Mechanical Design of Axial Flow Fans for Air-Cooled Condensers

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Challenges

- Unique demands in ACC applications:
  - Size
  - Mechanical Stress - both Static and Dynamic
  - Noise
  - Assembly and Maintenance
  - Efficiency
- Fan needs to meet the required performance, for the life of the system

Durability allows a fan to meet all other objectives over the life of the system

Design Process Overview

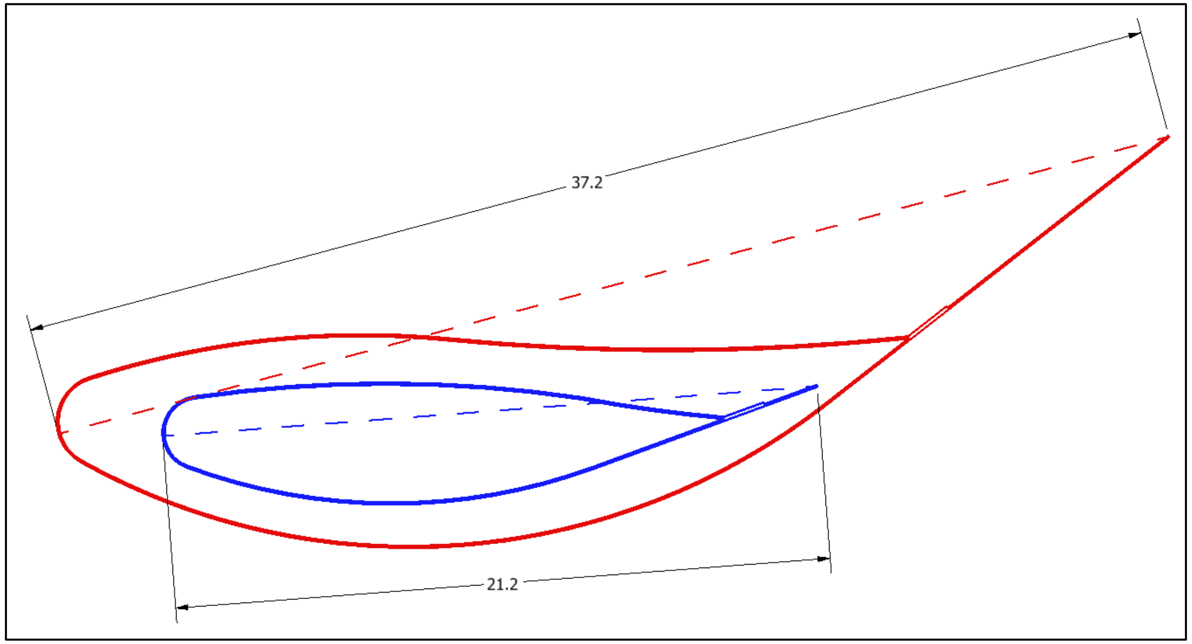
1. Define Objectives
2. Aerodynamic Design
3. Structural Design
4. Analysis
5. Testing and Validation
6. Repeat……

Design Objectives

- High aerodynamic efficiency to reduce energy consumption and improve overall system performance
- Robust structural design to withstand both expected static loads and realistic dynamic forces
- Fatigue resistance to ensure *long service life* under real-world operating conditions
- Material selection to avoid corrosion and provide *long service life*
- Ease of assembly and installation for smooth integration into customer systems
- Minimal maintenance requirements to reduce downtime and total lifecycle cost

Aerodynamic Design

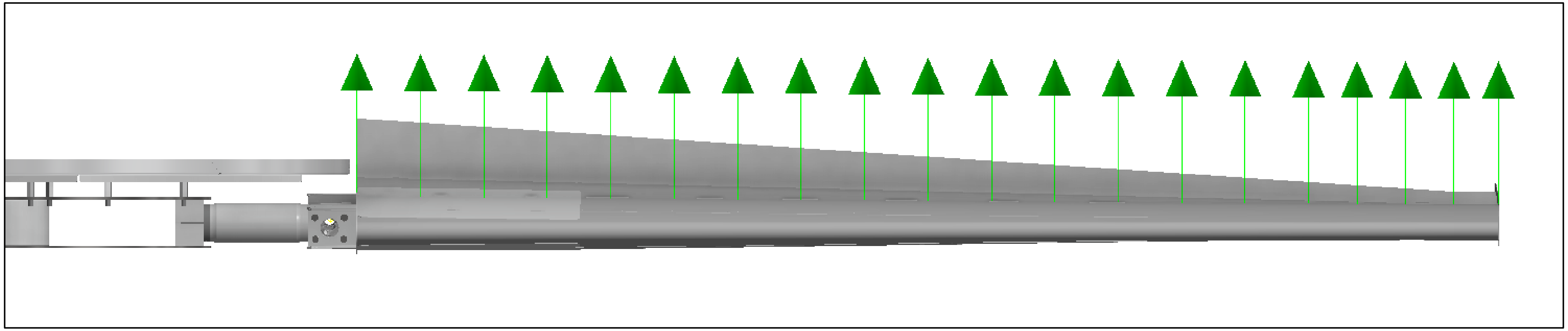
- Capability for desired airflow volume and static pressure at operating rotational speed
- Optimized blade geometry for airflow behavior, from root to tip
  - Chord length
  - Angle of attack



Aerodynamic Design

Aerodynamic Design – Uniform Flow

- Generally uniform flow across the length of the blade

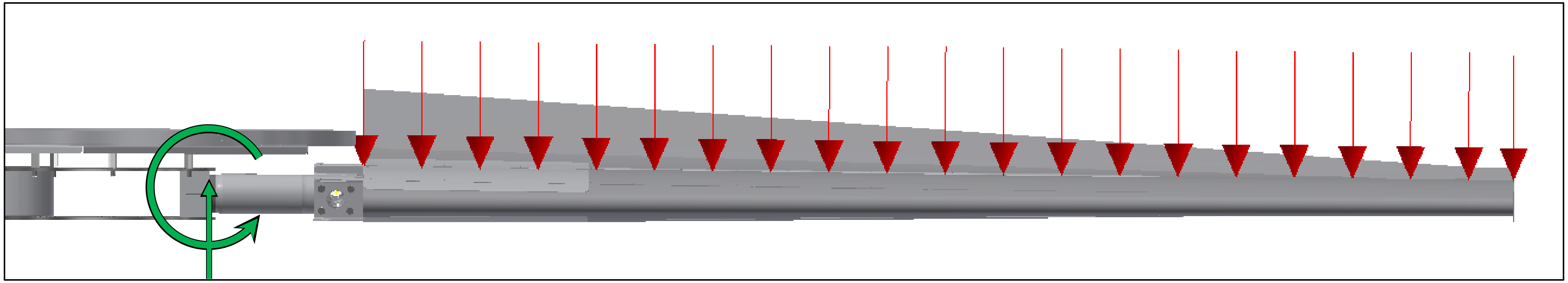


- Reduces turbulence, localized inefficiencies and mechanical imbalances

Basis for mechanical analysis

Structural Design

- Can be analyzed as a cantilevered beam



- Use expected operating conditions to calculate loads

Structural Design – Static Load Calculations

Use: Known fan characteristics and running conditions → To determine: Pressures, velocities, thrust load, and load per blade

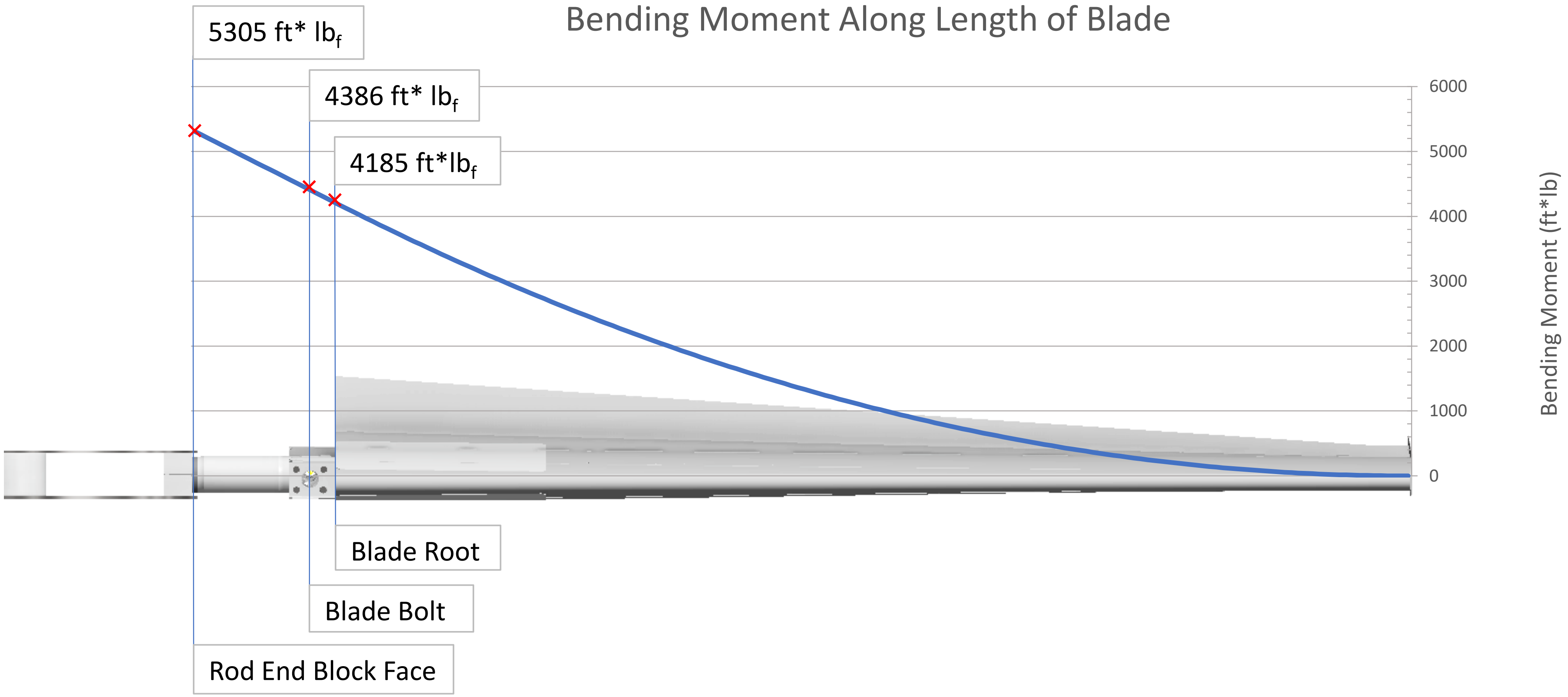
Fan Diameter:	34 ft	10.4 m
Hub Diameter:	96 inches	2.44 m
No. Blades:	7	
RPM:	112	
Tip Speed:	11,963 ft/min	60.77 m/sec
Density Ratio:	1	
Flow:	1,500,000 ACFM	708 m^3/sec
Static Pressure:	.82” H_2O	204 Pa

→

Free Area of Fan:	857.7 ft^2	79.7 m^2
Air Velocity:	1749.0 ft/min	8.88 m/s
Velocity Pressure:	0.19” H_2O	47.3 Pa
Total Pressure:	1.01” H_2O	251.3 Pa
Axial Thrust:	4506 lb_f	20044 N
Force per Blade:	643.8 lb_f	2865 N
Distributed Load:	49.5 lb_f/ft	723 N/m

Determining the expected running load

Structural Design – Static Load



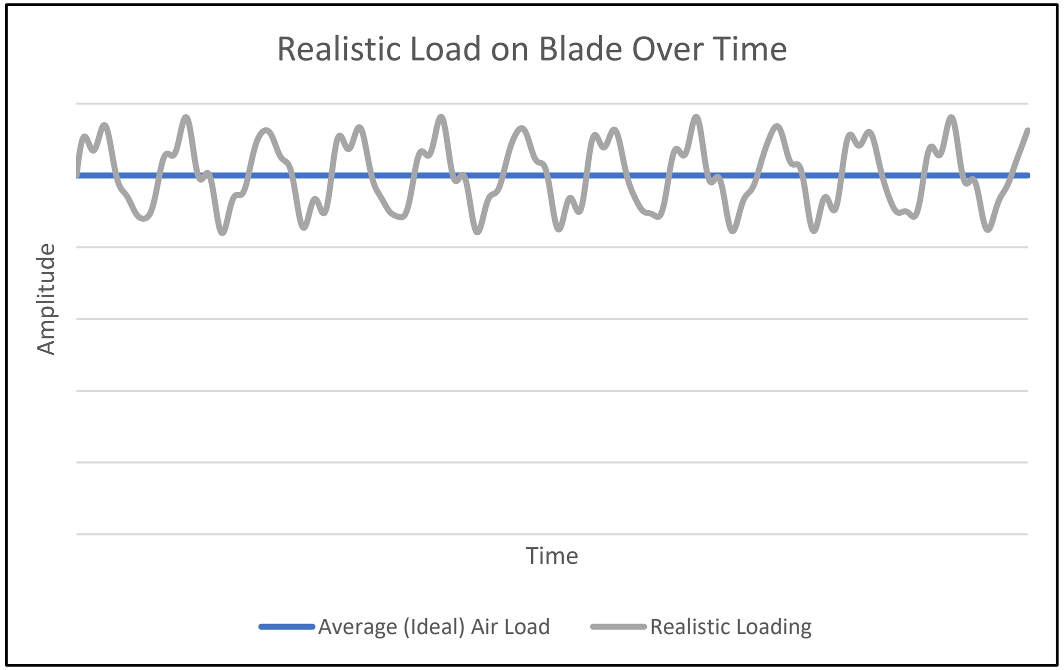
Highest loading closest to the hub

Structural Design – Static Load

Static Load Verification

Structural Design – Dynamic Load

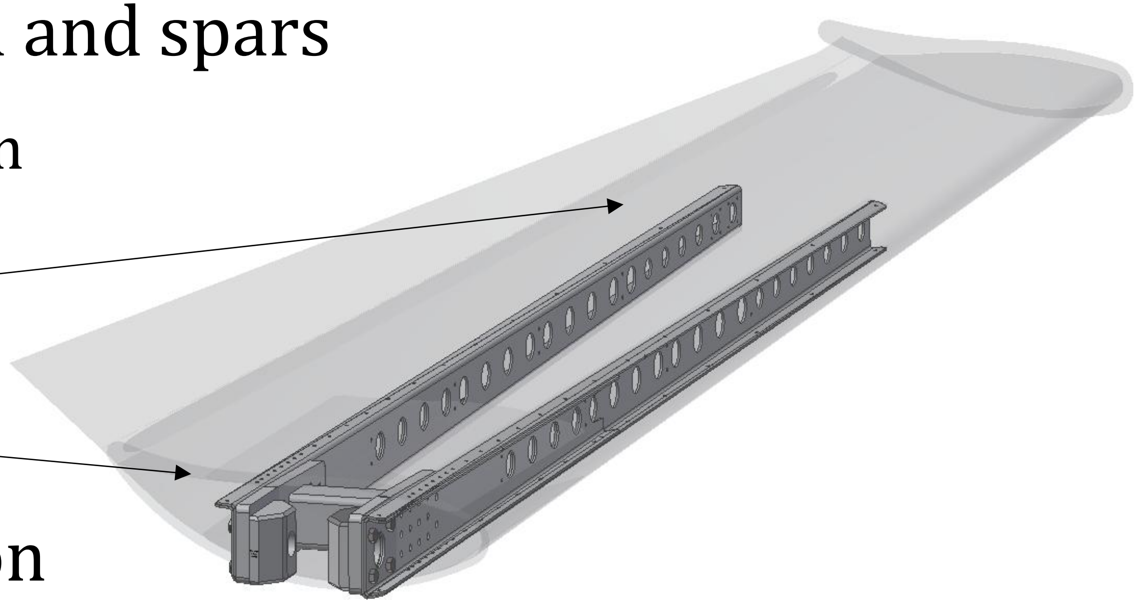
- Perfectly ideal environment = perfectly constant (static) air load
- Real world dynamics:
  - Crosswinds
  - Flow obstructions
  - System-induced vibrations



Real factors that induce alternating stress

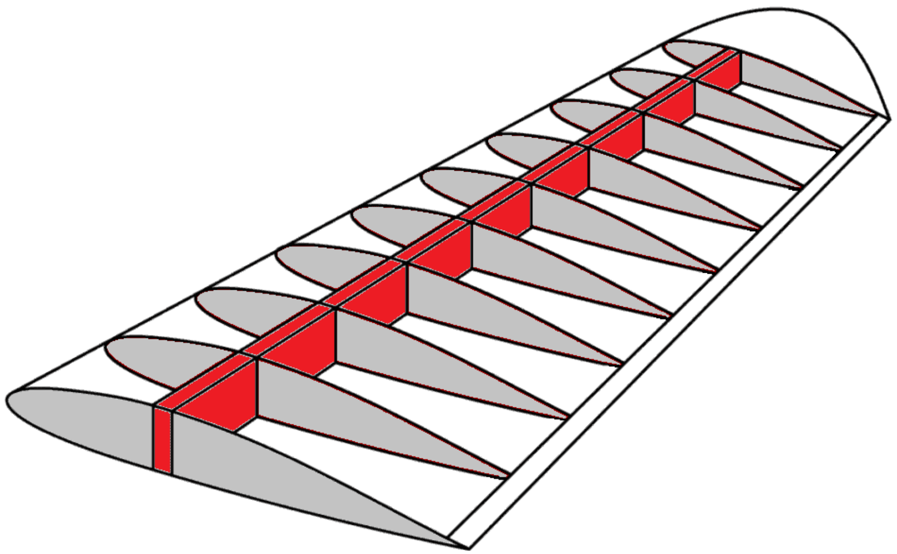
Structural Design

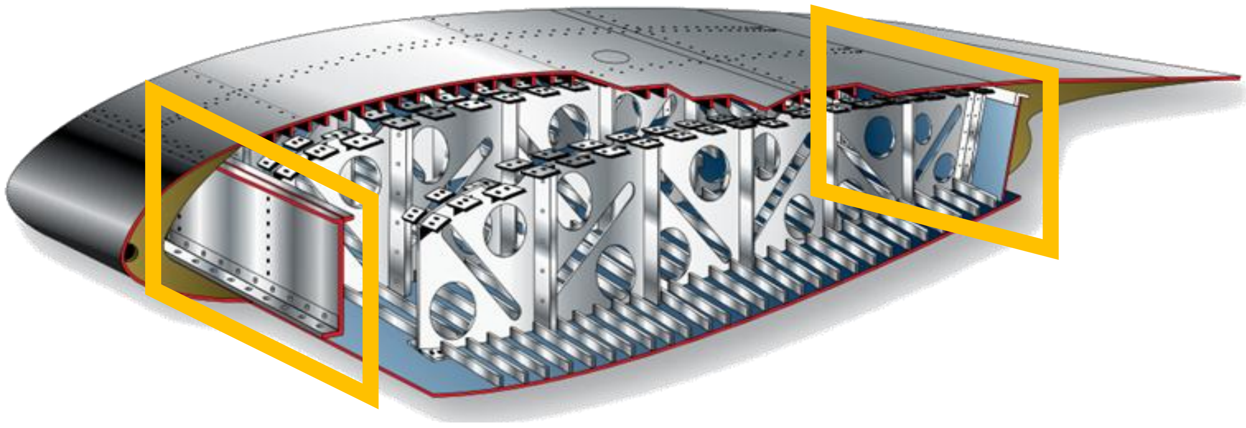
- Balances strength, efficiency, practicality
- 5052 Marine Alloy aluminum skin and spars
  - Proven in over 60 years of fan design
- Lightweight support towards tip
- Robust support at root
- Allows individual blade installation



Structural Design

- Very similar in materials and structure to the airplane that brought most of you to Dallas

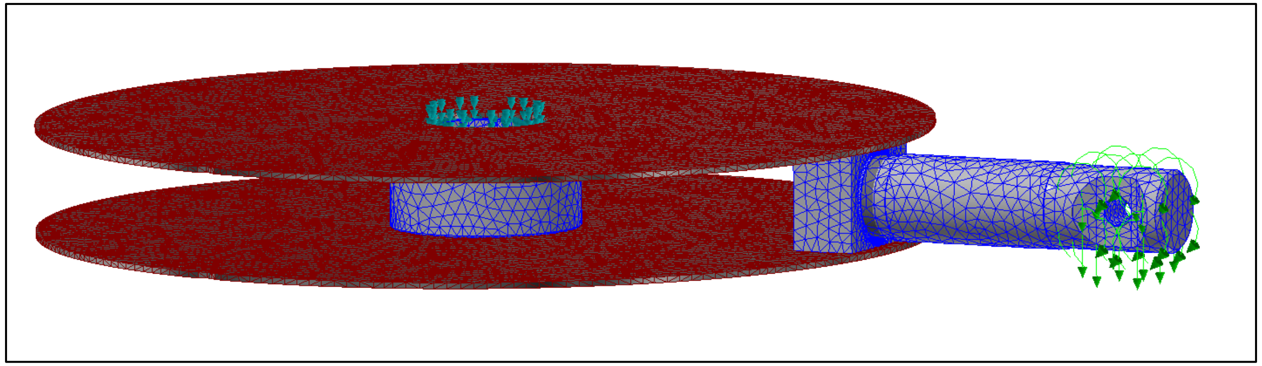


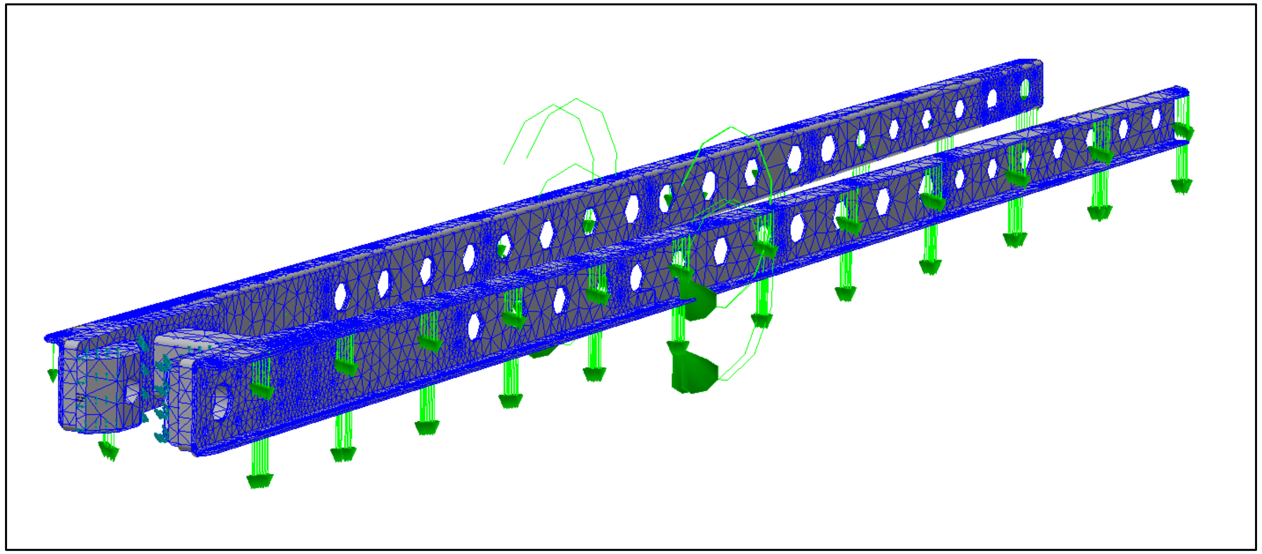


Internal support structure for aluminum airplane wings

Design Stress Analysis – FEA

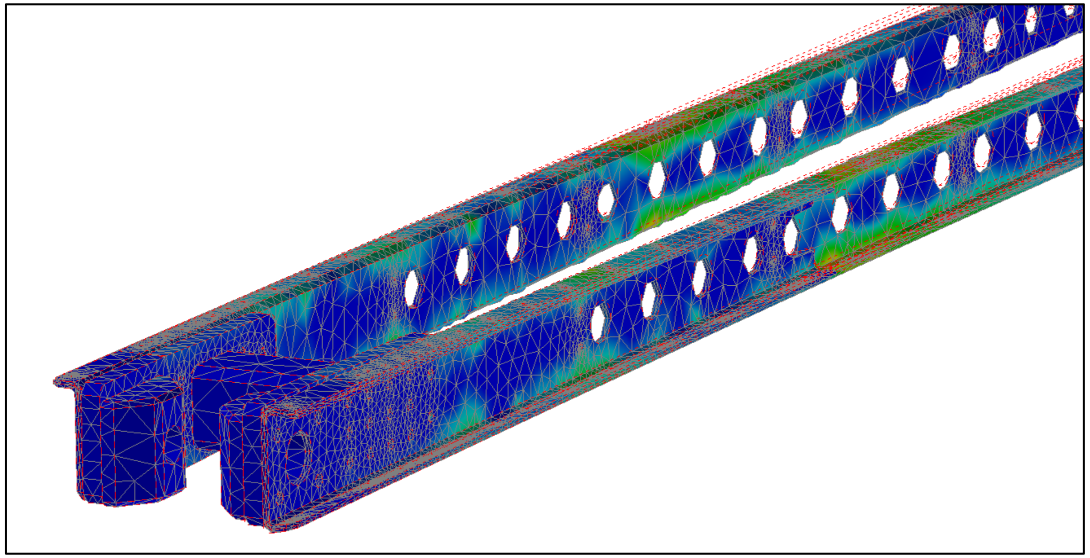
- Each major component group analyzed with realistic loading
  - Made possible through simplified interfaces and known boundary conditions
- Mesh generated for parts, focusing on critical geometry

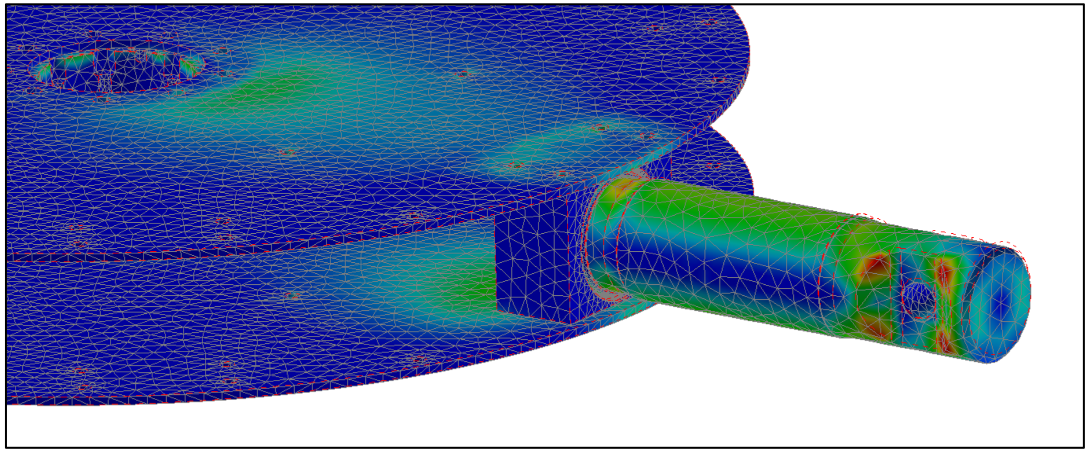




Design Stress Analysis – FEA

- Component groups analyzed conservatively
  - Ex: Spars without skin adding additional support (~50% added strength)
- Each component evaluated and design refined
  - Plate thickness
  - Reinforcement layouts
  - Fastener patterns
  - Mating interfaces

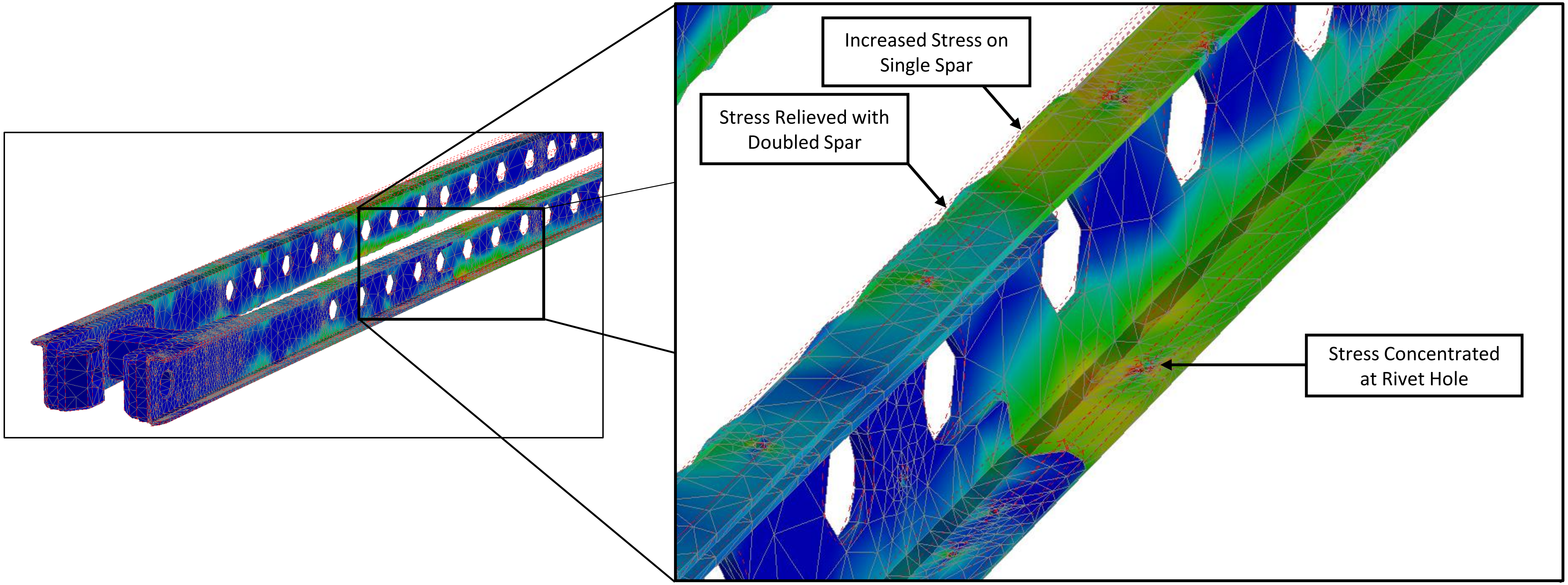




Color scales relative- red highlighting highest stress, not necessarily failure

Design Stress Analysis – FEA

- Locations of Stress concentration are analyzed further



Color scales relative- red highlighting highest stress, not necessarily failure

Moore FANS

Designing for Infinite Life

- All stresses need to be safely below fatigue strength to prevent crack initiation
  - One week at 112 RPM yields more than 1 million cycles
  - “Infinite” life means enduring hundreds of millions of cycles
- Account for turbulence, system dynamics, and intermittent overloading

Designing for Infinite Life

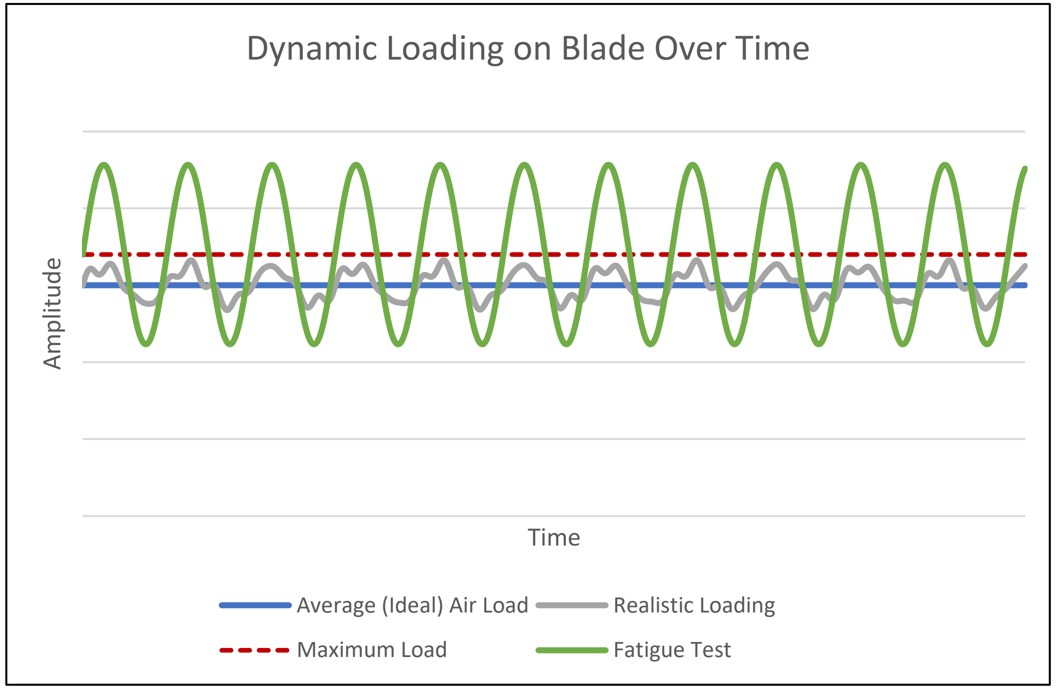
Fatigue Factor of 3 provides safe margin for unknowns

Validation through Physical Testing

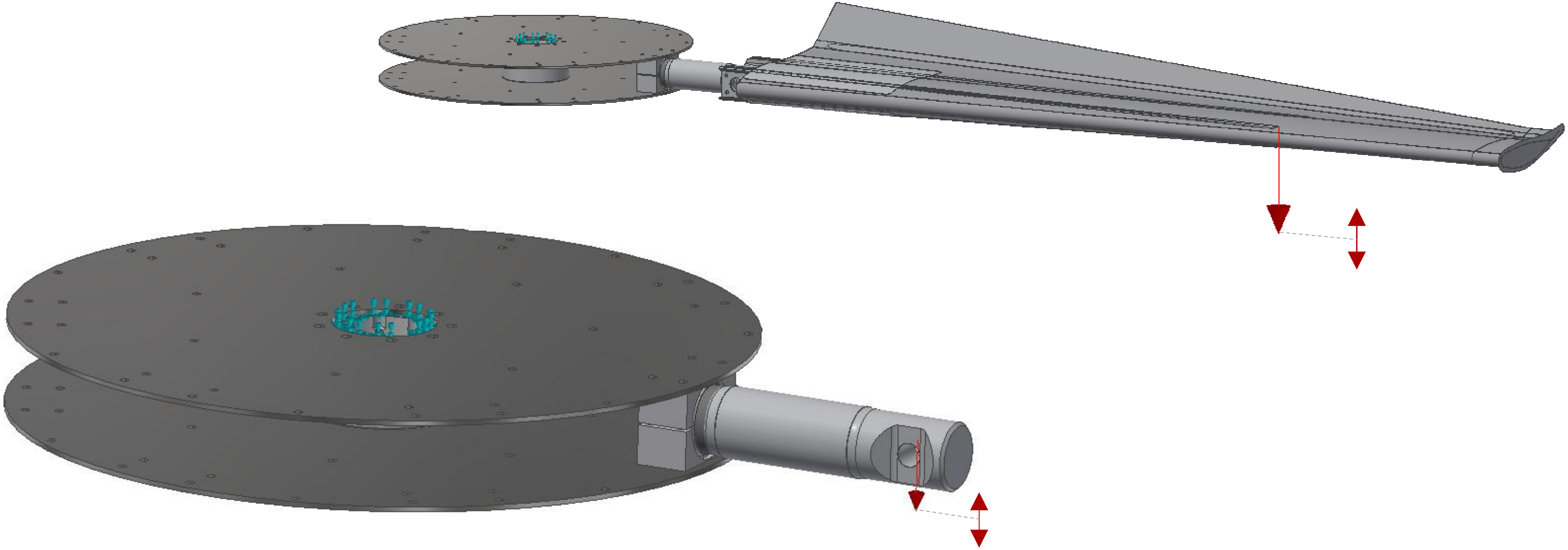
- Two mechanical tests: “Fatigue” and “Life”
- Both test and validate mechanical strength and fatigue resistance
- Both impose amplified stress to simulate long term operating stress in compressed timeframe

Physical Fatigue Testing

- Point load applied to component/group, with DC preload and AC cycling
- Simulates a particular stress level at a particular point
- Provides rapid feedback on design
- Controlled and repeatable for validating components



Physical Fatigue Testing



Physical Fatigue Testing

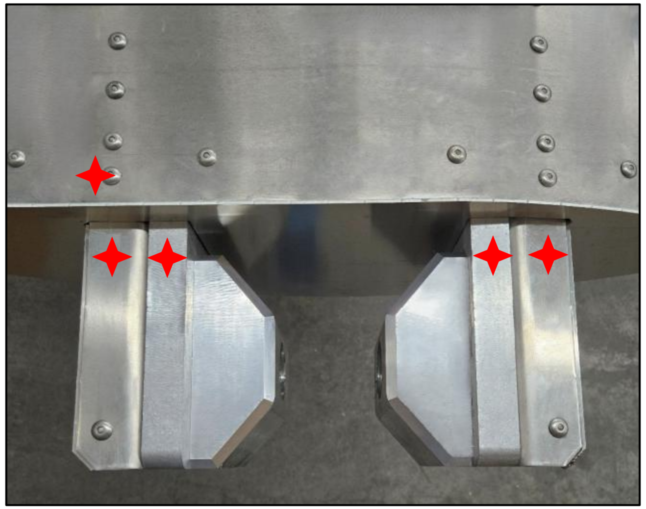
Physical Life Testing

- Fan assembly testing with increased power per blade
- Induces all natural stresses: aerodynamic, centripetal, torsional
- Target number of high stress cycles as determined by Acceleration Factor.
  - Ex: 60 days of Life Testing equivalent to 10 years of operation

$$Acceleration\ Factor = \left(\frac{70\ [bhp]}{25\ [bhp]}\right)^4 = 61.5$$

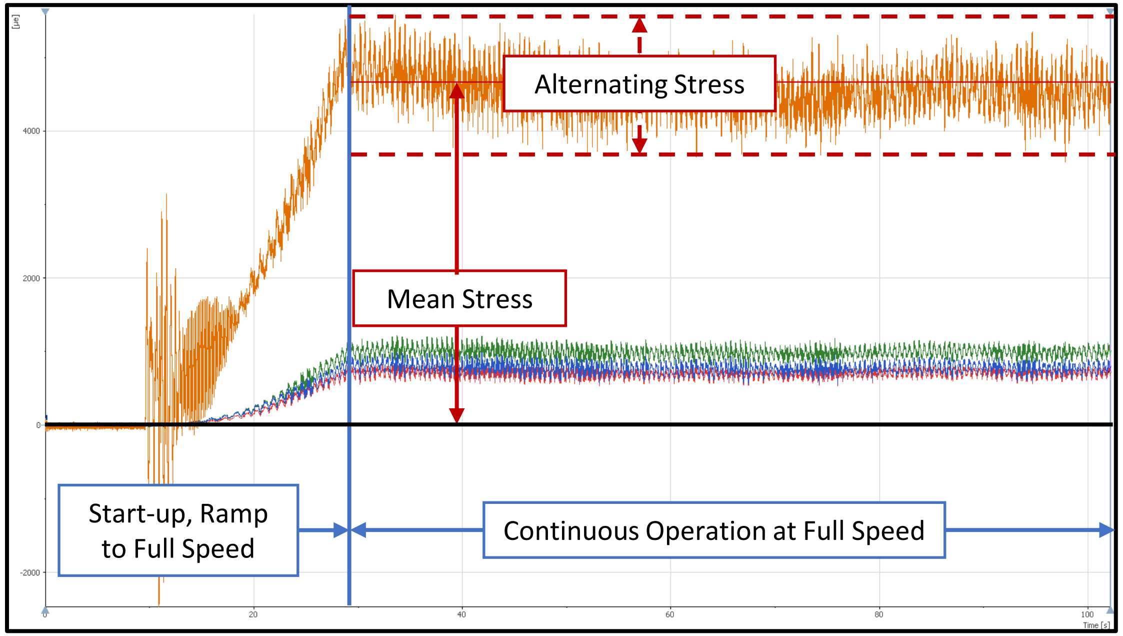
$$Accelerated\ Life\ Test = \frac{3650\ [days]}{61.5} = 59.4\ [days]$$

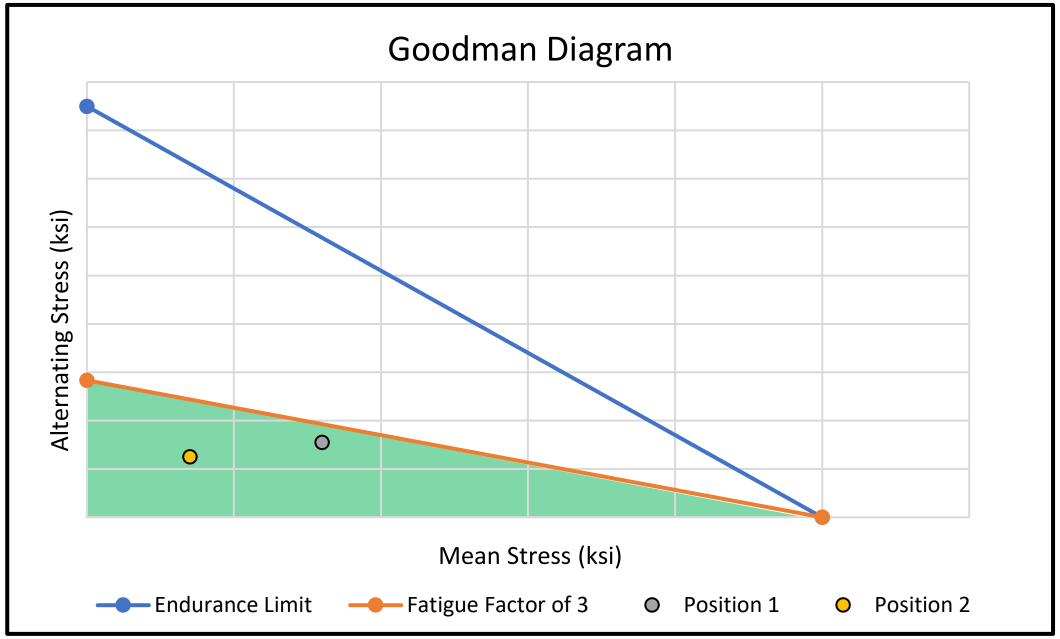
- Critical locations strain gaged and monitored during test
- Aerodynamic performance confirmed



Physical Life Testing

- Stress measured and plotted on Goodman Diagram





- Confirmed "infinite life" even under amplified loading, with conservative factor of 3 margin

Design Iteration and Improvements

- Vulnerable points identified
- Design adjustments can be made:
  - Part geometry
  - Fastener patterns
  - Reinforcements
  - Material selection
- Quick iterations of: Design → Analyze → Test → Redesign
- Improvements always possible

Conclusion

- Complete engineered solution to meet the demands of ACCs
- Design process that validates Design Objectives
  - ✓ High aerodynamic efficiency
  - ✓ Structural design that holds designed loads
  - ✓ Fatigue resistance for long life
  - ✓ Corrosion resistant materials
  - ✓ Easy assembly and installation
  - ✓ Low maintenance
- Proven reliability in the field

Questions

More Information

moorefans.com/resources/tech-notes-engineering-papers/