AME 485 – Aerospace Structures

Project 3

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Part 1

- Use a spacecraft example from the literature and point the main components of the spacecraft and their purpose (2pt)
  - James Webb Space Telescope
    - Primary Mirror
      - The main mirror spanning 6.5 meters catches faint light from distant objects to see further into space
    - Secondary Mirror
      - Reflect light from the primary mirror. Corrects the light path and ensure data clarity
    - Integrated Science Instrument Module
      - Houses all of the main instruments such as near-infrared camera, spectograph, mid0infrared instruments, and guidance sensors
    - Sunshield
      - Protects telescope from sunlight and maintains the instruments at good temperatures
    - Spacecraft Bus
      - Main body that contains power, thermal, and communication systems
    - Propulsion System
      - Maintains telescopes position and at a stable spot
    - Communications System
      - Transmits data to earth and receives commands for the telescope in deep space

Part 1

- Explain the primary failure modes of spacecraft (2pt)
  - Structural failure
    - Mechanical stresses or fatigue beyond design limits from launch vibrations, thermal cycling, or incorrect material
  - Propulsion System Failure
    - Malfunctions in engines, thrusters, or fuel systems from contamination, leakage, or valve failure
  - Power System Failure
    - Solar panels going bad, batteries going bad, power distribution boards working improperly
  - Thermal Control Failure
    - Radiators, heat shields, insulation doesn’t work making valuable components overheat or freeze
  - Communication System Failures
    - Issues with antenna transponders or other communication devices resulting in communication to and from SC being impossible
  - Attitude Control Failure
    - Gyroscopes, reaction wheels, or control thrusters not working result in bad orientation and a failed mission
  - Software or Computer Failure
    - Bugs or bad computer system result in the SC doing undesired things

Part 1

- Provide 10 examples of space mechanisms failures and lessons learned (2pt)
  1. Mars Climate Orbiter 1999 Navigation Failure
     - Navigation error by mismatch between metric and imperial units in the software
     - Importance of ensuring consistency in units across teams and systems
  2. Hubble Space Telescope 1990 Mirror Failure
     - Primary mirror had a aberration due to bad manufacturing making blurry images
     - Need for rigorous testing before launch
  3. Apollo 13 1970 Tank Explosion
     - Oxygen tank exploded from due to improper tank insulation and wiring
     - Redundancy in critical life support systems is essential
  4. NOAA-19 2003 Solar Array Deployment Failure
     - Spacecraft dropped during assembly damaging solar array system causing deployment failure
     - Proper handling protocols and careful mechanical procedures are essential
  5. Mars Polar Lander 1999 Premature Engine Shutdown
     - Incorrect software logic forced engines to shutdown ultimately made the SC crash into mars
     - Simulations are very important before flight
  6. Galileo High-Gain Antenna 1991
     - Didn’t fully deploy due to friction
     - Testing in proper environments is essential as a zero-gravity environment caused it to not deploy
  7. Phobos-Grunt 2001 Systems Reboot
     - Control system messed up due to reboot placing SC in wrong orbit
     - Have more autonomous systems
  8. Beagle 2 2004 incomplete solar panel deployment
     - Lander did not deploy all solar panels properly making communication to Earth impossible
     - Ensuring redundancy is very important
  9. Juno 2016 Thruster Valve Issue
     - Thruster valve issues delayed planned orbit
     - Pre-flight testing is essential
  10. Rosetta Lander 2014 Mechanism Failure
      - The harpoon system intended to anchor it to comet failed to fire
      - Backup anchoring systems are important

Part 1

- Use the Ariane's Users Manual to describe to the types of test that need to be conducted to validate a spacecraft design (2pt)
  - Structural and Mechanical Testing
    - Vibration testing simulates vibrational forces during launch verifying the SC and components can endure environment
    - Shock tests assess the SC ability to withstand sudden mechanical shock from deployment or stage separations
    - Static load testing applies forces to spacecraft structure to verify it can withstand mechanical loads
  - Thermal Testing
    - Thermal vacuum testing tests temperature extremes in space
    - Thermal cycling exposes SC to repeated heating and cooling fluctuations like in orbit
  - Environmental Testing
    - Radiation testing simulates exposure to cosmic radiation
    - Outgassing and contamination tests makes sure materials do not evaporate in space
  - Performance Testing
    - System integration testing makes sure all subsystems work together properly
  - Launch Readiness Testing
    - Fit check ensures physical dimensions
    - Separation testing ensures proper separation from launch vehicle after reaching wanted orbit
  - End-to-End testing
    - Mission simulation ensures mission scenarios are calculated, and mission can be successful under conditions
    - Ground segment testing tests communication and control link between mission control and the spacecraft

Part 1

- Explain the types of failure conditions/loads that are imparted on a spacecraft in orbit vs launch ascent/ground. (2pt)
  - While in orbital position the loads on the vehicle are decreased in the zero-gravity environment and instead the most common failure modes will revolve around instrument alignment and communication. Orbit of the spacecraft is at risk of failure from metritides and debris. At the ground failures can include shipping vibrations and as a result defects to coatings and lubricants. During ascent you cannot count on preload and friction instead a mechanical devices are preferred also during ascent, thermal failures are much more prevalent and the time varying forces, and pressure are much more prevalent.

- Download SMC-S-016 and explain the types of test that should be performed on a spacecraft to validate the design from the environments perspective. (2pt)
  - When a spacecraft must operate in space a thermal vacuum cycle test is needed Also thermal cycling for the cold and hot temperatures is needed to ensure the spacecraft will be able to maintain operational at the coldest and hottest temperatures it will need to withstand. On top of that, the electronic units are also tested in a pressure chamber reduced to the required vacuum to ensure everything maintains operational requirements. There are also humidity test performed to see if performance withstands 55% less humidity. As well, as sand and dust tests to ensure contamination isn't a possible failure method.

Part 2

1. Watch all ten parts of *Challenger: The Untold Story*
   1. *Part 1*
      - January 28th, 1986, at 11:38 am at the Kennedy space center, Challenger begins to launch with a civilian and suffered a malfunction
      - Regan addresses the nation, 7 astronauts are dead including a high school teacher
      - Shuttle and parts are on the ocean floor. The shuttle has over 2 million separate components
      - Regan sets up a committee to investigate the disaster made up of experts, scientists, and politicians. There is also a noble prize winner physicist. They call several witnesses and engineers to publish and explain what happened.
      - In 1984, Christa McAuliffe, learns about a NASA program that will choose a civilian to go to space. She was fascinated by this and applied.
      - Morton Thiokol is an engineering company based in Utah who is contracted for the solid rocket boosters on the shuttle program. The shuttle program is in full swing and in 1985, Discovery mission STS 51-C landed safely back from a mission. Furthermore, engineers at Thiokol are worried about the shuttle and know that it has flaws which include cracks in turbine blades to faulty heat exchangers. These issues don't prohibit the shuttle from flying.

   Part 2
      - Solid Rocket boosters are made up of 4 motor segments and are filled with solid fuel made to be reusable. The joints between each segments are sealed using O-rings. These joints are crucial, the person in charge for this at Thiokol is Roger Boisjoly.
      - Boisjoly was in charge of inspecting the joints on the STS 51-C Discovery mission. He discovered that hot gas from propulsion had compromised the primary O-ring in one of the segments and burned the second O-ring.
        - There are two O-rings in the joint where the rocket boosters are joined together, a primary and a secondary. One for redundancy. The O-rings form a seal against the propellant exhaust gases during launch.
      - Boisjoly found that the temperature of the O-rings during the STS 51-C flight was 51°F, which was far below the optimal temperature. As a result, the O-rings were not flexible, and the primary seal failed to function properly, allowing hot gases to escape. The second O-ring, however, did manage to work.
      - He reports this to NASA, but it is determined to not be a serious issue and shuttle launches continue.
      - Further tests suggested the O-rings could also fail at room temperature
      - Boisjoly tell his boss, but his manger kept it a secret
      - NASA had a very strict schedule, and Thiokol didn't want to hinder any further contract negotiations by releasing this information, delaying the project.
      - Boisjoly is suppressed and his information never makes it to NASA.

Part 2

1. Watch all ten parts of *Challenger: The Untold Story*
   1. *Part 3*
      - Shuttle was the most complex machine NASA had ever made; Its first launch was in 1981 but was not as safe as planned
        - Shuttle was larger than anticipated and the original plans had the shuttle positioned along side the rocket boosters instead of on top
      - William Rogers commission assembled by Regan brought on Richard Feynman an award-winning physicist who helped construct the atom bond. He offered a new perspective on the investigation committee.
      - Boisjoly is called into the hearing to explain how the solid rocket boosters worked.
        - He tells them about the O-rings and the failures he found
      - Because Thiokol was in Utah, the solid rocket boosters had to be made in segments to enable transportation – The committee began its investigation on the O-rings.

   Part 4
      - More than 700 components on the shuttle are designated critical 1, if they fail the shuttle could be destroyed
      - NASA was taking risks with bearings, cracking, etc.… and kept flying
      - There is a calculated risk on every flight
      - Finalist for the NASA program undergo serious testing and evaluations. They are told about the risks from the commander.
      - NASA claimed every 1 out 100,000 launches would fail, the engineers like Boisjoly, though the risks were much higher.
      - Boisjoly finds another O-ring failure and tells management again

   Part 5
      - A task force is made to look into the O-ring failure after Boisjoly asked several times to management 5 months before launch.
        - 4 weeks later, the task force failed and didn't get anything done
      - Christa McAuliffe wins the competition and begins training for the shuttle flight.
      - Challenger flight was postponed several times
        - Weather (lighting storms)
        - Handle of the access hatch was stuck, engineers dealt with the problem, but caused another delay
      - Cold temperatures of the launch were expected on the new day of launch, this bothered the engineers and Boisjoly
        - A shuttle has never launched in such cold temperatures, roughly 20 degrees F.

Part 2

1. Watch all ten parts of *Challenger: The Untold Story*
    1. *Part 6, Part 7, Part 8, Part 9, Part 10*
        - Each of the delays, NASA's public image went down, they felt the pressure.
        - NASA calls Thiokol and a team of 5 engineers who are trying to cancel the launch, because O-rings don't work in freezing conditions.
            - NASA is reluctant of their advice again, unless there is very hard evidence.
            - A joined meeting was commenced and Thiokol gathered as much data as they could.
            - Thiokol recommends NOT TO FLY
            - NASA solid booster manager agrees with Thiokol and doesn't defy what the contractors suggest but scrutinizes Thiokol
            - Under more pressure, Thiokol management goes against there own engineers and tells NASA to proceed.
        - The investigation committee reviews this information and focusses on Thiokol management overruling their engineers
            - The focus then shifts to NASA solid booster program management
        - NASA knew the danger and took a calculated risk.
        - The temperatures during launch are extremely low, 24 degrees F, icicles are seen on the shuttle and launch pad.
        - Later in the day, temperatures are 36 degrees F, the coldest launch ever
        - Puff of black smoke is coming from the lower part of the righthand booster
            - The primary O-ring did not seal, the secondary O-ring was empiercing an immense amount of pressure from the propellant gasses
        - 56 seconds into the flight, part of the first O-ring had burned away, and hot gases are burning the other O-ring
        - 61 seconds, the flame is burning a hole in the booster and the flame is in contact with the liquid hydrogen tank
        - 64 seconds, the heat burns a hole in the hydrogen tank
        - 70 seconds, pressure in the hydrogen tank drops due to the new hole
        - 72.3 seconds, flame burns through the support of the right-hand booster
        - 72.5 seconds, a swinging motion caused by the nozzle shifting directions
        - 72.6 seconds, hydrogen is pouring out of the tank
        - 72.9 seconds, the instruments fail
        - 73.1 seconds, the hydrogen tank separates and falls away
        - 73.5 seconds, the engine shuts down and a combustion with the hydrogen cause an explosion and tears the shuttle apart
        - May 2nd, 1986, the investigation committee concludes no one person is to blame. It was the O-rings and a failure at the management level (cultural issues).

Part 2

2. Watch The documentary *The Flawed Design That Led To The Space Shuttle Columbia Disaster*
    - This documentary was conducted 5 weeks after the disaster.
    - February 1st , 2003 – Space Shuttle Columbia fell to the ground and disintegrated on reentry.
    - NASA funding after the moon landing in the 60's diminished leading to a subpar shuttle design
    - Example of NASA forgetting about safety - Ejection system during the launch was put into the first two shuttle launches but taken away later
    - The United States (President) supported the space race not out of curiosity but because it supported political motives. NASA had to cooperate with the DOD in order to get funding. The space shuttle needed to meet certain needs of the government (i.e. large, heavy vehicle to house DOD satellites). This is very inefficient.
    - Cost cutting measures were taken wherever possible (solid rocket booster structure) – Challenger disaster
    - Challenger disaster could have used ejection seat and pressure suit – since then this has been implemented in all shuttle astronaut suits
    - Foam debris was seen hitting the space shuttle wing during launch on Columbia that came from insulation. NASA engineers examined the footage and claimed it didn't cause any damage to the structure of the wing.
    - NASA estimated at the time of this documentary over 8,000 large pieces of debris. There could be millions of pieces of debris that are untracked. One theory for Columbia disaster is space debris hitting the shuttle.
    - Two steep of reentry could cause the shuttle to burn up, two shallow and the shuttle will bounce back into orbit. Initial NASA designs of a shuttle program was a small fixed wing orbiter but that never worked because of little funding from Richard Nixon and requirements made by the DOD and military. NASA was pushed into an uncomfortable position.
    - The Airforce wanted a large payload bay and a high cross range capability (glide more than its ground track). This affected the intended design of the shuttle making the wings larger and the structure larger. This meant, that it would take a longer time to reenter, and the heat shields had to withstand a larger time delta
    - If debris hits the heat shield tiles, there would be a failure because of the brittle and soft properties. There was an immense amount of calculation done to see how the heat tiles failed, where they would fail, and how they would react to debris impacts.
    - Breach of the heat shield on reentry was very probable, if the tiles had failed, it could have caused the disaster
    - The shuttle was pulling to the left, so the engines tried to correct the pulling. According to the expert, it was due to the added drag on the left wing caused by potentially a puncture in the wing structure.
    - NASA knew that the heat shield could have been damaged and didn't do enough to prevent its failures.
    - Challenger was a consequence of bad decisions and oversight
    - What is the best way to reduce risks for a reasonable amount of money - This is what NASA needs to do.

Part 2

3. Questions discussed by Thomas Brand
    1. Why do failures generally occur in aerospace systems? Are the issues connected to technical, cultural, or combination? Can you comment on the Columbia Shuttle Investigation?

    A. 90% of failures are due to lapses in system engineering. System engineering disciplines are being ignored.
    B. The direct cause for the Columbia shuttle was found to be the heat shield tile failure. The Challenger direct cause was the compromised O-ring. Management was truly the cause for those issues, tremendous pressure to stay on time. Both these examples were caused by organizational issues. The root cause was schedule pressure, management, pressure to launch at all ricks, and to take risks.
    C. Engineers didn’t articulate the issues properly to management with the shuttle issues. As an engineer we are responsible for this. Engineers follow the advice of managements, if management doesn’t take the job seriously engineers will also follow those footsteps. Its up to management to set a good example and establish a good workplace.
    D. Fine line between cutting corners and doing a good job. A lot of programs move fast that sometimes you don’t realize your cutting corners. The engineering team needs to come together, and peer review each other.

Part 2

3. Questions discussed by Thomas Brand

   2. What is root cause versus direct cause? Is it important to always achieve root cause? What is the importance of securing the investigation site and developing a timeline of events?

   A. Investigations are aimed at looking for a direct cause – what happened to cause that failure, something that if that item failed on itself, it would cause the anomaly (the whole system to fail). Investigations can be caused from multiple direct causes because they are collateral events. Seeing which one came first is sometimes very hard to see.

   B. Contributing cause is where if a failure happens on itself, it will not cause the whole system to fail. Enough contributing cause can lead to a bigger failure.

   C. Root cause, is taking a deeper look at the failure, "what cause the valve to fail". The root cause all the way back to management.

   D. Companies have investigative plans in place. You put a small team together, you lock down the investigation site, take all the digital data off of computers, take witness statements. Taking photos, show where the photo takes place, have a map, catalogue everything, and remove the wreckage. Need to be careful with contamination it's a forensics investigation.

   E. A timeline is the first thing an investigation team needs to do, it needs to be very exact down to the microsecond. This is to determine what happened first, is the failure from collateral damage or is it a direct cause…..etc. Its about making a correlation between data, images, and telemetry. Does the timeline make sense for the failure? IMU and telemetry data is not that fast and is hard data to analyze. Timing and data correlation is very important.

   F. Signatures in the telemetry are found by comparing past flight data; how did it compare to the max values; how did it compare in family.

   3. Can you describe the difference between Fishbone versus Fault Tree? How are the 5 Why's used? Which one is your favorite?

   A. He uses Fault Trees and its his favorite; he is a visual person who likes to see data all Infront of him.

   B. 5 Why's are not too different than a fault tree. This method is okay and sometimes you need to go deeper then only 5 Why's

   C. These are just tools; Fishbones are fine as well. An instigation is about thoroughness and these tools can help you with the investigation.

   D. Documentation is the key to a successful investigation. You don't want any bias and never forget the lesson.

   E. At a certain point in the investigation, the team will develop scenarios based on the detailed timeline.

Part 2

3. Questions discussed by Thomas Brand

    4. How is refuting evidence versus supporting evidence used in adjudicating items from the Fishbone or Fault Tree?

    A. A balancing act against your own logic, refuting something is part of the logical process. Another dimension of doing the failure investigation and keeps the focus away from just answering the problem rather, looking at both sides of the problem. Don't get myopic, open the perspective and look at all potential answers.

    B. Always say that you screw up, always own it.

    5. How are corrective actions implemented?

    A. Even when an investigation doesn't get to the bottom of the failure or (root cause), direct causes can be found, and corrective action can be implements on all the direct causes.

    6. Why is it so important to develop a Failure Modes Effects and Analysis as part of the design process?

    A. FMEA is a bottom-up analysis looking at the component level before it is in a system. This is important because, if a component fails it can show you how the system will react to that failure, and it can help you in your system design. The FMEA allows the engineer to see where single point failures occur and how they react. From that combined knowledge you can truly understand your design.

    B. A top-down investigation is also very important where you start at a failure and work down to a component. If you do a top-down you can use FMEA to correlate and see what type of affects you see during the investigation.

    C. If you already have a FMEA to begin with it allows you to work faster and more efficiently. FMEA can help engineers correlate issues and see if components or systems are related. As a designer a FMEA is a must to see how the design works, can you withstand failures, where are the failures. FMEA can lead to a better design.

    7. Career advice?

    A. Have to be comfortable in the uncomfortable. You must be willing to embrace difficult situations.

    B. Be a learner.

Part 3

Explain the benefits of the Failure Modes Effects and Analysis within the context of the product life cycle.

- The benefits of failure modes effects and analysis revolves around providing the opportunity to determine areas in the final product that impacts the customers. In terms of a product life cycle that signifies that once a product is designed and initially tested when it is released to the public can have a negative effect on the user if it fails for example if it’s a public bridge failure modes effects and analysis will aid in determining risk and fix designs before it can be released and possible harm others because of non-proper analysis. Other benefits include aiding in the designers being able to the manner in which a design will most likely fail and draws attention to possible failures modes that may be overlooked or less likely to be identifies. These aspects of the failure modes effects and analysis aid in the design aspect of the productlife cycle and it will become more developed before introduced to the market.

Why is team environment so important?

- To be a successful engineer one needs a team and be open to listening and learn as it will provide the opportunity to work in diverse environments and having more perspectives and minds when faced with difficults problems or challenges. With the team all can have input and work on the which challenges need to be faced, and the the goals that need to be tackled.

Part 3

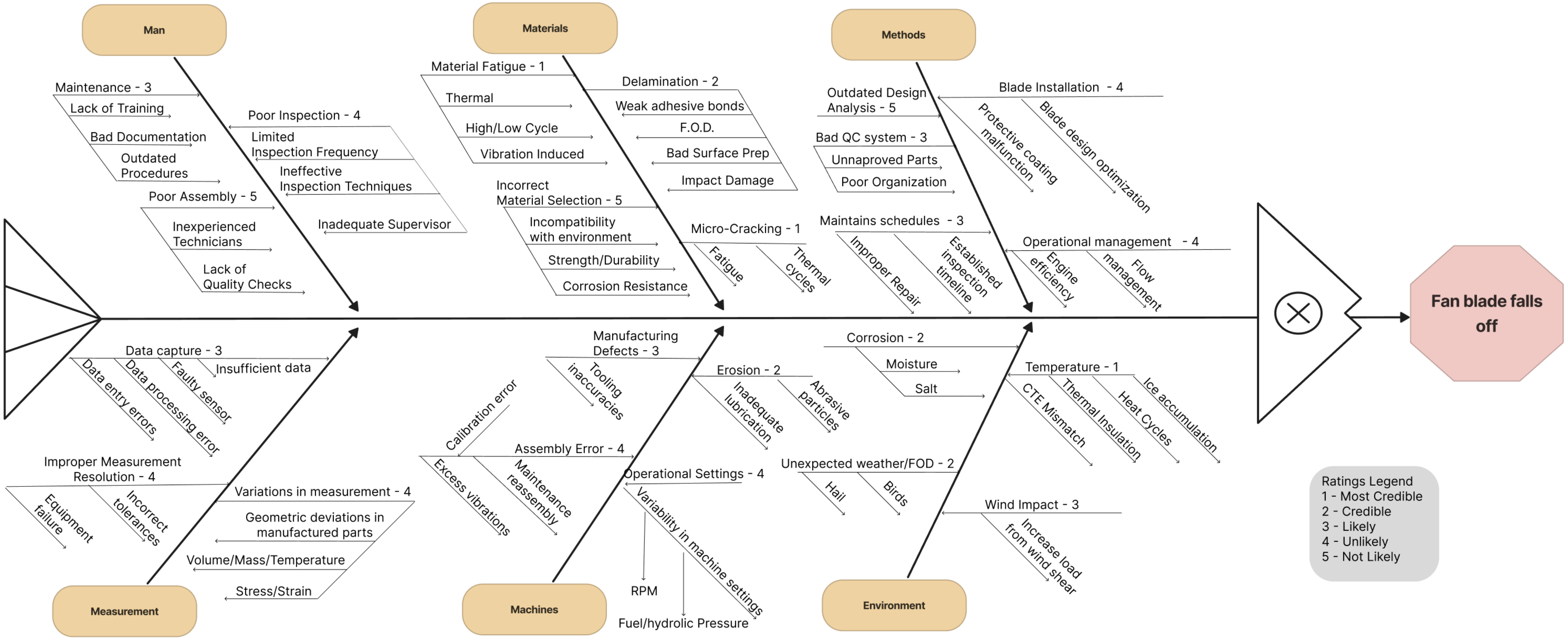
- What is the “Why” Analysis?
  - The Why Analysis revolves around analyzing the problem and describing any observations, then questioning the problem and begin brainstorming, and examine underlying conditions until the root cause can be discovered and keep asking why until the root causes are found.

- Explain the step by step process in a failure investigation?
  - When going through a failure investigations it's important to consider all the inputs to the design/situation that may have not gone to plan. On top of that discussing each possible failure mode and ranking their respective consequences severity. As well as identifying the potential reasons and explanations for failures and their respective detection levels through the engineering cycle. Finally, then making a recommend action plan.

6. Download the paper (in the following page) and write 10 lessons learned

Part 3: Fishbone

Scenario: An aircraft had an engine failure; a fan blade came off and hit the aircraft causing damage to the fuselage. There was a Southwest Airlines incident that had this issue.



Ratings Legend
1 - Most Credible
2 - Credible
3 - Likely
4 - Unlikely
5 - Not Likely

10 lessons learned

1. Importance of thorough data collection
    - Ensuring sufficient data is collected to make a final determination
2. Significance of fatigue as a common failure mode
    - Fatigue is a common failure mode in many documented cases
3. Routine visual and photographic documentation
    - Documenting the failure site with macro and microscopic photos for detailed analysis
4. Impact of corrosion on failure
    - Corrosion can initiate failures particularly in environmental conditions like humidity and salt exposure
5. Necessity of QC in manufacturing
    - Errors in manufacturing processes can reduce longevity of structural components
6. Critical role of fractographic analysis
    - Examination of fracture surfaces helps identify root cause of fatigue, corrosion, etc.
7. Importance of NDT like ultrasonic and dye penetrant
    - Really important for identifying hidden cracks
8. Simulation as a predictive tool like FEA
    - FEA helps simulate stress concentration
9. Significance of material selection for structural integrity
    - Poor material choice can lead to stress/corrosion cracking and fatigue
10. Chemical and Elemental analysis for material validation
    - Routine chemical checks can confirm material composition and identify contaminants that can lead to failure

Part 4

Finite Element Analysis of an Aircraft Fuselage – Confirmation all students have completed the analysis.

- Analysis Summary: An aircraft fuselage was analyzed under cabin pressure differential. The pressure differential occurs due to the external pressure around the aircraft dropping. This creates a dP which exerts a force outward on the aircraft fuselage

- Material Summary
  - Solid model was made out of an Aluminum Alloy

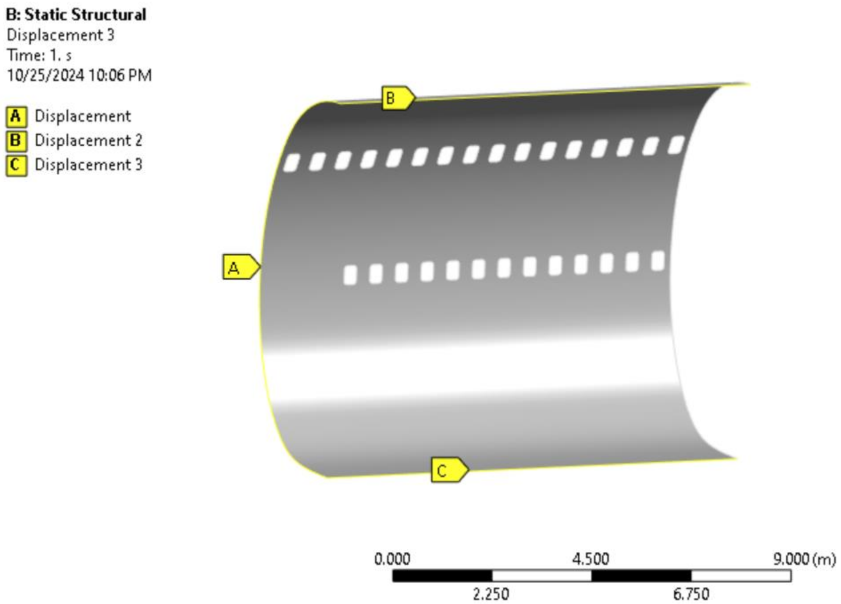
Material	Modulus of Elasticity (Pa)	Poisson Ratio	Tensile Ultimate Strength (psi)
Aluminum Alloy	7.10 * 10^10	0.33	3.10 * 10^8

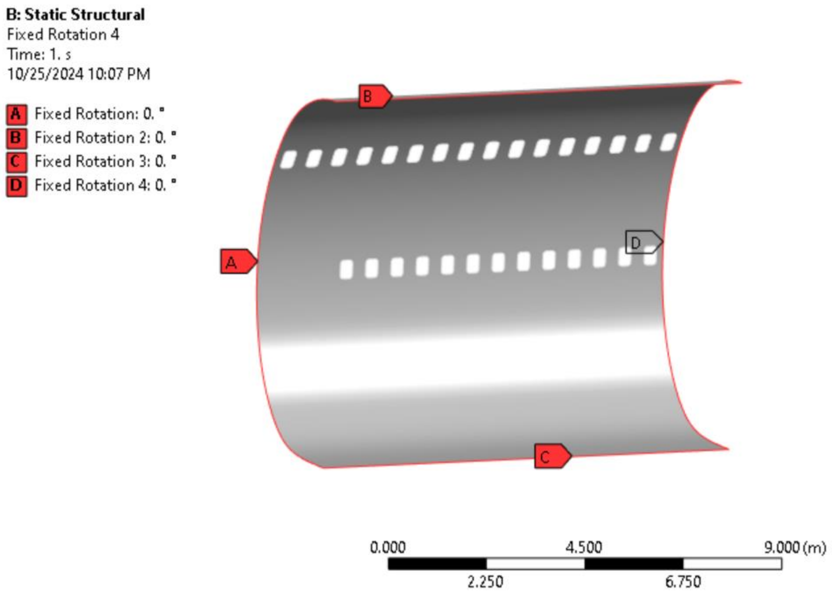
- Source: ANSYS Material Database

Part 4

Finite Element Analysis of an Aircraft Fuselage

- Boundary Conditions:



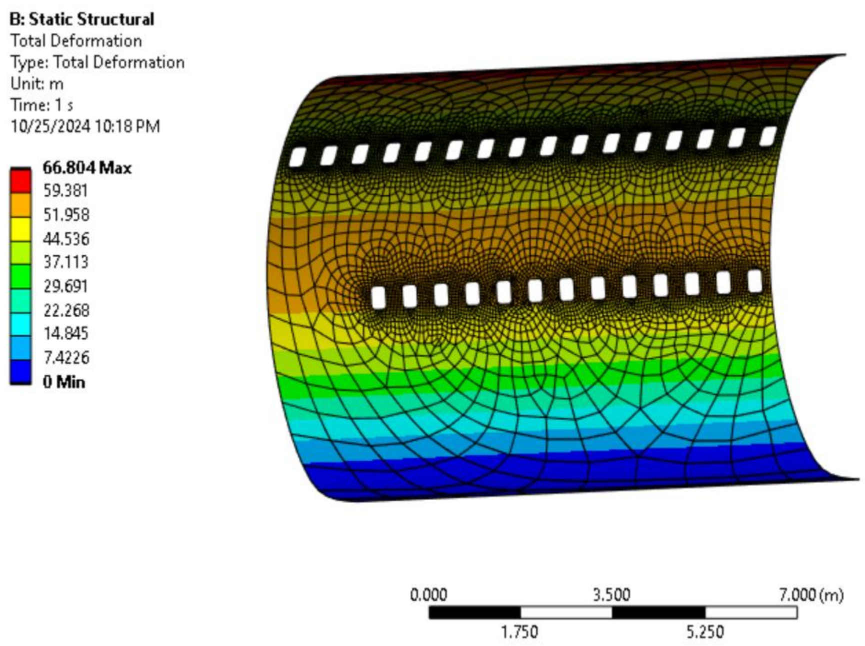


The sub-model of the aircraft fuselage was constrained at the 4 edges with a fixed displacement support and a fixed rotation support. These constraints constrained the aircraft in 6 DOFs at the edges, not allowing for any deformation or rotations. When we plot the final deformation results we should see the constraint locations not move.

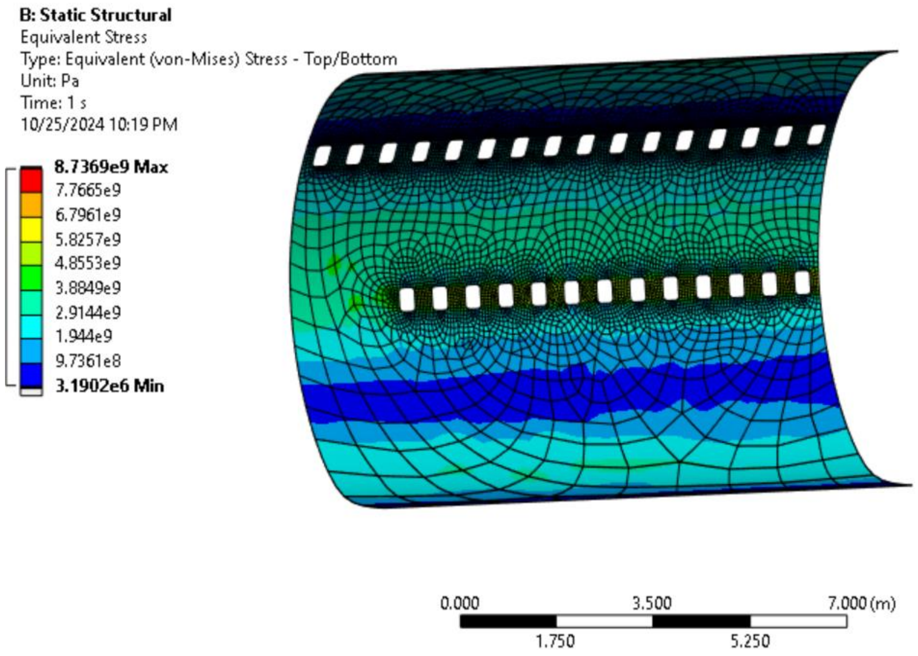
Part 4

Finite Element Analysis of an Aircraft Fuselage

- Results:



Deformation



Von Mises Stress

Part 4

Finite Element Analysis of an Aircraft Fuselage

- Explanation:
- The max stress experienced by the aircraft fuselage occurs at the location of the windows according to our ANSYS simulation. This result makes sense and could be confirmed empirically by a first order hand calculation. Holes see stress concentrations, which is why the rest of the fuselage sees a lower stress
- To combat the stress in the area of the windows, fuselages can be built with a local buildup around windows (tapers) to allow for a lower stress and prevent the part from yielding