebook, recording the project history, data and team member commitments.
- Lead the design review presentation.
- Make sure that everyone is working on the same airplane, and that the presentations and reports are properly coordinated.
- Leader could serve as the Deliverables lead, but it's strongly recommended that some other member of the team be assigned this responsibility.

# Five Key Attributes of An Effective Leader

1. **Effective Two-way Communicator**
   - ✓ *Active Listener, not just talker*
   - ✓ *Powerful facilitator and negotiator*


2. **Exceptional Organizational Skills**
   - ✓ *Pays attention to detail, and proactively follows through*
3. **Excellent Interpersonal Skills**
   - ✓ *Respectful of team members, treats them fairly with honesty*
   - ✓ *Is accountable, and holds team members accountable*
4. **Open-minded Decision Maker**
   - ✓ *Not judgmental--able to impartially and objectively weigh evidence*
5. **Ability to *"Herd Cats"***
   - ✓ *"Barking" works only with sheep!*
   - ✓ *It's about accommodation, not command & control*

***Effective Leader: the Right Combination of Character, Competence, and Conduct***

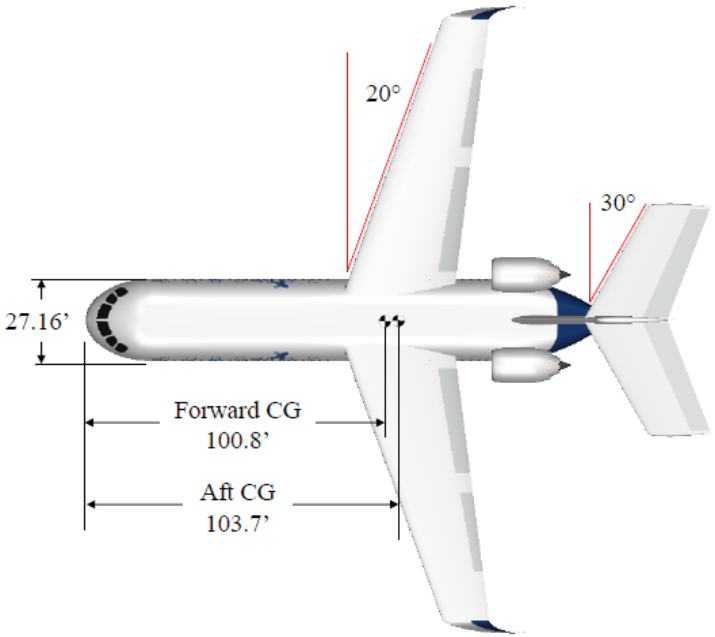

Image Source: Internet

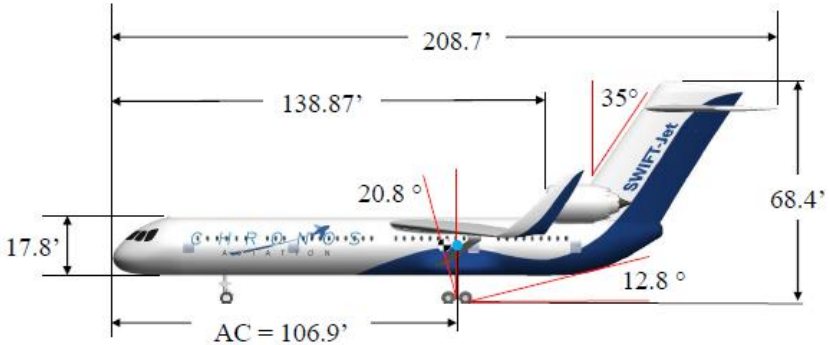
# "Herding Cats"
## *Explained in One Minute*


https://www.youtube.com/watch?v=EZOx1RhMHIo

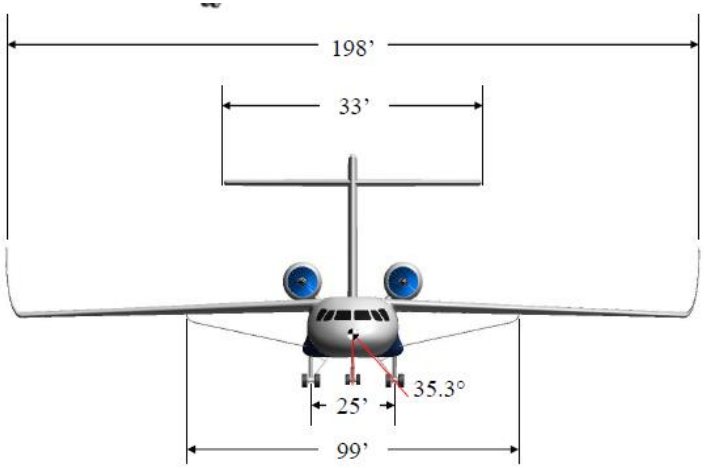
# Configuration Layout and Loft

## (Configurator or System Integrator)




| Aircraft Specifications | |
|---|---|
| Max. TOGW (lbs) | 453,156 |
| Seat Capacity | 400 |
| Design Range (nm) | 3,500 |
| Max. Climb Rate (fpm) | 5,500 |
| Cruise Mach No. | 0.78 |
| Cruise Altitude (ft) | 40,000 |
| Service Ceiling (ft) | 43,500 |






*Source: 2020 VT Swift-Jet (AIAA Undergrad Team Aircraft Design)*

# Configuration Layout and Loft Lead R&Rs (aka Configurator/ System Integrator)

- **Using CAD, convert the inputs from team members into a configuration layout. *This primarily means drawings!!***
  - Provide the group with the design information required to perform analysis of the concept.
  - A high-quality 3-Vu and Inboard Profile are critical!
  - *Kirschbaum's Aircraft Design Data and Layout Guide* is a key resource
- **It's more—much more—than just CAD skills!**
  - Design a smooth outer mold line (OML) with neither excess nor inadequate internal volume.
  - Cleverly arrange internal components to minimizes major rearrangement downstream.
  - Work in close collaboration with subteam leads to promptly resolve technical issues using engineering data from trade studies to reach a compromise

***Does the airplane BALANCE?***

# Configuration Layout

- **Recommended Reading**

| Topic | Recommended References |
|---|---|
| **Configuration Layout and Loft** | |
| Configuration Layout and Loft | Chapter 7, Raymer, Ref. AVD 2 |
| Aircraft Design Aid and Layout Guide | All chapters, Kirschbaum with Mason, Ref. AVD 6 |

# ***Aerodynamics***

***"They own OML (Outer Mold Line)"***

**– Lee Nicolai**

# Aerodynamics Lead R&Rs

## Responsible for Configuration Aerodynamic Design and Analysis

- Define the OML "design drivers." What's the best configuration for the required mission *from an aerodynamic point of view*?
- Ensure the concept is aerodynamically efficient. Think *streamlined*!
- Provide the neutral point to the configuration designer (use analysis codes, such as Vortex Lattice Method, etc.).
- Estimate zero lift drag, including skin friction, wave, form, and misc. drag. The FRICTION code is available for the skin friction and form drag estimate.
- Estimate the induced drag, establish a target span "$e$." (LIDRAG, etc.)
- Select the specific airfoils and design the wing (sweep, taper, twist) - details in the second semester preliminary design
- Make the drag polars, and make sure *they are trimmed*.
- Provide estimates of $C_{Lmax}$ (*trimmed*) for landing and takeoff and define the high-lift concept required to achieve that $C_{Lmax}$
- Work with Stability and Control: achieve target $C_{m_0}$, $C_{m_\alpha}$, etc.

***Does It TRIM?***

# Aerodynamics

- ## Recommended Reading

| Topic | Recommended References |
|---|---|
| **Aerodynamics** | |
| Review of Practical Aerodynamics | Chapter 2, Nicolai & Carichner, Ref. AVD 1 |
| Selecting the Planform and Airfoil Selection | Chapter 7, Nicolai & Carichner, Ref. AVD 1 |
| High-Lift Devices | Chapter 9, Nicolai & Carichner, Ref. AVD1 |
| Estimating Wing-Body Aerodynamics | Chapter 13, Nicolai & Carichner, Ref. AVD 1 |
| Aerodynamics | Chapter 12, Raymer, Ref. AVD 2 in PR |
| Wing Design | Chapter 5, Sadraey, Ref. AVD 5 |
| The Anatomy of the Wing | Chapter 9, Gudmundsson, AVD 4 |
| Aircraft Drag Analysis | Chapter 15, Gudmundsson, Ref. AVD 4 |
| Aircraft Drag | Chapter 9, Kundu, Ref. AVD 8 |
| *Aircraft Drag and Wing Design* | *See Aerodynamics folder in Supplemental Reference Material folder on course site* |

# AeroPropulsion Integration



*Image Source: Internet*

# AeroPropulsion Integration Lead R&Rs

**Responsible for Propulsion System Integration with the Airframe**

- Select the type of propulsion system appropriate for the specified design requirements
  - turboprops, turbojets, turbofans, hybrid-electric, all electric, …
- For an aircraft with turbine engines, define the thrust and fuel flow throughout the flight envelope. As a table, this is known as the *"Engine Deck"* from the days when the data was contained in a box of computer cards. Also, supply scaling and weight data to the performance person.
- Define the appropriate engine inlet and nozzle, or propeller system for each aircraft concept the group is investigating.
- Size the inlet capture area for engines and size the propellers.
- Estimate the installation losses.
- Jointly with Aero and S&C sub-team,
  - define the thrust-drag bookkeeping system**.**

# Turbine Engine Selection Considerations

- **Choose a suitable engine that can supply the required thrust**
- **Realistic propulsion expectations are essential**
  - New engines built from scratch are VERY (VERY, VERY, VERY) expensive
    - Deciding to use a 'rubber' engine should take this real cost into account
  - Much of your load is fuel, so you better know how your engine will perform to justify fuel load
  - Real engines have real dimensions, (dry) weights, mass flow rates, inlet and exhaust flow effects, and noise
  - **Use extensive engine databases** for availability, performance, cost, etc.
- **Sometimes new airframes do require new engines to meet stringent efficiency and emissions requirements**
  - New technologies enable engines with (i) lean combustion for low Nox; (ii) high-temperature turbine materials for efficiency; (iii) transonic compressor/turbine designs; (iv) noise reducing inlets and exhausts



*Courtesy of Profs. Mason and Lowe*

# AeroPropulsion Integration

- **Recommended Reading**

| **AeroPropulsion Integration** | |
|---|---|
| Propulsion System Fundamentals | Chapter 14, Nicolai & Carichner, Ref. AVD 1 |
| Turbine Engine Inlet Design | Chapter 15, Nicolai & Carichner, Ref. AVD 1 |
| Corrections for Turbine Engine Installation | Chapter 16, Nicolai & Carichner, Ref. AVD 1 |
| Propeller Propulsion Systems | Chapter 17, Nicolai & Carichner, Ref. AVD 1 |
| Propulsion System Thrust Sizing | Chapter 18, Nicolai & Carichner, Ref. AVD 1 |
| Propulsion | Chapter 13, Raymer, Ref. AVD 2 |
| Propulsion and Fuel System Integration | Chapter 10, Raymer, Ref. AVD 2 |
| Propulsion System Design | Chapter 8, Sadraey, Ref. AVD 5 |
| Selecting the Power Plant | Chapter 7, Gudmundsson, Ref. AVD 4 |
| The Anatomy of the Propeller | Chapter 14, Gudmundsson, Ref. AVD 4 |
| Aircraft Power Plant and Integration | Chapter 10, Kundu, Ref. AVD 8 |
| *DEP, Hybrid Electric, Propellers and Open Rotors* | *See API folder in Supplemental Reference Material folder on course site* |

# Vehicle Performance

# Vehicle Performance Lead R&Rs

**Responsible for Demonstrating that the Vehicle Can Perform the Mission**

- Develop the mission profile(s).
- Make sure the airplane can perform the design mission, and define the fallout capability for other missions. This includes operation of the sizing code and generation of carpet plots illustrating the basic sizing in terms of thrust and wing area, and the constraint lines imposed by takeoff, landing, maneuver and acceleration requirements. Find and use the BCA/BCM (Best Cruising Altitude/ Best Cruising Mach number). Compute field performance.
- Make use of information from the
  - configuration designer regarding geometry
  - aero sub-team for aerodynamic characteristics
  - propulsion sub-team for basic “engine deck” data and corrections to account for installation
  - weights sub-team to establish system weights

*Note:* each one of the sub-teams should check the *output from sizing* to make sure that the data being used is correct.

# Importance of Accurate Vehicle Performance Prediction

- **Teams predict flight performance for all segments of the mission using appropriate analyses and simulations**

- **If actual flight performance differs from predictions, project faces undue risk:**
  - **Loss of Credibility**
    - "Cannot Deliver What Was Promised"
  - **Potential for Schedule Slip and Additional Cost**
    - Flight Test "Surprises" →Schedule Slips and Additional Costs due to Design Modifications
  - **Dissatisfied Customer**
    - Do Not Like Out-of-Spec Product or Late Delivery or Increased Cost

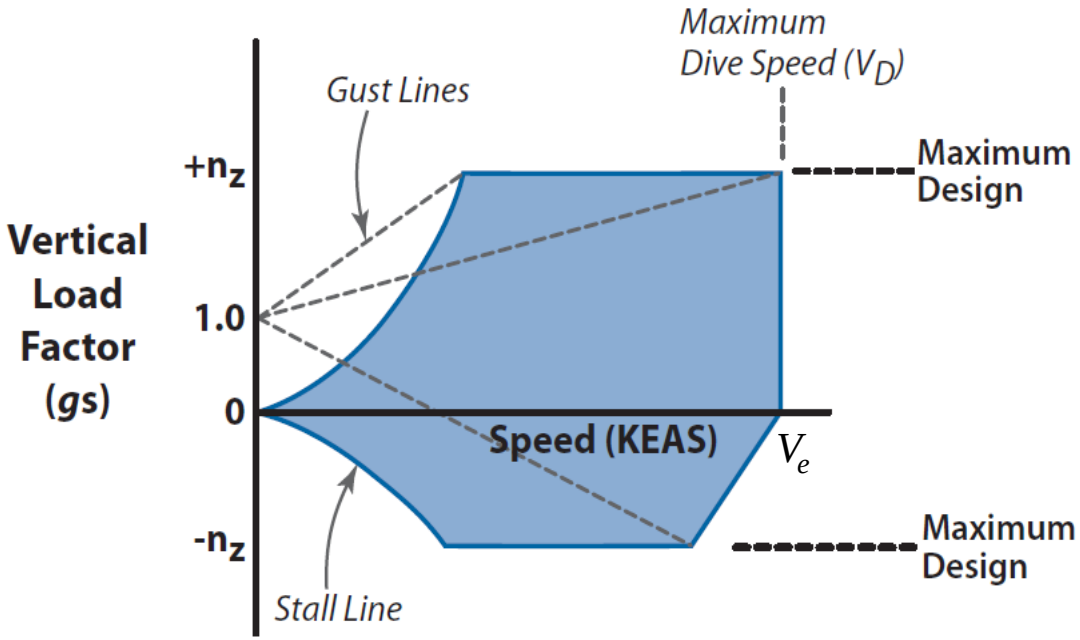
***Timely Identification, Assessment, and Mitigation of Risks Ensures Project Success***

# Vehicle Performance

- **Recommended Reading**

| **Air Vehicle Performance/ Mission Analysis** | |
|---|---|
| Aircraft Performance Methods | Chapter 3, Nicolai & Carichner, Ref. AVD 1 |
| Takeoff and Landing Analysis | Chapter 10, Nicolai & Carichner, Ref. AVD 1 |
| Performance and Flight Mechanics | Chapter 17, Raymer, Ref. AVD 2 |
| Performance (GA Aircraft) | Chapters 16 thru 22, Gudmundsson, Ref. AVD 4 |
| Aircraft Performance | Chapter 13, Kundu, Ref. 8 |
| *Performance* | *See Performance folder for misc documents in Supplemental Reference Material on course site* |

# Structures & Materials



# Structures & Materials Lead R&Rs

- Develop an appropriate materials basis
  - cost/complexity
  - example: compare volumetric efficiency of composites vs. wave drag penalty at supersonic speeds
- Define a structural concept that "supports" the configuration, *i.e.*, *identify the load paths* for wing, landing gear, tail, etc.
- Define critical loads requirements for defining structural design basis. Good V-n diagram info in many reference books as well as Part 23 or Part 25 FAR and MIL-SPEC documents.
- Define Operational Limits (Dive speeds, etc.)
- Size the structural components (skin, bulkheads, *etc*.) second semester
- Consult primary references: books by Nicolai, Raymer, Niu, Roskam, and Torenbeek.

# Structures & Materials

- **Recommended Reading**

| **Structures & Materials** | |
|---|---|
| Structures and Materials | Chapter 19, Nicolai & Carichner, Ref. AVD 1 |
| Structures and Loads | Chapter 15, Raymer, Ref. AVD 2 |
| Aircraft Structural Layout | Chapter 5, Gudmundsson, Ref. AVD 4 |
| Aircraft Loads | Chapter 5, Kundu, Ref. AVD 8 |
| Airframe Structural Design | Book by Michael C.Y. Niu, Ref. STR 1 |
| Composite Airframe | Book by Michael C.Y. Niu, Ref. STR 2 |
| *Structural Sizing* | *See Structures folder in Supplemental Reference Material on course site* |

# ***Subsystems***

# Air Vehicle Subsystems Lead R&Rs

- Identify and make a list of systems for the aircraft per Design Guidelines
  - Landing Gear
  - Crew station requirements and cockpit layout
  - Avionics system
  - Flight control system and actuators
  - Passenger and cargo arrangement (volume and weight)
  - Weapons system if appropriate
  - Environmental Control System (ECS)
  - Thermal Management System
  - Fuel system
  - De-icing system
  - …
- In Conceptual Design phase (1st semester):
  - Focus on relevant technology developments and current systems used
  - Concentrate on **SWaP**, i.e., size (volume), weight, and power requirements
- In Preliminary Design phase (2nd semester):
  - Select specific systems with more actual SWaP values

# Subsystems

- **Recommended Reading**

| **Air Vehicle Subsystems** | |
|---|---|
| Crew Station, Passengers, and Payload | Chapters 9 & 11, Raymer, Ref. AVD 1 |
| Fuselage Design | Chapter 7, Sadraey, Ref. AVD 5 |
| Systems Architecures | Chapter 5, Moir & Seabridge, Ref. AS 1 |
| Aircraft Systems Examples | Chapter 10, Moir & Seabridge, Ref. AS 1 |
| Power Systems Issues | Chapter 11, Moir & Seabridge, Ref. AS 1 |
| Key Characteristics of Aircraft Systems | Chapter 12, Moir & Seabridge, Ref. AS 1 |
| Aircraft Subsystems Integration | Book by Moir and Seabridge, Ref. AS 2 |
| Civil Avionics Systems | Book by Moir and Seabridge, Ref. AS 3 |
| Military Avionics Systems | Book by Moir and Seabridge, Ref. AS 4 |
| Undercarriage | Chapter 7, Kundu, Ref. AVD 8 |
| Landing Gear and Subsystems | Chapter 11, Raymer, Ref. AVD 2 |
| Landing Gear Design | Chapter 9, Sadraey, Ref. AVD 5 |
| The Anatomy of the Landing Gear | Chapter 13, Gudmundsson, Ref. AVD 4 |
| Aircraft Landing Gear Design | Book by Currey, Ref. AS 5 |
| *Fuselage, Fuel Systems and Landing Gear* | *See Subsystems folder in Supplemental Reference Material folder on course site* |

# Stability & Control

| Dynamic Mode | MIL Stability Requirement |
|---|---|
| Phugoid | $\zeta_{ph} \geq 0.04$ |
| Short Period | $0.3 \geq \zeta_{sp} \leq 2.0$ |
| Roll Subsidence | $T_R \leq 1.4$ |
| Spiral | $T_{2s} \geq 20$ |
| Dutch Roll | $\zeta_d \geq 0.08$ |

# Stability & Control, Flight Control, and Handling Qualities Lead R&Rs

- Develop stability & control (S&C) requirements (criteria) for the mission.
- Decide how best to meet the requirements,
  - stable or unstable configuration?
  - canard or aft tail, etc.
- Estimate your design's control power (be able to trim with adequate control margin at critical points in flight envelope).
  - Are the control power requirements defined above met?
  - Use *X*-plots (scissor plots) to size the tails
- Assess design stability (use DigitalDATCOM or AVL or Tornado or some other Vortex Lattice Method).
- Decide on control system, such as fly-by-wire or fly-by-light.
- Meet MIL-SPEC and FAR requirements for flying qualities.

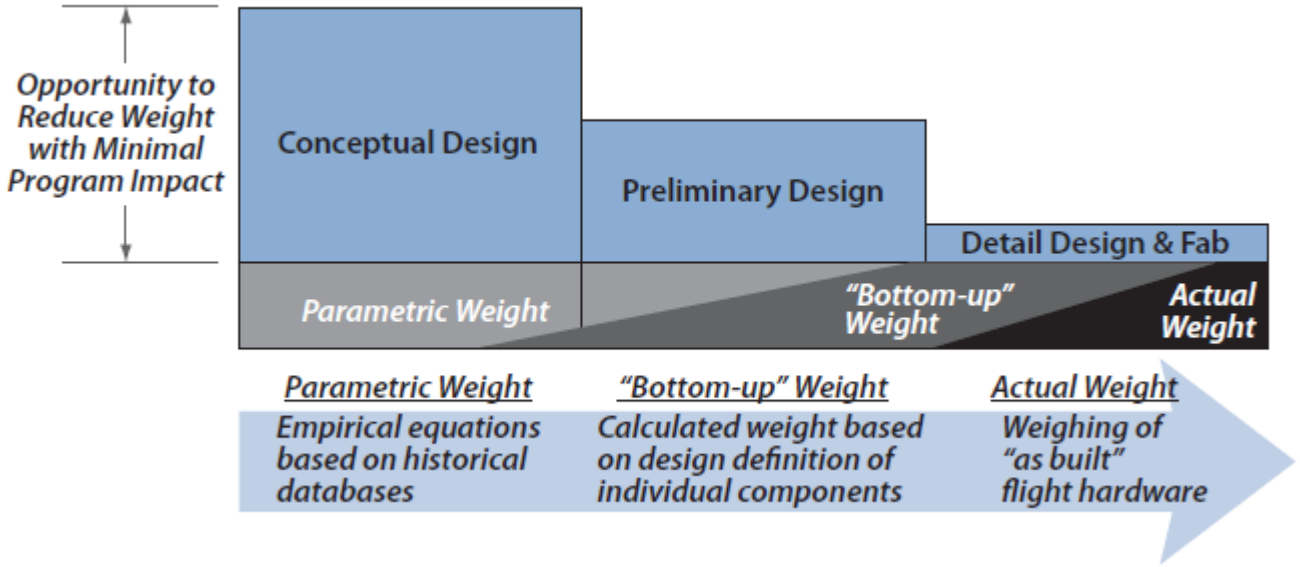
Contribute to the design concept and philosophy

# Stability & Control

- **Recommended Reading**

| **Stability & Control** | |
|---|---|
| Static Stability and Control | Chapter 21, Nicolai & Carichner, Ref. AVD 1 |
| Trim Drag and Maneuvering Flight | Chapter 22, Nicolai & Carichner, Ref. AVD 1 |
| Control Surface Sizing Criteria | Chapter 23, Nicolai & Carichner, Ref. AVD 1 |
| Stability, Control, and Handling Qualities | Chapter 16, Raymer, Ref. AVD 2 |
| The Anatomy of the Tail | Chapter 11, Gudmundsson, Ref. AVD 4 |
| Tail Design | Chapter 6, Sadraey, Ref. AVD 5 |
| Design of Control Surfaces | Chapter 12, Sadraey, Ref. AVD 5 |
| Stability Considerations Affecting Aircraft Configuration | Chapter 12, Kundu, Ref. AVD 8 |
| *Boeing S&C Course Notes and Empennage Design* | *See Stabilty & Control folder in Supplemental Reference Material on course site* |

# Weights (Mass Properties) & Balance



# Weights (Mass Properties) & Balance Lead

- **Responsible for estimation, prediction, determination, management, and tracking of weight, moments, centers of gravity, moments of inertia, and products of inertia**
- Estimate weights using weights equations in Nicolai, Raymer, Torenbeek, and Niu
  - Roskam provides an entire book on weights estimation!
  - Shevell presents the Douglas wing weight Equation
- Generate the standard weight statement
- Using the concept layout sketch, provide the configuration designer/ integrator with *c.g.* estimate
- Include the ***c.g.* travel** with load and mission *(check out the following link for the critical importance of managing c.g. travel)*

http://www.military.com/video/military-aircraft-operations/aviation-accidents/cargo-shift-blamed-for-747-crash/2472237220001/

# Weights & Balance

- **Recommended Reading**

| **Weights & Balance** | |
|---|---|
| Refined Weight Estimate | Chapter 20, Nicolai & Carichner, Ref. AVD 1 |
| Weights | Chapter 15, Raymer, Ref. AVD 2 |
| Weight Control and Balance | Chapter 16, Niu, Ref. AS 1 |
| Aircraft Weight and Center of Gravity Estimation | Chapter 8, Kundu, Ref. AVD 8 |
| Aircraft Weight Analysis | Chapter 6, Gudmundsson, Ref. AVD 4 |
| Weight of Components | Chapter 10, Sadraey, Ref. AVD 5 |
| Aircraft Weight Distribution | Chapter 11, Sadraey, Ref. 9 in PR |
| *CG Limits and Weights & Balance* | *See Weights & Balance folder in Supplemental Reference Material on course site* |

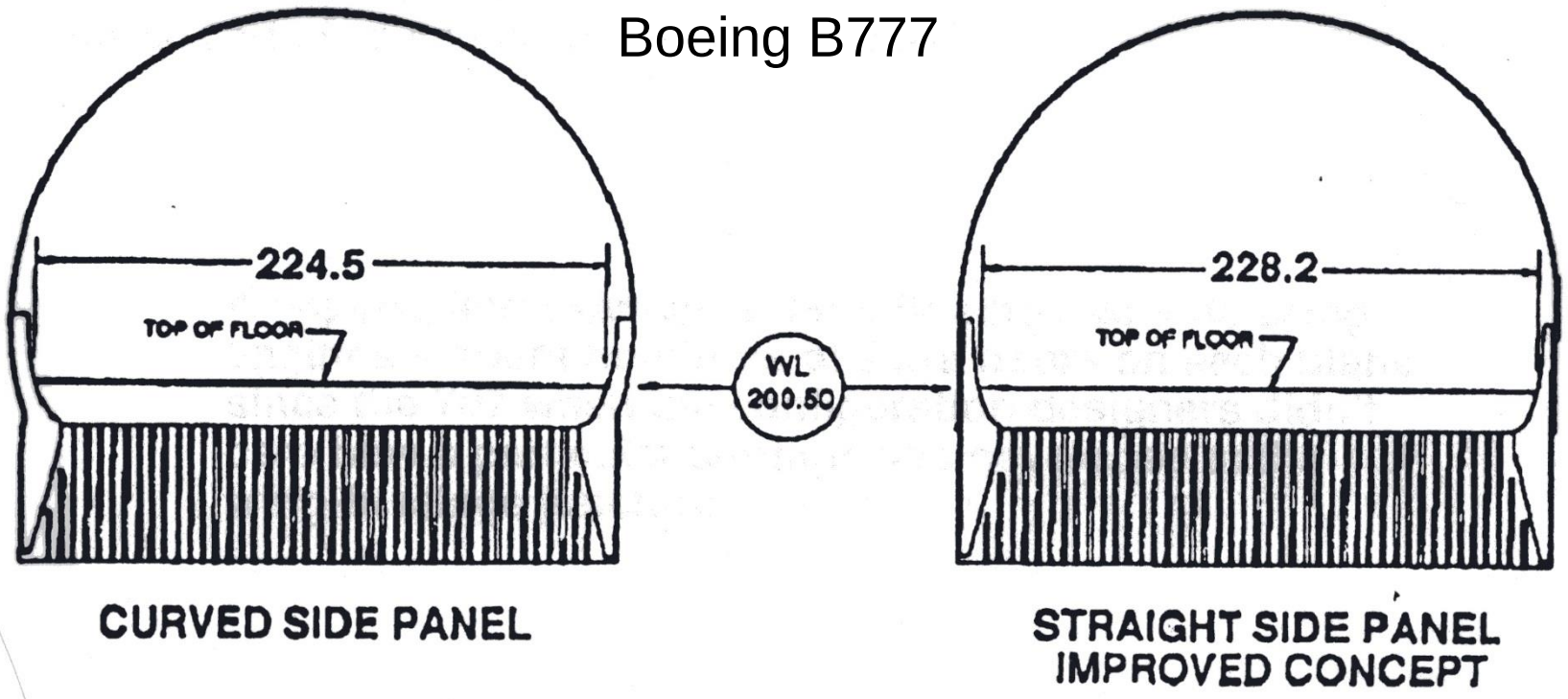
# Cost & Manufacturing

**Table 2 Baseline financial profile for a representative aircraft program**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Development and Manufacturing Costs | | | | | |
| Cost Item | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 |
| Development Engineering | $958,226,808 | $958,226,808 | | | | | | | | |
| Annual Sustaining Engineering | | | $163,179,558 | $326,359,115 | $489,538,673 | $652,718,231 | $652,718,231 | $489,538,673 | $326,359,115 | $163,179,558 |
| Annual Fixed Expenses | $19,164,536 | $19,164,536 | $3,263,591 | $6,527,182 | $9,790,773 | $13,054,365 | $13,054,365 | $9,790,773 | $6,527,182 | $3,263,591 |
| Total Operating Expense | $977,391,345 | $977,391,345 | $166,443,149 | $332,886,298 | $499,329,447 | $665,772,595 | $665,772,595 | $499,329,447 | $332,886,298 | $166,443,149 |
| | | | | | | | | | | |
| Annual Number of Aircaft Sold | | | 50 | 100 | 150 | 200 | 200 | 150 | 100 | 50 |
| Cummulative Sales | | | 50 | 150 | 300 | 500 | 700 | 850 | 950 | 1,000 |
| | | | | | | | | | | |
| Unit Manufacturing Cost | | | $31,903,038 | $21,014,255 | $17,235,169 | $15,017,889 | $13,629,344 | $12,822,210 | $12,375,688 | $12,143,647 |
| Annual Manufacturing Cost | | | $1,595,151,881 | $2,101,425,486 | $2,585,275,307 | $3,003,577,753 | $2,725,868,836 | $1,923,331,494 | $1,237,568,757 | $607,182,375 |
| Annual Total Costs | $977,391,345 | $977,391,345 | $1,761,595,030 | $2,434,311,784 | $3,084,604,754 | $3,669,350,348 | $3,391,641,431 | $2,422,660,940 | $1,570,455,055 | $773,625,523 |
| | | | | | Annual Sales and Profits | | | | | |
| Annual Total Sales | $ 1,124,000,046 | $ 1,124,000,046 | $ 2,025,834,284 | $ 2,799,458,552 | $ 3,547,295,467 | $ 4,219,752,900 | $ 3,900,387,646 | $ 2,786,060,082 | $ 1,806,023,313 | $ 889,669,352 |
| Average Sales Price | | | $40,516,686 | $27,994,586 | $23,648,636 | $21,098,765 | $19,501,938 | $18,573,734 | $18,060,233 | $17,793,387 |
| Annual Gross Margin (Dollars) | $ 165,773,238 | $ 165,773,238 | $ 430,682,403 | $ 698,033,065 | $ 962,020,160 | $ 1,216,175,148 | $ 1,174,518,810 | $ 862,728,588 | $ 568,454,556 | $ 282,486,977 |
| Annual Gross Margin (percent) | 14.7 | 14.7 | 21.3 | 24.9 | 27.1 | 28.8 | 30.1 | 31.0 | 31.5 | 31.8 |
| | | | | | | | | | | |
| Annual Profit Before Tax | $ 146,608,702 | $ 146,608,702 | $ 264,239,254 | $ 365,146,768 | $ 462,690,713 | $ 550,402,552 | $ 508,746,215 | $ 363,399,141 | $ 235,568,258 | $ 116,043,829 |
| Cumulative Profit | $ 146,608,702 | $ 293,217,403 | $ 557,456,658 | $ 922,603,425 | $ 1,385,294,138 | $ 1,935,696,691 | $ 2,444,442,905 | $ 2,807,842,046 | $ 3,043,410,305 | $ 3,159,454,133 |
| | | | | | | | | | | |
| Annual Percent Profit on Sales | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | | | | | | | |
| Average Unit Cost | $ 24,222,482 | | | | | | | | | |

# Cost & Manufacturing Lead R&Rs

- **Cost estimation: The Critical Area—Start Early!**
  - ***All Team members should factor in cost considerations of their assigned area into every decision***
  - ***See CM A1***
- **Manufacturing planning**




*Source: AIAA 93-1139*

# Production Facility Design Considerations

- **All planes must be made on a single line**
- **Simple yet effective production process**

http://www.aero-news.net/images/content/genav/2004/CessnaFactory-1204b.jpg

- **Location needs to be central and economic**
- **Kanban system**
- **“Lean Manufacturing” / Just-in-time production (JIT)**

# Cost & Manufacturing

- **Recommended Reading**

| Topic | Recommended Reading |
|---|---|
| **Cost & Manufacturing** | |
| Life Cycle Cost | Ch. 24, Nicolai & Carichner, Ref. AVD 1 |
| Cost Analysis | Ch. 18, Raymer, Ref. AVD 2 |
| Aircraft Cost Analysis | Ch. 2, Gudmundsson, Ref. AVD 4 |
| Aircraft Cost Considerations | Ch. 16, Kundu, Ref. AVD 8 |
| Aircraft Manufacturing Considerations | Ch. 17, Kundu, Ref. AVD 8 |
| *Miscellaneous relevant topics* | *See **Cost & Manufacturing** subfolder in Supplemental Reference Material folder on Canvas course site* |

# *Epilogue*

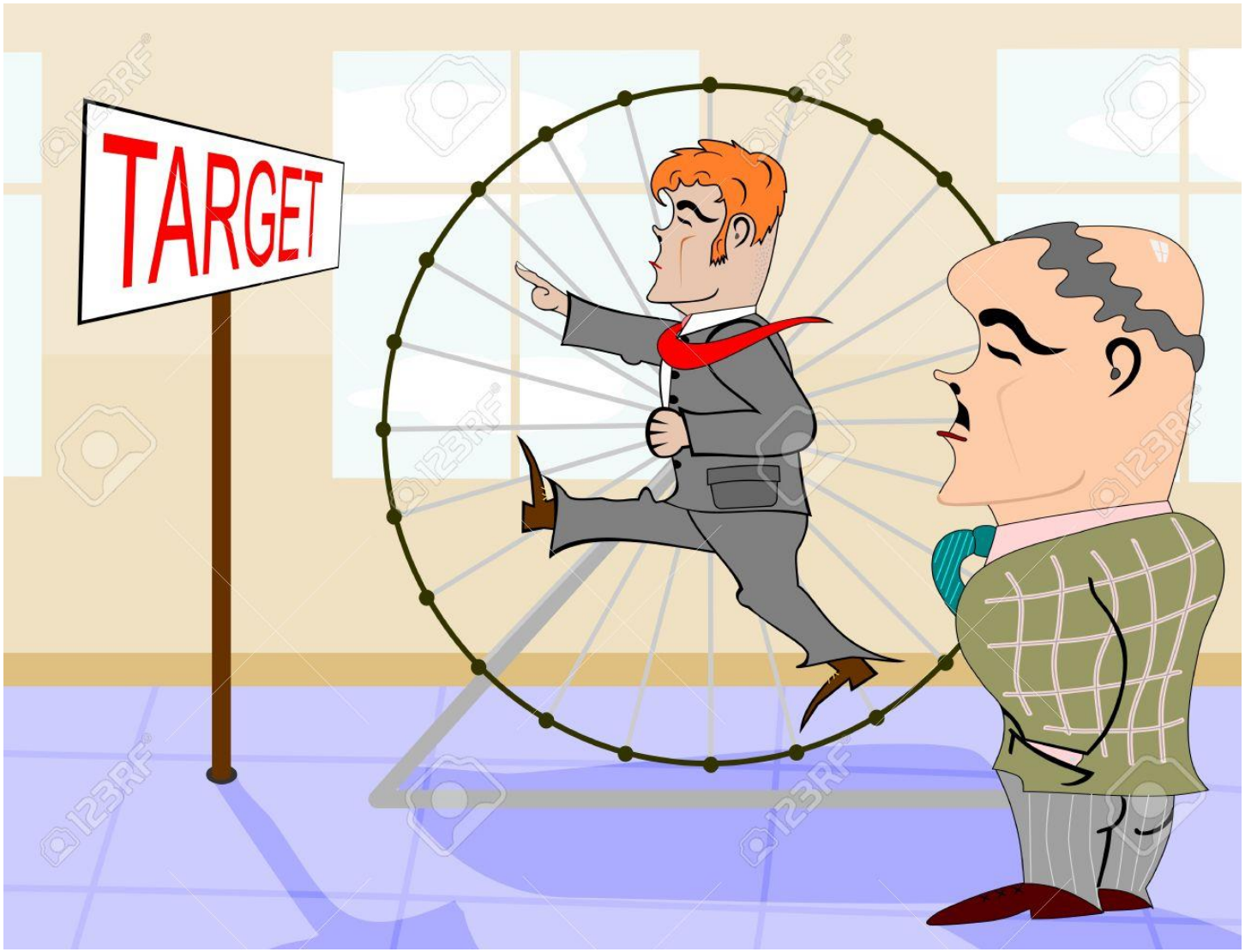
# Getting Things Done – The Benjamin Franklin Way

- **Less Talk, More Action**
  - *"Well done is better than well said."*
- **Don't Procrastinate**
  - *"Never leave that till tomorrow which you can do today."*
- **Be Prepared**
  - *"By failing to prepare, you are preparing to fail."*
- **Avoid Busywork**
  - *"Never confuse motion with action."*
- **Give Yourself Permission to Make Mistakes**
  - *"Do not fear mistakes.*
  - *You will know failure. Continue to reach out."*
- **Keep Going**
  - *"Diligence is the mother of good luck."*
- **Know [Prove] Yourself**
  - *"There are three things extremely hard: steel, a diamond, and to know one's self."*
- **Don't Give Up**
  - *"Energy and persistence conquer all things."*
- **Wise Up**
  - *"Life's tragedy is that we get old too soon and wise too late."*




*Source: Unknown, Probably a HBR Post*

# Work Hard, But Be Smart!




***"Never confuse motion with action."*** ***-- Benjamin Franklin***

*Source: Internet*