REEF Subsonic Wind Tunnel Articulating Robotic Arm

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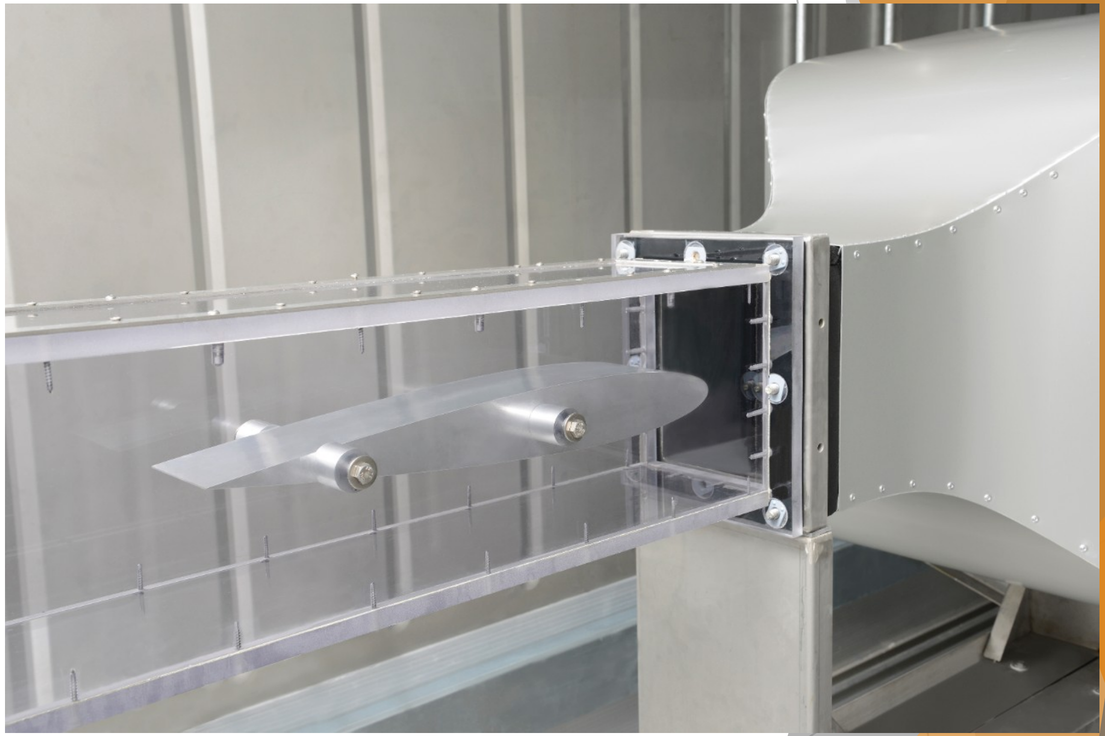
What is a Wind Tunnel?

- Research tool to recreate flight conditions
- Cost effective controlled environment
- Models scalable through the use of dimensionless properties

NASA Wind Tunnel, 2 Strut Specimen Mount

Open and Closed Test Sections

Open Test Section



Closed Test Section

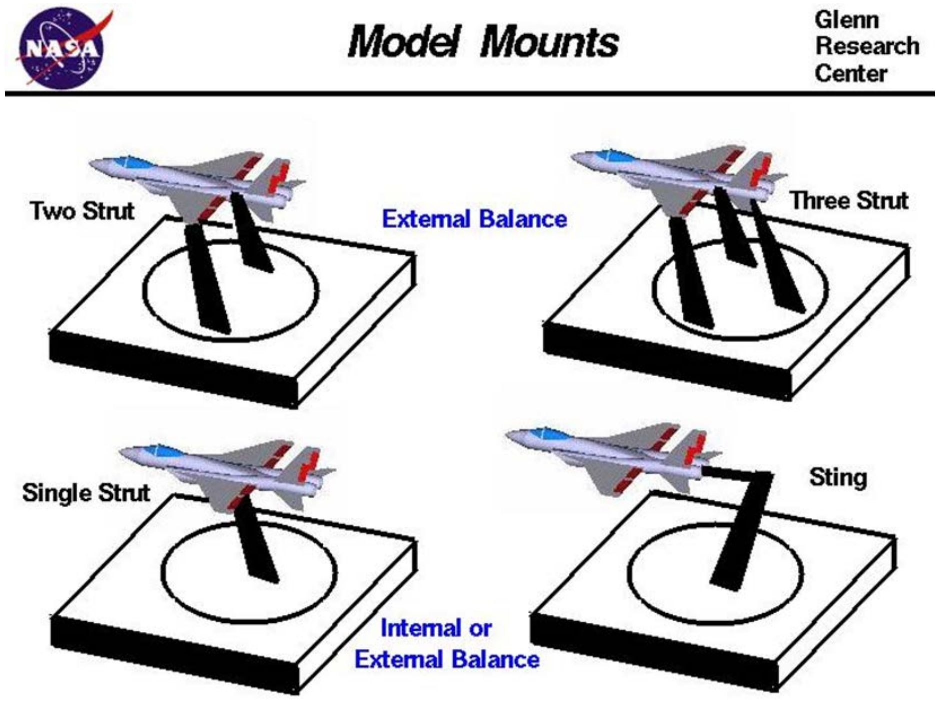
Test Specimens in Wind Tunnels

Example of a sting mounted model

Testing the aerodynamic properties of a truck

Specimen Mount Designs

- Researched strut and sting mounts for design considerations
- Sting design chosen
  - Less intrusive
  - Less effect on upstream flow
  - Can maintain location easily



Example Models of Various Mounts

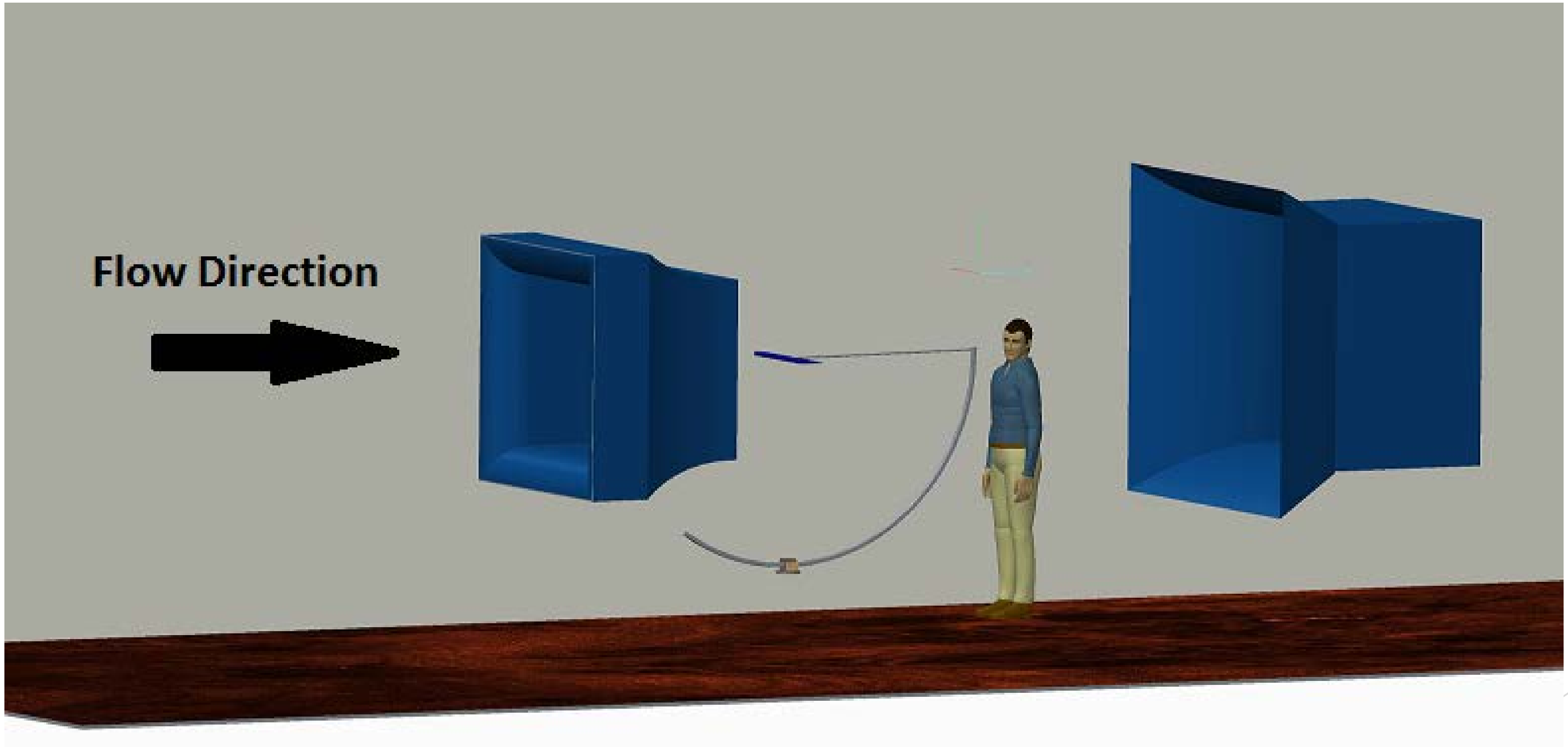
Problem Statement

- To produce a cost effective articulating robot arm for use in an open section subsonic wind tunnel for the REEF facility
  - The current arm and mount are being removed, therefore a new system is needed in order for testing to continue
  - Need a cost effective solution with limited resources and budget
  - Quotes from companies that will design/build systems exceed $100,000
  - Working with a budget of $2,000

Design Constraints

- Model must remain centered during manipulation
    - Center of rotation for pitch and yaw to be fixed
- Minimally flow intrusive mounting system
    - Maximum blockage (<10%)
- Range of Motion: ±30° angle of attack and ±20° yaw
    - Resolution of ± 0.1º
- 42”x42” tunnel jet inlet
    - Center of the inlet is 82” off ground

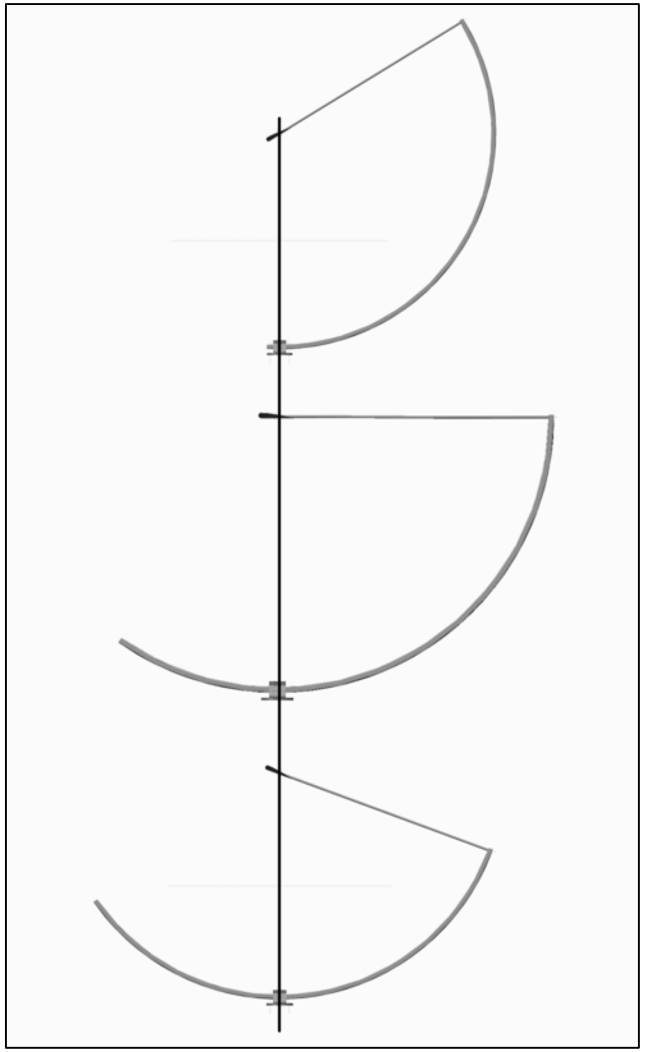
Open Section Wind Tunnel with Arc

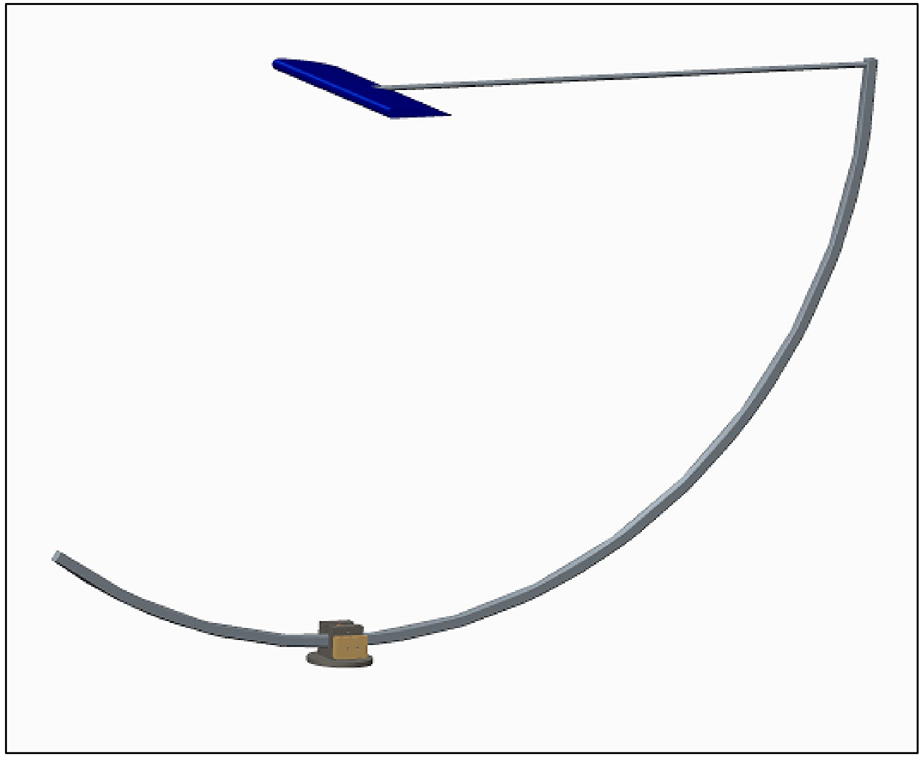


Design Concept – Structural Design

- Circular arc to adjust pitch while maintaining model in center
  - Arc will be actuated at the base with a stepper motor
- Turn table under model center to adjust yaw
- Designed to have least impact on flow
- Rhomboidal arc cross-section for aerodynamic flow
- Circular cross-section for sting mount
- Factor of safety > 3

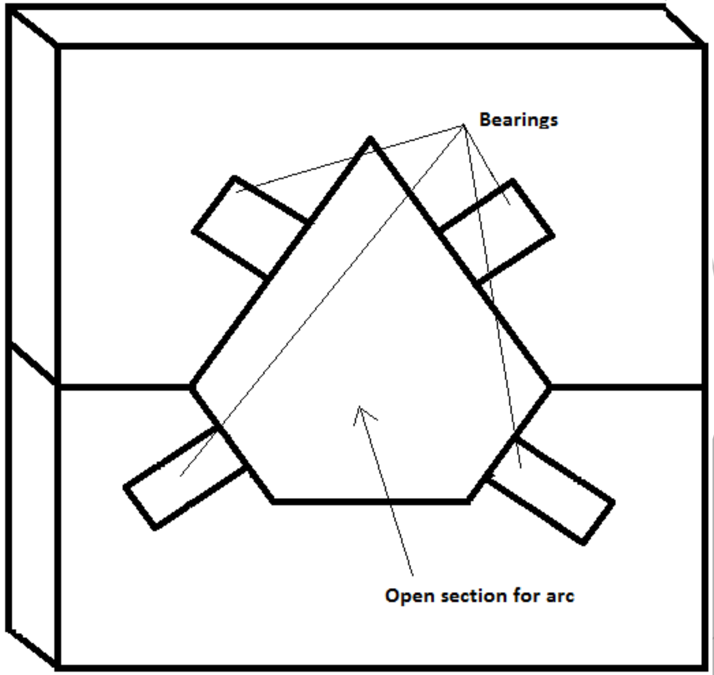
Design Concept - How it Works





Design Concept - How it Functions

- Arc mounted at base
  - Utilize bearings
- Underside of arc will have teeth for actuation
  - Gear train
- Stepper motors for
  - Actuation of arc (pitch)
  - Turn table (yaw)
- Frontend will be designed with LabView
  - Input desired pitch and yaw



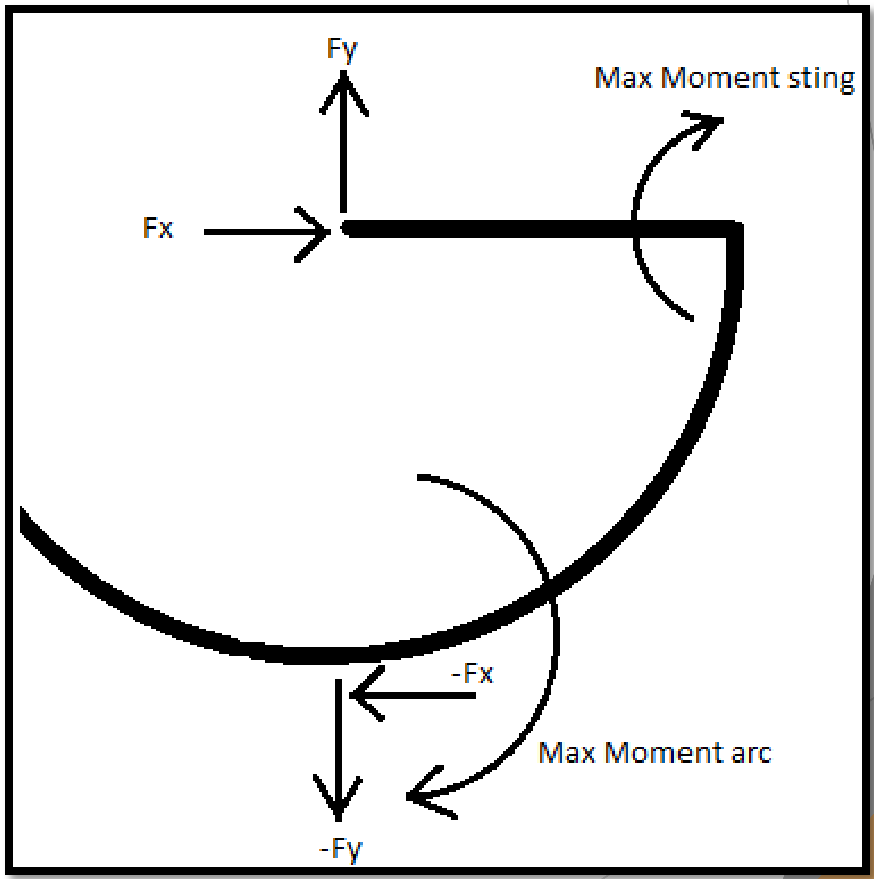
Potential mounting system

Assumptions for Load and Moment Calculations

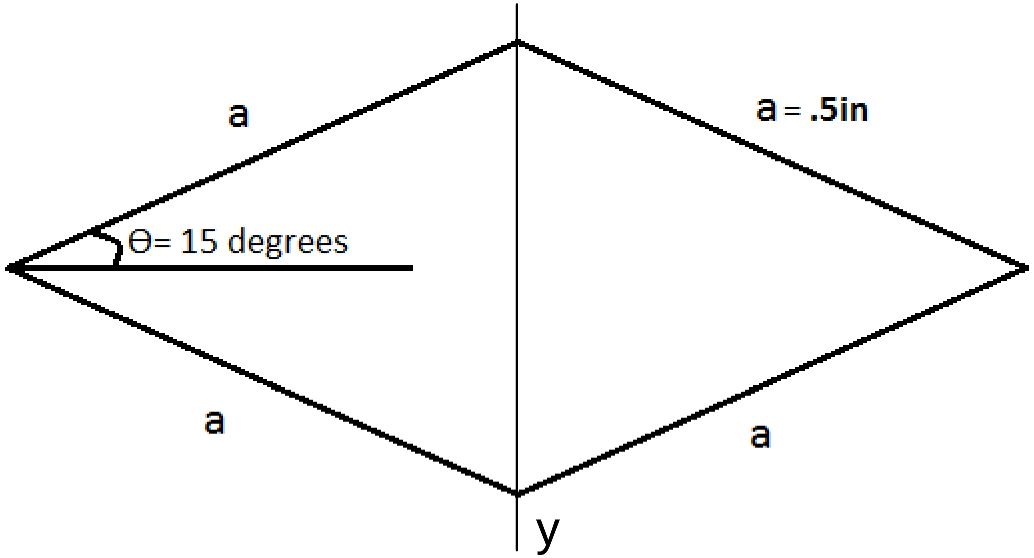
- Maximum flow blockage by the system of 10%
- Maximum lift coefficient of 2
- Max coefficient of drag
  - 0.1 for rhomboidal cross-section
  - 1 for specimen
- Multiplier of 1.5 to account for unsteady loads
  - Prior to factor of safety

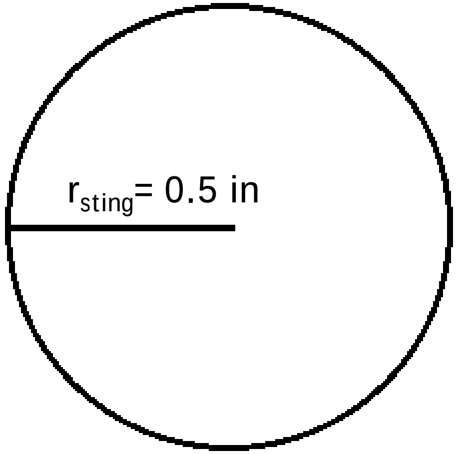
Analysis - Forces and Moments

- $F_x = F_{D-specimen} + F_{D-arc}$
  - $F_{D-specimen} = q_\infty A_{max} * C_{D-specimen\, max}$
  - $F_{D-arc} = q_\infty A_{arc\, in\, flow} * C_{D-arc\, shape}$
  - $q_\infty = \frac{1}{2} * \rho_{air} V_{max}^2$
- $F_y = F_L$
  - $F_L = q_\infty A_{max} * C_{L-max}$
- $MaxMoment_{sting} = F_y * l_{sting}$
- $MaxMoment_{arc} = F_x * r_{arc}$



Analysis - Arc and Sting Cross-sections





$$A_{rhomboid} = a^2 * \sin(2\theta) = .281\ in^2$$

$$A_{circle} = \pi r_{sting}^2 = 0.785 in^2$$

$$I_{yy\ rhomboid} = \frac{1}{3} a^4 \sin(\theta) \cos(\theta)^3 = 0.025 in^4$$

$$I_{circle} = \frac{1}{4} \pi r_{sting}^4 = 0.049 in^4$$

Analysis - Principle Stress and Factor of Safety

$$\sigma_{bend\ arc} = \frac{(M_{arc\_max} * y_{max})}{I_{yy\_rhomboid}}$$

$$\sigma_{bend\ sting} = \frac{(M_{sting\_max} * y_{max})}{I_{circle}}$$

$$\tau_{xy\_arc} = \frac{4 * F_y}{3 * A_{arc}}$$

$$\tau_{xy\_sting} = \frac{3 * F_y}{2 * A_{sting}}$$

$$\theta_{1,2} = \frac{\theta_{bend}}{2} \mp \sqrt{\left(\frac{\theta_{bend}}{2}\right)^2 + \tau_{xy}^2}$$

$$n = \frac{\theta_{\max\_allowable}}{\theta_{1,2}}$$

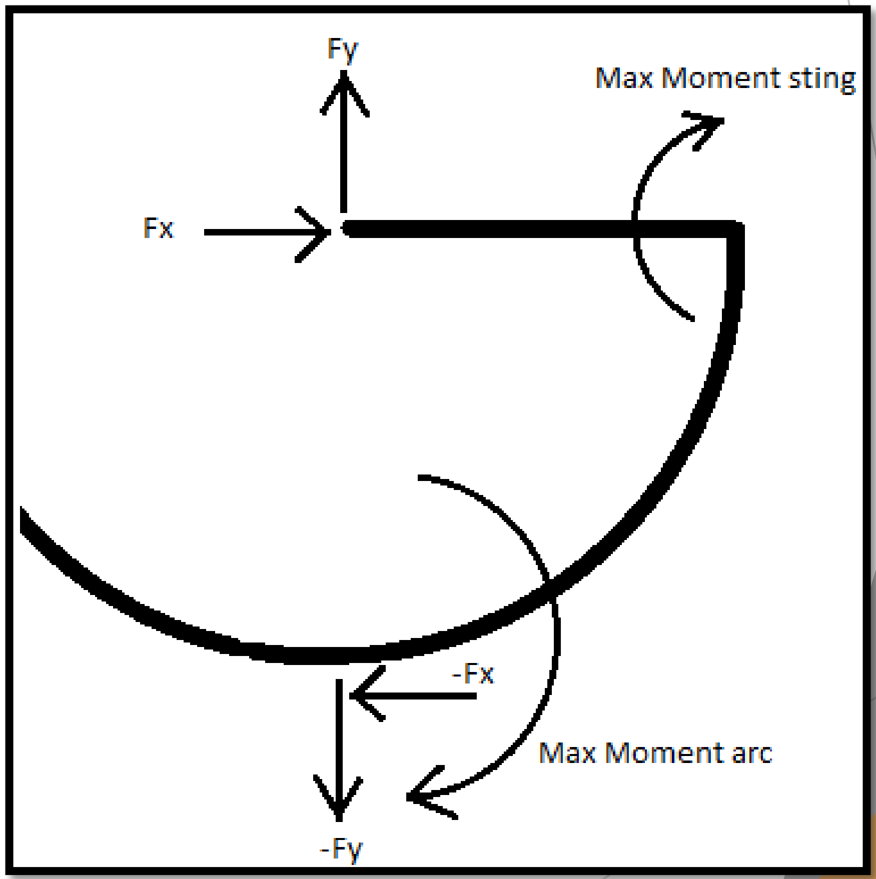
Jacob Kraft

Analysis - Results

- Material selection
  - 6061 Aluminum
- Arc radius and sting rod length
  - 4ft = 48in
- Factors of safety (N) based on chosen dimensions and materials
  - $N_{sting} = 3.5$
  - $N_{arc} = 9$
- Bearing reaction force (Fy)
  - 67N at base of arc

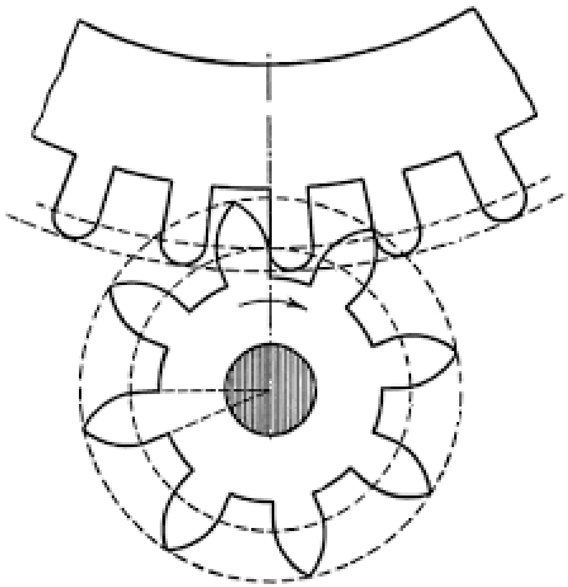
Analysis - Motor Selection

- Compound gear train
- Motor and gear train must supply torque **greater than the moment** for actuation
- Must supply a minimum 11.5 N*m of holding torque
- Specifications of motor will depend on budget and desired actuation speed



Challenges

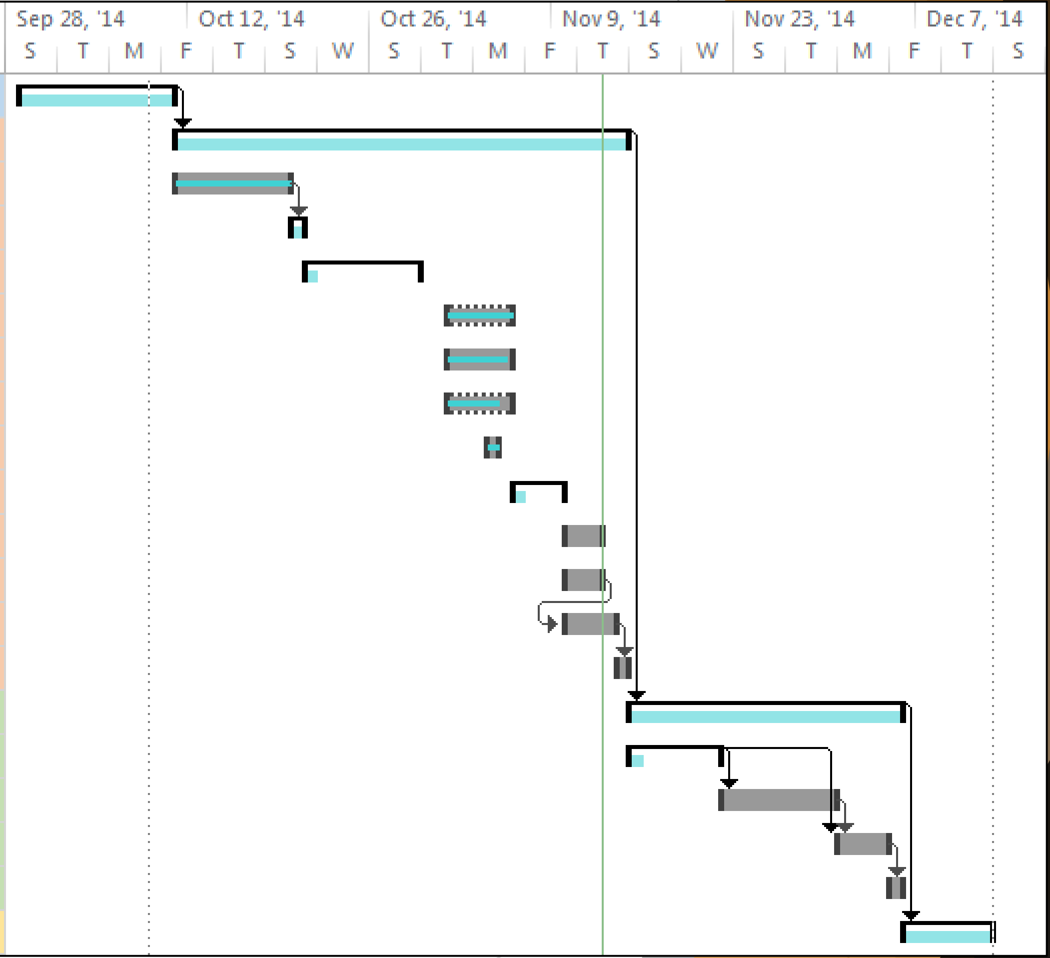
- Design system of actuation for arc
- Machining of arc
  - Gear teeth along length of arc
  - Arc mounting
- Possible instability
- Staying within allotted budget



Example Gear Mesh for Arc Actuation

Schedule

	Task Name	Duration	% Complete
✓	**Intial Design Formation**	**10 days**	**100%**
	Preliminary Design	**26 days**	**63%**
✓	Coordinate Visit to REEF	7 days	100%
✓	**Visit Facility and Meet with Sponsor**	**1 day**	**100%**
✓	**Make Adjustments to Design Based on Facility Visit**	**7 days**	**100%**
✓	Determine Actual Structure Dimensions	4 days	100%
	Determine Primary Material	4 days	95%
	Approximate Weight of Structure	4 days	75%
✓	Meet with Advisor	1 day	100%
	Calculations	**3 days**	**60%**
	Design Circuitry	3 days	0%
	3D Model Preliminary Design	3 days	0%
	Discussion of Preliminary Drawings with Sponsor	4 days	0%
	Receive Design Feedback	1 day	0%
	Final Design	**16 days**	**0%**
	Make Adjustments to Design Based on Discussion with Sponsor	**6 days**	**0%**
	Run Final Calculations and 3D Model Testing	7 days	0%
	Submission and Sponsor Approval of Final Drawings	4 days	0%
	Final Design Drawings Complete	1 day	0%
	Purchase of Materials and Parts	**6 days**	**0%**



Future Work

- Dimensioned drawings with appropriate tolerances for completed design
- Check specifications of sponsor donated components against needs
- Appropriate stepper motor (responsible for pitch) selection
- Design the circuitry of electrical components
- Programming of user interface
- Purchase orders for all parts and materials to construct design

Questions

Would you like to follow our project?

Check out our website!

http://eng.fsu.edu/me/senior_design/2015/team12/

References

- Wind Tunnel Image: http://www.nasa.gov/audience/forstudents/k-4/stories/what-are-wind-tunnels-k4.html#.VGFFcfnF-So
- Closed Section image: http://www.european-coatings.com/Raw-materials-technologies/Production-and-testing/New-wind-tunnel-allows-anti-icing-tests-under-realistic-conditions
- Open section image: http://www.rtri.or.jp/rd/maibara-wt/English/ID3.HTML
- Pitch gif: http://www.grc.nasa.gov/WWW/k-12/airplane/Animation/airpar/Images/aptch.gif\
- Yaw gif: http://www.grc.nasa.gov/WWW/k-12/airplane/Animation/airpar/Images/ayaw.gif
- Jet in tunnel: http://www.nasa.gov/content/unitary-plan-wind-tunnel-11-by-11-foot-transonic-test-section/#.VGEAF2PYHTo
- http://www.ramforum.com/f41/roof_spoiler-46649/index3.html