Crew Exploration Vehicle Parachute Assembly System

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The Crew Exploration Vehicle (CEV) Parachute Assembly System (CPAS) project is responsible for the design, development, fabrication, qualification, and delivery of the CEV parachute system to support the Orion pad/ascent flight tests and the first three orbital flight tests, including the first human mission. Project tasks include: (1) to conduct testing and analysis on the prototype (i.e., Generation 1 (Gen-1)); (2) to define system requirements and fabricate the flight engineering development unit; and (3) to support the Orion (CEV) vehicle flight testing (primarily Pad Abort 1 (PA-1)).

Generation 1 testing and analysis

The Gen-1 CPAS design is a scaled-up version of the Apollo Earth Landing System. In the CPAS design, two mortar-deployed drogue parachutes stabilize and decelerate the vehicle to conditions that allow for safe deployment of the main parachutes. On release of the drogues, three mortar-deployed pilot parachutes are fired, each of which individually deploys a main.

The CPAS test team conducted three tests: Main (Parachute) Development Test 3 (MDT-3), Cluster Development Test 3 (CDT-3), and Cluster Development Test 2 (CDT-2). For MDT-3, the team tested a single parachute to determine how it performed on its own; for CDT-3 and CDT-2, the team used a "cluster" of parachutes to determine how the parachutes functioned as a set. The team then analyzed and reviewed the data from these tests, as well as from cluster and drogue tests conducted in 2007 (figure 1).

Fig. 1. *Three inflated main parachutes during CDT-1.*

The MDT-3 test consisted of an overload test using a deployment dynamic pressure 30% higher than the design limit load for a single main parachute. This test condition, based on analysis from the prior two single-main parachute tests, takes advantage of the inflation characteristics of the main at the extremely low reefing ratio chosen for the first stage.

The canopy performed flawlessly, providing an opportunity to allow higher dynamic pressures and improve main parachute applicability for future CEV flight tests.

For the CDT-3, the cluster was deployed from a low-velocity air drop (LVAD) pallet, using two CPAS drogues as programmer parachutes to stabilize the pallet and static-line deploy the mains.

Posttest analysis indicates that while the average full-open performance met the pre-flight prediction, the variation in rate of descent exceeded expected dispersions, and the observed variation was greater than in the three-main parachute cluster test, CDT-1. The variation in payload attitude under full-open main parachutes also exceeded the desired ±5 deg. Lockheed Martin Space Systems Company (LM) (Bethesda, Md.) and the Landing and Recovery System team will use these data to simulate the performance for further analysis.

As part of the CDT-2 design activities, the team conducted a series of wind tunnel tests and computational fluid dynamics analysis to better understand the flow field and interaction between the parachute test vehicle (PTV) and the LVAD. CDT-2 was intended to be a full-up deployment of the CPAS from a PTV that accurately simulated the storage, rigging, and attachment of the CPAS to the CEV. In this test, the PTV, attached to the LVAD pallet, was extracted from a C-17 and released just after the assembled PTV/pallet cleared the aircraft (figures 2 and 3).

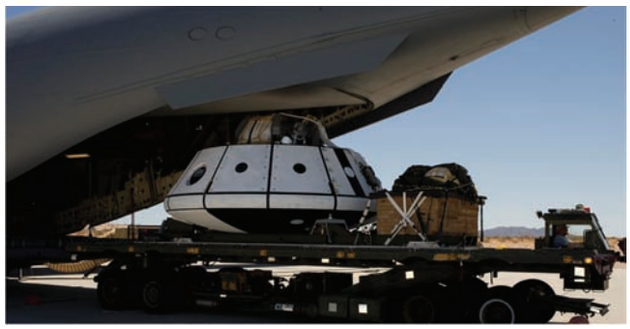

Fig. 2. *A PTV and its Critical Phase Software System (CPSS) are loaded onto a C-17 in preparation for a drop test.*

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continued

The PTV separated from the pallet and the programmer parachutes deployed successfully; however, due to the attachment configuration of the programmers to the PTV, the wake deficit of the vehicle, and the close-coupled programmer parachutes, the primary programmer parachute failed to remain inflated.

As a result, the PTV and the two small programmer parachutes went into a large limit cycle that did not damp. The drogue parachutes deployed and inflated outside the intended attitude box, the drogue risers were severed, and the PTV eventually crashed. No one was hurt, but the PTV and associated on-board hardware were a total loss.

Analysis and model development

The team updated the design limit loads for the drogues and mains based on the Gen-1 flight and ground testing to facilitate implementation of the existing CPAS into the PA-1 test.

The team also extensively modified the decelerator system simulation to support the concept of operations development for the CDT-2. Based on the initial conditions from the CPSS vendor, a substantial risk existed that the PTV would tumble into an apex-forward orientation following separation from the CPAS. Based on modeling and analysis of this separation, the design team added an intermediate programmer parachute attach point to the PTV so the deployed programmer chute could reposition and maintain the PTV at the intended 180-deg angle of attack.

Flight requirements and engineering development unit

The CPAS team worked with LM to develop a vehicle-level architecture change that was approved as the baseline for CPAS integration into the CEV. Due to this change, the CEV forward bay cover (FBC) deploys all of the main parachutes, and the drogues attach to the crew module via the FBC using a multi-point attach harness. The team generated an independent estimate of the flight design CPAS reliability, derived from solid rocket booster experience and accounting for differences between the two architectures.

Based on Gen-2 (flight design) analysis, requirements for minimum-altitude deployment (pad-abort scenario), maximum allowable loads imparted to the CEV, and allowable system weight for the CPAS appeared to be an over-constrained problem with no unique solution.

Gen-2 system requirements were approved and baselined, and an Internal Design Review (IDR) was conducted for the design based on those approved requirements. The IDR indicated that the design failed to meet two major requirements: (1) loads imparted to the CEV were too high, and (2) the main parachute pack density exceeded the limit of 38 lb/ft^3.

Fig. 3. *CPAS team members route a pilot riser in the PTV.*

The team will continue to update requirements as the design process continues. Team members will also examine how long the CEV "rides the drogues" on a pad-abort deployment to optimize both the attitude at main chute deployment and the design limit load for the mains.

The team performed initial compatibility testing at NASA White Sands Test Facility (WSTF) to determine how CEV Reaction Control System exhaust products affect high-tenacity parachute materials.

The CEV preliminary design architecture publication included a parachute system to prevent the FBC rate of descent from exceeding that of the CEV under three full-open mains.

Project members worked with Rice University (Dr. Tayfun Tezduyar, Houston) to develop a modeling approach to help engineers understand the nature of the main parachute oscillations in full-open performance without modifying and testing the hardware.

Canopy joint efficiencies were reviewed in detail, including ground testing and redesigning joints that did not meet a minimum efficiency of 80%.

Orion vehicle flight testing

CPAS completed much work to support Orion flight testing, including CPAS to Flight Test Article integration fit checks for PA-1. Engineers supplied attach harnesses (or slings) to NASA Langley Research Center for proof-loading, and submitted detailed rigging and integration procedures for use at WSTF.

As a response to trajectory design issues, the deployment envelope boundaries were relaxed by (1) raising the limit dynamic pressure for the mains, (2) opening up the first stage of the drogues as far as possible, and (3) removing all margin from the drogue design limit load definition.

Ground testing for environments (primarily vibration) continues to address identified risks and determine whether the CPAS can be implemented without changes on PA-1.

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