CubeSat Functionality and Microgravity Testing Platform: Aerodynamics

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Agenda

• Overall Program
  – Background
  – Objectives
  – Operations

• Aerodynamics Team
  – Objectives
  – Background
  – Preliminary Analysis
  – Original Design
  – Updated Design
  – Results
  – Conclusions
Overall Program
Program Background

• NASA Grant
  – Evaluate the microgravity research method of dropping package from high elevation

• Microgravity
  – Pull of gravity is very weak
  – Need to know how things react in space
  – Research techniques exist, but are very expensive
Program Background
Current Technologies

• “Vomit Comet”
  – Aircraft
  – Parabolic flight path
  – 20-25 seconds microgravity

• Drop Tower
  – Drag shield
  – 2.2 seconds of microgravity
Program Objectives

• Develop high quality, inexpensive microgravity testing platform
  – Evaluate the concept of a microgravity testing platform dropped from a balloon at high altitude
  – Microgravity quality of $1 \times 10^{-3}$ g or better
• Investigate practical microgravity quality experienced during drops
• Investigate costs of operation
Program Operations
Design Teams

• Manufacturing and Assembly
• Recovery, Frame/Nose Cone Design
• Communications and Data Acquisition
• Aerodynamics
• Attitude Control
Program Operations
Platform Design

- Drop methodology
  - Weather balloon
  - 30,480 m (100,000 ft.) AMSL
- 20 seconds free fall
  - CubeSat technology
- Parachute Deployment
- Recovery
Aerodynamics Team
Team Objectives

• Determine optimal aerobody design to provide highest quality microgravity
  – Lower coefficient of drag=Lower drag
    =Better microgravity
  – Better restoring moments
• Experimentally quantify drag
• Locate center of pressure
• Experimentally determine restoring moments
• Observe boundary layer effects
Background – Aerobody Shape

• Two profiles based on Goldschmeid design
  – Well known aerodynamicist in 1960s
• Low Coefficient of Drag
• Passive boundary layer control
  – Controls flow separation
  – Lowers the pressure drag on the body
Background – Boom and Tail Fins

• Original design incorporates boom and tail fins
  – Shifts center of pressure further aft of the center of gravity
  – Greater restoring moments

• Consequences
  – Very heavy compared to rest of design
  – Can induce vibrations

Original design w/ boom and tail fins
Background – Turbulator Tape

• Additional passive boundary layer control
• Causes turbulent flow to develop earlier on the body
  – Helps lower pressure drag at the back of the body
• Used in industry
  – Airplanes
  – Wind Turbines

“Zig-Zag” tape from Wings and Wheels
Dimpled tape from Wings and Wheels
Background – Wind Tunnel Mount

- Tooling Foam Centrepiece
- Datum Rod
- Threaded Rod Mount
- Threaded Aluminum Sleeve

Wire frame model of mounting system
Background – Wind Tunnel Mount

Monocoque mounted in wind tunnel

Drag Force

Mount

Air
Preliminary Analysis

• Wind Tunnel – Testing Apparatus
  – Strain gauges on cantilever beams measure deflection due to drag and lift forces
  – Calibrate drag force to corresponding strain gauge voltage
  – Resistive wiring heats glycerin to create smoke for streamlines
Preliminary Analysis

• Wind Tunnel – Streamline Tests:
  – Resistive wires coated in glycerin
    • Creates consistent smoke trail
    • Low heat of vaporization
  – Resistive wiring can be moved horizontally or vertically, parallel to the wind tunnel walls
    • Allows for proper streamline placement
  – Visualize flow separation location
    • Locate separation point over range of Reynolds numbers
    • Compare separation location to cusped designs
Preliminary Analysis

• Wind Tunnel - Drag Quantification:
  – Assumptions:
    • $C_D$ is a function of Re only
    • Re at ground level can be equated to Re at elevation
  – Wind tunnel velocity equation:
    \[
    v_G = \frac{\mu_G \rho_E}{\mu_E \rho_G} v_E
    \]
  • Testing velocities become much smaller
Matching Flight Conditions for Wind Tunnel Testing

- Velocity (m/s)
- Time (s)
- Re

Graph showing the relationship between velocity, time, and Re.
Original Design – Restoring Moments

• Two sets of load cells measure drag and lift forces
• Lift and drag operate through center of pressure
  – Both cells measure at center of mass
  – Restoring moment is observed at center of mass
• Lift measurements at varied angles of attack
Original Design – Center of Pressure

• Center of pressure location affects freefall behavior
  – Restoring moments depend on location
  – Helps determine use of X- and Y- axis reaction wheels

• Theoretical determination
  – Goldschmied paper includes plot of static pressure coefficient as function of body length

• Experimental determination
  – Pressure taps along body, measure static pressure and sectional diameter
  – In practice, results were inconclusive
Original Design – Center of Pressure
Original Design – Center of Pressure

\[ CP = \frac{\sum \left( \frac{1}{2} C_P \rho \infty v \infty^2 + P \infty \right) xL}{\sum \left( \frac{1}{2} C_P \rho \infty v \infty^2 + P \infty \right) L} \]

Center of Pressure for Original Design

- CP Sum: 14.923, 47.998
- CP (m - in): 0.3109, 12.200
- CP % (x/L): 0.49961

Goldschmeid Pressure Distribution

Free Stream C_p

BLC Cusp Location

Goldschmeid Pressure Distribution
Cusp Design

Cusp Vertex

Aftbody

Forebody

\[ U_0 \]

\[ \epsilon \]
Drag Coefficients for Various Designs Over a Range of Reynolds Numbers: With Boom and Tail Fins

- Original Design
- Original Design w/ Turbulator Tape
- Ringleb Cusp Design
- Ringleb Cusp Design w/ Turbulator Tape

CD vs. Re

Reynolds Numbers: 4.0E+04 to 1.2E+05

CD: 0.00 to 0.50

Inset: Photo of a model rocket with boom and tail fins.
Drag Coefficients for Various Designs Over a Range of Reynolds Numbers: Without Boom and Tail Fins

- Original Design
- Original Design w/ Turbulator Tape
- Ringleb Cusp Design
- Ringleb Cusp Design w/ Turbulator Tape

Re

$C_D$

4.0E+04 5.0E+04 6.0E+04 7.0E+04 8.0E+04 9.0E+04 1.0E+05 1.1E+05 1.2E+05

0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50
Results

Flow Separation on Original Design
Results

Flow Separation on Final Design
Conclusions

• Final design won’t be determined until after initial test flights
• Any design with the boom will increase the drag
• Initial cusp design results are very encouraging
• Turbulator tape results are also encouraging
Questions?
Appendix
Original Design– Drag Quantification
Original Design– Drag Quantification
Cusp Design – Testing Results

Cusp, No Boom, No Turbulator Tape

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Turbulator Tape – Testing Results

Turbulator Tape, With Boom

Re

1.50E+04 3.50E+04 5.50E+04 7.50E+04 9.50E+04 1.15E+05

C₀

0.15 0.25 0.35 0.45 0.55 0.65

Turbulator Tape – Testing Results

Turbulator Tape, No Boom

![Graph showing test results for Turbulator Tape, No Boom across different trials and Re values.]

- 3-15-2017 Trial 1
- 3-15-2017 Trial 2
- 3-26-2017 Trial 1
- 3-26-2017 Trial 2

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