



# **ORION ARTEMIS I DESCENT AND LANDING PERFORMANCE**

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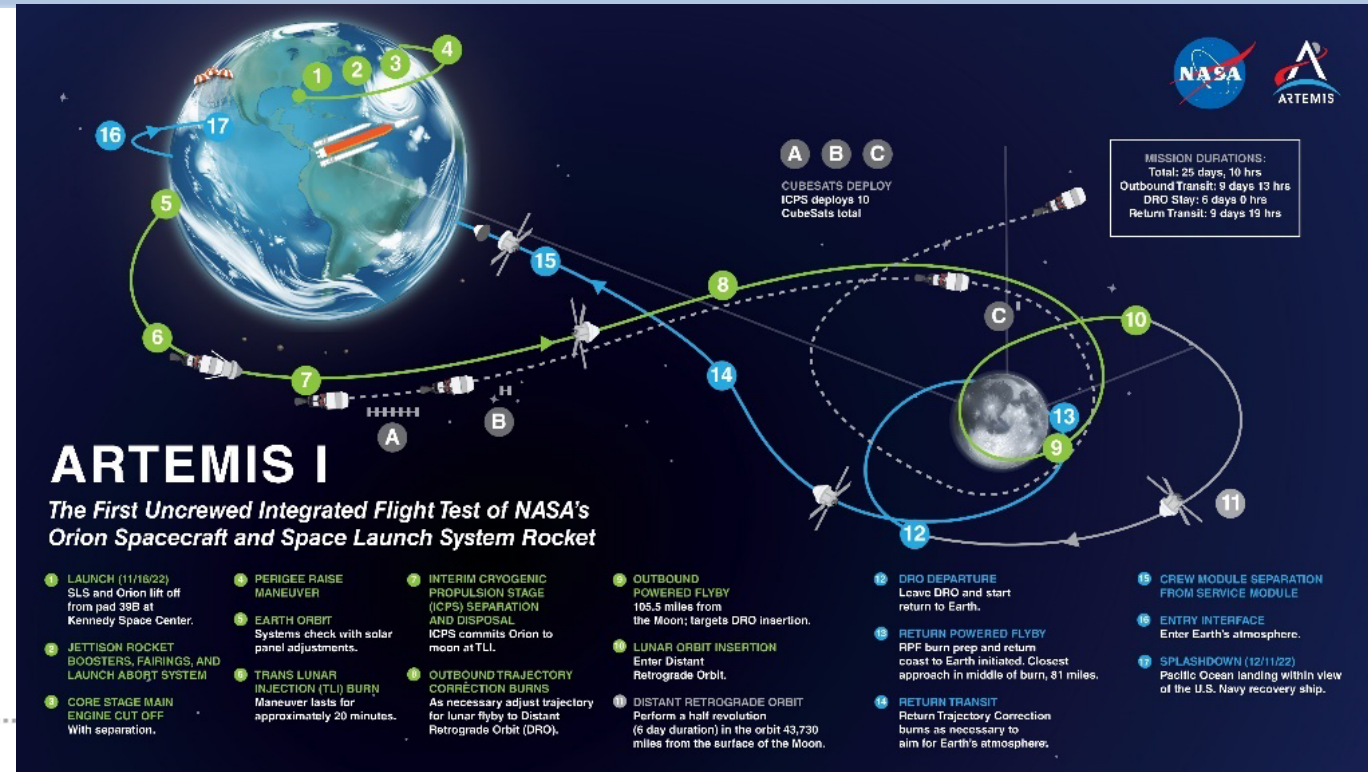


# ARTEMIS I



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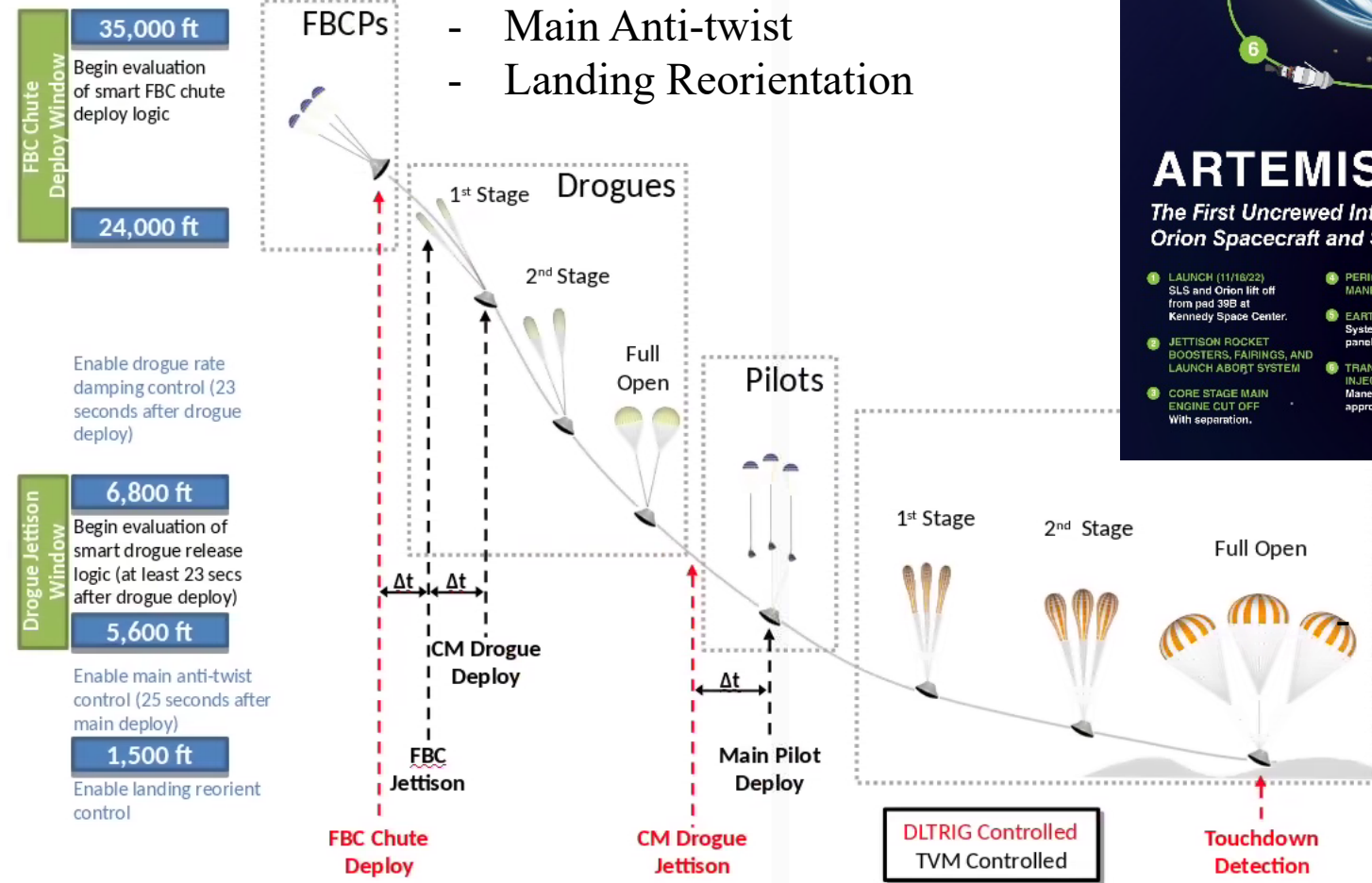
- Descent is the time under parachutes
- Three control modes during decent:
  - Drogue Rate Damping
  - Main Anti-twist
  - Landing Reorientation



Launched: November 16, 2022 at 1:47 am  
Mission Duration: 25 days, 10 hours, 53 minutes

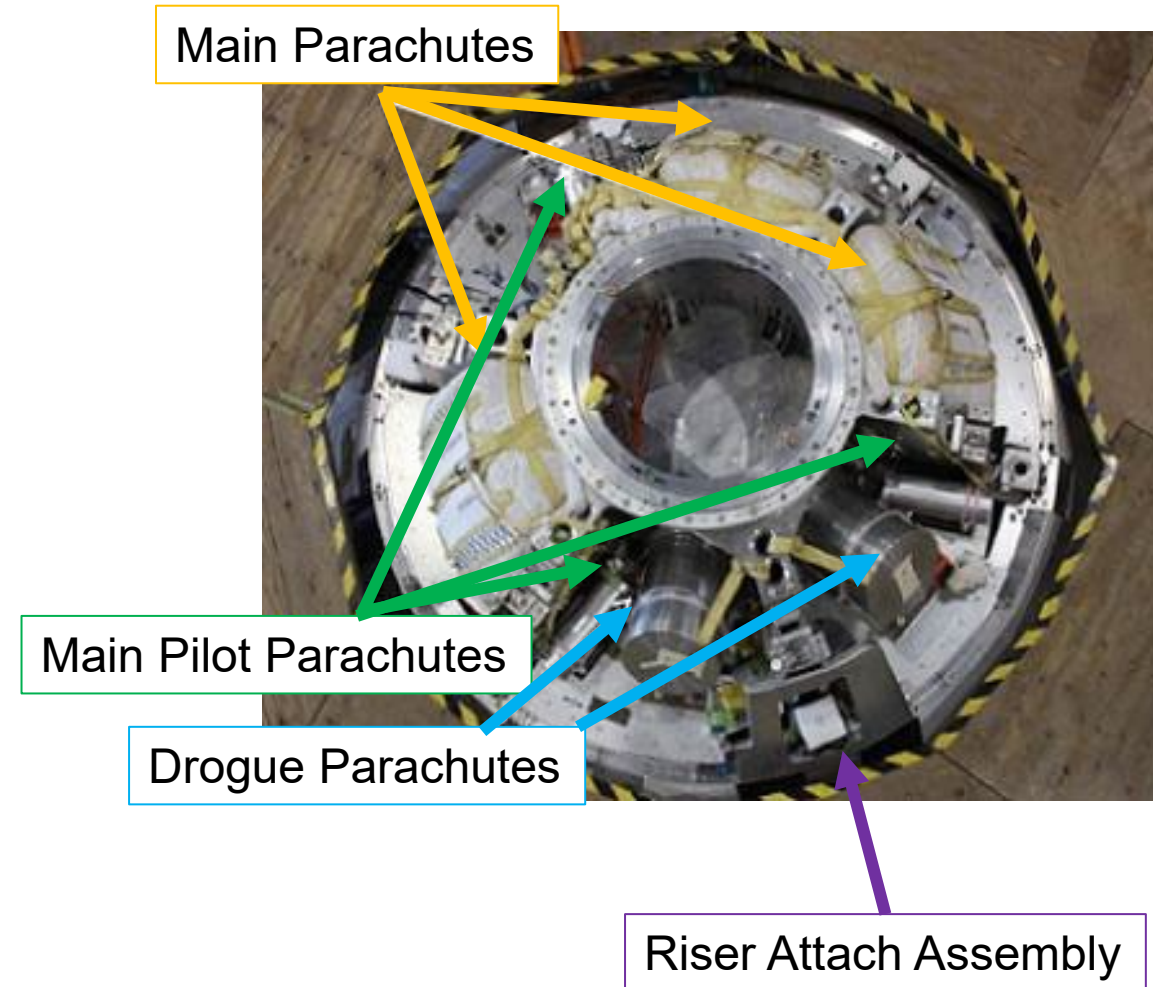
After Entry Interface (16) three primary events occur in the trajectory:

- Forward Bay Cover (FBC) Jettison and Drogue Deployment
- Drogue Chute Jettison and Main Chute Deployment
- Splashdown



# Capsule Parachute Assembly System (CPAS)

- CPAS is stowed in the Crew Module (CM) Forward Bay:
  - Three 7 ft reference diameter ( $D_0$ ) Conical Ribbon Forward Bay Cover Parachutes (FBCPs)
  - Two 23 ft  $D_0$  Variable Porosity Conical Ribbon (VPCR) drogue parachutes
  - Three 9.85 ft  $D_0$  Conical Ribbon main pilot parachutes
  - Three 116 ft  $D_0$  Quarter Spherical Ringsail main parachutes
- Drogue and main risers are attached through the Fairlead and Riser Attach Assembly
- Forward Bay Cover parachutes (FBCPs) are attached to the Forward Bay Cover (FBC) and are mortar deployed
- Drogue parachutes are mortar deployed
- Main pilot parachutes are mortar deployed and are attached to the main parachute extraction bags for extracting the main parachutes
- Main parachutes have three reefing stages



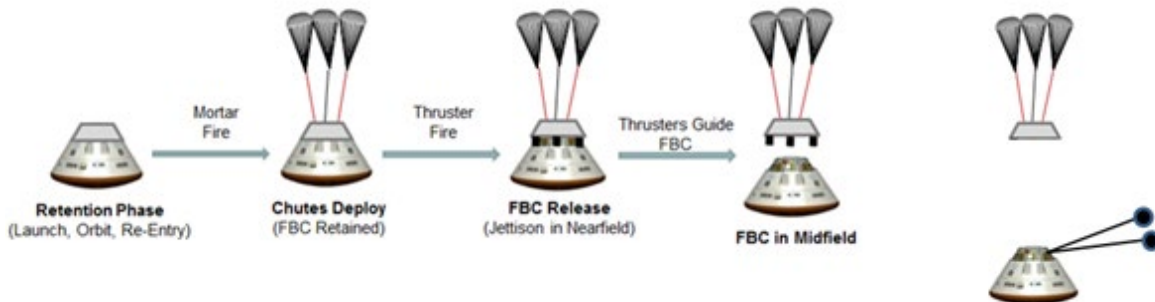
# FBC and Drogue Deploy

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The Descent and Landing Triggers (DLTRIG) Computer Software Unit (CSU) is responsible for setting flags that initiate parachute deployment events and mode control during descent operations.

| Flag                            | Description                                                                                                                                       |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| FBC_Chute_Deploy_Cmd            | Command to initiate the drogue deploy sequence.<br>(includes Forward Bay Cover (FBC) parachute deploy, FBC jettison, and drogue parachute deploy) |
| Drogue_Jettison_Main_Deploy_Cmd | Command to initiate the sequence that jettisons the drogue chutes and deploys the main chutes                                                     |
| Touchdown_Detected              | Flag indicating detection of CM touchdown<br>(inhibits CM RCS control and initiates transition into post-landing activities)                      |
| CM_Touchdown_Cntrl_Mode         | Flag indicating current touchdown control mode<br>(modes between Drogue Rate Damping, Main Anti-twist, and Landing Reorientation control mode)    |

## FBC Jettison and Drogue Deploy



- Starts with FBCP mortar fire ejecting three mortar lids and three FBCP sabots which deploy the parachutes.
- FBC parachutes are inflated and held for 1.4 sec
- FBC is jettisoned
- Drogue mortar fire is initiated 2.0 sec after FBC jettison
- Mortar lids and drogue sabots and drogue bags are ejected
- Drogue parachutes are deployed

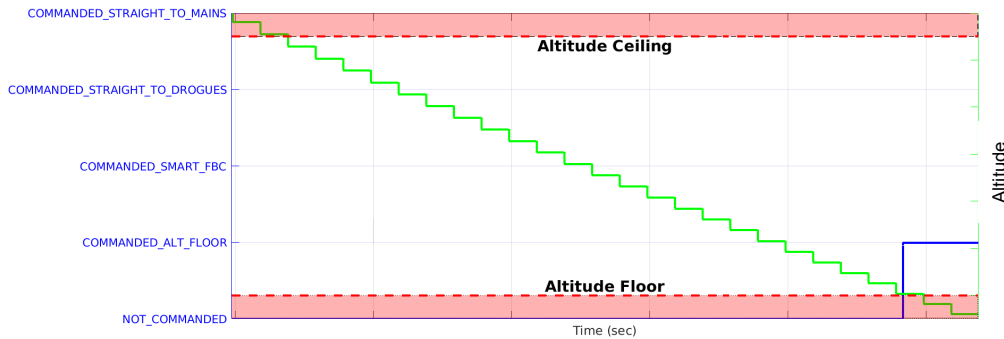
# Artemis I FBC Jettison and Drogue Deployment

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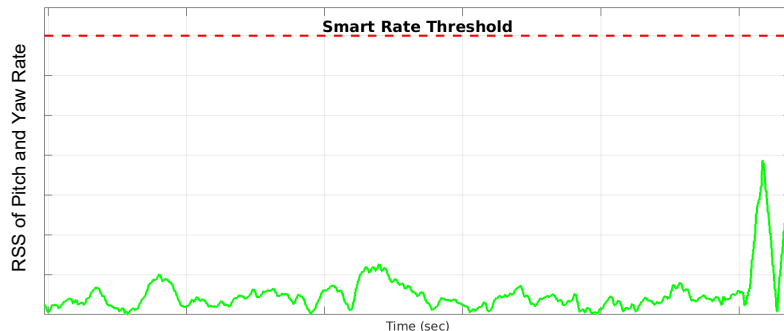
Drogue deployment initiation is nominally triggered by an altitude floor.

- It is desired to actively guide the vehicle for as long as possible to achieve precision landing at the desired landing target
- After parachutes deploy the vehicle trajectory becomes a function of environmental winds.

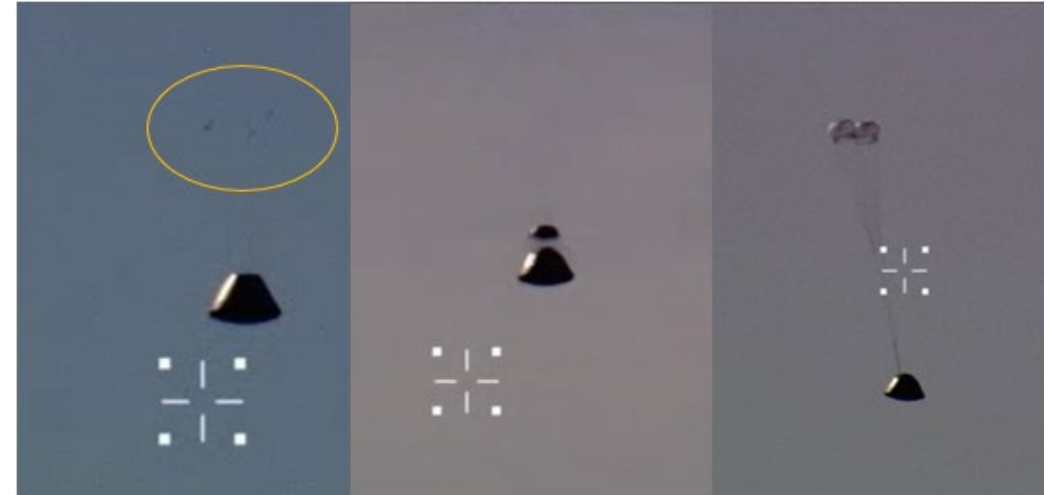
To protect against CM tumbling due to reduced stability in subsonic flight, FBC deploy may be triggered early after a minimum altitude threshold has been met by Smart FBC chute deploy logic.



The FBC jettison sequence was initiated at the altitude floor for Artemis 1



Imagery confirmed successful FBC jettison and drogue parachute deployment

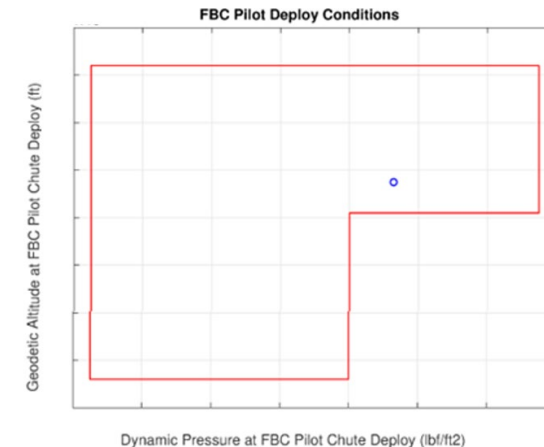
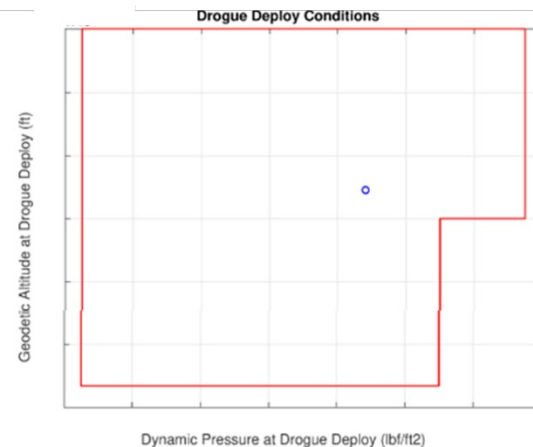


FBC Pilots

FBC Jettison

Drogue Deploy

FBC pilot and drogue parachuted deploy conditions fell within the design envelopes





# Drogue Jettison and Main Deploy

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Drogue Jettison and Main deploy initiation is nominally triggered by Smart Drogue Release (SDR) logic

- After a maximum altitude threshold is reached SDR logic monitors body angular rates and attempts to release drogues when angular rates are at a minimum to decrease the risk of tumbling

In off nominal situations, such as a loss of a drogue parachute, angular rates may remain high and main deploy is initiated after an altitude floor has been reached

Main Deployment Involves

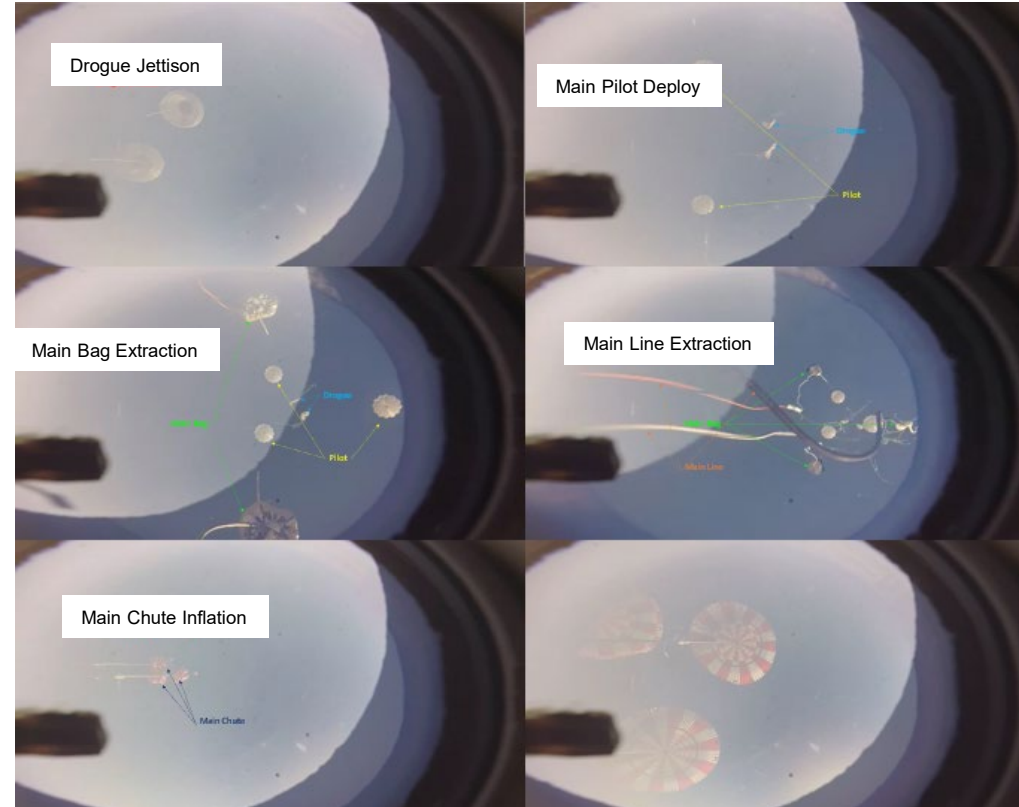
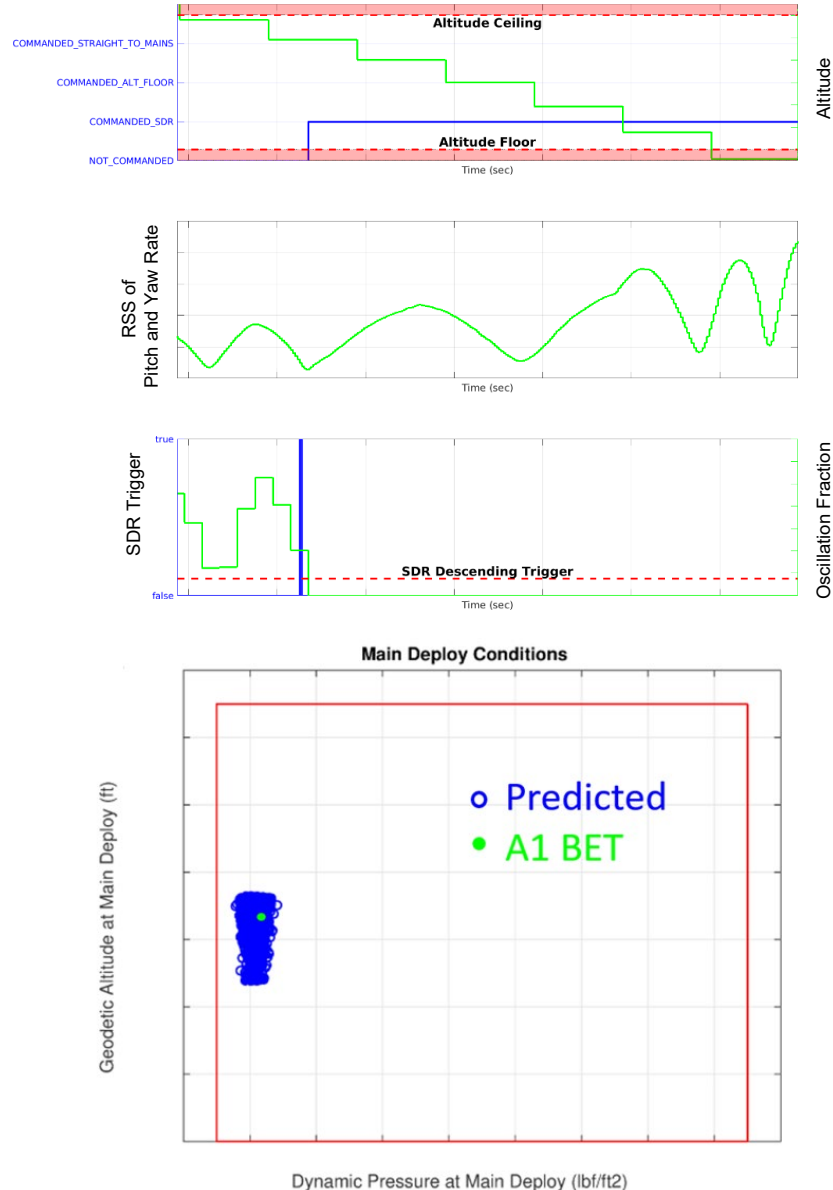
- Cutaway of drogue parachutes
- Main pilot chute mortar fire
  - Ejects 3 mortar lids and 3 pilot sabots with bags
  - Pilot parachutes deploy
- Main bags extracted ~4.3 s later
  - Three main parachutes deploy



Main parachutes are sized such that they can decelerate the CM safely even if one of the parachutes fails to deploy. Drogue parachutes are only allowed to be jettisoned after the configurable minimum time under drogues. Drogue jettison and main deploy has an altitude ceiling and floor.

# Artemis I Drogue Jettison and Main Deploy

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- Guidance Software commanded the drogue jettison and main deploy sequence per SDR logic when oscillation was decreasing as desired
- Main deploy conditions were within the deploy envelope and in-family with Monte Carlo simulation results
- Imagery confirms successful jettison of drogue parachutes and deploy of main parachutes.



# Touchdown Detection

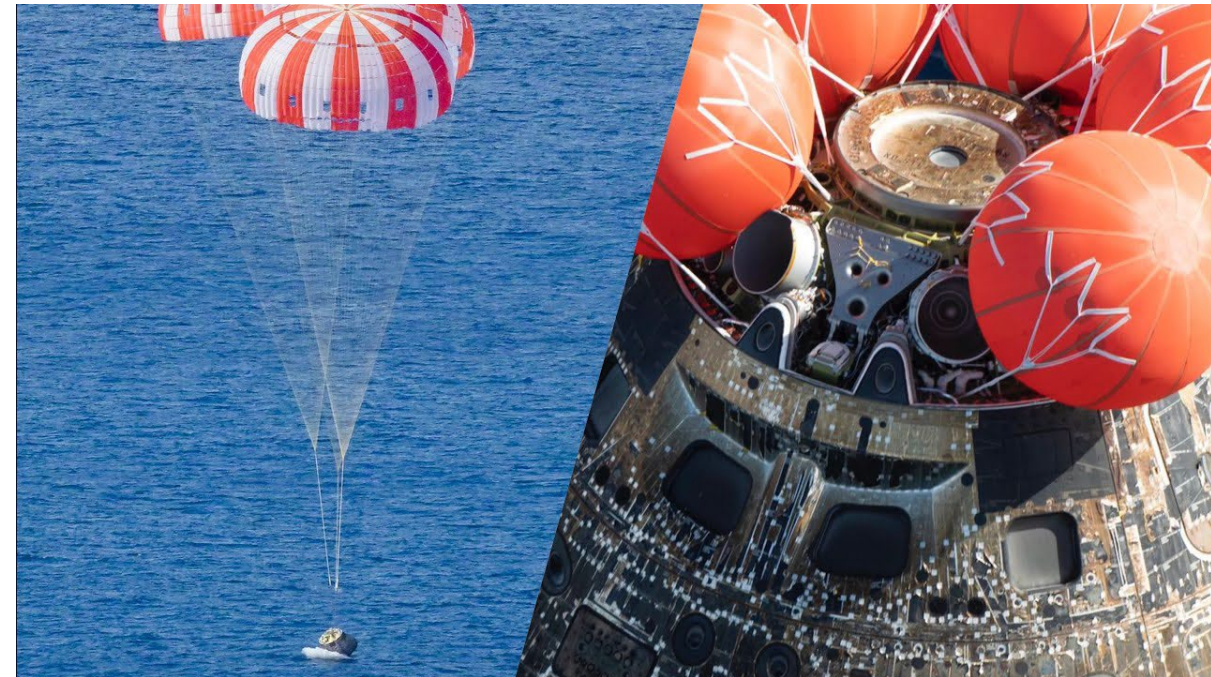
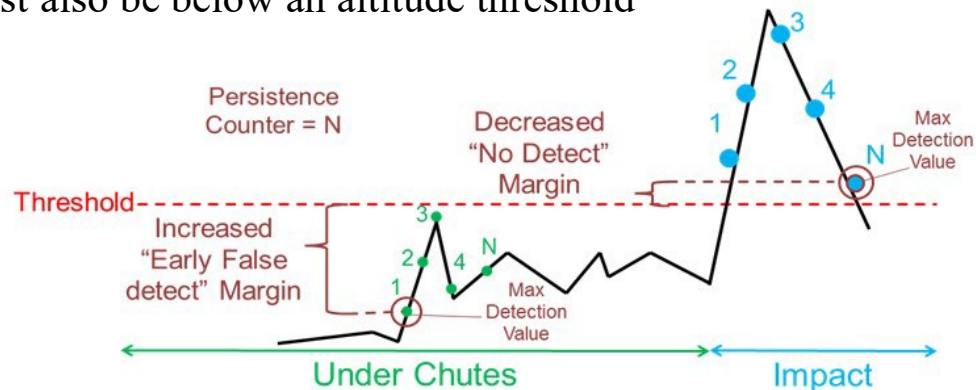
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Touchdown (TD) detection is critical to the mission as it:

- Ensures the shutdown of CM RCS at touchdown preventing RCS thrusters from firing while submerged
- Transitions the vehicle into post-landing activities that cut the main risers and deploys the CM uprighting system (CMUS)
  - Artemis II+ missions there is a delay between touchdown and main cutaway to allow time for crew to confirm that touchdown occurred prior to sequencing transitioning into post-landing activities.

TD detection logic:

- Senses CM splashdown based on 200 Hz acceleration data from the IMU.
- Is evaluated once a specified time since main pilot chute deploy has elapsed to prevent main deploy and inflation dynamics from causing false touchdown detection and
- If navigated altitude accuracy indicates that altitude is valid, CM must also be below an altitude threshold

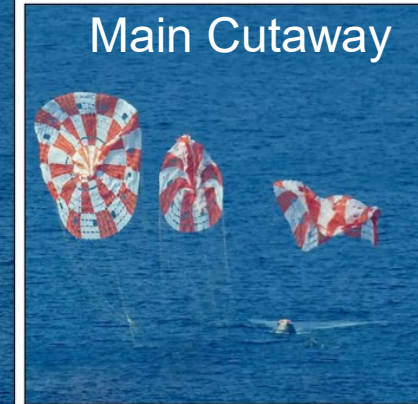
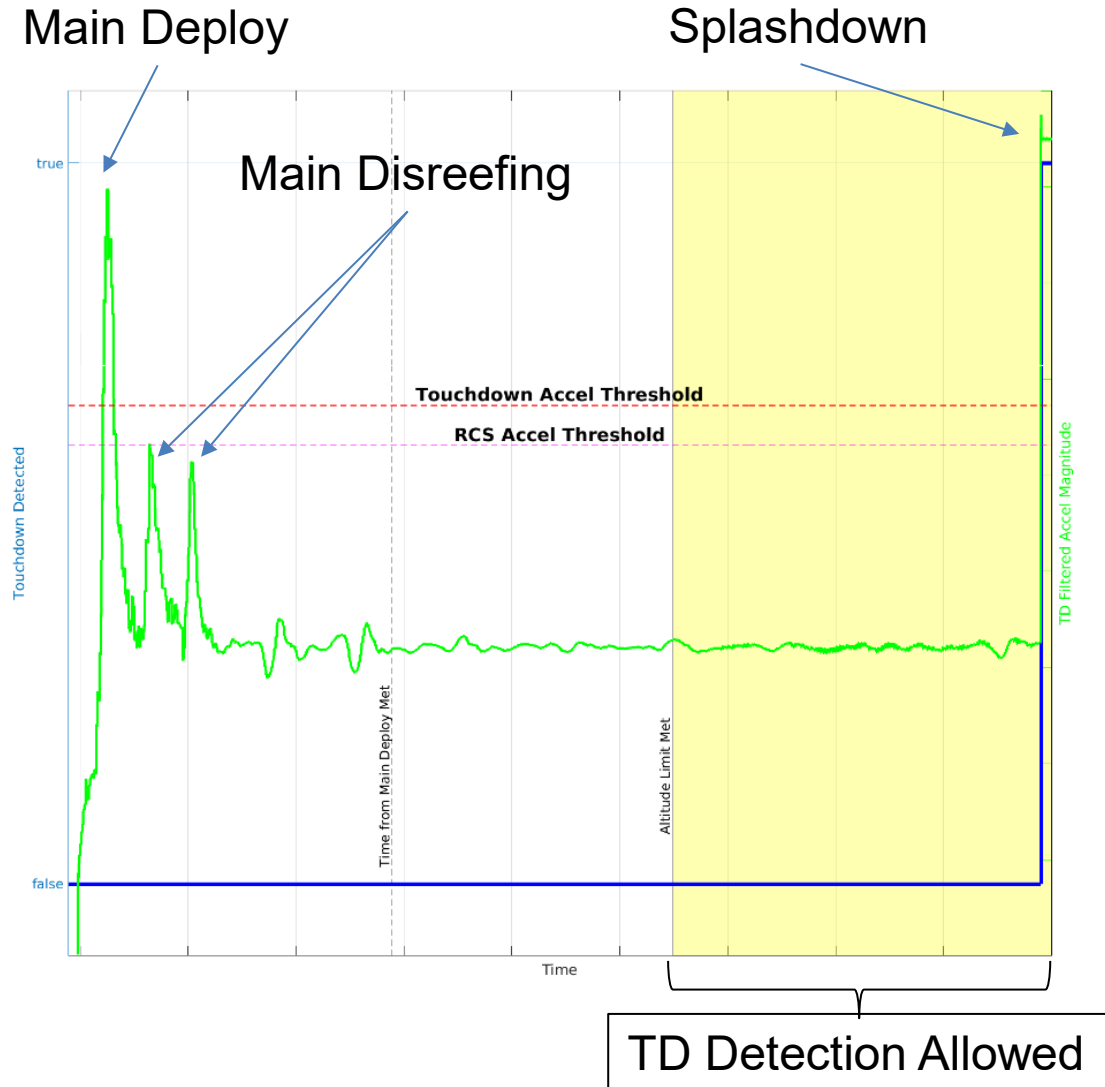




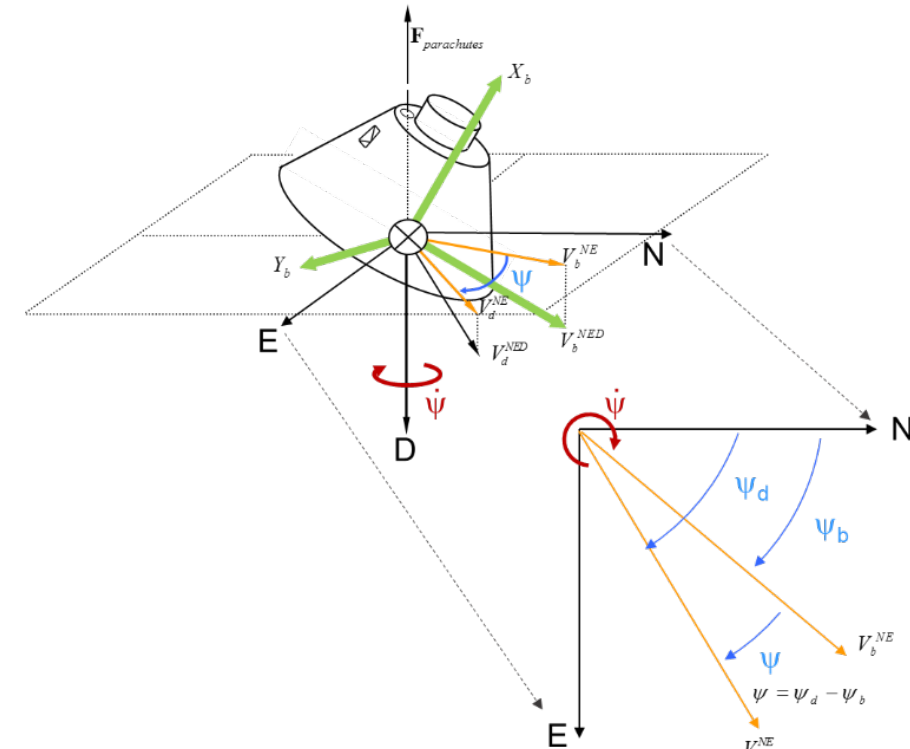
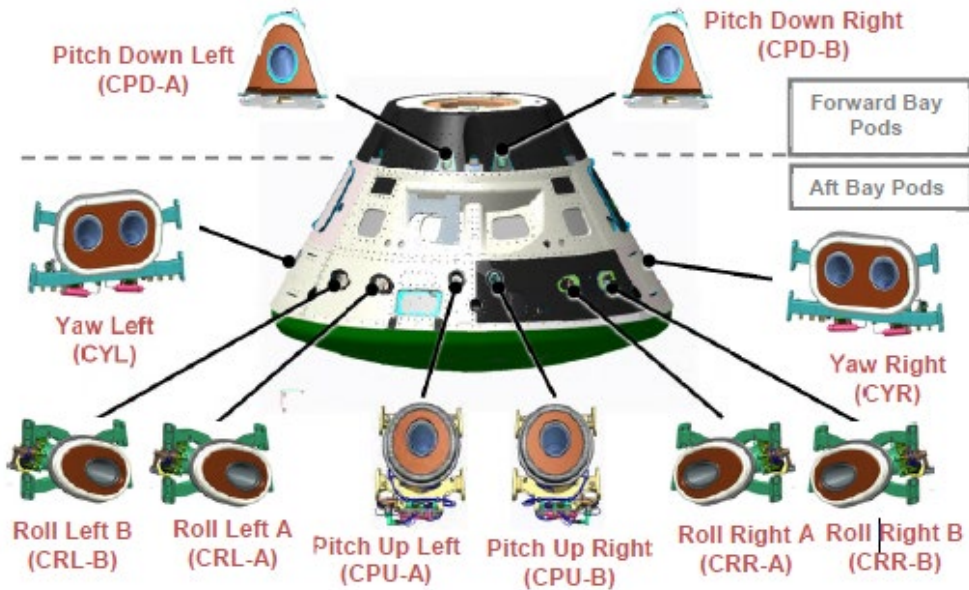
# Artemis I Touchdown Detection



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# Crew Module Reaction Control System (RCS)



## Crew Module Reaction Control System (RCS)

- Attitude control is achieved by commanding reaction control thrusters that produce torque about the vehicle body axis
  - Two fully redundant strings of thrusters
  - Six thrusters per string
  - Each thruster produces a nearly pure torque in one direction about the primary body axis
- Under parachutes the free rotation axis is about the local vertical direction
- Thruster commands are generated using heading error, heading error rate, and heading error acceleration
- During drogue parachute decent the roll thrusters are commanded to damp rates, however, due to the hang angle observed under main parachutes the roll and yaw thrusters are fired simultaneously to produce a torque about the local vertical axis

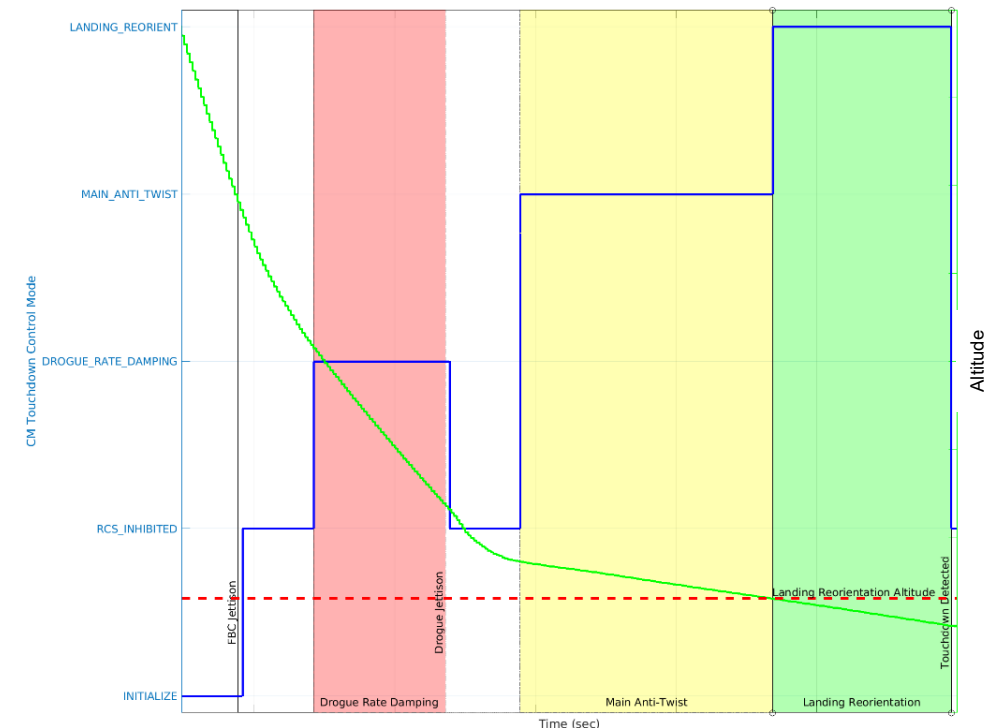


# CM Touchdown Control Mode

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- CM RCS is inhibited during drogue and main parachute deploy to allow for the parachutes to properly inflate.
- Three main control modes while under chutes: Drogue Rate Damping, Main Anti Twist, and Landing Reorientation
- Drogue Rate Damping control keeps the vehicle from spinning excessively around the drogue chute attach point prior to main chute deployment.
- Main Anti Twist and Landing Reorientation are mutually exclusive and are active after main pilot chute deploy and before TD
- Logic allows the control mode to switch back and forth between main anti-twist and landing reorient depending on the current altitude
- Main Anti Twist prevents the vehicle from twisting up the parachute lines and reducing the ability of the control system to properly orient the vehicle at landing due to line twist-torque
- Landing Reorientation ensures that the vehicle is pointed towards the correct heading at touchdown

Artemis I CM Touchdown Control Mode

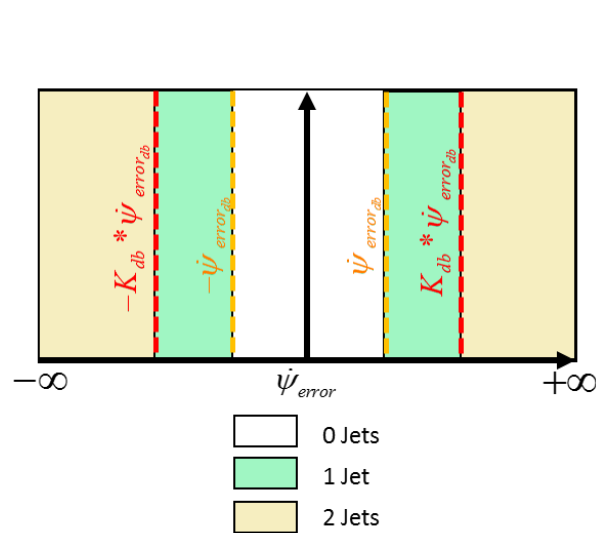


| Enumeration         | Definition                           |
|---------------------|--------------------------------------|
| INITIALIZE          | Default initialization value.        |
| RCS_INHIBITED       | Inhibit CM RCS control.              |
| DROGUE_RATE_DAMPING | Perform drogue rate damping control. |
| MAIN_ANTI_TWIST     | Perform main anti-twist control.     |
| LANDING_REORIENT    | Perform landing reorientation.       |

# Drogue Rate Damping and Main Anti Twist

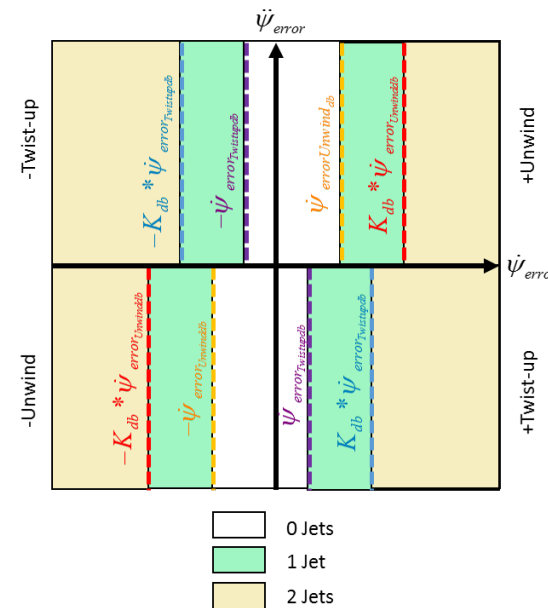
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- Primary purpose of drogue rate damping is to restrict angular rate to meet main deploy constraints
- Implemented as a bi-level algorithm
- Rates observed under drogue parachutes during the Artemis I mission did not exceed the rate threshold necessary to trigger a thruster firing

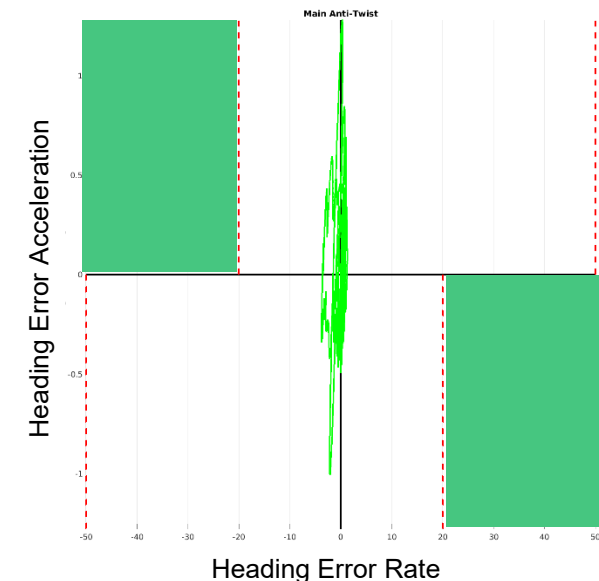


Drogue Rate Damping Control Logic

- Main Anti Twist control is used to limit the heading rate under the main parachutes while allowing parachute line twist to unwind
- Implemented as a bi-level algorithm
- Dynamics during the ride under main parachutes were benign and did not cause any CM RCS firings to occur during the Artemis I mission



Main Anti-twist



Artemis I Main Anti-twist



# Landing Reorientation

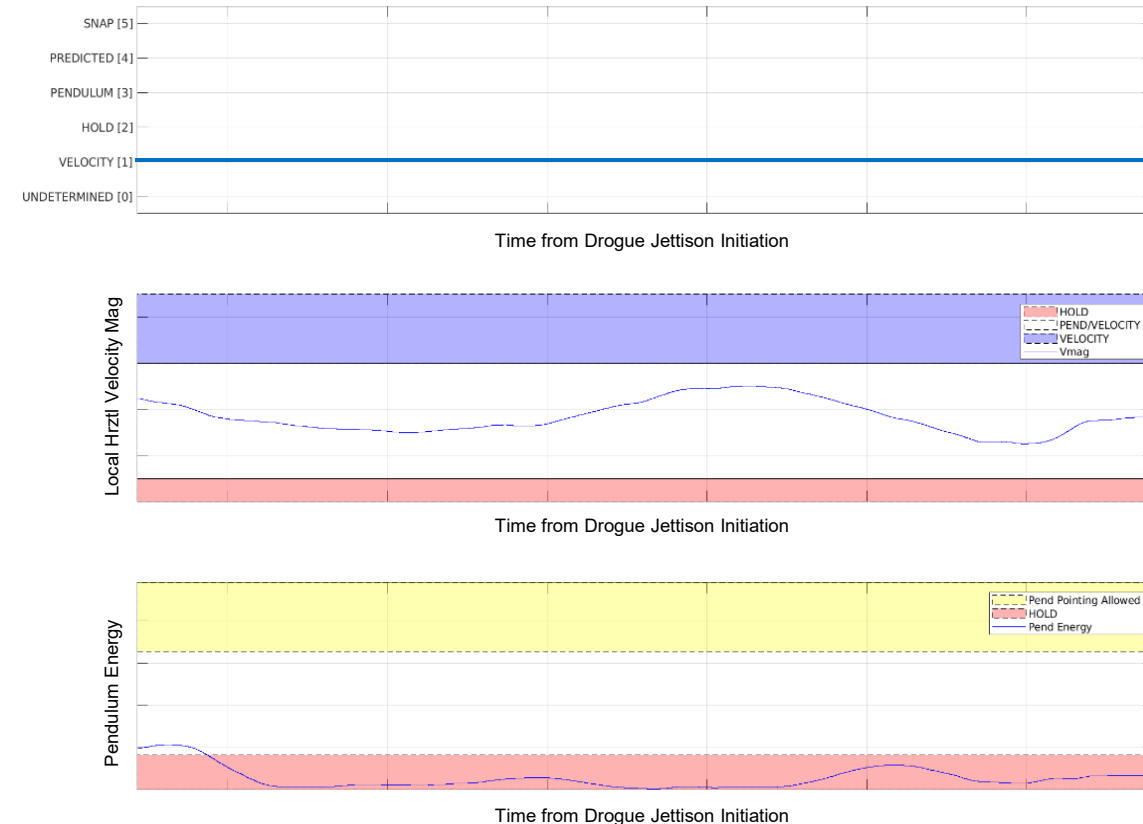
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Landing reorientation is used during the final phase of descent to maneuver the vehicle such that the body alignment axis is aligned in the desired direction to reduce touchdown impact loading on the crew.

## Pointing Direction Modes:

- Pendulum
  - Point perpendicular to the swing plane.
  - Used when the horizontal velocity magnitude is below a specified threshold and when large pendulum swing amplitude is detected.
  - Once the pendulum mode is selected it is not allowed to change to the velocity pointing direction.
    - This is to prevent rapid swapping of the desired pointing direction. Down modes (Hold/Predicted) are preserved.
  - The pendulum pointing mode is inhibited until the touchdown control mode indicates that landing reorientation is being performed.
- Velocity
  - Point towards the direction of travel in the local horizontal plane.
- Hold
  - Point toward the last known “good” value.
  - Used when:
    - Velocity magnitude is very low
    - The pendulum mode has been activated and the observer diverges.
    - The pendulum mode has been activated and the pendulum energy is low.
- Predicted
  - Point towards a predicted direction based on the weather forecast for landing winds
  - Used when GPS fails.

Artemis I Selected Touchdown Pointing Direction



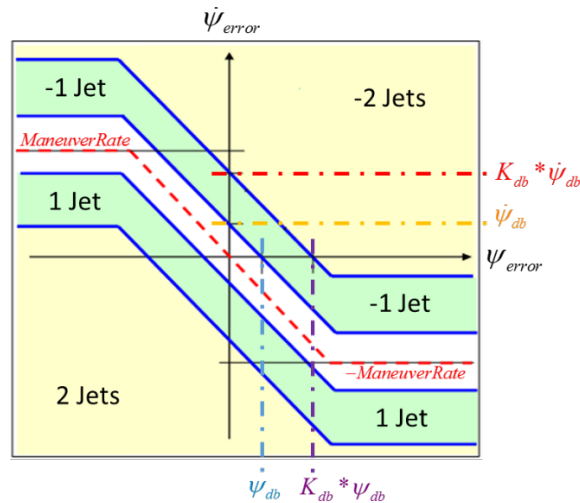
**The Artemis I touchdown pointing direction was constant and in the direction of horizontal velocity.**

# Landing Reorientation

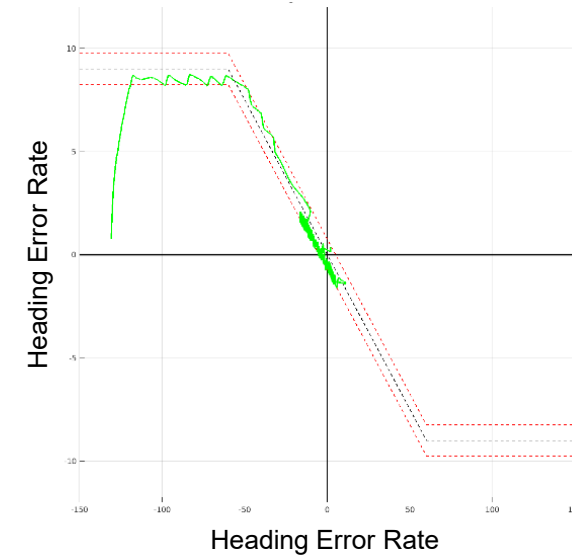
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Landing reorientation control logic is a bi-level phase plane defined by the heading dead band  $\psi_{db}$ , heading rate dead band  $\dot{\psi}_{db}$ , and the maneuver rate limit

Outer dead band is the inner dead band multiplied by a scale factor



**Control Law Switch Curves in the Attitude Error Phase Plane**



**Artemis I Landing Reorientation Phase Plane**

# CONCLUSION

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- Artemis I successfully triggered all deployment events
  - FBC Jettison, drogue deploy, and drogue cutaway were fully successful
- Artemis I successfully detected touchdown
  - Main cutaway and CMUS deployment were fully successful
- Touchdown control moding was as expected
- Touchdown control successfully reoriented the vehicle prior to splashdown in the direction of horizontal velocity
- Acknowledgements
  - All current and former Entry MODE team members

We would also like to thank our families for their support and encouragement!