Dynamic Propagation of Discrete-Event Drag Modulation for Venus Aerocapture

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Aerocapture Overview

- Orbital maneuver to capture into orbit using atmospheric drag
- Anticipated large savings in mass and cost compared to traditional propulsive capture
- Unlike aerobraking (repeated trips through atmosphere), aerocapture is accomplished via single atmospheric pass
Aerocapture Control

**Lift Modulation**
- Changes in the L/D of vehicle used to alter trajectory
  - Bank angle control or angle-of-attack control

**Drag Modulation**
- Changes in ballistic coefficient, $\beta$, of vehicle used to alter trajectory
  - Continuous or discrete-event drag modulation
Vehicle Overview

Vehicle 1
- Aeroshell + Drag Skirt
- $m = 68.3$ kg, $A = 1.77$ m²
- $\beta_1 = 31.42$ kg/m²

Vehicle 2
- Aeroshell
- $m = 36.2$ kg, $A = 0.12$ m²
- $\beta_2 = 274.7$ kg/m²

Ballistic Coefficient Ratio
$\beta_2/\beta_1 = 8.74$
Study Overview

Objectives:
• Is the vehicle stable before, during, and after the jettison event?
• If using a separable drag skirt, what is the likelihood of re-contact after jettison?

Analyses:
• CFD simulations:
  • Generate static aero database for each vehicle configuration
  • Analyze tip-off forces and moments during jettison event
  • Dynamically propagate aeroshell / drag skirt following jettison
  • Probabilistically constrain risk of re-contact

• Ballistic range testing:
  • Validate CFD simulation results
Cart3D Overview & Benefits

Cart3D CFD Software:
• Supports steady-state and **time dependent** solutions
• Component-wise analysis allows for dynamic motion of related bodies
• Built-in features for aero database generation and dynamic propagation
Static Aerodynamics

Aeroshell Aerodynamic Coefficients, $M = 40$

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<th>$\alpha$</th>
<th>$C_D$</th>
<th>$C_L$</th>
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Density Profile, $M = 40$

Compared to Pioneer Venus aerodynamics: $C_D \sim 1.05$, minimal variation with $\alpha$
• Working throughout summer with NASA Ames to develop CU dynamic simulation capabilities
• Simulation goals:
  • Run over range of potential trajectories (M, α)
  • Probabilistically constrain risk of re-contact
  • Investigate other drag skirt shapes (e.g. ADEPT)
Ballistic Range Validation

- Ballistic range testing will be performed at Ames throughout FY19
- Results will help validate CFD stability results and dynamic propagation simulations
Summary

• Discrete-event drag modulation is being used in a mission concept to Venus

• CU Boulder is responsible for CFD simulation capabilities to further investigate drag skirt jettison event

• Results & work-to-go:
  • Static aero database capabilities have been developed
  • Develop dynamic simulation capabilities through summer 18
  • Simulate range of trajectories to probabilistically constrain risk of instability / recontact
  • Ballistic range testing through FY19 to validate simulation results
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