2008 Accomplishments for CEV Parachute Assembly System (CPAS)

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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). This article will discuss the technical and research achievements accomplished in calendar year 2008, broken into three key categories: prototype testing and analysis (also referred to as the Generation 1 design), system requirements definition and design of the flight engineering development unit, and support for the Orion vehicle flight testing (primarily Pad-Abort 1).

Three inflated main parachutes during CDT-1.

Generation 1 Testing and Analysis

The Generation-1 (Gen I) CPAS design is a scaled up version of the Apollo Earth Landing System. This design starts by firing two mortar-deployed drogues that stabilize and decelerate the vehicle to conditions that allow for safely deploying the main parachutes. The drogues are attached to a single gusset via their individual risers. Upon release of the drogues, three mortar-deployed pilots are fired, each pilot individually deploying a main parachute. The main parachute cluster is attached via a harness assembly to three of the gussets on the top of the CEV; the individual mains and the three attach harness legs meet at a confluence fitting 16 feet above the vehicle.

Three tests were conducted in calendar year 2008: Main Development Test 3 (MDT-3), Cluster Development Tests 3 and 2 (CDT-3 and CDT-2). Analysis of the data from these tests was completed and reviewed; analysis of data from CDT-1 and Drogue Development Tests 2 and 3 (DDT-2 & DDT-3), all of which were conducted late calendar year 2007, was completed and reviewed as well. In support of CDT-2, a series of wind tunnel tests and computation fluid dynamics analysis were conducted to improve understanding the flow field and interaction of the Parachute Test Vehicle (PTV) with the Cradle and Platform Separation System (CPSS), the low-velocity air drop pallet used to extract the PTV from the C-17. These tests and analysis looked at both the combined/rigged test article and the near-field interference as the two bodies separated. The results of this testing, aerodynamic force, and moment coefficients, as well as flow-field wake deficit, were implemented in the multi-body separation analysis conducted to support the design of CDT-2.

MDT-3, performed 29 January 2008, consisted of a single-main overload test where the deployment dynamic pressure was 30% higher than the Design Limit Load for the main. This test condition was designed based on the analysis of the prior two single main tests taking advantage of the inflation characteristics of the main at the extremely low reefing ratio that was chosen for first stage. The canopy performed flawlessly, confirming the opportunity to take these mains to dynamic pressures higher than originally designed for and improving their applicability (as existing assets) to CEV flight tests still being designed, which are intended for use in implementing the Gen-1 CPAS.

CDT-3, conducted 17 June 2008, consisted of a two-main cluster test deployed from an LVAD pallet. Two CPAS drogues were used as programmer parachutes to stabilize the pallet and to static-line deploy the mains.

Post-test analysis indicates that, while the average full-open performance met the pre-flight prediction, the variation in rate of descent exceed expected dispersions, and the observed variation was greater than that observed in the three-main cluster test CDT-1. Additionally, the variation in payload attitude under full-open mains exceeded the desired +/- 5 degrees. The rate of descent and attitude data has been provided to Lockheed Martin (LM) and the Landing and Recovery System (LRS) team in order to simulate the performance of the landing system at the observed performance. No attempts were made to improve the variations in steady-state performance pending the results of CDT-2 (a three main cluster test).

A PTV and its CPSS are loaded onto a C-17 in preparation for a drop test.

CD-T 2, conducted 29 July 2008, was intended to be a full-up deployment of the CPAS from a PTV that accurately simulated the storage, rigging, and attach of the CPAS to the CEV. The test involved extracting the PTV attached to a pallet out of a C-17 and releasing the PTV just after the assembled PTV/pallet cleared the aircraft. The separation worked and the programmer parachutes were successfully deployed; 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. This in turn resulted in deploying and inflating the drogue parachutes outside the intended attitude box. The drogue risers were severed and the PTV eventually crashed. No individuals were hurt, but the PTV and the associated hardware onboard were a total loss.

Analysis and Model Development

Design Limit Load updates were generated for the drogues and mains based on the Gen-1 flight and ground testing. The primary impetus for this work was to facilitate implementation of the existing CPAS to the Pad-Abort 1 (PA-1) test.

A parachute modeling Technical Interchange Meeting (TIM) was held to establish how the CPAS will be modeled for trajectory design and concept of operations development.

The Decelerator System Simulation (DSS) was extensively modified to support the concept of operations development for the Cluster Development Test 2 (CDT-2); this primarily involving the separation of the Parachute Test Vehicle (PTV) from the pallet (referred to as the CPSS) that extracts it from the C-17. Based on the initial condition the CPSS vendor provided, a substantial risk existed that the PTV would tumble off into an apex-forward orientation following separation from the CPSS. The modeling and analysis of this separation eventually resulted in adding an intermediate attach point on the side of the PTV for the programmer parachute when it was initially deployed. The programmer would subsequently reposition to hold the PTV at the intended 180-degree angle of attack in order to proceed with the nominal drogue deployment and CPAS sequence.

Flight Requirements and Engineering Development Unit

The following list of analysis, designs and reviews completed in 2008 represent the major CPAS team accomplishments associated with the flight design of CPAS.

January 2008: Vehicle-level architecture changes were taken to the LM Engineering Review Board (ERB) and approved as the baseline for CPAS integration into the CEV. Due to the change, the CEV Forward Bay Cover (FBC) deploy the mains, rather than each main being deployed by an individual pilot (Gen-I); and drogues attach to the CM via the FBC with a multi-point attach harness

March 2008: Review of the preliminary Generation II requirements was conducted with the Crew Module Office (CMO) and LM.

April 2008: Gen-II (aka Flight Design) kickoff. This preliminary design was based on the requirements finalized in March. Based on this analysis it appeared that the requirements for minimum-altitude deployment (which occurs on a pad-abort scenario), the maximum allowable loads imparted to the vehicle, and the allowable system weight for the CPAS were an over-constrained problem with no unique solution.

July 2008: Gen-II System Requirements Review (SRR) was held. The Review Item Discrepancy (RID) Board was closed and resolved September 2008.

October 2008: Project Technical Requirements Specification (PTRS) was submitted for signature (officially released January ’09).

December 2008: Internal Design Review (IDR) was conducted. A design was presented that attempted to meet the requirements established at the SRR and provided a baseline for how the CPAS would be integrated into the CEV. The design failed to meet two major requirements, exceeding the loads imparted to the CEV and resulting in a main parachute pack density that exceeded the limit of 38 lb/ft^3.

Several requirements updates are expected by no later than the end of February 2009, which will allow for another design cycle for the drogues and mains prior to the CPAS Preliminary Design Review (PDR) scheduled for June 2009. These updates will include implementation of the Version 0.52 Orion Aerodynamic Databook in the flight dynamics models that hand off to the CPAS deployment conditions for both nominal drogue deployment and pad-abort main deployment scenarios. Other follow-up actions are being pursued including examining the length of time the CEV “rides the drogues” on a pad-abort deployment to optimize both the attitude at main deploy and the design limit load for the mains.

Throughout 2008

Initial compatibility testing was performed for high-tenacity parachute materials with exhaust products from the CEV Reaction Control System (RCS) which will be used to orient the vehicle prior to landing (while under the main parachutes). This testing was conducted at White Sands Test Facility.

Architecture and preliminary design for a parachute system to prevent the Forward Bay Cover rate of descent from exceeding that of the CEV under three full-open mains was published for use in CEV design.

The team worked with Rice University (Dr. Tayfun Tezduyar) to develop a coupled Computation Fluid Dynamics (CFD) and Finite Elements Method (FEM) solution for the performance of the CPAS main parachutes (this approach to modeling structures that can deform in the presence of an aerodynamic flow field is referred to as Fluid Structures Interaction or FSI). These models are being used to understand the nature of the oscillations in full-open performance potential fixes prior to committing to modification and testing of hardware.

CPAS team members route a pilot riser in the PTV.

A detailed review of canopy joint efficiencies was conducted, including redesign and ground testing of those that did not meet a minimum efficiency of 80%.

An independent estimate of the flight design CPAS reliability was generated based on Solid Rocket Booster (SRB) experience accounting for differences between the two architectures.

Orion Vehicle Flight Testing

Many actions, analyses, and reviews occurred in 2008 to support Orion flight testing. Integration fit checks of the CPAS to the Flight Test Article (FTA) for PA-1 were completed. Attach harness (or slings) were supplied to Langley Research Center (LaRC) for use in the proof loading of the FTA. Detailed rigging and integration procedures were submitted for approval and use in rigging the CPAS to the FTA at White Sands Test Facility.

The PA-1 test team worked to understand trajectory design issues resulting from the Gen-1 constraints memo. As a result, the deployment envelope boundaries were relaxed by 1) raising the limit dynamic pressure for the mains (taking advantage of the main parachute performance observed during the Gen-1 development testing), 2) opening up the first stage of the drogues as far as possible (the drogues never have the chance to disreef on PA-1 as they are released too soon), and 3) removing all margin from the definition of the drogue Design Limit Load (DLL).

An EA assessment was conducted from March-December 2008 to identify risks to CPAS associated with implementation on PA-1. Ground testing for environments (primarily vibration) is ongoing and the results will determine whether the CPAS can be implemented without changes on PA-1.