

Artemis II Descent and Landing: A Preliminary Performance Assessment of the Orion Parachute System

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The Artemis II mission, which sent four NASA astronauts to the vicinity of the Moon for the first time in over 50 years, ended with a safe touchdown in the Pacific Ocean courtesy of a series of 11 parachutes. An initial assessment of the Orion parachute system during the mission can be performed with preliminary air-to-air imagery captured during the descent and landing. Due to both planned and unplanned nonrecovery of jettisoned parachute hardware, as well as the absence of individual riser load measurements, analysis will rely heavily on high-resolution imagery. Interrogation of this imagery can provide insight into not only parachute performance, but also into important Entry, Descent, and Landing (EDL) triggers and actions. While the terminal performance of the system appears nominal and consistent with previous drop test and missions, anomalies related to vehicle debris liberation and parachute reefing are apparent.

I. Introduction

The Orion Parachute system, otherwise known as the Capsule Parachute Assembly System (CPAS), was developed by NASA and its contractors as the aerodynamic deceleration system for Orion. An iterative design process was used to determine the architecture and system design, beginning with the Generation I (Gen I) series from 2007 to 2008. As detailed in Ref. [1], Gen I largely focused on using drop testing to determine the inflation and terminal performance characteristics of the canopy designs, as well as beginning the process of collecting data to build analytical parachute models. This development continued through the Engineering Development Unit (EDU) phase and Qualification, where the system was demonstrated and verified to meet system requirements. The uncrewed Exploration Flight Test

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1 (EFT-1) and Artemis I missions provided the first system demonstrations in a flight environment. These were followed by the first crewed return of the Orion spacecraft on the Artemis II mission on April 10, 2026.

II. System Architecture

The Orion parachute system consists of 11 total parachutes, spanning 4 different phases, to decelerate the capsule from up to 350 miles per hour on entry down to less than 20 miles per hour for splashdown. The first set of parachutes deployed are the Forward Bay Cover Parachutes (FBCPs) which are 12-gore, variable porosity conical ribbon parachutes with a nominal diameter of approximately 7 feet (Ref. [2]). The purpose of the FBCPs is to aid in the near-field and far-field removal of the Forward Bay Cover (FBC). Following jettison of the FBC, two Drogue parachutes are mortar-deployed. These 23-foot, variable porosity conical ribbon parachutes provide initial deceleration and vehicle stability as the system descends. When triggered by the flight software, these Drogues are jettisoned through the actuation of pyrotechnic cutters and three 10-foot Pilot ribbon parachutes are deployed. The Pilots' purpose is to deploy the three nearly 11,000 square feet ring-sail Main parachutes.

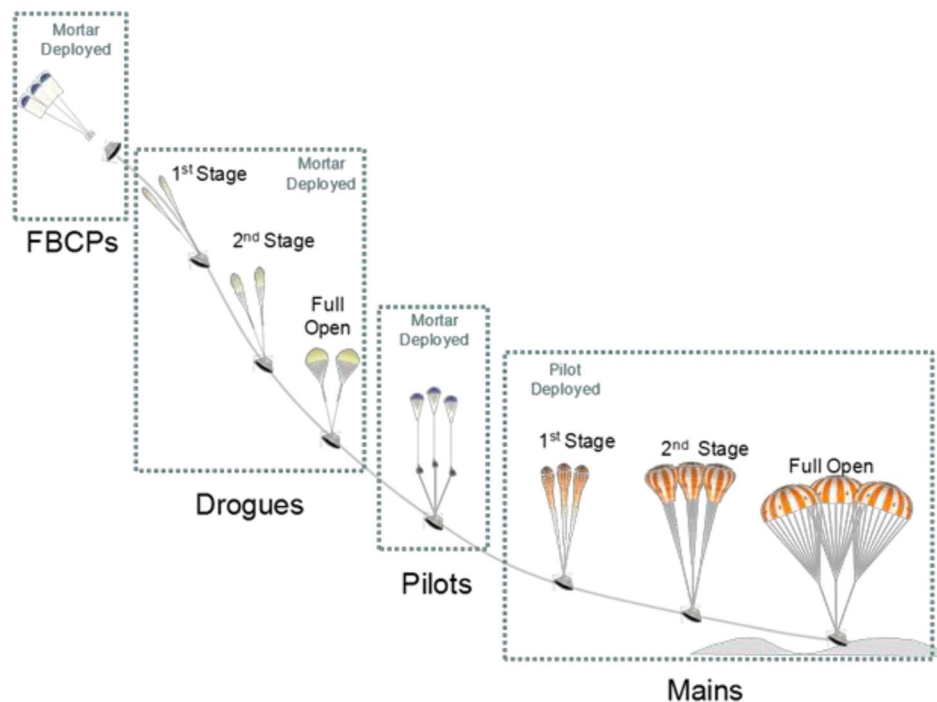


Fig 1. Orion parachute deployment sequence.

III. Planned and Realized System Surveillance

As described in Ref. [3], surveillance of crewed space parachute systems, particularly for NASA's Artemis and Commercial Crew Program (CCP), requires three critical elements to be present; high-quality imagery, data/trajectory reconstruction, and hardware recovery and inspection. Using precedents such as the failure of one of the Apollo 15 main parachutes, it is clear that high-quality imagery is of the utmost importance and is a primary requirement to ensure the understanding and ongoing safety of these complex systems. In addition to this imagery, reconstruction of both the vehicle trajectory and the inflation/performance of the parachute canopies themselves provides the detailed insight that is required to compare performance with past experience and to identify any potential differences between the test and flight environments. Lastly, hardware recovery and inspection are crucial for identifying any unpredictable conditions or events, corroborate observations seen in imagery and data, and quantify the extent of both expected and unexpected damage.

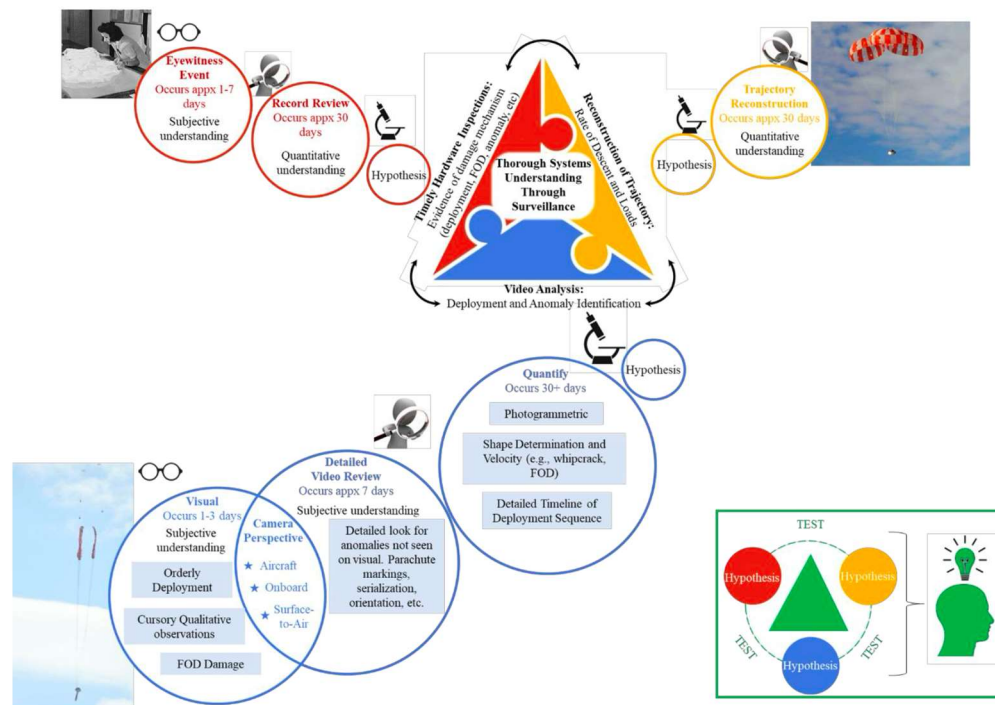


Fig. 2 Model for post-flight surveillance of crewed spacecraft parachute systems (Ref. [3]).

The Artemis II mission was resolved by multiple aircraft, both fixed-wing and helicopters, from various altitudes. At the time of publication, the quality of the delivered imagery has been excellent and will likely be the primary data source for assessment of the parachute system. The qualified configuration of the parachute system and attach points

has integrated compression load cells, or load bars, used to directly measure individual riser load time histories for all Drogue and Main parachutes. Due to programmatic and technical vehicle limitations, the data channels were not available for collection of this data. The load bars were integrated per the certified configuration, but the wires were cut and no data was collected. As for the final leg of the surveillance triangle - recovery and inspection - unfortunately limited parachute hardware was recovered. Other than the main parachutes and vehicle-attached main parachute retention and release system, no attempt was made at recovery of the assets due to various factors including the wide footprint from high-altitude jettison, sink rate of the jettisoned hardware in the ocean, and limited recovery resources. As for the main parachutes which are jettisoned immediately after touchdown, while recovery of the parachutes was planned by the recovery forces, no parachutes were recovered. The retention and release system was recovered due to its integration into the vehicle structure.

IV. Preliminary Flight Observations

A number of initial observations have been identified by the NASA parachute team:

A. Deployment Sequence Timing

As discussed in Ref. [4], the parachute sequence begins by mortar-deployment of the FBCPs at approximately 24,000 ft altitude. The Guidance, Navigation, and Control (GNC) system employs a smart algorithm to monitor the vehicle attitude and rates to command FBCP deploy to reduce the likelihood of subsonic tumbling of the vehicle. Following descent under the Drogues, the GNC system again monitors vehicle attitude and rates to determine an optimal time to jettison the Drogues and deploy the Pilots and Mains in such a way to minimize the likelihood of vehicle tumbling during transition. These smart deploy windows can be seen overlaid on the descent sequence in Figure 3 (Ref. [4]).

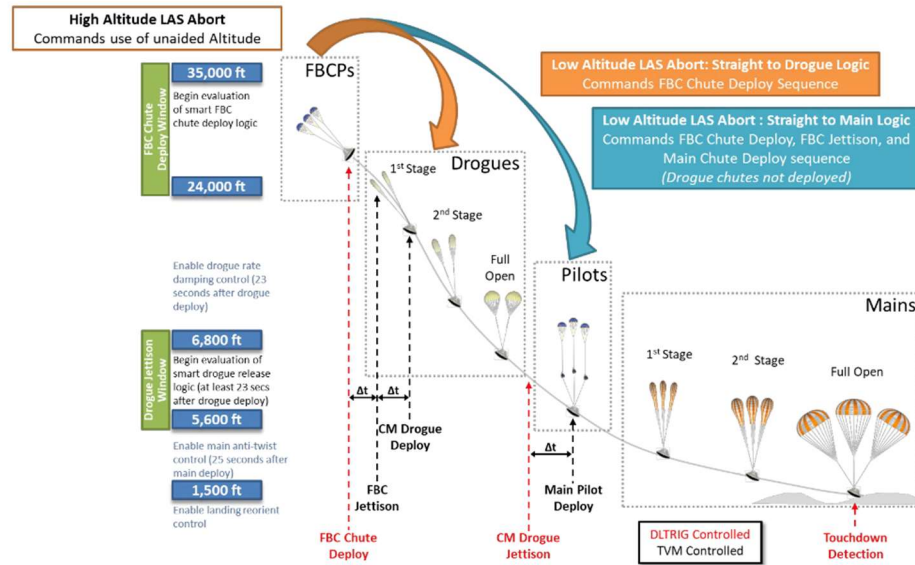


Fig. 3 Descent and landing triggers nominal logic (Ref. [4]).

Lastly, per Ref. [5], a touchdown detection algorithm is implemented that monitors filtered acceleration data from the Inertial Measurement Units (IMUs) to identify splashdown, while providing safety margin against early cut caused by premature triggering of the algorithm due to vehicle dynamics. To maximize crew safety, the system incorporates a Reaction Control System (RCS) inhibit function that automatically disables the Reaction Control System thrusters (used while under main parachutes to keep the vehicle pointed in the same direction of the vehicle horizontal velocity vector) immediately once touchdown is confirmed.

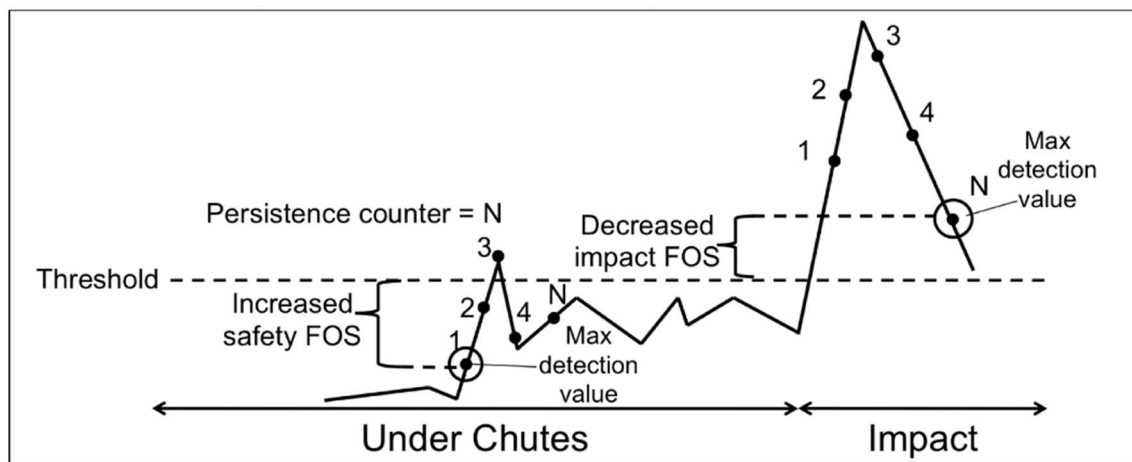


Fig. 4 Visualization of logic on acceleration data for touchdown detection algorithm (Ref. [4]).

B. Debris Environment and Strike Evidence

Significant amounts of debris, shed from the vehicle, are seen in both visible and infrared wavelengths during the parachute deployment phases. Similar environments were noted on Artemis I, driving significant amounts of testing and analysis to determine the risk to the system due to parachute damage from debris impacts. Potential debris types include Thermal Protection System (TPS) tile pieces, charred heatshield, Multilayered Insulation (MLI) blankets, as well as expected debris such as parachute lids, deployment bags, and sabots.

A relatively significant debris strike to one or more FBCPs is seen in both the infrared and visible spectrums. This occurs after FBCP inflation and prior to FBC jettison, and at the time of writing, the debris source is not confirmed. Unfortunately, due to the lack of recovered hardware and subsequent inspection, the extent of any possible parachute damage is unknown, although all three FBCP canopies can be seen in an inflated state when the FBC impacts the water.

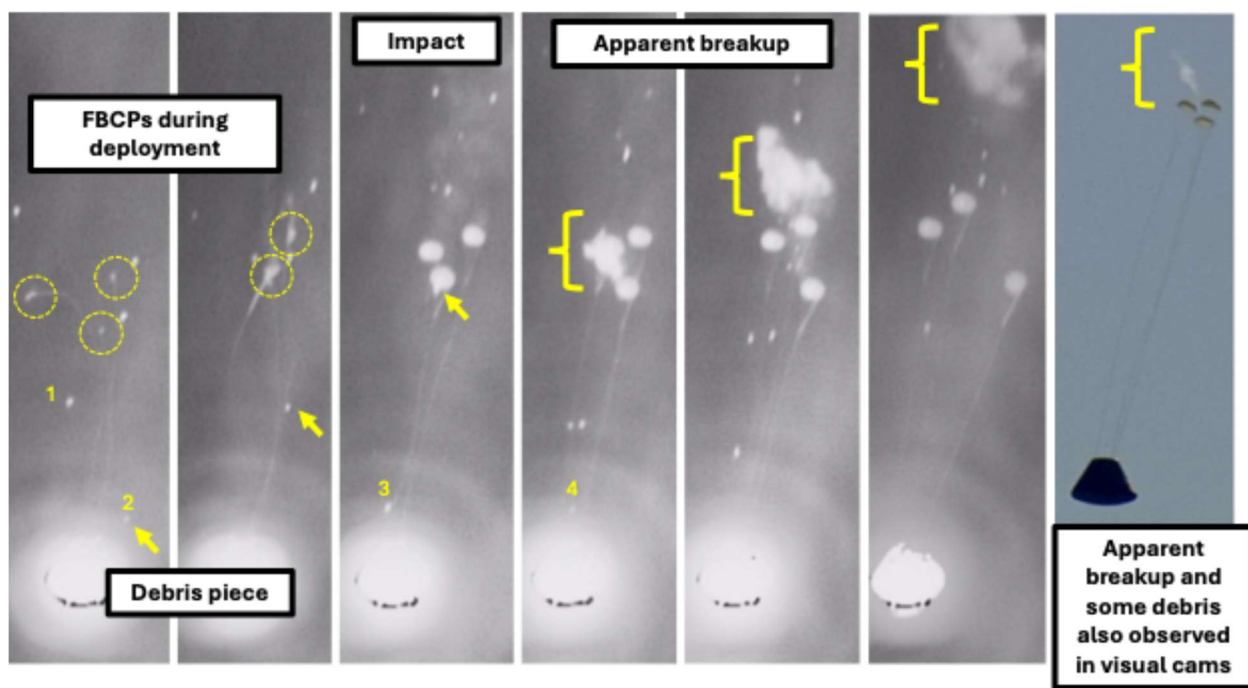


Fig. 5 Apparent debris strike on FBCPs.

C. Reefing System Anomalies

Visual inspection of various air-to-air imagery sources suggests two potential reefing system anomalies that warrant further analysis. The first is regarding the timing of the reefing line cutter events which transition the parachutes through various stages of drag area. Within each Drogue and Main parachute are four pyrotechnic reefing

line cutters, two of which actuate at 8 seconds post-deploy and the other two at 16 seconds post-deploy. It is observed that there are multiple instances of reefing line cutters firing earlier than their peers, earlier than expected but still within the modeled cutter performance. In addition to those interesting cutter firing times, a possible hesitation in the disreef is seen in one canopy as it transitions from first to second stage.

D. Touchdown Roll Control

As previously mentioned, the flight software utilizes the vehicle roll control RCS thrusters to maintain vehicle pointing during the final stages of the terminal descent, allowing the vehicle to knife into the water, rather than bellyflopping. This is visibly apparent in the infrared imagery as the roll control jets fire intermittently all the way until vehicle touchdown.

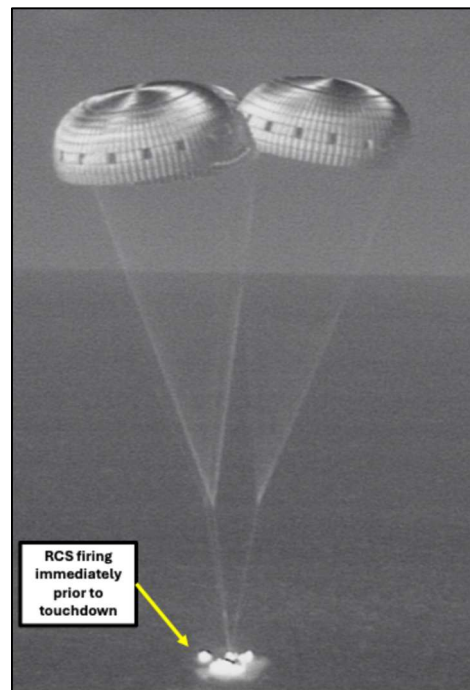


Fig. 6 RCS roll control jets firing prior to splashdown.

E. Parachute Jettison and Sinking

Immediately following detection of vehicle touchdown (whether by crew input or automated algorithm), several actions occur including the triggering of pyrotechnic cutters to sever the Main parachute risers. This is implemented to prevent the parachutes from acting as a sail or sea anchor and influencing capsule position or velocity after touchdown. While critical for crew safety, for Artemis I and Artemis II this resulted in the main parachutes sinking

before recovery crews could recover the hardware. This sinking occurs in less than ten minutes and eliminates the ability for engineers to inspect and assess the state of the hardware after use.



Figure 7 Jettison and subsequent sinking of Main parachutes.

V. Conclusion

Significant forward work remains for the NASA parachute team in their ongoing assessment of the performance of the system on Artemis II. As higher-quality imagery and onboard vehicle data is received, additional insight and understanding will be established, which is critical for the ongoing surveillance of the system. Unfortunately, due to the lack of hardware recovery and lack of individual riser load history, the team must primarily rely on the high-quality imagery gathered during the descent and landing. Although some notable off-nominal observations have already cropped up, such as apparent debris strikes and possibly reefing line cutter anomalies, the system successfully delivered the Artemis II crew to a soft landing after their historic mission around the moon.

References

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