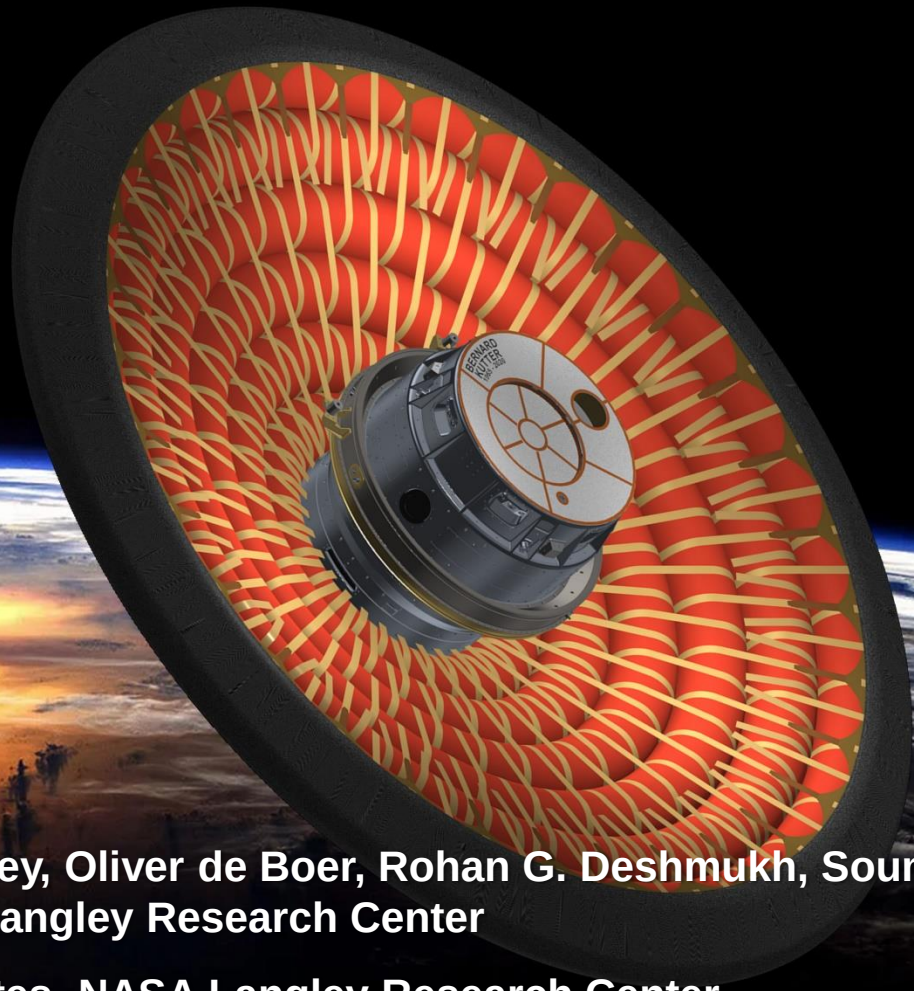
Low-Earth Orbit Flight Test
of an Inflatable Decelerator

National Aeronautics and
Space Administration

# Tracking and Recovery of the LOFTID RV

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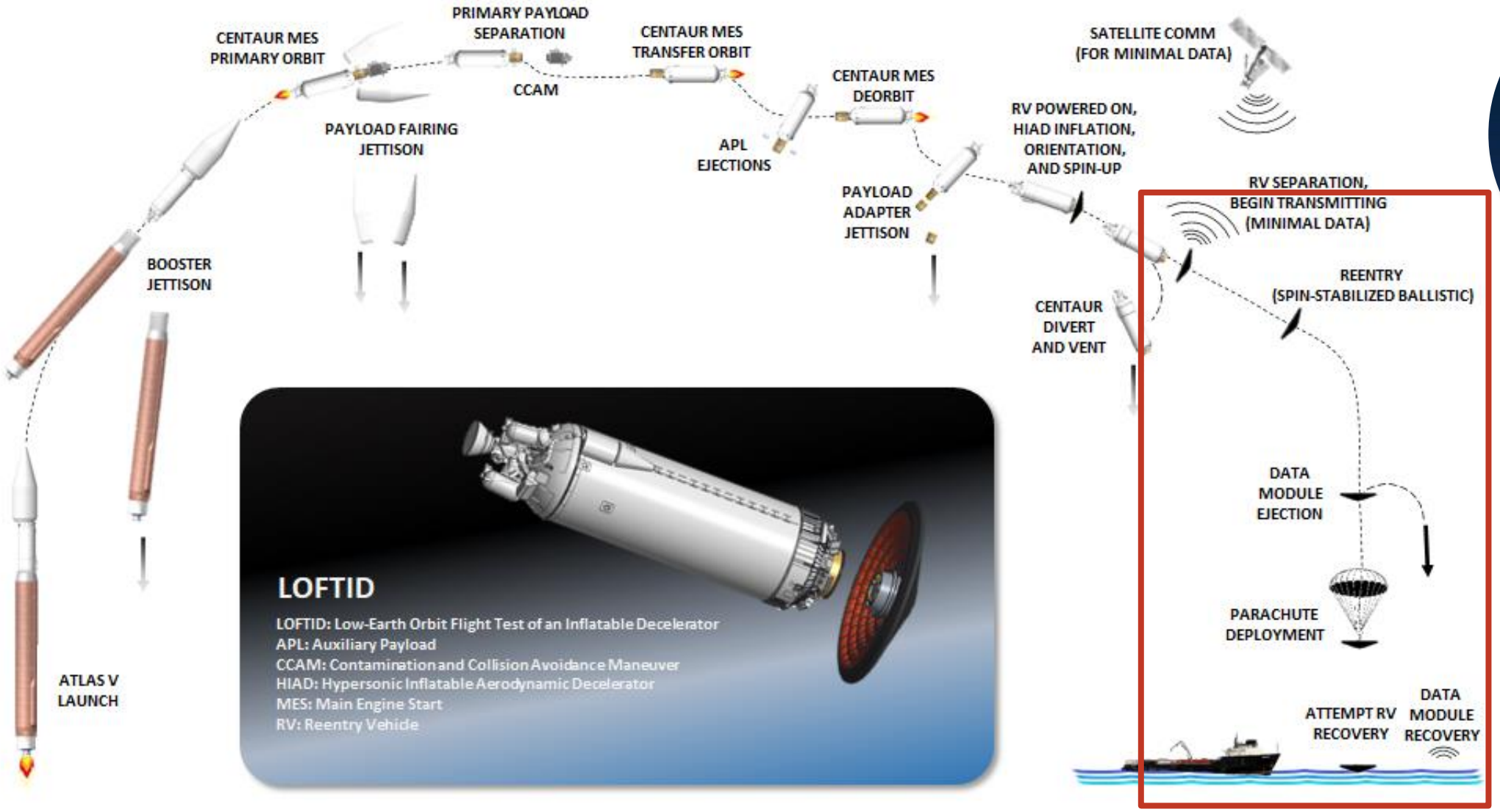
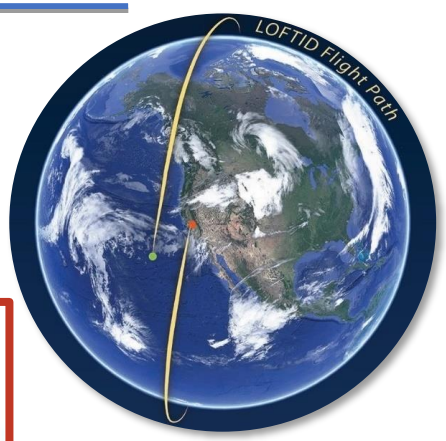
# Mission Overview

- LOFTID: Low-Earth Orbit Flight Test of an Inflatable Decelerator
- Largest blunt-body yet flown: 6m diameter
- Launched late on November 10, 2022, from Vandenberg Space Force Base
- Splashed down 2 hours 5 minutes later, 550 miles east of Honolulu
- Successfully demonstrated inflatable aeroshell technology at scale and conditions relevant to Earth and Mars EDL
- Hardware recovered after splashdown


- This presentation discusses some recovery design elements that might be of use to future missions, then how events went on day of flight.

# LOFTID Concept of Operations



# Major Conops Points

- LOFTID launched on an Atlas V from Vandenberg, with the Joint Polar Satellite System 2 (JPSS-2) as the primary payload.
- Delivery of JPSS-2 into a sun-synchronous orbit meant LOFTID would splash down east of Hawaii about 2am local time.
- As a secondary payload, LOFTID had to accept and plan for possibility of bad weather at splashdown site.
- LOFTID remained powered off until after delivery of JPSS-2, then inflated while attached to the Centaur upper stage.
- The Centaur provided the deorbit burn and 3rpm spin for reentry stability before releasing LOFTID, then performed a collision avoidance maneuver.

# Design Features to Ensure Data Recovery

- Obtaining flight data showing reentry performance was critical to mission success [as discussed earlier by DiNonno/Cheatwood], but bandwidth & power were insufficient to transmit all data in flight.
- Therefore, the flight data was recorded onboard the RV for retrieval. In case the RV sank before recovery, the data was also recorded on a buoyant ejectable data recorder (EDR) to be released after reentry.
- The EDR was hardened to survive independent splashdown and included a GPS locator designed to transmit for at least 30 days in case of bad weather at the splashdown site.
- RV also carried a GPS locator, and a parachute to slow splashdown to 13mph.
- Recovery of either data recorder was sufficient for mission success. Mission plans called for recovering the RV first to reduce its risk of sinking and allow inspection of flight materials.

# Additional Recovery Design Features

- **Parachute includes a saltwater release device, activating on submersion.**
  - Detaches the canopy so can't drag the RV underwater
  - Detaches most of the riser length, but leaves four 20' riser legs attached to the RV for lifting it out of the water
- **Camera lights remain on through splashdown, along with four blinking aircraft collision avoidance lights & several optical reflectors, to help with locating the RV at night & in bad weather.**
- **RV & EDR locator beacons, in addition to Iridium signals, also transmit signals via the RF LoRa protocol, line of sight without the Iridium data lag.**
  - Recovery team brought several LoRa relays on ship, & weather balloons to send them aloft to detect signals further away than receiver on ship
- **Infrared video camera from KSC on board the recovery ship to image the RV while descending under parachute.**

# Recovery Ship

- **Rented by United Launch Alliance, our partner on LOFTID.**
- **Evaluated several ships – including Coast Guard, NOAA, & Univ. of Hawaii – but most ships don't have enough open deck space for the 20x20' recovery stand that'll hold the RV.**
- **Offshore supply vessel Kahana II:**
  - 220' long with a 138x37' flat cargo deck
  - Onboard crane rated for 3 tons at full extension of 40'
  - 2 small boats for recovery operations
- **10-knot cruising speed**
  - Leave Honolulu 2½ days before launch
- **Also arranged for pier & warehouse space at University of Hawaii Marine Ops Center**

# Monitoring LOFTID in Flight

- **Video camera on Centaur recorded RV inflation & release. (15min downlink lag)**
- **After releasing LOFTID, Centaur would transmit as-released trajectory data.**
- **Ten seconds after release, LOFTID Real-Time Beacon (RTB) would start transmitting GPS info and limited engineering / performance data via Iridium small data burst. (up to 5min downlink lag)**
- **So the recovery team knew the RV was safe to approach, RTB data included:**
  - Confirmation of venting of inflation system nitrogen tanks after reentry
  - Confirmation of pyrotechnic firing signals & release of spring-launched EDR
- **Shortly after sending confirmation of EDR release and parachute deployment, the RTB would be powered off & the hardened locator powered on.**
  - Recovery team held multiple practice tests, tracking down an EDR engineering unit, to get ready for day of flight.

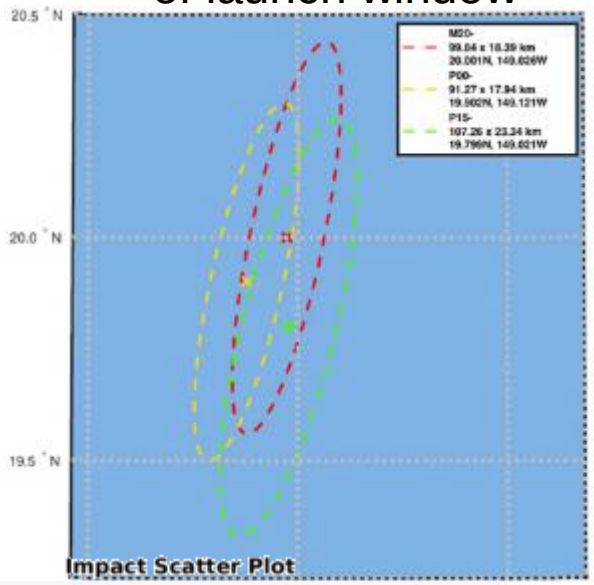
# Airborne Imaging of Reentry

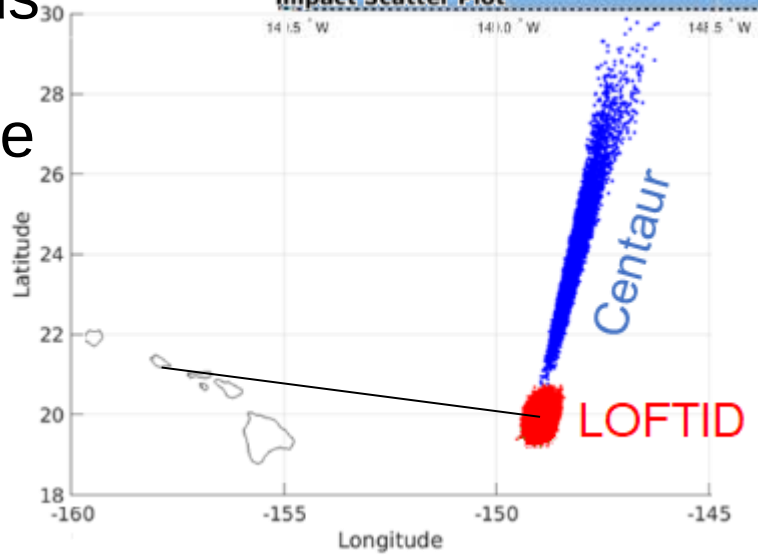
- **Scientifically Calibrated In-Flight Imagery (SCIFLI) team provided remote imaging of LOFTID RV during the reentry heat pulse.**
- **Flew seven science instruments, including radiometers and spectrometers, on gimballed mounts on NASA Gulfstream IV outside RV's splashdown ellipse.**
- **Provided time-resolved thermal / spectral imagery.**
- **Available to provide contingency help locating RV.**


# Splashdown Ellipse

- **Pre-launch splashdown ellipse was ~57x11 miles, with long axis to northeast. The center was 550 miles east of Honolulu, at 19.9N, 149.1W.**
- **The ellipse was updated regularly as launch approached; it shrunk slightly as atmospheric uncertainty dropped.**
- **Centaur reentry debris was predicted to land north of the RV, with slight overlap of ellipses.**
  - At start & end of launch window: <1:1,000,000 odds of recovery ship impact; project approved placing recovery ship at center of splashdown ellipse, since plans called for launching at start of window
  - Toward middle of launch window: >1:1,000,000, ship to move outside ellipse until after time of Centaur debris splashdown

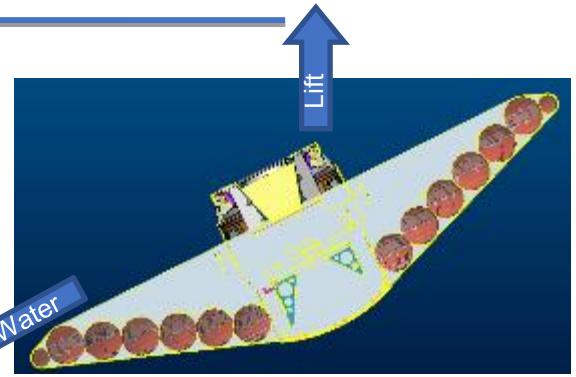
Ellipse at start/mid/end of launch window

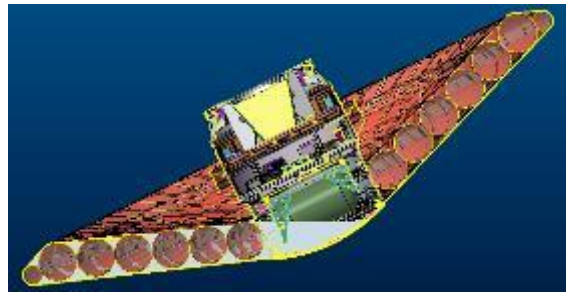


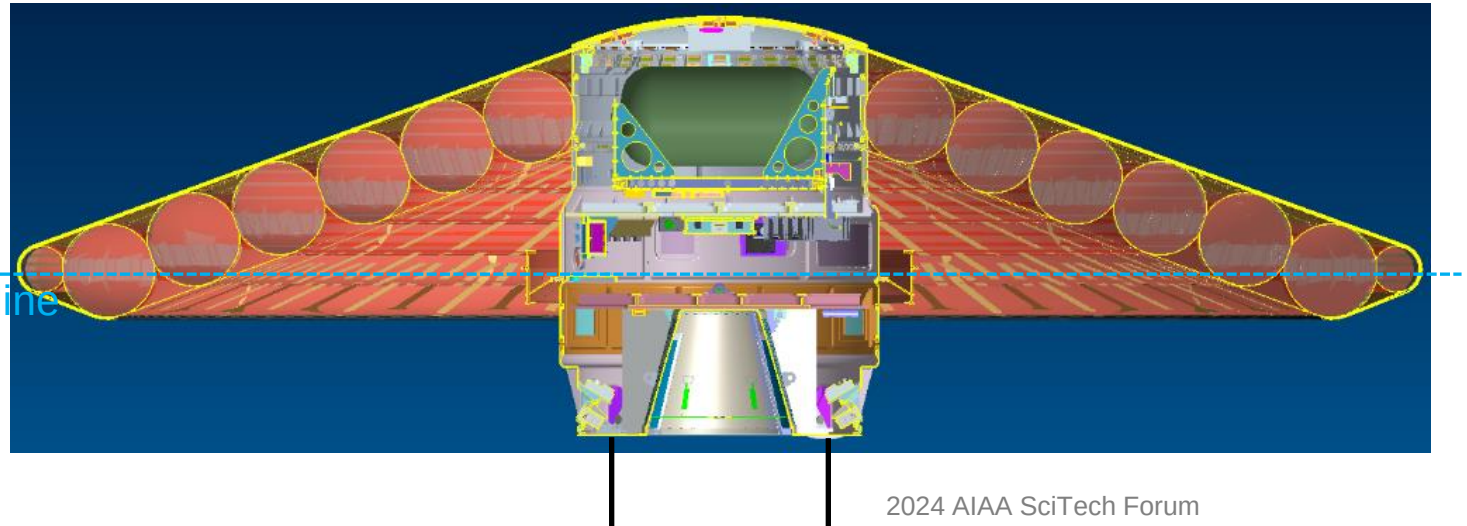



# Handling Off-Nominal Conditions

- **Bad weather or rough seas may affect RV state in water.**
- **RV taking on water → attach flotation buoys to parachute riser legs until can attach crane.**
- **RV full of water, too heavy for crane → perform tilted lift by 2 adjacent riser legs (out of 4 total) to drain water.**
- **RV nose-up, parachute riser legs out of reach underneath → use 30’ poles to reach under RV and retrieve parachute riser legs, then lift by 2 adjacent legs until RV flips upright.**





# Operations on Day of Flight

- Recovery team, prepositioned at splashdown site, watched Atlas launch online (via KSC Starlink terminal).
- Due to a late hold in the countdown, launch occurred near the middle of the window, so we repositioned the recovery ship 6 miles west, outside the splashdown ellipse.
- Did not receive RTB data as scheduled after separation from Centaur…
- After several uncomfortable minutes, video from Centaur showed successful inflation and release of LOFTID RV.
- Later analysis showed that the final launch slip had moved reentry into a gap between the closest Iridium satellites.

# Operations on Day of Flight (Cont.)

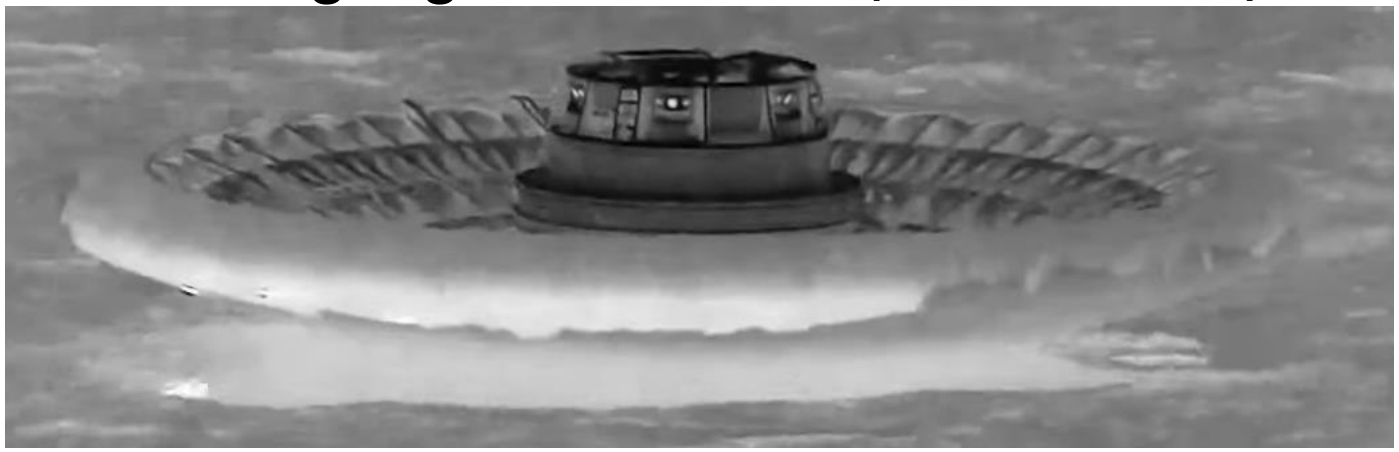
- The as-released RV trajectory received from the Centaur allowed an in-flight update of the splashdown ellipse, intended to remove the launch uncertainties and shrink the ellipse.
- However, the Centaur update came into the trajectory code via a unique subroutine, with a later-discovered typo; the updated ellipse was centered ~200 miles south of previous estimates…
- Since splashdown was imminent and relocation would take 20 hours, the recovery team stayed on location – and about 5 minutes later got data from the RTB confirming the RV's location nearby.
- Splashdown of the RV was ~10 miles from ship, only ~6 miles from the center of the earlier predicted ellipse.

# Splashdown!

- The weather was excellent for recovery: calm seas and mostly clear skies.
- With the GPS data providing a direction vector, the recovery team was able to spot the lights on the RV, descending slowly under parachute. The IR camera team tracked the RV to splashdown.
- Navigation became simple once the RV was in sight – the ship headed for the light in the sky! The RV disappeared over the horizon briefly at splashdown but came back into view as the ship approached.

# Securing the RV

- Ship reached the RV about an hour after splashdown.  RV was in great shape, floating high in the water, nose-down, and recovery went smoothly.



- Ship deployed a small boat with three members of the recovery team and a pilot from the ship's crew.
- Attached the parachute riser legs to a lifting ring for easy connection to the ship's crane, and attached tag lines that were needed to stabilize the lift.
- Towed the RV to the ship, connected the crane, and lifted the RV into the recovery stand on the ship's deck.

# Securing the EDR

- After securing the RV in the recovery stand, the ship headed for the EDR's GPS coordinates, waiting an extra hour for sunrise to avoid running it over in the dark.
- Once the EDR was spotted, the ship maneuvered close, and EDR was retrieved from the water with a fishing net on 30' pole before returning to port.

# Processing in Port

- Once in port, craned RV and recovery equipment ashore at the University of Hawaii Marine Operations Center / Honolulu pier 34.
- Closely inspected & photographed the RV.
- Downloaded flight data from ejectable recorder & RV internal recorder, and removed the individual cameras to download the uncompressed video from them.
- Deflated the aeroshell and packed everything back into the shipping containers to go home to Langley.



# Summary

- **Both the LOFTID RV and EDR were successfully recovered after splashdown.**
- **It was very helpful to have multiple to locate the hardware when some systems didn’t perform exactly as expected.**
- **Even with multiple practices and ground tests, flight tests rarely have everything go as planned – design for those contingencies and be ready to adapt on the fly anyway.**



# Questions?