Orion Touchdown Heading Control

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At touchdown Orion must be aligned so that the crew person's feet are forward in the direction of the horizontal velocity. To ensure that this requirement is met active heading control is being implemented on the Orion crew module. This technique reduces probability of roll-over during splashdown, assures axial loads on the crew at touchdown, and alleviates structural requirements on impact allowing for a light-weight structural design. On-board sensors are used to measure current vehicle orientation and horizontal velocity used in generation of the heading error signal. Linear velocity measured by the IMU drifts while under parachutes due to wind gusts and has to be corrected by GPS; this makes GPS critical for successful landing. Jet fire logic is achieved by use of a phase-plane and commands are realized by using roll jets from the reaction control system (RCS); using pre existing hardware eliminates additional hardware and structural requirements. Touchdown performance is measured by an orientation envelope that was co-developed with structures so that the performance requirements overlap adding system redundancy. Heading control also introduces new difficulties to be addressed such as parachute line twist torque as well as increasing vehicle sensitivity to wind shifts and sea states. Solving these difficulties requires added complexity to flight software as well as increasing the propellant required to achieve successful touchdown. While offering promising results, the criticality of GPS along with a significant propellant cost raises questions on the effectiveness of using touchdown heading control.

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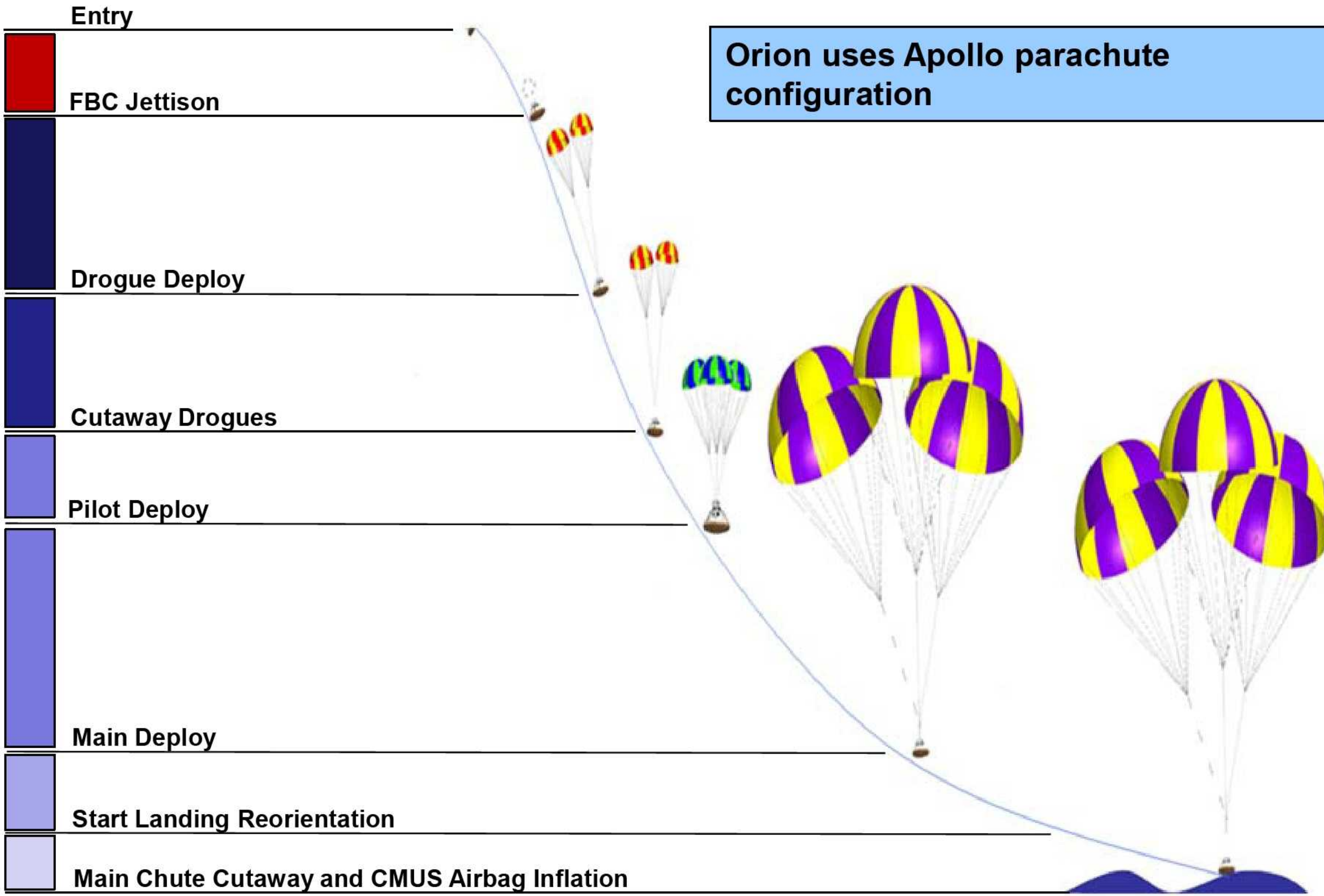
Overview

- Parachute Sequence
- Vehicle Configuration
- Why Heading Control is Used
- Touchdown Heading Control Design
- Anti-Twist Control
- Aerodynamic Drivers
- Current Reaction Control Regions
- Closing Comments

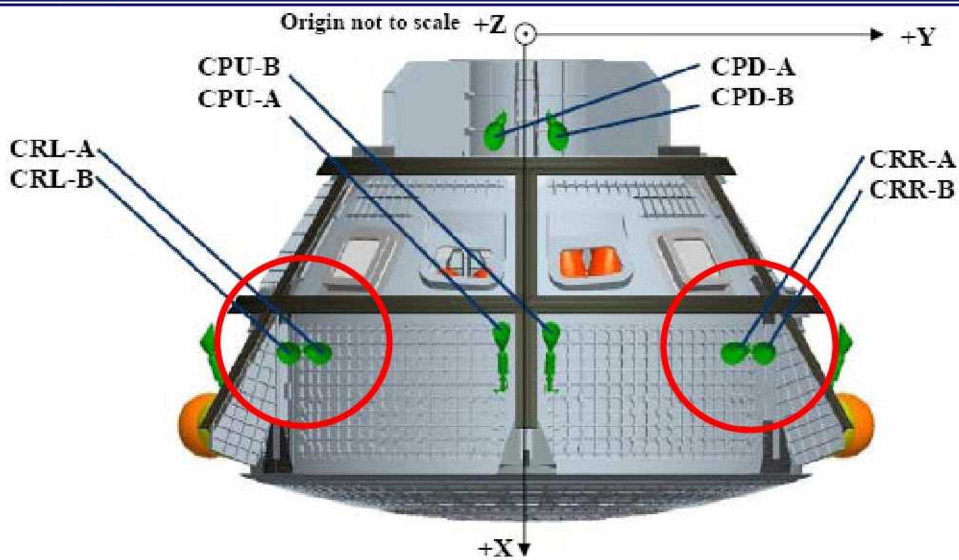
Parachute Sequence

Touchdown Heading Control

Orion uses Apollo parachute configuration

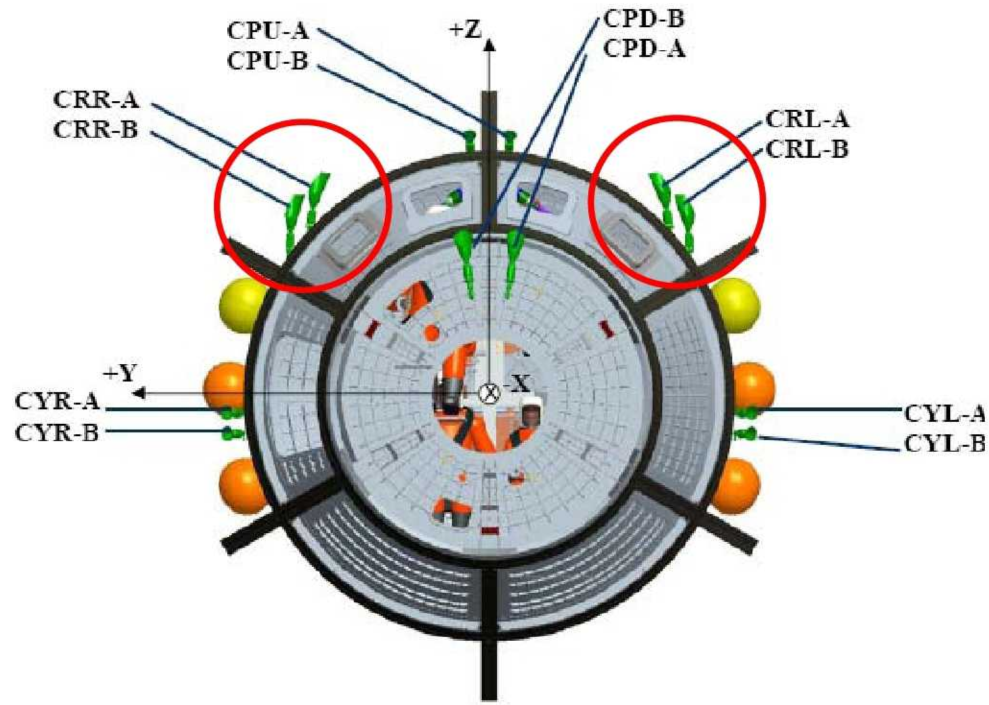


Heading Control Effectors



Jet ID Code: 123-4
1: C – CM RCS
2: RPY – Roll, Pitch, Yaw
3: RLUD – Right, Left, Up, Down
4: AB – String A or B

- **Hydrazine Thrusters**
- **6 jets per string (+/-roll, +/-pitch, +/-yaw)**
- **2 redundant strings of jets**
  - ➢ **12 total jets; one fault tolerant**
- **Both strings can be used simultaneously**
- **Only roll jets are used for touchdown heading control**

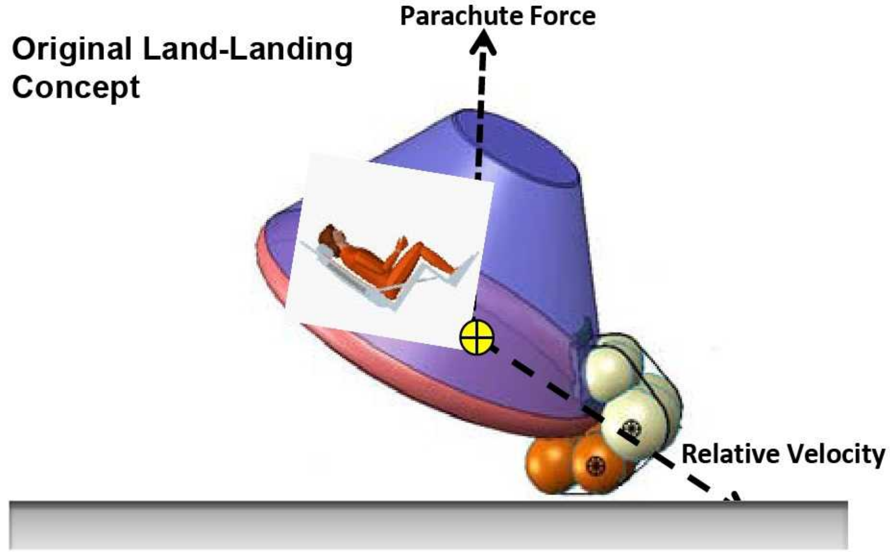


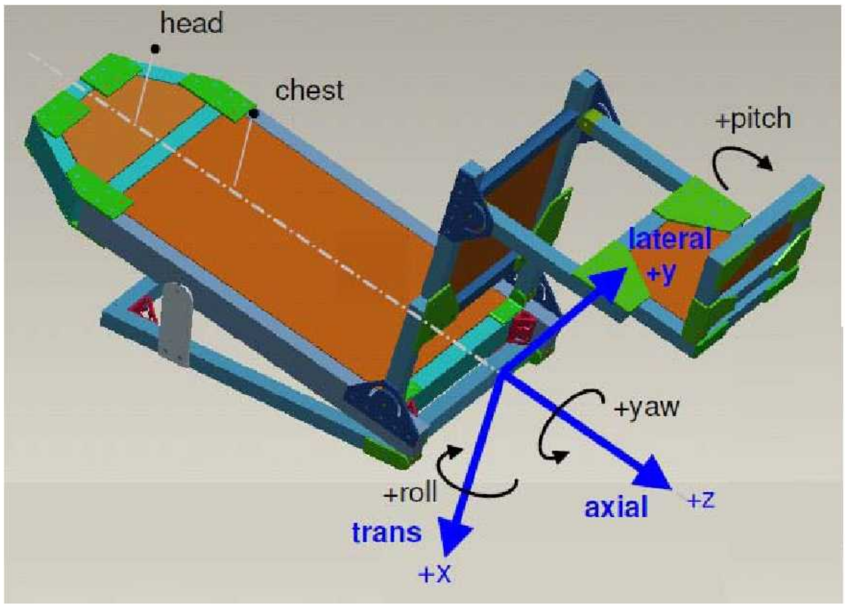
Why Heading Control?

REQUIREMENT:

At touchdown, the capsule must be aligned so that the crew person's feet are forward in the direction of the horizontal velocity.

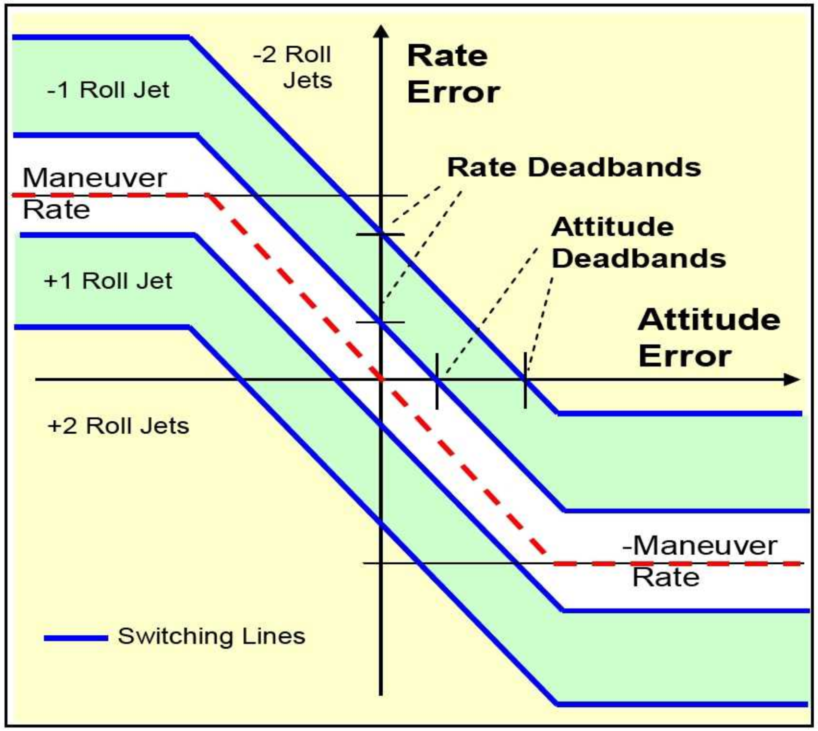
- **Originally required to orient vehicle for airbag impact.**
  - **Airbags have been replaced by crushable structure for water-landing**
- **Axial Impact is easier on the crew**
- **Volume limitations restrict seat stroke**
  - **Larger axial seat stroke when compared to lateral stroke**
  - **8 in stroke along x and z axis**
  - **4 in stroke along y axis**



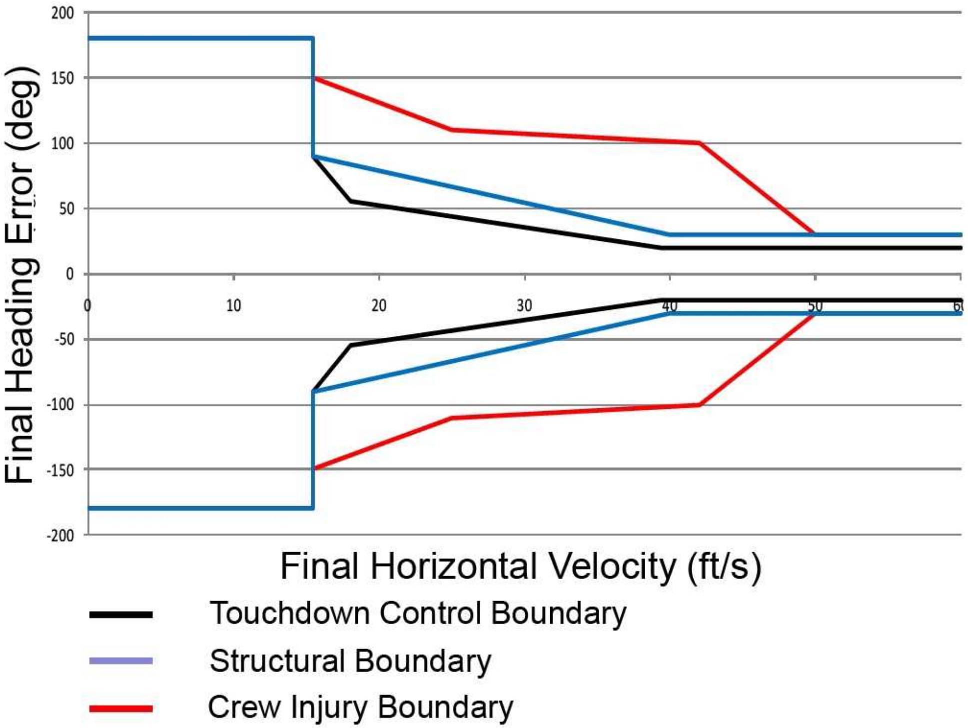


Touchdown Control Design

Rate and Attitude Errors are used in conjunction with the touchdown control phase plane to determine jet firings.



Performance Boundaries



Success is determined by the performance boundaries:

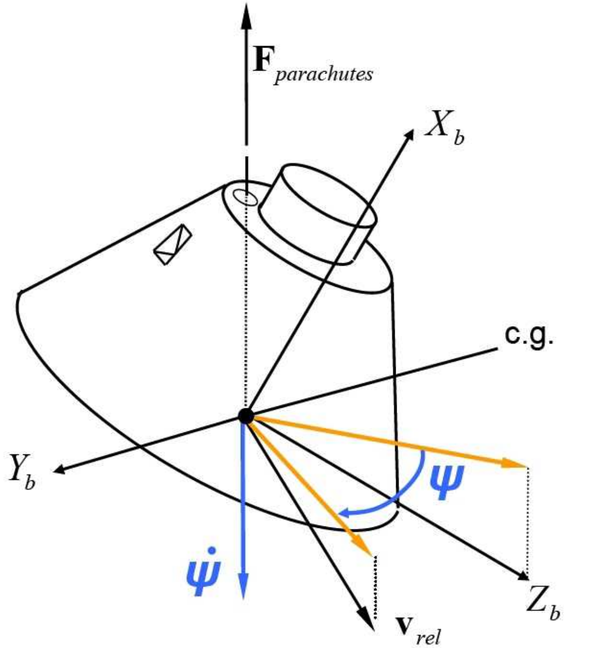
- There is no requirement at low horizontal velocities
- As horizontal velocity increases, the orientation requirement becomes more restrictive

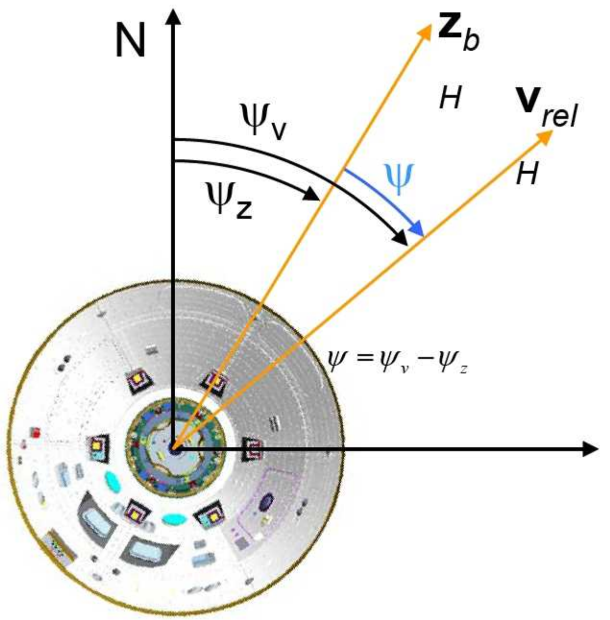
Boundary requirements overlap to ensure crew safety.

Calculation of Heading Error

Heading is the difference between the direction of the horizontal velocity and the orientation of the vehicle in the topodetic frame.

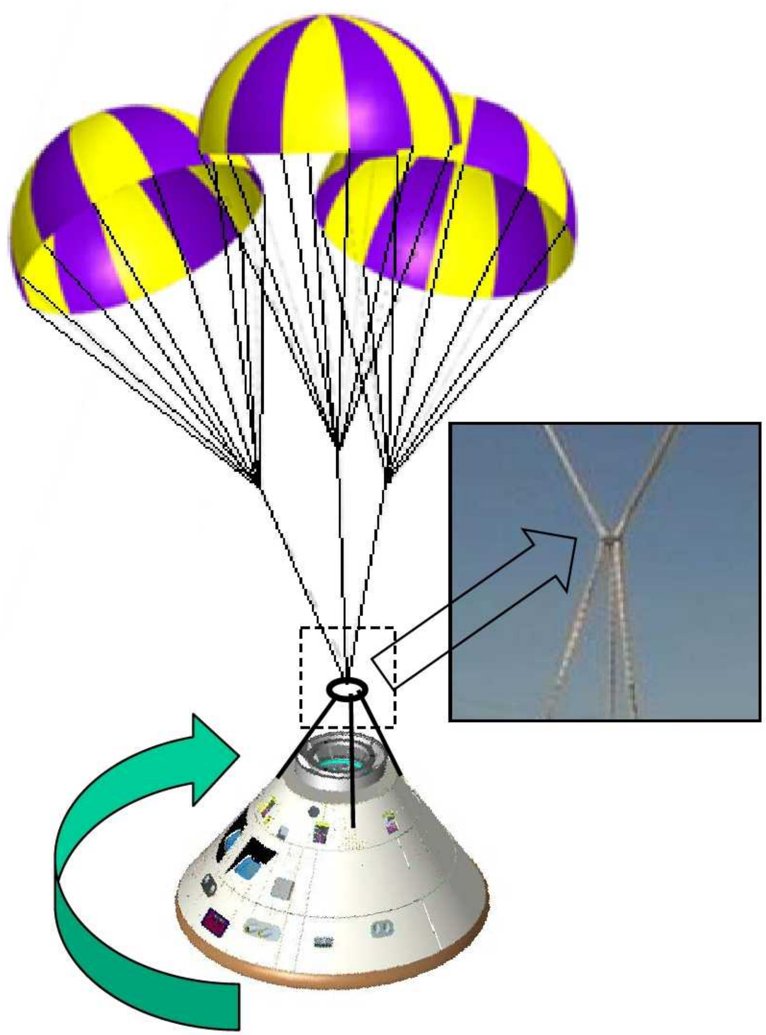
- On-board IMU measures body orientation
- GPS is used for determination of the relative horizontal velocity
  - GPS is critical to generate an accurate heading error ; the linear accelerometers in the IMU do not provide an accurate horizontal velocity and are corrected by GPS
  - At low velocities navigation does not provide an accurate heading error primarily due to wind-shift changes and sensor noise

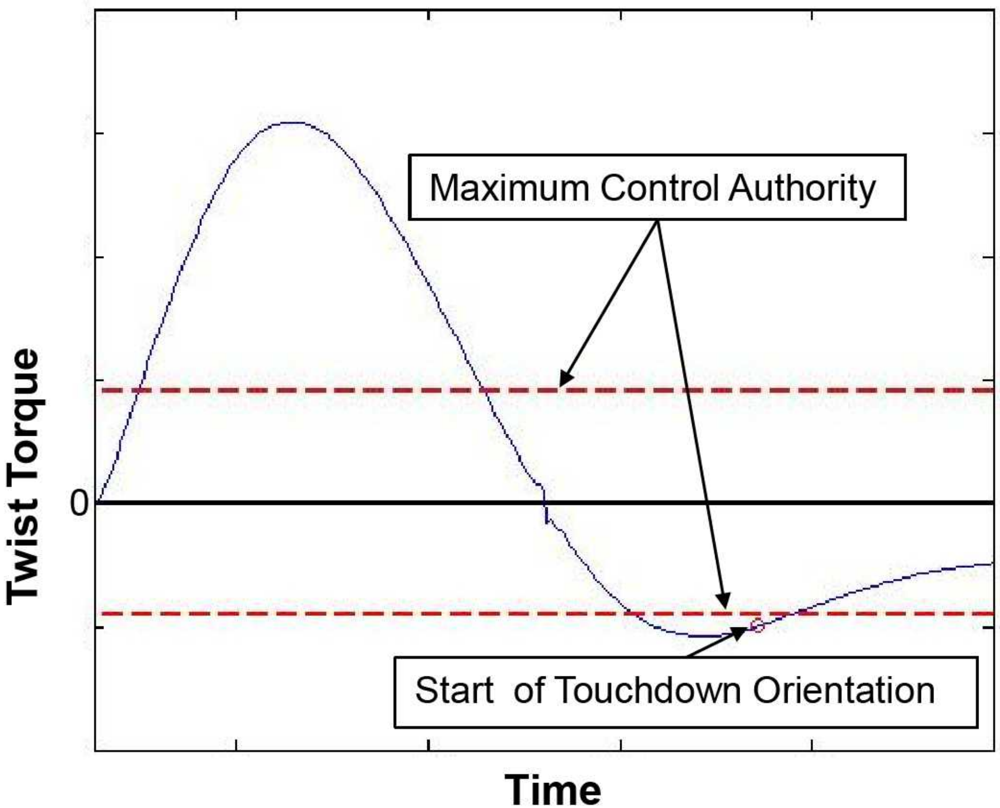




GPS is critical for heading calculation.

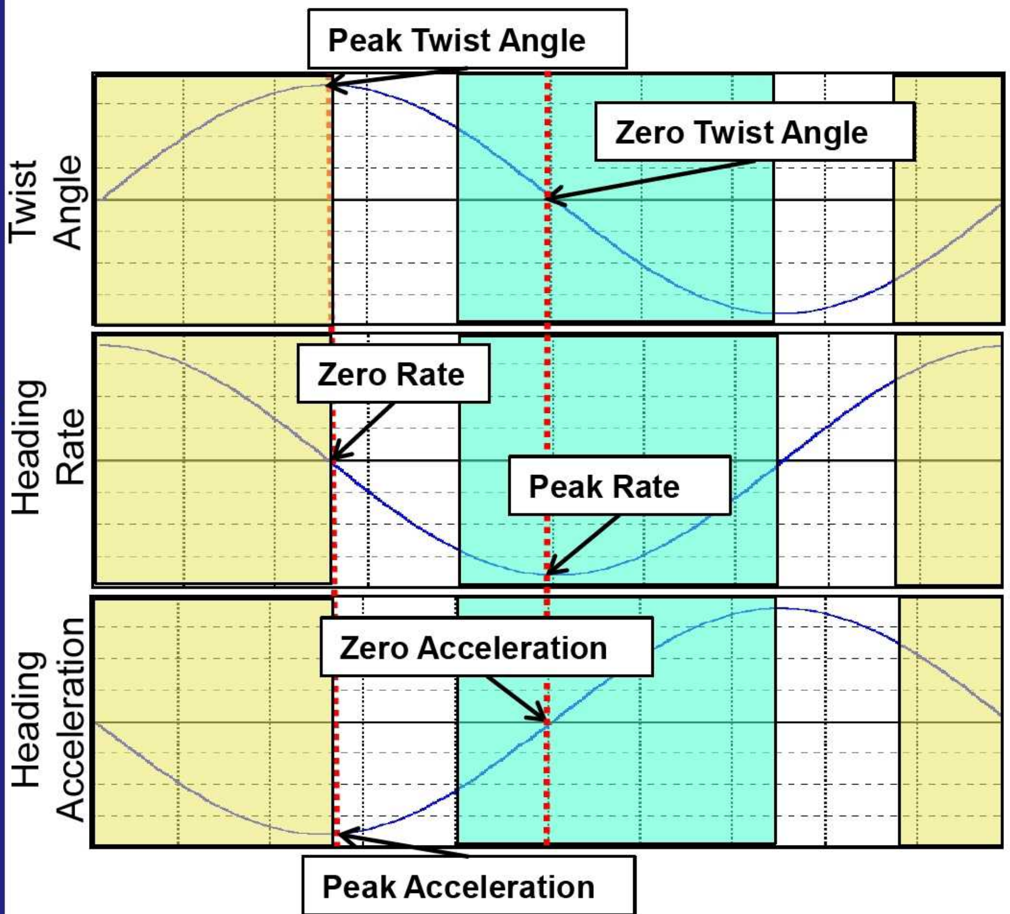
Parachute Line Twist Torque



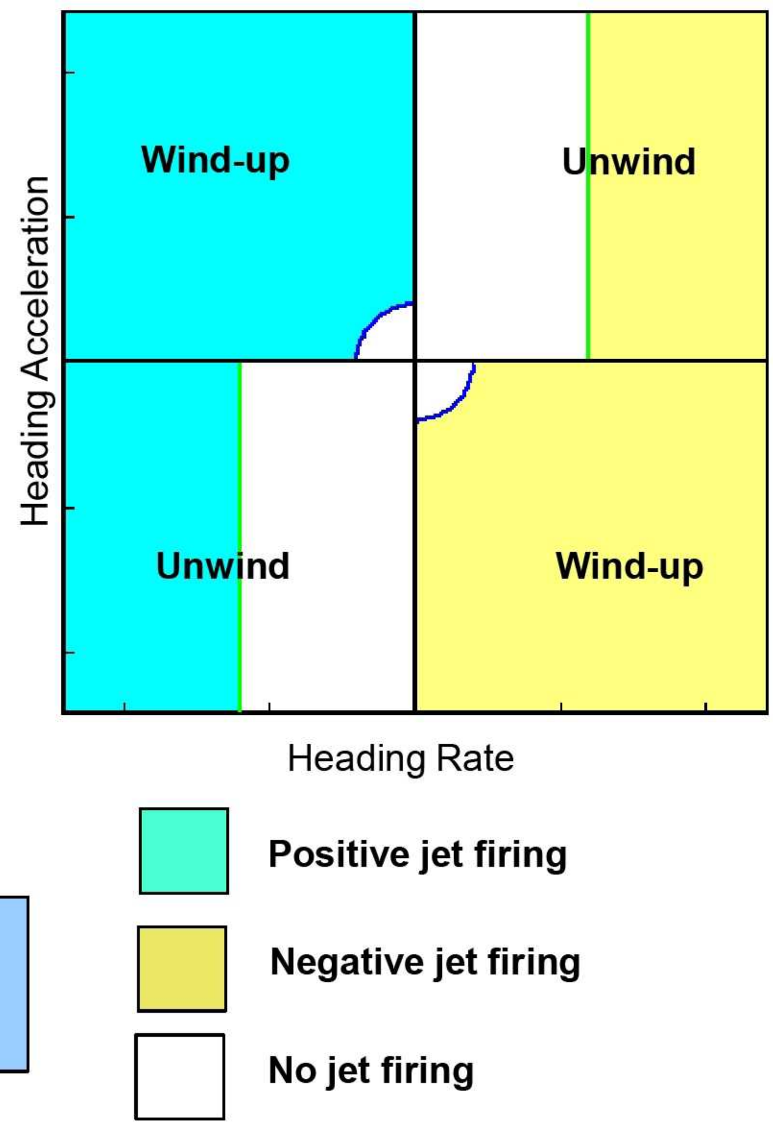


Twist torque can exceed control authority impacting heading control performance

Anti-Twist Control



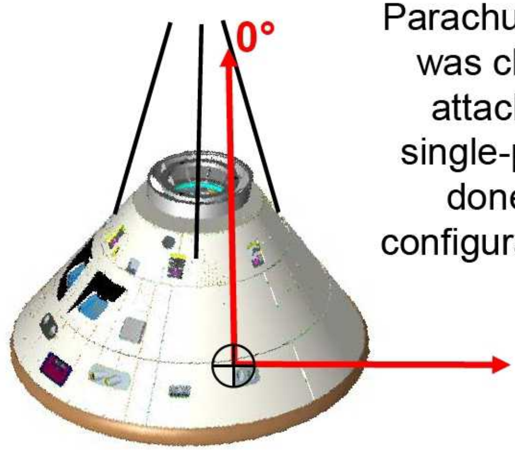
Anti-Twist Phase Plane



Anti-twist control allows the vehicle to unwind while preventing wind-up thus improving performance and a reducing propellant cost

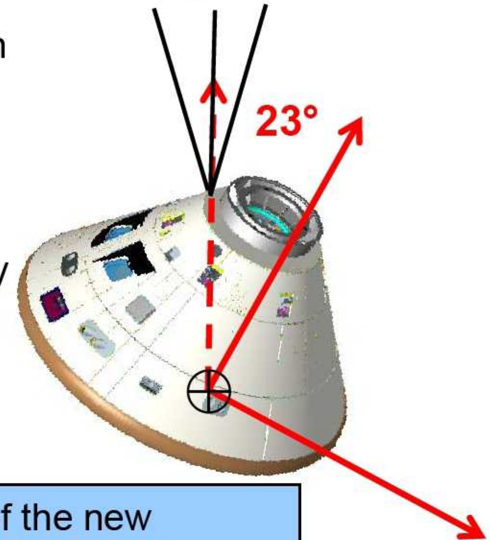
Parachute Attach Changes

Modified Apollo: Multi-Attach Configuration

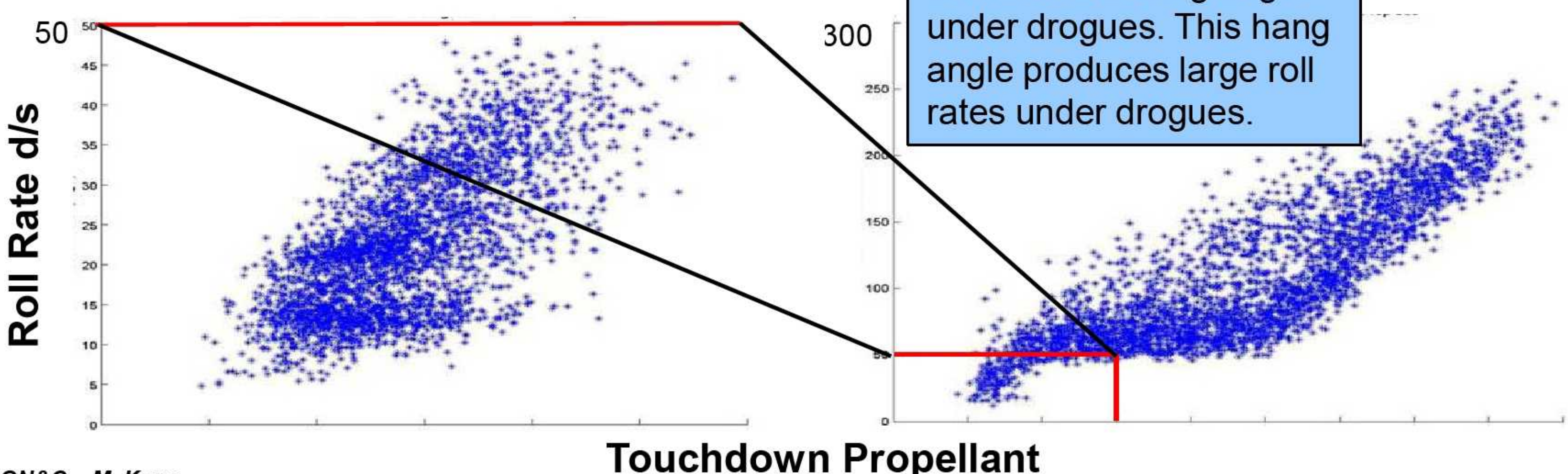


Parachute attach configuration was changed from a multi-attach configuration to a single-point attach. This was done to simplify mortar configuration needed to deploy chutes.

Apollo: Single Point Attach Configuration

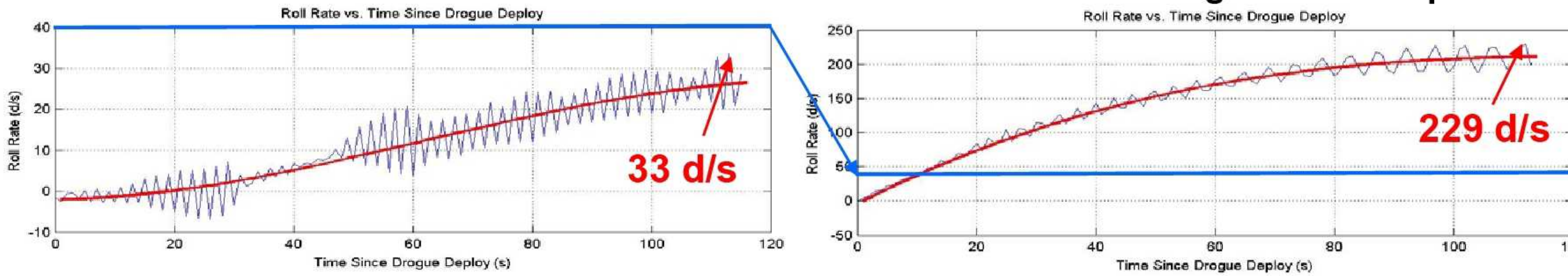


A result of the new configuration was the addition of a hang angle under drogues. This hang angle produces large roll rates under drogues.



Aerodynamic Drivers

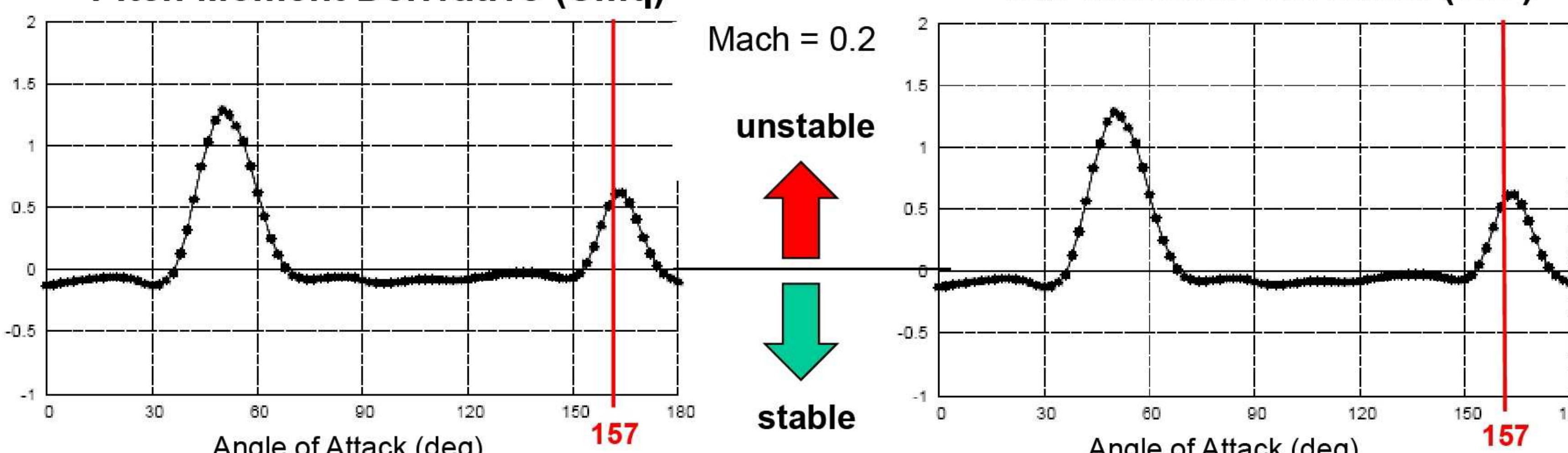
Nominal Aerodynamic Coefficients | **Nominal Aerodynamic Coefficients with Worst Case Yawing Moment Dispersion**



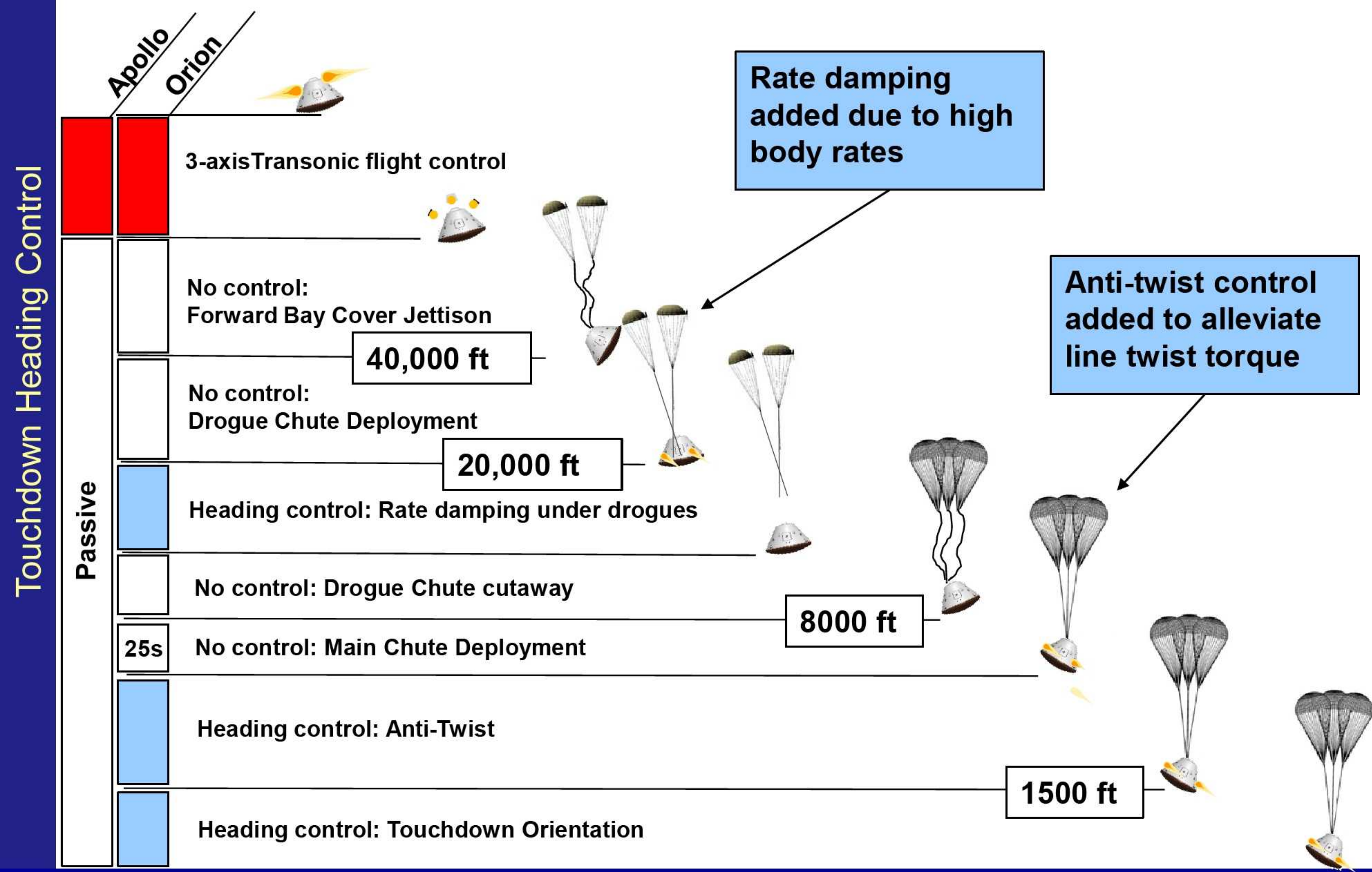
Simulation Data — Poly-fit curve

Yawing moment (Cn) is driven by the hang angle and with the new configuration produces an aerodynamic torque component about the vertical roll axis. The hang angle places the vehicle in an unstable area of the aerodynamic rate damping curves.

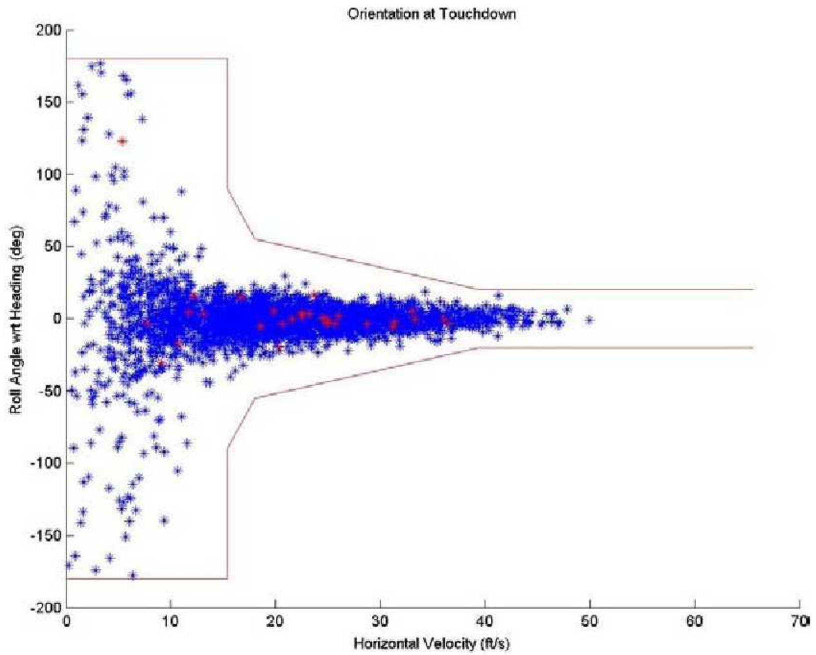
Pitch Moment Derivative (Cmq) | **Yaw Moment Derivative (Cnr)**



RCS Control Regions



Heading Control Summary



In the current configuration heading control is able to successfully re-orient the Orion crew module at touchdown.

Advantages
Allows for reduction in structural mass
Uses existing reaction control system
Reduces probability of vehicle roll-over at splashdown
Guarantees axial loads on crew at touchdown

Disadvantages
Requires significant additional propellant
Reaction control system is less effective in the atmosphere and may impact parachute performance
GPS is critical to successful heading control
Parachute line twist torque reduces control authority
Sensitive to environmental conditions

Closing Comments

- Structural and mass limitations require vehicle to be oriented appropriately during touchdown
- GPS is critical to touchdown control
- Twist-torque proved to be an issue that could be solved efficiently
- New chute architecture is producing challenging vehicle dynamics

Current body rates raise concerns that GPS will be able to acquire signal lock needed for touchdown control. Due to GPS criticality and crew safety concerns an ongoing study is being performed to remove active touchdown control and move to a passive system similar to Apollo.