DEVELOPMENTAL FLIGHT INSTRUMENTATION SYSTEM FOR THE CREW LAUNCH VEHICLE

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ABSTRACT

The National Aeronautics and Space Administration is developing a new launch vehicle to replace the Space Shuttle. The Crew Launch Vehicle (CLV) will be a combination of new design hardware and heritage Apollo and Space Shuttle hardware. The current CLV configuration is a 5 segment solid rocket booster First Stage and a new Upper Stage design with a modified Apollo era J-2 engine. The current schedule has an Ascent Development Test Flight (ADFT-0) with a First Stage and a dummy structurally identical, but without engine, Upper Stage. The ADFT-0 test results will determine if there will be multiple ADFT flights. There will be a minimum of two test flights with a full complement of flight hardware. After the completion of the test flights, the first manned flight to the International Space Station is scheduled for late 2014.

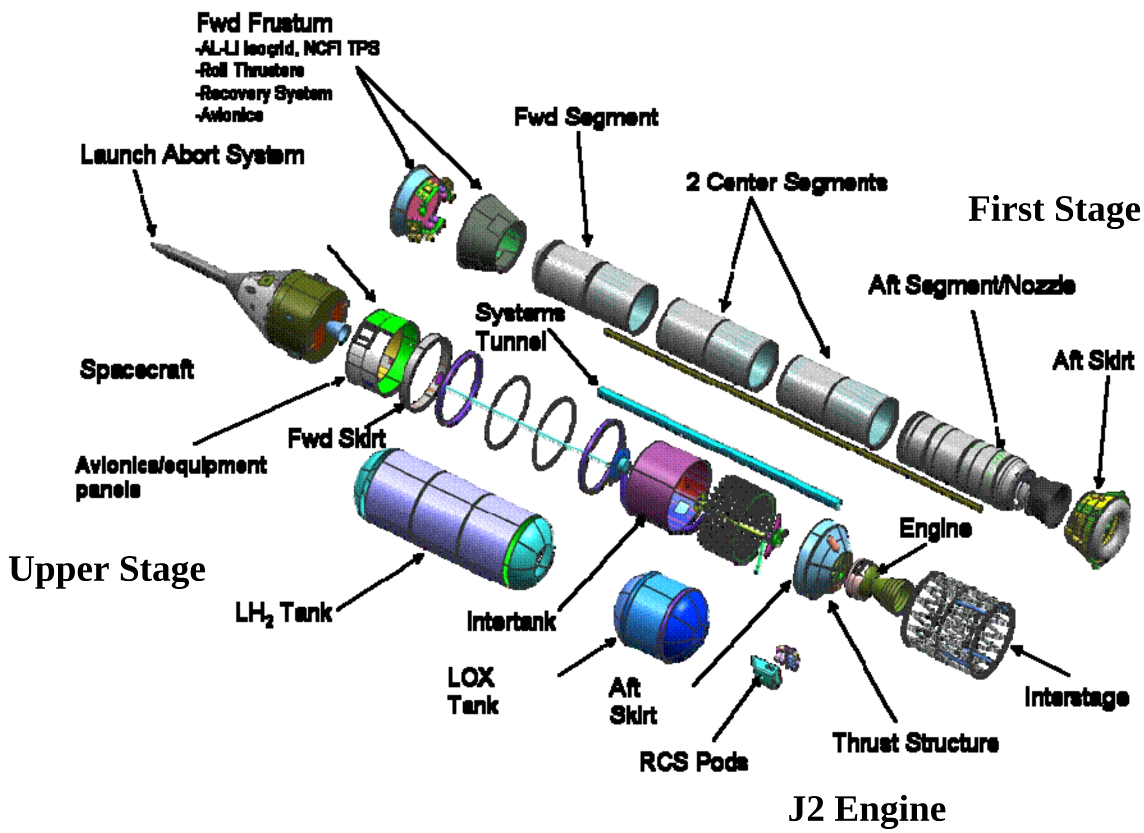
To verify the CLV's design margins a developmental flight instrumentation (DFI) system is needed. The DFI system will collect environmental and health data from the various CLV subsystems' and either transmit it to the ground or store it onboard for later evaluation on the ground. The CLV consists of 4 major elements: the First Stage, the Upper Stage, the Upper Stage Engine and the integration of these elements together. It is anticipated that each of CLV's elements will have some version of DFI. This paper will discuss a conceptual DFI design for each element and also of an integrated CLV DFI system.

KEY WORDS

Developmental Flight Instrumentation, Crew Launch Vehicle

INTRODUCTION

The National Aeronautics and Space Administration is developing a new launch vehicle to replace the Space Shuttle. Marshall Space Flight Center (MSFC) has been given the task to lead the development of the Crew Launch Vehicle (CLV). The CLV will be a combination of new design hardware and heritage Apollo and Space Shuttle hardware. The current CLV configuration is a 5 segment solid rocket booster First Stage and a new Upper Stage design with a modified Apollo era J-2 engine. Figure 1 shows an expanded view of the CLV's First Stage, Upper Stage and Upper Stage Engine. Due to program issues, the flight schedule is continually changing. However, the first test flights are scheduled to start in 2009 and continue on until the first manned flights to the space station in 2014.

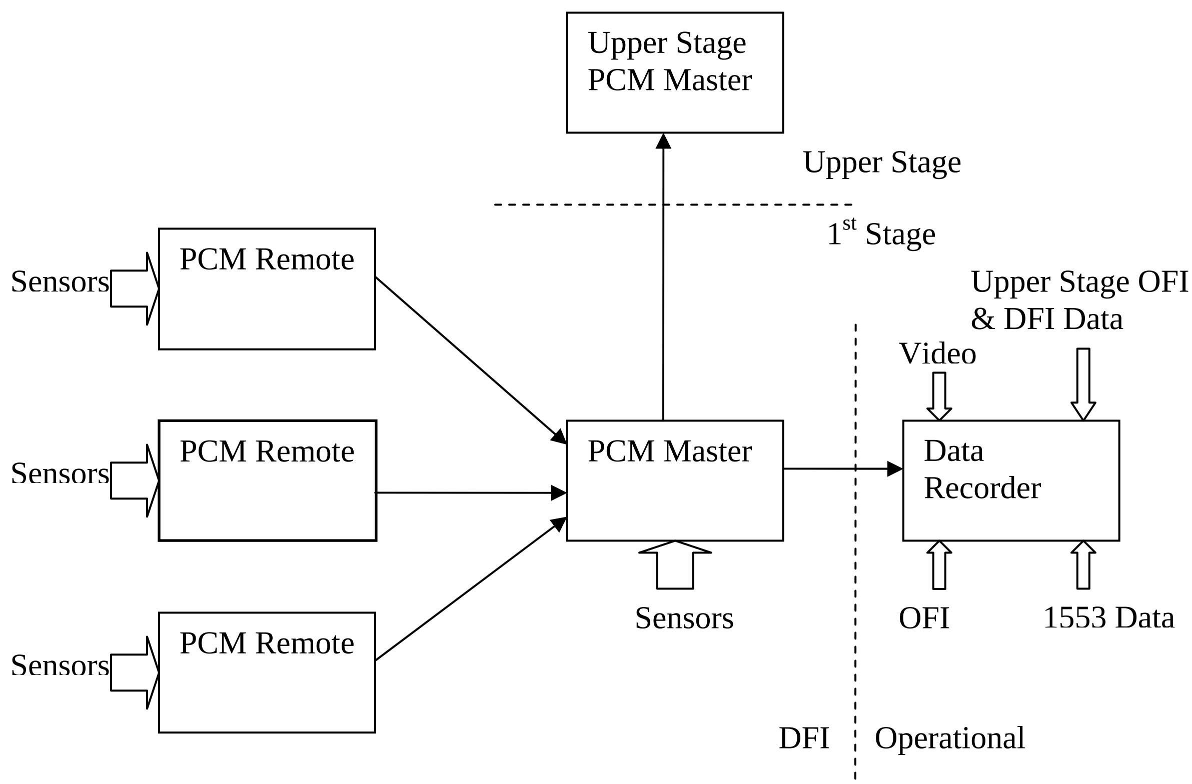


Expanded View of the CLV's Elements
Figure 1

Since this is essentially a new launch vehicle, there is a lot of uncertainty with the environments that the CLV will encounter. To verify the CLV's design margins, a developmental flight instrumentation (DFI) system is needed. The DFI system will collect environmental and health data from the various CLV subsystems' and either transmit it to the ground or store it onboard for later evaluation on the ground. The CLV consists of 4 major elements: the First Stage, the Upper Stage, the Upper Stage Engine and the integration of these elements together. It is anticipated that the First Stage, Upper Stage and Upper Stage Engine will have some version of DFI. This paper will discuss a conceptual DFI design for each element and also of an integrated CLV DFI system.

FIRST STAGE

The First Stage is a five segment solid rocket booster. The current space shuttle uses two four segment solid rocket boosters; therefore the extra segment adds a lot of uncertainty to the vehicle. The CLV will travel faster and higher than the shuttle's solid rocket boosters (SRB's) before First Stage separation. The prime contractor for the First Stage is ATK. Like the SRB's, the segments will be fabricated in Utah and shipped to Kennedy Space Center (KSC) and the booster will be assembled at KSC by United Space Alliance personnel.



Conceptual DFI System for First Stage
Figure 2

The First Stage will be the main focus of the first test flights. In late 2009, a five segment booster with a dummy Upper Stage test flight is planned. Depending on the results of this test flight, more test flights with a dummy Upper Stage could take place. Regardless of flight configuration, a DFI system will be required for these flights. The main purpose of the First Stage DFI system on these test flights will be to collect ascent and descent environmental data, recovery system data and water impact data.

Like the SRB's, the First Stage will be recoverable. Since it will be recovered, no data will be transmitted from the First Stage. The only radio frequency (RF) system on the First Stage will be part of the range safety system. Figure 2 shows a conceptual DFI design for the First Stage.

The DFI system will collect data from accelerometers, temperature sensors (resistance thermal devices (RTD's) and thermocouples), pressure sensors, calorimeters, strain gages, microphones, and discrete measurements. The sample rates will be from 1 sample per second up to 40,000 samples per second. The total sensor count will be between 500 and 600. The sensor count could go up, but due to weight considerations the number will not be much above 600. Figure 2 shows three PCM remote units, this number could change depending on the final measurement list. Each PCM unit will have some unused capability; this will allow the measurement list to change between flights. The format of the PCM system could change during the mission. For example, prior to water impact the accelerometer sample rate may increase. The DFI system will be located in the forward frustum of the First Stage.

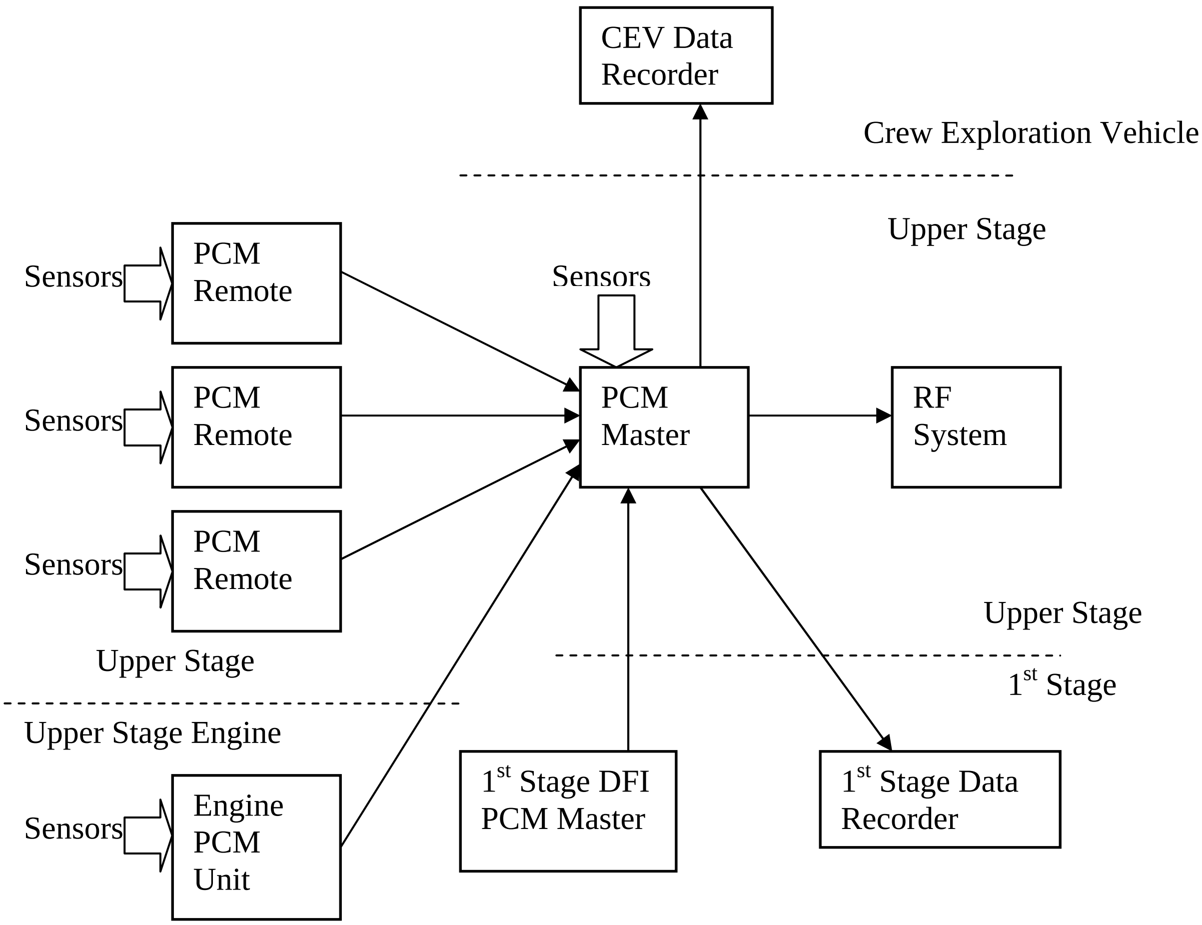
The DFI system will be a self contained system providing its own power distribution system. As shown in Figure 2, the only interface with the operational system will be with the data recorder and this could change with the PCM Master having its own memory for data storage. After the test flights and typically the first one or two manned flights, the DFI system is removed. The deletion of the DFI system is the main reason that the DFI and operational instrumentation is not integrated. An independent DFI system allows minimal impact to the operational system when it is removed. However, a minimal set of DFI could be required for all flights of CLV. If this happens, then the DFI hardware should be incorporated into the operational system.

Upper Stage

The Upper Stage is a new design managed by Marshall Space Flight Center (MSFC). MSFC will lead the design of the Upper Stage and give the design to a fabrication contractor for fabrication, assembly, integration, and test. The Upper Stage will be built at Michoud Assembly Facility by the fabrication contractor. Glenn Research Center (GRC) was given the task to design and develop the Upper Stage DFI system. GRC has conducted several trades and analysis to determine the optimal DFI system.

The initial use of the Upper Stage DFI system will likely occur during the first test flights. Although there will be a dummy Upper Stage, the dimensions of the Upper Stage will be flight like. Therefore, the vehicle designers will want environmental data from the Upper Stage. Other than the sensor suite, the Upper Stage DFI system for the test flights should be identical to the DFI system for the operational Upper Stage DFI system test flights. The DFI system will be independent from the operational system. The DFI system will have its own power distribution system and RF system. This will allow minimal impact to the operational system when the DFI system is removed. Figure 3 shows a conceptual design for the Upper Stage DFI system.

The main challenge for the Upper Stage DFI system is to get all of the data to the ground. When ground stations are available the DFI data rate will probably not be an issue. However, when the data has to go thru the tracking and data relay satellite system (TDRSS) data rates to the ground become a main issue. One solution to this problem is to record all of the Upper Stage DFI data on a dedicated CLV data recorder that is located on the crew exploration vehicle (CEV) while still transmitting a subset of data to the ground.



Conceptual DFI System for Upper Stage
Figure 3

The DFI system will collect data from accelerometers, temperature sensors (resistance thermal devices (RTD's) and thermocouples), pressure sensors, calorimeters, strain gages, microphones, and discrete measurements. The sample rates will be from 1 sample per second up to 20,000 samples per second. The total sensor count will be approximately 600. Table 1 shows a possible list of sensors and data rate for the Upper Stage DFI system. Table 1 is not the final Upper Stage measurement list, but a starting point. The sensor count could go up, but due to weight considerations the number will not be much above 600. Figure 3 shows three PCM remote units, this number could change depending on the final measurement list. Each PCM unit will have some unused capability; this will allow the measurement list to change

200 Temperature Sensors @ 1 Sample/ Second
200 Strain Gauges @ 10 Samples/ Second
100 Pressure Sensors @ 10 Samples/ Second
25 Heat Flux @ 50 Samples/ Second
25 Leak Detector Sensors (O_2, H_2) @ 10 Samples/ Second
25 Microphones @ 1000 Samples/ Second
25 Accelerometers @ 20k Samples/ Second

Example of Measurement List for Upper Stage
Table 1

between flights. The format of the PCM system could change during the mission. For example, after First Stage separation the sample rates for accelerometers may change to collect data during the Upper Stage Engine ignition. The DFI system will be distributed throughout the Upper Stage. To reduce cable weights, one PCM remote will be located towards the aft segment of the upper stage, one PCM remote in the intertank region of the Upper Stage and the PCM master in the forward segment of the Upper Stage. However, the locations could change depending on where the sensors are located.

Upper Stage Engine

The Upper Stage Engine is a modified Apollo era J-2 engine. Since this engine has not been manufactured in many years, it will be essentially a new design. Pratt Whitney Rocketdyne (PWR) is the prime contractor for the Upper Stage Engine (USE). The engines will be built in California and tested at Stennis Space Center.

PWR is studying how to incorporate DFI into their design to minimize the impact to the operational system. They basically have three options. They can incorporate DFI into the operational system engine controller, have their own DFI PCM unit or use the Upper Stage DFI system. As shown in Figure 3, the logical solution is to have a dedicated PCM unit for the USE. Who owns the unit can be debated, but the output of the box will go into the Upper Stage PCM master for multiplexing the data.

The PCM unit will collect data from accelerometers, temperature sensors (resistance thermal devices (RTD's) and thermocouples), pressure sensors, flow sensors, microphones, and discrete measurements. The sample rates will be from 1 sample per second up to 20,000 samples per second. The total sensor count will be between 200 and 300. The sensor count will probably be closer to 200 than 300. Figure 3 shows one PCM unit for the USE. If additional measurements are required, then the USE may be able to use some of the unused capability of the Upper Stage PCM remote located in the aft segment.

The USE DFI system will be independent from the operational system, but will be integrated into the Upper Stage DFI system. Even if the USE provides its own PCM unit, the USE DFI system will require power from the Upper Stage DFI system and the Upper Stage DFI system will have to account for the USE in determining their telemetry data rates. Since the USE is a new engine, they may require a DFI system for more flights than the Upper Stage.

Integrated Vehicle

MSFC has been given the integration lead for CLV. The First Stage will be assembled at KSC like the SRB's. The Upper Stage and Upper Stage Engine will be integrated and tested at Stennis Space Center and shipped to KSC. Then all elements will be integrated in the vehicle assembly building.

Although the First Stage, Upper Stage and Upper Stage Engine may have their own independent DFI system, they will be integrated together to provide as much redundancy as possible. The DFI system traditionally is not redundant. This redundancy is in the method of getting the data to the ground. As shown in Figure 2 and Figure 3, the data is shared between elements and each element has different ways of getting the data to the ground, either transmitted or stored on a data recorder and recovered after the flight. During the First Stage of flight, all of the First Stage DFI data and all of the Upper Stage DFI data will be recorded on the First Stage operational data recorder and all of the Upper Stage DFI data and a subset of the First Stage DFI data will be transmitted to the ground. After First Stage separation, the First Stage will continue to record DFI data on its operational data recorder and the Upper Stage will transmit all of its DFI data to the ground. The Upper Stage Engine DFI data will be incorporated into the Upper Stage DFI data. Hopefully, there will be a dedicated CLV recorder on the crew exploration vehicle and will be a backup to all transmitted data. At this point of the program, there have been no agreements made to share the data between the elements. Hopefully, the sharing of data as shown in Figure 3 will take place.

Summary

Since the inception of the crew launch vehicle program one year ago, much work has gone into vehicle studies, trades and analysis. Usually avionics definition does not get started until other subsystems are already in the design phase. CLV has started the avionics design along with the other subsystem design. This way the design can be done with an iterative process and arrive at an optimal design. The element's DFI systems are being done this way. All of the elements are aware that a DFI system will be required and are trying to define the DFI requirements.

This paper showed a conceptual DFI system for each element of the CLV. However, there is no one right way of developing a DFI system. Each element should evaluate the CLV and element requirements and develop a system that meets its needs.

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