MECH 460 Team Design Project 2018: Active Rocket Apogee Control for Queen's Rocket Engineering Team

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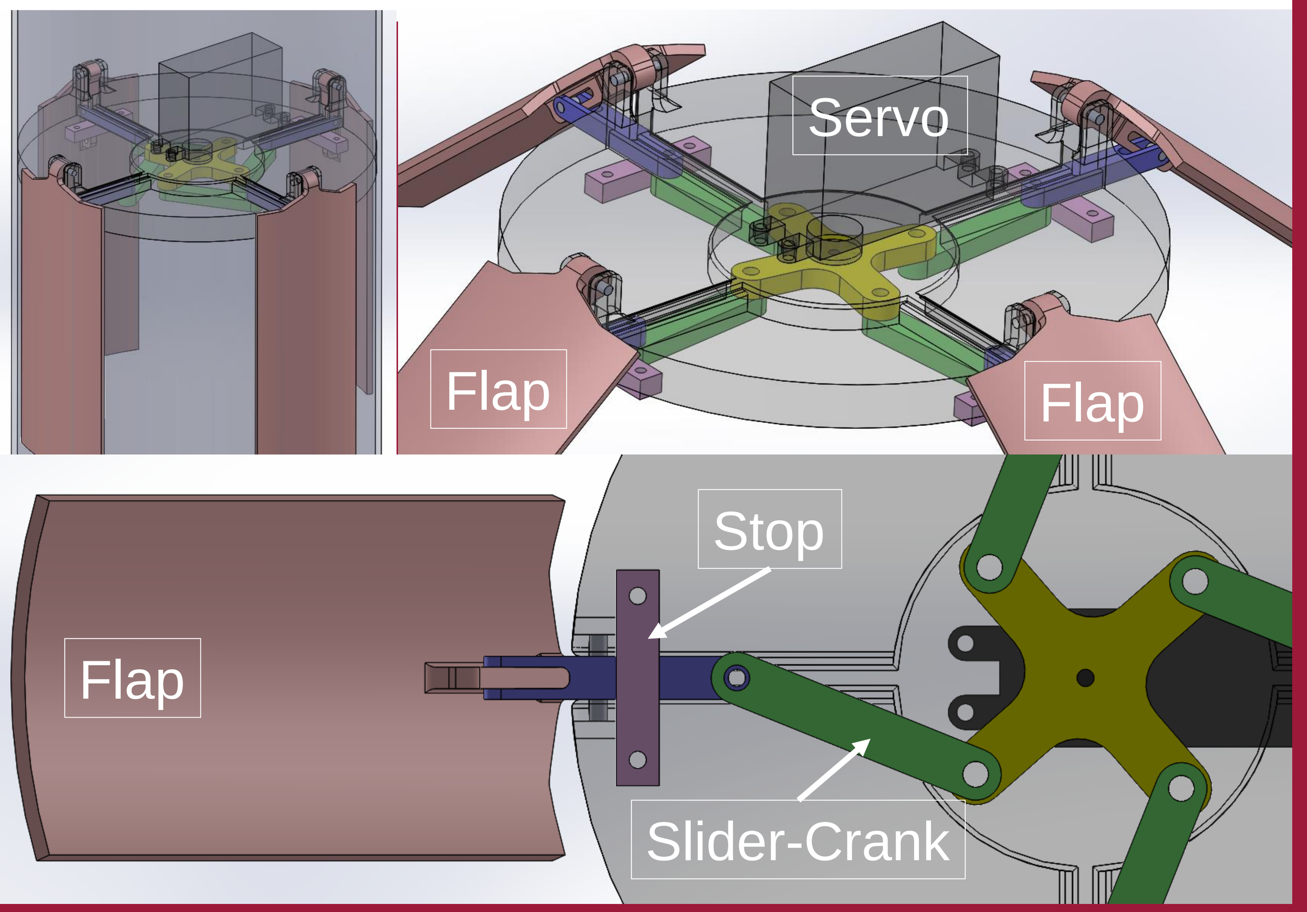
ABSTRACT

A system, referred to as the Active Rocket Apogee Control (ARAC) system, was developed for the Queen's Rocket Engineering Team (QRET) by which the apogee of their rocket, Brigid, may be controlled. The ARAC system functions by actively adjusting the drag coefficient, C_d, of the rocket during flight such that the target apogee of 3,048 m (10,000 ft) is achieved. To adjust C_d, flaps actuated by a servomotor protrude from the surface of the rocket and into the free-stream air during flight, increasing Brigid's effective area. A high-level control model was developed, identifying the key inputs required for system autonomy. Analysis of the fluid flow at various rocket speeds was conducted to determine fluid behaviour and drag magnitude caused by the flaps. Additionally, analysis was conducted to confirm the mechanics of the system will handle the expected aerodynamic loads.

CAD MODEL

A 3D model of the ARAC system was developed which featured four flaps symmetric about the rocket tube. When actuated by their respective slider-crank mechanism, the flaps enter the free-stream air around the rocket, increasing the drag force. The mechanisms are powered by a single servomotor such that each flap actuates equally; the mechanism was limited to flap angles up to 45º by mechanical stops to prevent singularity. The weight of the system was minimized to decrease affects on Brigid's centre of mass. The components were also designed to fit within the rocket tube.



COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS

Objectives:

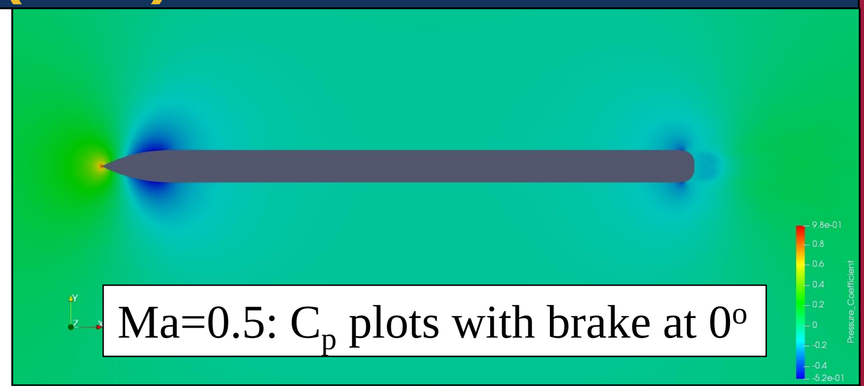
- Determine maximum aerodynamic loads on the flap.
- Investigate CFD's ability to determine the change in drag.
- Investigate re-circulation region behind the flap.
- Determine safe operating velocities for flap deployment.

Methodology:

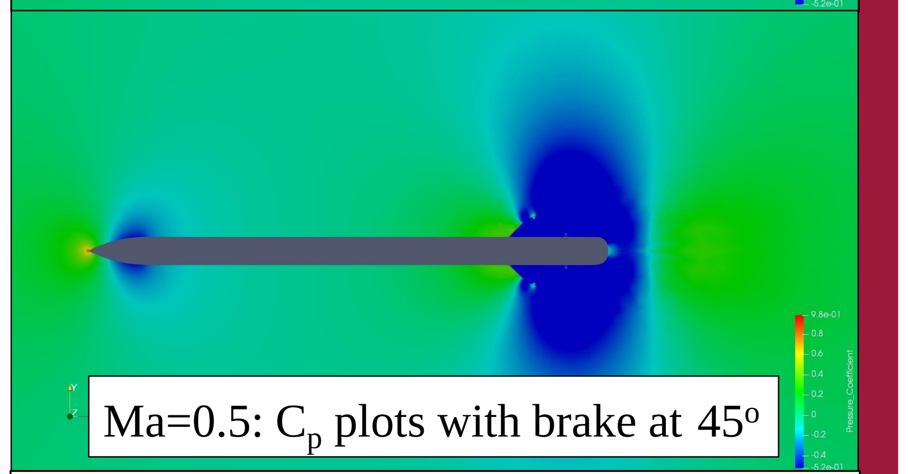
- Hybrid structured mesh made in Pointwise.
- Brake at 0º: 0.3 million cells, brake at 45º: 1.2 million cells
- 2-D RANS steady state simulation using SU² CFD software
- Mach (Ma) = [0.2, 0.3, 0.4, 0.5, 0.6] tested
- Computed on the computer cluster at the Advanced Aircraft Design Lab at RMC.

Results:

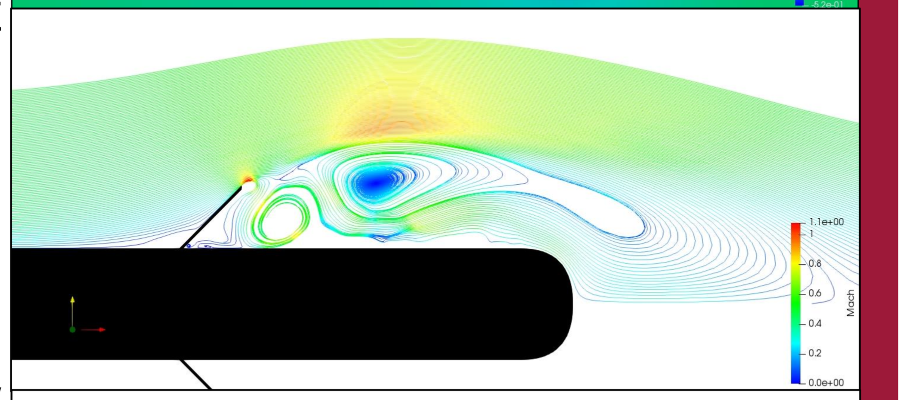
- Drag did not match empirical models at low speeds.
- Recirculation region grew past rocket base for Ma>0.4
- Deploying airbrake at Ma>0.5 deemed risky due to flow acceleration close to Ma=1. Weak shocks may form.
- Max load on flap determined to be 427N at Ma = 0.6 and 45º flap angle.
- To maintain stability, flap actuation at Ma>0.25 will be limited to below 45º regardless of drag required for apogee. More analysis required to determine specific ranges.



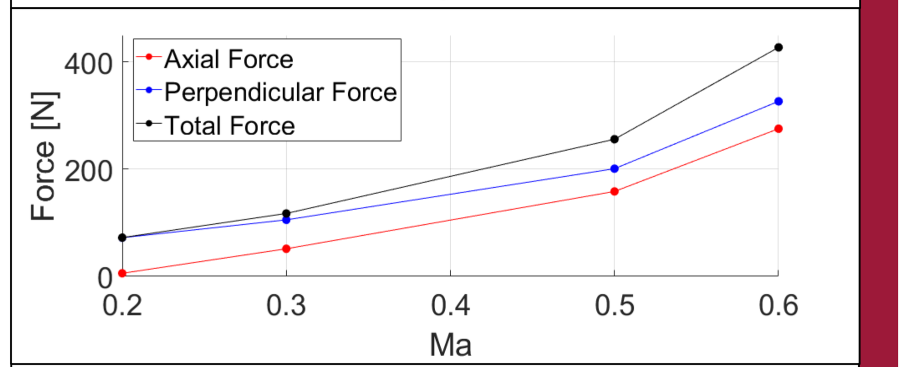
Ma=0.5: C_p plots with brake at 0º



Ma=0.5: C_p plots with brake at 45º



Recirculation regions at Ma=0.5



Ma vs Aerodynamic force on 45º flap

FINITE ELEMENT ANALYSIS (FEA)

Objectives:

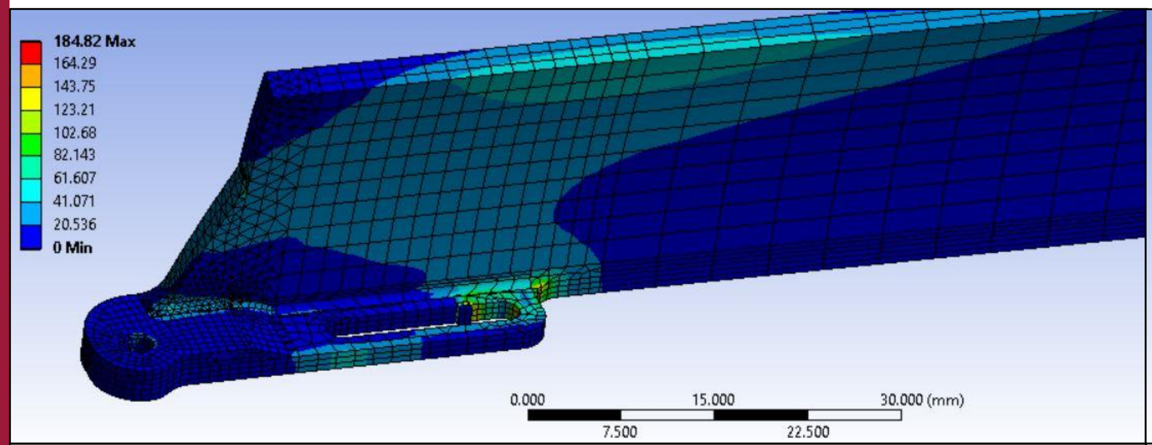
- Ensure mechanical components will not fail under aerodynamic loads determined from CFD

Methodology:

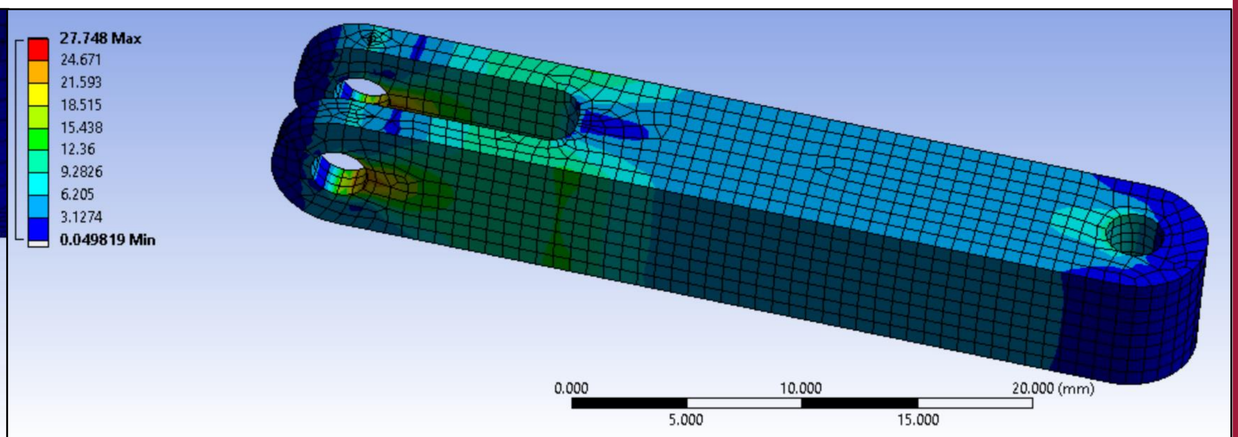
- Von Mises stress and deflection of Al 6061 considered: σ_y = 276 MPa, E = 68.9 GPa, v = 0.33
- Failure constraints: δ_{Flap}<2 mm; $\delta_{Linkage}$<0.5 mm; SF_{σ}>1.5
- Structured hexahedral mesh mainly used with few tetrahedral elements required to accommodate complex geometries.
- Fine mesh density applied in areas of interest and naturally occurring stress concentrations.
- Singularities caused by boundary constraints ignored as these do not exist in real system.
- Single, steady state, maximum load case of 100N (Mach 0.25, 45º flap angle) applied to flap.
- Reactions that maintain boundary conditions applied in appropriate direction to following part.

Results:

- Yield limit satisfied with minimum safety factor of 1.68 on flap's neck; maximum deflections in tolerable range for flap and all linkages.

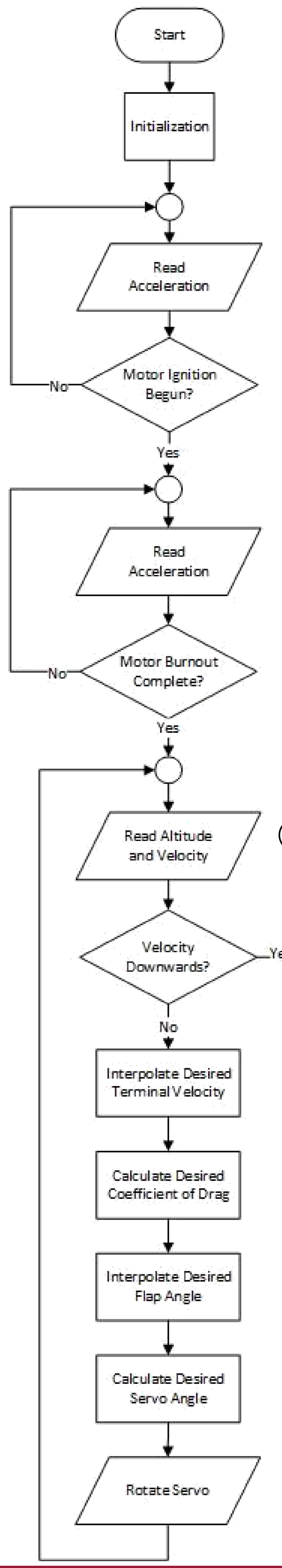


Flap stress contour plot [Mpa]



Linkage stress contour plot [Mpa]

CONTROL SYSTEM



Key Components:

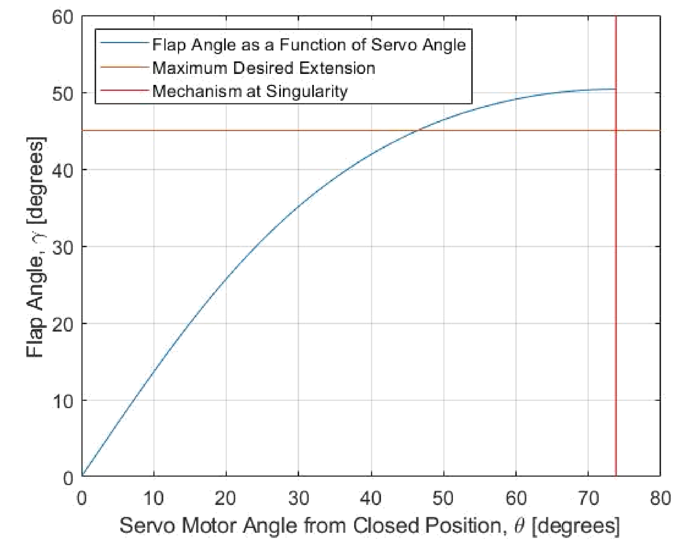
- Microcontroller
- Accelerometer
- Servo
- Altimeter
- Pitot tube

Apogee Prediction:

$$z_{max} = \frac{v_t^2}{2g}\ln\left(\frac{v^2+v_t^2}{v_t^2}\right)+z$$

Where:

- z_{max}: Apogee
- v_t: Terminal Velocity
  - $v_t = \sqrt{\frac{2mg}{C_d \rho A}}$
- z: Current Alt.
- v: Current Velocity
- g: Gravity
- m: Mass
- C_d: Coefficient of Drag
- ρ: Air Density
- A: Area



CONCLUSIONS AND RECOMMENDATIONS

CFD analysis revealed that flap actuation could increase rocket drag to significantly affect apogee. At speeds above Ma 0.4, the recirculation bubble may impinge on fin effectiveness. At speeds above Ma 0.25 and angles of 45º, minor asymmetricity in flaps may cause instability. It was recommended that the airbrake be limited in actuation above Ma 0.25 to prevent instability; further analysis required to better define angular limits depending on Ma. It was also recommended that a 3D CFD model be made to study vortex affects on fin effectiveness and stability. The maximum load on a single flap was limited to be 100N based on Ma 0.25 and flap angle of 45º. FEA of the mechanics concluded the design would safely handle these loads. An assembly level contact analysis was recommended to better calculate deflections. Testing was recommended to confirm slider-crank mechanism will not seize under loaded deflection.

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