Flight Avionics Sequencing Telemetry (FAST) DIV Latching Display

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The NASA Engineering (NE) Directorate at Kennedy Space Center provides engineering services to major programs such as: Space Shuttle, International Space Station, and the Launch Services Program (LSP). The Avionics Division within NE, provides avionics and flight control systems engineering support to LSP. The Launch Services Program is responsible for procuring safe and reliable services for transporting critical, one of a kind, NASA payloads into orbit. As a result, engineers must monitor critical flight events during countdown and launch to assess anomalous behavior or any unexpected occurrence. The goal of this project is to take a tailored Systems Engineering approach to design, develop, and test Iris telemetry displays. The Flight Avionics Sequencing Telemetry Delta-IV (FAST-D4) displays will provide NASA with an improved flight event monitoring tool to evaluate launch vehicle health and performance during system-level ground testing and flight. Flight events monitored will include data from the Redundant Inertial Flight Control Assembly (RIFCA) flight computer and launch vehicle command feedback data. When a flight event occurs, the flight event is illuminated on the display. This will enable NASA Engineers to monitor critical flight events on the day of launch. Completion of this project requires rudimentary knowledge of launch vehicle Guidance, Navigation, and Control (GN&C) systems, telemetry, and console operation. Work locations for the project include the engineering office, NASA telemetry laboratory, and Delta launch sites.

Nomenclature

CARDS	=	Computer Aided Render Display System
CCAFB	=	Cape Canaveral Air Force Base
CDR	=	Critical Design Review
CONOPS	=	Concept of Operation
DCR	=	Design Certification Review
DLPS	=	Delta Launch Processing System
DOC	=	Delta Operations Center
DOD	=	Department of Defense
ELV	=	Expendable Launch Vehicle(s)
FAST-D4	=	Flight Avionics Sequencing Telemetry Delta IV
FF	=	Functional Flow
HOQ	=	House of Quality
KSC	=	Kennedy Space Center
LCC	=	Launch Control Center
LSP	=	Launch Services Program
MSID	=	Measurement Identification
NASA	=	National Aeronautics and Space Administration
NE	=	NASA Engineering
PCM	=	Pulse Code Modulation
PDR	=	Preliminary Design Review
PM	=	Project Manager
RAM	=	Random Access Memory
RIFCA	=	Redundant Inertial Flight Control Assembly
SE	=	Systems Engineering
SRR	=	System Requirement Review
TDP	=	Telemetry Data Processing
TPM	=	Technical Performance Measurement
ULA	=	United Launch Alliance
USRP	=	Undergraduate Student Research Project
V&V	=	Validation and Verification

I. Introduction

The National Aeronautics and Space Administration (NASA) has been a space exploration leader since 1958 in three core competencies: research and technology, flight hardware and development, and mission operations. The NASA Engineering (NE) branches servicing the Launch Services Program (LSP) contributes to the third competency of NASA by procuring safe and reliable services for transporting critical, one of a kind, NASA payloads into orbit. To provide this reliability, engineers must monitor critical flight events during launch to assess any anomalous behavior or unexpected occurrence. One of the launch vehicles used by NASA is the Delta IV rocket built by United Launch Alliance (ULA). Part of NASA Engineering's responsibility is to evaluate vehicle health and performance during system level pad testing and flight. To assist NASA engineers in reviewing vehicle data, a new tool was developed to display flight events for the Delta IV launch vehicle. This project develops the Flight Avionics Sequencing Telemetry-Delta IV (FAST-D4) display which is a new telemetry display based on Iris. FAST-D4 provides the NE Expendable Launch Vehicle (ELV) Avionics branch with an independent assessment tool to evaluate health and performance of the Delta IV launch vehicle. This tool functions by illuminating flight events on a display to alert the user that a command has been sent by the flight computer. FAST-D4 utilizes pre-existing telemetry hardware at Hangar AE and easily interfaces with the Iris and Winplot data display systems. The contents of this paper describe the design and development of the FAST-D4 display with a tailored Systems Engineering (SE) approach.

II. NASA Engineering's Role in the Launch Services Program

The Launch Services Program Office is located at the Kennedy Space Center (KSC) and is responsible for the vehicle selection and management of expendable launch vehicle missions. The principal objectives are to provide safe, reliable, cost-effective, and on-schedule processing. LSP also provides mission analysis, spacecraft integration, and launch services for NASA and NASA-sponsored payloads needing a mission on an ELV. LSP is responsible for the success of its missions and implements a technical oversight approach to ensure the reliability of each vehicle. Unlike commercial companies, NASA does not buy insurance for their spacecraft; instead, the LSP program ensures mission success by mitigating risk.

LSP acquires avionics and flight control systems engineering services from the NE directorate. These services include clarifying the technical objectives required for each mission and reviewing flight hardware, which includes analyzing the design and development of new implementations. The branch also provides technical oversight during integrated launch vehicle checkout and console support during day of launch activities. The fleet of launch vehicles that NE oversees includes the Delta, Atlas, Taurus, and Pegasus vehicles (Fig. 1).

Figure1. The NASA LSP Fleet (from the left: Delta IV, Atlas V 500 Series, Atlas V 400 Series, Delta II, Taurus, and Pegasus).

III. Problem Statement and Solution

NASA Engineering needs a telemetry display for the Delta IV launch vehicle to capture short duration sequencing events such as 180ms ordnance events. NASA Engineering requires a display to aid in monitoring the vehicle's health. The design needs to be compatible with existing telemetry architecture to reduce cost, and the formatting needs to be similar to previous architectures to facilitate the user's navigation of the page. . Since ordnance events are too quick for the existing telemetry display, a latch needs to be included on the display that will keep the flight event illuminated until the user issues a reset command. The latch will keep the flight event illuminated until the user issues a reset command. Each page should also show a quick view of the 1st or 2nd stages to keep the engineer informed of flight events from both stages at all times. The final product should provide NASA Engineering with a useful tool for viewing Delta IV flight event telemetry.

IV. Systems Engineering Approach

A tailored Systems Engineering (SE) approach (Fig. 2) is applied to the organizational structure of this project to ensure the quality of the final product. The process begins with soliciting the stakeholder's needs. Stakeholders are individuals or groups that have an interest in or need for the final project. Once the stakeholders' needs have been identified, a timeline (Fig. 3) is created to establish critical SE milestones. Next, two diagrams are produced to provide the basis for developing the system level requirements and to clarify the technical processes involved. The first diagram is the Functional Flow (FF) which is a flow diagram that describes in words the technical steps that occur in the final product. The second diagram is the Concept of Operation (CONOPS) which provides a pictorial representation of how the final product will function within the system. Afterwards, a System Requirement Review (SRR) is conducted to baseline the system level requirements with the stakeholders. Next, a preliminary design or prototype is developed and data collection begins. The next step develops the design-to requirements which describe how the system level requirements will be implemented. After all requirements have been defined, the design team holds a Preliminary Design Review (PDR) to baseline the design-to requirements and ensure that the project is on schedule, the technical performance meets the stakeholders standards, and the prototype meets system level requirements. Once the PDR is accepted by the stakeholders, the product begins development. The development process iterates many cycles of prototype production and Validation and Verification (V&V) processes which confirm that the right product was produced, the stakeholders' needs were met, and that it was built according to the system level and design-to requirements. Then, a Critical Design Review (CDR) is conducted to verify with the stakeholders that the product is mature enough for finalization. Once the stakeholders approve the CDR, the project is finalized and the V&V process is completed. Finally, the Design Certification Review (DCR) certifies the design for release.

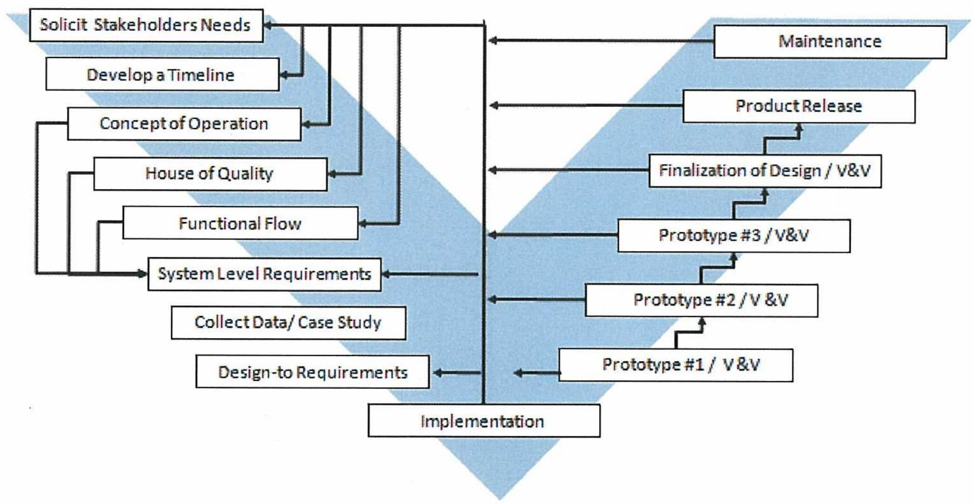

Figure 2. Tailored Top-Down/ Bottom-Up Systems Engineering Development Process

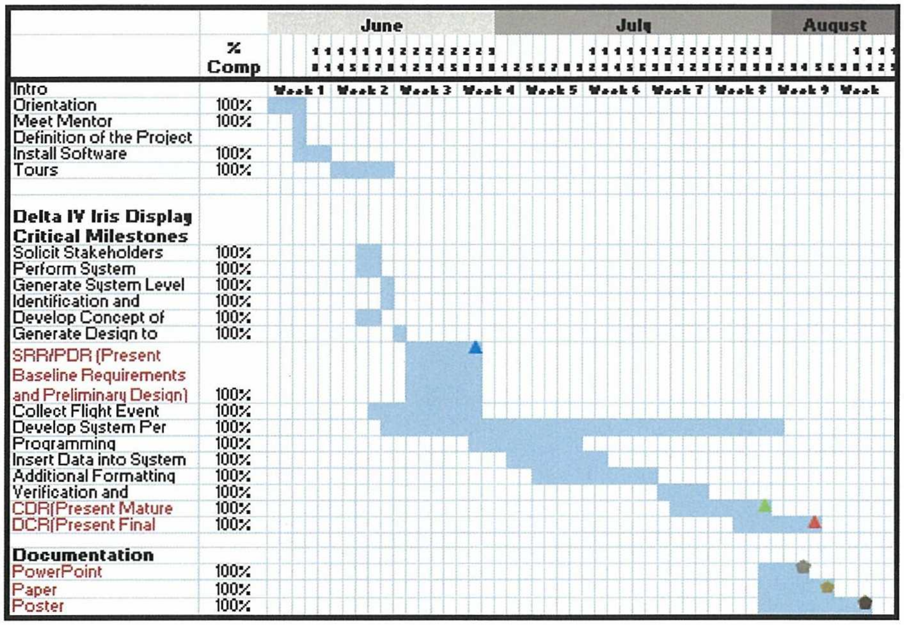

Figure 3. Project Timeline

V. Stakeholders Needs

The Stakeholders are identified according to their influence in Fig. 4. Stakeholders for this project include NASA, the Engineering directorate, LSP, the design team, ULA, and Hangar AE. The stakeholders' needs are assessed through meetings, interviews, or direct requests. Many of these stakeholders are involved in the SRR, PDR, CDR, and DCR Systems Engineering processes to discuss their needs with the design team. Table1 defines the needs of the stakeholders for the FAST-D4 display.

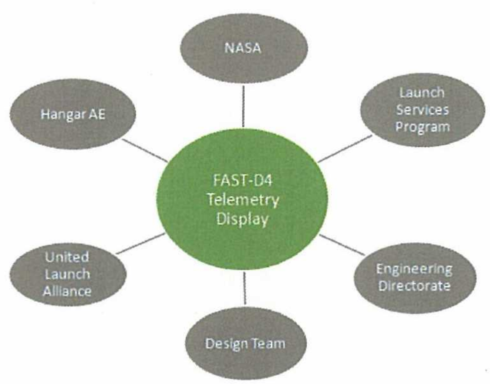

Figure 4. FAST-D4 Project Stakeholders

Table 1. Stakeholder Requirements

No.	Stakeholder Requirements
I	The stakeholder needs a toolbox to display telemetry to illustrate flight events for Delta IV.
II	The stakeholder needs the toolbox to be compatible with existing telemetry architectures.
III	The stakeholder needs the toolbox to be easy to use.

VI. Case Study

An important part of the SE process is to identify which method would be the best approach to execute the project. OpenOffice and Microsoft Power Point were studied to assess the pros and cons of using either software. Power Point offered some convenient tools for creating a telemetry display. First, Power Point can be easily converted into a web page which enables the engineering team to view how the final design would look at Hangar AE. Power Point also automatically adjusts the display size to fit the console monitor where it is being viewed. It is also easy to insert clip art and manipulate the size of the widgets. However, the FAST-D4 telemetry display requires a very large number of telemetry signals that would require a great amount of time to insert into Power Point and be difficult to organize. OpenOffice offered a better solution to that issue since existing cells allow data to be inserted more easily. OpenOffice also has a hiding feature that allows informative data such as the Measurement Identification (MSID), description, and raw signal to be accessible yet not displayed. This is important, because space is limited for flight events on the consol. Hangar AE can use either software program; however, the case study concluded that OpenOffice provides the best approach to implementing a telemetry display with such a large number of parameters.

VII. Project Management Hierarchy

The Project Management Hierarchy is a part of the SE process that defines where all contributors of the project stand within the internal structure. Figure 5 indicates the hierarchy for the FAST-D4 display. All members of the structure work together, and some participate in multiple areas. The project manager oversees the implementation of the design and is responsible for the success of the project. The Systems Engineers assist in the application of proper systems engineering techniques to ensure the quality of the final product. Hangar AE provides technical support regarding pre-existing telemetry systems. Avionics Engineers provide flight controls and operational support necessary for successful completion of the design.

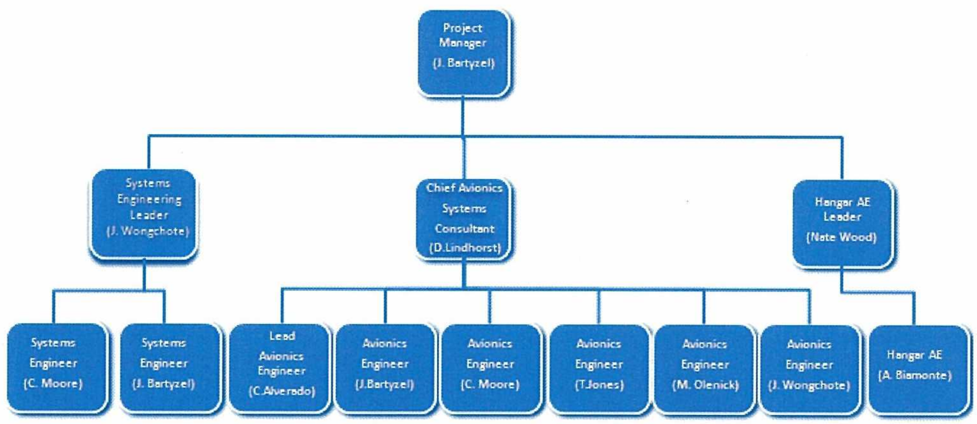

Figure 5. FAST-D4 Project Management Hierarchy

VIII. Concept of Operation

The CONOPS for the FAST-D4 display are shown in Fig. 6 and 7. Figure 6 shows the CONOPS for the telemetry system as a whole, and Figure 7 shows the CONOPS for the telemetry processing inside Hangar AE that directly relates to FAST-D4. When the launch vehicle is powered on, telemetry data is sent directly to the Launch Control Center (LCC) by hard line. At approximately T – 6 minutes the launch vehicle begins transmitting telemetry by radio frequency through S band. The S band telemetry goes through a system of downrange telemetry assets and eventually is relayed to Hangar AE. Inside Hangar AE the patch panel receives the telemetry and routes it to the Telemetry Data Processing (TDP) unit. The TDP handles real-time front end processing of Pulse Code Modulation (PCM) streams. It consists of a bit synchronizer and PCM decommutator. From the TDP, the telemetry is sent to Scramnet which is the Random Access Memory (RAM) for two computers; CARDS and Frame Capture. The telemetry takes two separate paths at this point to be distributed to two separate programs. The Frame Capture computer captures PCM frames into files for storage and then sends the frames to Winplot Archiver. Winplot Archiver stores every sample and then sends the stream to Winplot. Winplot, a software strip-charting tool, receives all samples used for real-time and post-test analysis. Unlike Frame Capture, the CARDS computer does not store every sample; instead, it collects data into packets for the Iris telemetry program. The Iris hardware and software de-couples raw telemetry and graphically displays all measurements. It is designed to be scalable and easily deployable to different locations depending on the location of the launch. FAST-D4 detects flight events by looking at changes in the discrete telemetry from Iris.

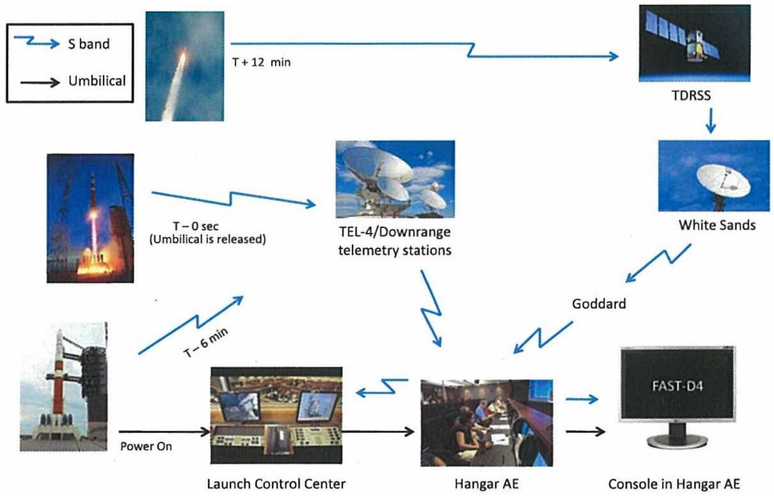

Figure . FAST-D4 Concept of Operations of Existing Architectures

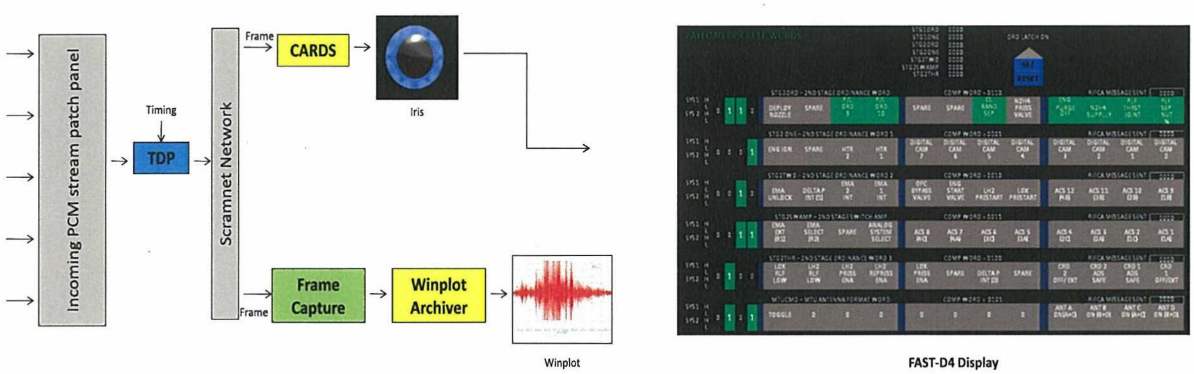

Figure 7. FAST-D4 Concept of Operations inside Hangar AE

IX. Functional Flow

The Functional Flow (FF) shown in Fig. 6 provides a flow chart of how the actual product will function. FAST-D4 begins with the Launch Vehicle (LV) broadcasting telemetry (TLM) and ends with the flight event being illuminated on the screen.

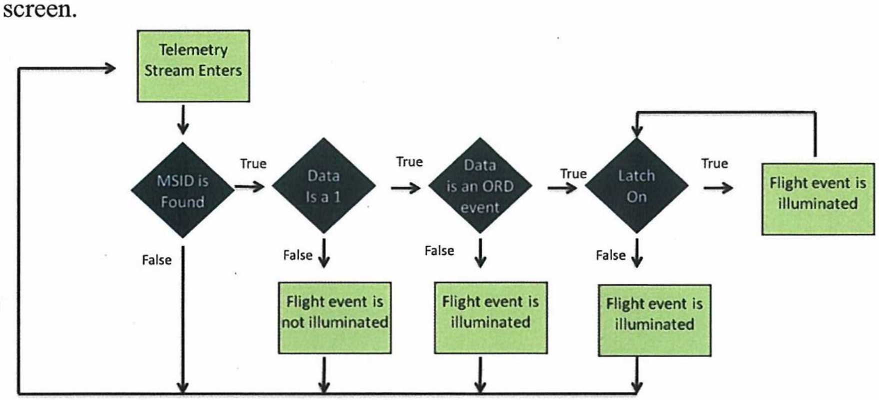

Figure 8. FAST-D4 Functional Flow Logic in Each Cell

X. Prototype

A prototype provides a visual sample of how the final project will work or how it will look. The first prototype shown in Fig. 9 looks very different from the final project, but many of the same concepts are implemented. This prototype labels daily events, and illuminates a green box when an event occurs. For example, the bit designated for waking up was activated, so the corresponding box is illuminated. The second prototype in figure 10 appears much more like the final product, but contains very different functional logic.

	Charlotte's Daily Events(no Macros)							
Evt#	MSID	Alt Name	Description Value	Units	Green Box	Time Stamp	Value	Binary
1	abc1	wkup	Wake up	snooze buttons	1	6:00am	1	0000000000000001
2	def2	brkfst	Eat Breakfast	cheerios	1	6:16am	2	0000000000000010
3	geh3	gt rdy	Get ready for work	activities	1	6:30am	4	0000000000000100
4	ijk4	dv2wk	Drive to work	turns	1	7:15am	8	0000000000001000
5	lmn5	shwbdg	Show Badge	slowing rate	0	7:45am	16	0000000000010000

Figure 9. Prototype 1: Charlotte's Daily Events

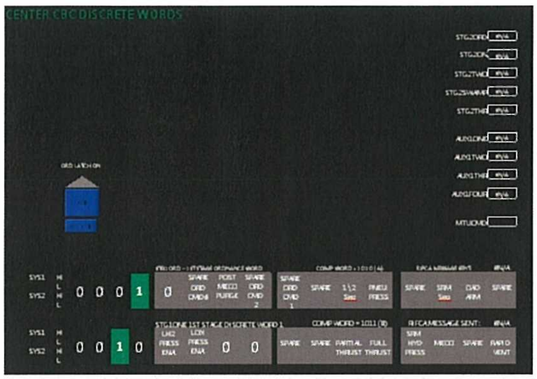

Figure 10. A) Prototype 2: CBC Display

Figure 10. B) Prototype 2: Upper Stage Display

XI. The System Level Requirements

Once the stakeholders needs have been identified and a case study has been performed, the system level requirements are determined. The system level requirements define the system architecture that must be implemented to meet the stakeholders' needs. For instance, the stakeholder needs the telemetry display to be compatible with existing architecture. One system level requirement is met by using OpenOffice since it interfaces easily to Iris as determined by the case study. The system level requirements for the FAST-D4 display are listed in Table 2 below.

Table 2. System Level Requirements

No.	System Level Requirements
I.A	The display shall contain all flight critical data.
I.B	Both displays shall illuminate flight events as received.
I.C	Both displays shall contain a resettable latching mechanism to capture ordnance events
II.A	The toolbox shall be compatible with the Iris Telemetry System.
II.B	The toolbox shall be compatible with Winplot.
II.C	The toolbox shall read the telemetry from the Launch Vehicle.
III.A	All display functions shall be easy to navigate
III.B	The toolbox shall follow a standard color scheme for the text and signals

XII. Design-to Requirements

The design-to requirements specify the desired outputs of the system. The Concept of Operation, Functional Analysis, and System Level Requirements form the basis for these specifications. For example, the system level requirement that the display shall contain all flight critical data will be implemented by displaying the true and complimentary flight parameters for system 1 and system 2.

Table 3. Sample of Design-to Requirements

No.	Design-to Requirements
I.A.1	Both displays shall list true and complimentary flight parameters for system 1 and system 2.
I.A.2	Both displays shall contain the MSID for each telemetry signal.
I.A.3	Both displays shall contain the IRIS description for each telemetry signal.
I.A.4	Both displays shall be compatible with East and West coast NASA telemetry labs.
I.A.5	Both displays shall contain RIFCA telemetry data.
I.A.6	The Upper Stage display shall contain a quick view of the CBC display.
I.A.7	The Upper Stage display shall contain 2nd stage flight events.

XIII. Implementation

Implementation of the FAST-D4 display consisted of various design methods including data collection, problem solving, programming, and communication systems analysis. During the implementation phase of the systems engineering process, three iterations of the FAST-D4 display were produced, tested, and revised to meet the stakeholders' requirements. Peer reviews, code analyses, and system testing were used to satisfy design solutions and verify specified requirements.

Prior to the implementation of the FAST-D4 display, a spreadsheet requiring programming skills similar to those needed for the second prototype was produced. This initial prototype listed the system engineer's daily events such as waking up and included examples of data such as MSID, alternate name, and description. Each event was coupled to a grey indicator box that would illuminate green when the event occurred. These events, like flight events, are assigned to bits in specific words which make up the frames used for telemetry. The illumination criterion was the presence of a binary '1' or 'bit' from a specified location within a 16-bit word. Since the inputs to the display were in decimal representation, the first step to implement this requirement was to convert the decimal input to binary. Excel comes with a binary to decimal converter function; however, it was discovered that this function only works for binary words less than or equal to 9 bits. Therefore, a macro was written to replace this function. The macro accomplished this task; however, to create a design comparison, an alternative method was investigated. The alternative method used a combination of different functions embedded in the spreadsheet that also successfully completed the conversion. Once the conversion was completed, a bit search function was utilized to locate the set bit or event trigger, and the cells were illuminated using conditional formatting. The spreadsheet passed all testing, and the design team was then ready to implement the FAST-D4 display.

The second prototype began with one page intended to contain all flight event data. The page contained visible cells designated for illumination of flight events and hidden cells containing parameter names, MSID's, description, Engineering Units (EU), and raw data for analysis. Each flight event contained two sets of data to provide system redundancy. This included system 1 HIGH, system 1 LOW, system 2 HIGH, and system 2 LOW parameters. Most of the MSID's were found in the ULA Delta IV Vehicle Assembly Launch Test Requirements document using the parameter name. The description, EU data, and raw data were then easily found by looking up the MSID in Iris. The remaining parameters were not found in this document, because they were latching parameters derived from ordnance events. Since ordnance events are often only 180ms long, these latching parameters illuminate when triggered by an ordnance event and stay on until the user turns them off. The latching mechanism requires formulas embedded in the spreadsheet to capture the trigger, and a macro to enable the latch. The ordnance event parameter names and corresponding MSID's were retrieved from a parameter file. The ordnance event MSID's were then used in Iris to look up their corresponding description, EU data, and raw data telemetry. The latch was created using two buttons titled 'set' and 'reset' in OpenOffice that contained two separate macros. A '1' was inserted into a hidden cell if 'set' was selected, and a '0' was inserted if 'reset' was selected. The next step was to add an additional column in the spreadsheet for latching parameters and insert embedded formulas to capture ordnance events. The embedded formulas required variables from the latch value, the discrete ordnance data, and the previous value of the formula. Since the formula required the cell to be referenced to itself, the output returned an error even after many data manipulations. OpenOffice was not storing the previous value of the cell, so the design team attempted to insert the formula into a macro. This solution was undesirable, because the macro could not process the inputs efficiently and would consistently freeze the application. It was concluded that the macro would not be stable enough for operation at Hangar AE, and the focus was then turned back to embedded formulas. Additional research was done on OpenOffice, and the design team found that the iterations option which allows a cell's previous value to be stored in the memory was disabled unless activated by the user. The iterations option was then enabled and the latching function worked nominally. After the technical issues were solved, conditional formatting for cell illumination and page layout were designed for usability and general aesthetics. Due to the number of events being captured and displayed, it was decided to split the screen into two pages for clarity and ease of use. Finally, testing was done at Hangar AE by running a playback of a previous Delta IV launch countdown. The non-ordnance flight events were illuminating nominally; however, several ordnance events were not triggering the latch. Also, the display size was too small for the console and needed to be enlarged.

Prototype three began with an ordnance event analysis using Winplot. Since the Winplot software displays full rate data from the launch vehicle, the ordnance events were verified in graphical format. The Winplot diagram revealed that the latch trigger did not function properly. This meant that there was an issue with how OpenOffice was retrieving data from Iris. The problem was that OpenOffice only updates raw or EU data from Iris once every second, and Iris only refreshes data every half-second. The Hangar AE team solved this problem by suggesting the cells be referenced to a monitor program associated with Iris instead of raw data. This monitor program evaluates high, low, and present-time values every half second from CARDS. The Iris monitor program detects flight events by evaluating changes in these outputs. For example, if the 180 ms ordnance event does not occur when the present time sample is taken, the high value would still be triggered and indicate that an ordnance event occurred. Some formulas had to be altered slightly to accommodate this change. Unlike raw data, data from the monitor file returned values other than '1' if a flight event occurred. A function was created to convert these values to a '1' if the ordnance event was triggered and a '0' if it was not. The latching cell was then referenced to the function to complete the technical troubleshooting. Next, the display size was adjusted to fit the console, and the font was enlarged to increase visibility. The display was tested again using the same playback data from the recorded launch. The project manager and design team concluded that the product was ready to be finalized.

Senior NASA Avionics Engineers reviewed the product in a Design Certification Review (DCR) and agreed that the product was mature enough for certification. The stakeholders' needs were met for a product that is easy to use, compatible with existing architectures, and monitors flight event telemetry for the Delta IV launch vehicle. FAST-D4 will be used in the upcoming Delta IV launch scheduled for September 2010 and will be tailored to other existing NASA fleet vehicles.

XIV. Verification and Validation

Verification and Validation (V&V) is a SE process that verifies that the right product was produced and validates that it was produced correctly. This process was completed at Hangar AE for prototypes 2 and 3 by running a playback of the GPS2F1 Delta launch. The V&V matrix shown in table 4 below indicates the specifications for each design-to requirement involving the second and final prototype. The first prototype is not included, because the design-to requirements do not match all of the design-to requirements of the final product. In this table, the first design-to requirement for testing all four parameters for each flight event was done July 23 and 30, 2010 by the Systems Engineer, Hangar AE, and Project Manager (PM) as an inspection and test. This concludes that the stakeholders' need was met appropriately and effectively.

V&V Matrix		V&V Method				Auditor			Dates	
Level	Requirement	I	A	T	D	SE	PM	AE	Prototype 2	Prototype 3
I.A.1	Both displays shall list true and complimentary flight parameters for system 1 and system 2.	✓		✓		✓	✓		7/23/2010	7/30/2010
I.A.2	Both displays shall contain the MSID for each telemetry signal.	✓				✓			7/23/2010	7/30/2010
I.A.3	Both displays shall contain the IRIS description for each telemetry signal.	✓				✓			7/23/2010	7/30/2010
I.A.4	Both displays shall be compatible with East and West coast NASA telemetry labs.	✓		✓		✓	✓	✓	7/23/2010	7/30/2010

Table 4. Sample Validation and Verification Matrix

XV. Final Product

FAST-D4 was approved for certification August 10, 2010. The final product is shown in Fig. 11 A and B below. The flight events properly illuminate when the appropriate signal is received from Iris, and the display is the correct size for the monitors at Hangar AE.

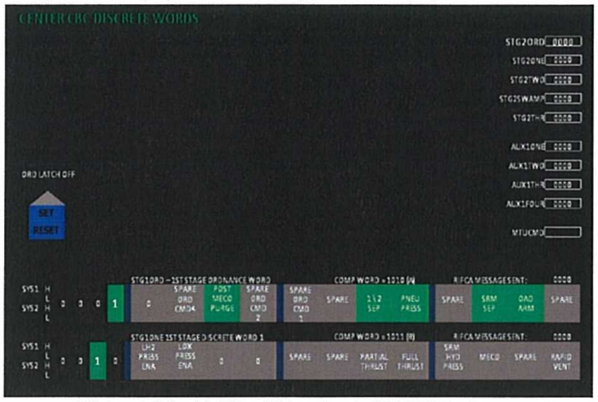

Figure 11. A) Final Product CBC Display

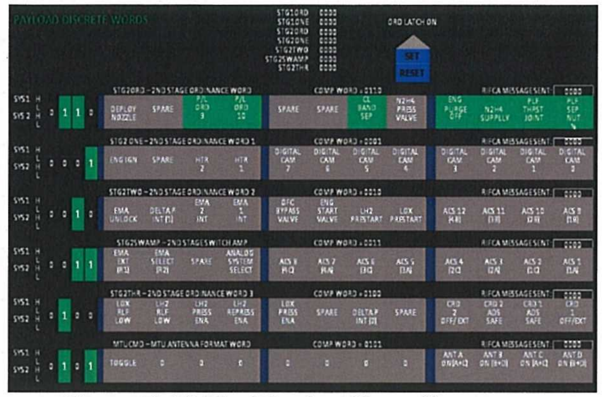

Figure 11. B) Final Product Upper Stage

XVI. Maintainability

Each NASA mission is unique; thus, for each mission, the sequence or presence of certain flight events may change. The FAST-D4 telemetry display was designed with this in mind and can be easily adjusted to accommodate new requirements. The spare flight event cells are ready to be used if required for the mission. The only implementation that would be needed is to insert the telemetry parameter for the new flight event, and determine the output value that would indicate that the flight event has occurred.

NASA Engineering routinely acquires ULA launch services for several vehicles other than Delta IV. The FAST-D4 display also provides a versatile foundation for creating new displays for other vehicles. All architectures within the display can also be adjusted at the user's discretion; this includes parameters, size, color, functions, macros, etc. This maintenance will ensure that the display is up to date and accurate for future missions.

XVII. Future Implementation

NASA Engineering constantly looks for new ways to improve existing capabilities. FAST-D4 is a new capability that has flexibility to allow for future enhancement, including quick access to Winplot, a time stamping tool, and a tool to locate flight events with a cursor in a flight sequence document.

A tool that provides quick access to Winplot would be beneficial to NE and the Hangar AE team. Implementation of this tool could be accomplished by creating a button with a macro that takes the user directly to the strip-charting tool. Since the display would allow direct access to Winplot, the user would save time and be able to verify flight events more accurately.

A time stamp would also be beneficial, because it would allow engineers to see exactly when a flight event occurred. This is important in launch vehicle diagnostics for determining the cause of any anomalous system behavior. Right now, Winplot is used as the primary tool for determining the time of flight events relative to important events. Although Winplot is very accurate, the flight event would have to be located in order to determine the time. This task is not too difficult, but a time stamp would provide a convenience to the engineer, so that they can focus on more critical objectives.

Engineers use a flight event sequence document to verify vehicle flight events. It can sometimes be difficult to track the flight events in this document since so many critical events are taking place. Some engineers have expressed interest in a tool that would display an arrow next to the flight event that is occurring in the document. This would facilitate the launch monitoring process.

These three implementations would contribute greatly to the FAST-D4 display by providing conveniences to the engineer. Quick access to Winplot, a time stamp, and a cursor following flight events would not be difficult to implement, however, they require a significant amount of time. Time constraints prevented the implementation of these features on the baseline release.

XVIII. Conclusion

NASA Engineering provided leadership, management, and flight expertise services to successfully implement the FAST-D4 display. By utilizing a systems engineering approach, I helped develop a product that met all stakeholder requirements: display flight events, use existing architectures, and implement a user friendly interface. FAST-D4 contains all flight critical events that illuminate correctly when the telemetry signal is received from Iris. The latch implementation also resulted in success by accurately capturing ordnance events under 180 ms. Senior

NASA Avionics Engineers have examined the display and certified the design for release. This product will be used for processing the upcoming Delta IV launch in September to assist engineers in monitoring the system for any anomalous behavior.

Appendix

Table 5. FAST-D4 Display Requirements

I. The stakeholder needs a toolbox to display telemetry to track and illustrate flight events for Delta IV.

- I.A The display shall contain all flight critical data.
  - I.A.1 Both displays shall list true and complimentary flight parameters for system 1 and system 2.
  - I.A.2 Both displays shall contain the MSID for each telemetry signal.
  - I.A.3 Both displays shall contain the IRIS description for each telemetry signal.
  - I.A.4 Both displays shall be compatible with East and West coast NASA telemetry labs.
  - I.A.5 Both displays shall contain RIFCA telemetry data.
  - I.A.6 The Upper Stage display shall contain a quick view of the CBC display.
    - I.A.6.i The quick view shall contain STG1ORD RIFCA telemetry.
    - I.A.6.ii The quick view shall contain STG1ONE RIFCA telemetry.
    - I.A.6.iii The quick view shall contain AUX1ONE RIFCA telemetry.
    - I.A.6.iv The quick view shall contain AUX1TWO RIFCA telemetry.
    - I.A.6.v The quick view shall contain AUX1THR RIFCA telemetry.
    - I.A.6.vi The quick view shall contain AUX1FOUR RIFCA telemetry.
  - I.A.7 The Upper Stage display shall contain 2nd stage flight events.
    - I.A.7.i The toolbox shall display the 2nd stage ordnance word vehicle telemetry.
    - I.A.7.ii The toolbox shall display the 2nd stage discrete word 1 vehicle telemetry.
    - I.A.7.iii The toolbox shall display the 2nd stage discrete word 2 vehicle telemetry.
    - I.A.7.iv The toolbox shall display the 2nd stage CNTL/GJ discrete word vehicle telemetry.
    - I.A.7.v The toolbox shall display the 2nd stage discrete word 3 vehicle telemetry.
    - I.A.7.vi The toolbox shall display the MTU antenna format word vehicle telemetry.
  - I.A.8 The CBC display shall contain a quick view of the upper stage display.
    - I.A.8.i The quick view shall contain 2nd stage ordnance word data RIFCA telemetry.
    - I.A.8.ii The quick view shall contain 2nd stage discrete word 1 data RIFCA telemetry.
    - I.A.8.iii The quick view shall contain 2nd stage discrete word 2 data RIFCA telemetry.
    - I.A.8.iv The quick view shall contain 2nd stage CNTL/GJ discrete word data RIFCA telemetry.
    - I.A.8.v The quick view shall contain second stage discrete word 3 data RIFCA telemetry.
    - I.A.8.vi The quick view shall contain MTU antenna format word data RIFCA telemetry.
  - I.A.9 The CBC display shall contain first 1st stage flight events.

I.A.9.i The toolbox shall contain 1st stage ordnance word from the vehicle.
I.A.9.ii The toolbox shall contain 1st stage discrete word from the vehicle.

I.B Both displays shall illuminate flight events as received.
I.B.1 Both displays shall contain 4 independent cells within each event block.
I.B.2 Both displays shall contain formulas for conditional formatting.

I.C Both displays shall contain a latching mechanism to capture flight events
I.C.1 The displays shall use Sun OpenOffice Macros for latching.
I.C.1.i The display shall contain a set button to initiate the latch.
I.C.1.ii The display shall contain a reset button to release the latch parameters.

II. The stakeholder needs the toolbox to be compatible with existing telemetry architectures.

II.A The toolbox shall be compatible with the Iris Telemetry System.
II.A.1 Each cell in OpenOffice shall be referenced to Iris.

II.B The toolbox shall be compatible with Winplot.
II.B.1 The toolbox shall be developed using OpenOffice Spreadsheet

II.C The toolbox shall read the telemetry systems from the Launch Vehicle.
II.C.1 The toolbox shall read telemetry from the Delta IV.

III. The stakeholder needs the toolbox to be easy to use.

III.A All display functions shall be easy to navigate
III.A.1 The toolbox shall use buttons to set and reset the ordnance events latch.

III.B The toolbox shall follow a standard color scheme for the text and signals
III.B.1 The displays for the IRIS software shall be designed using black for the background.
III.B.2 The displays shall use dark grey to indicate the disabled state of a component.
III.B.3 The displays shall use light green to indicate the active state of a component.

Note: Roman numerals indicate stakeholder's need, letters indicate System-level requirements, and numbers indicate design-to level requirements

	V&V Matrix	V&V Method				Auditor			Dates	
Level	Requirement	I	A	T	D	SE	PM	AE	Prototype 2	Prototype 3
I.A.1	Both displays shall list true and complimentary flight parameters for system 1 and system 2.	✓		✓		✓	✓		7/23/2010	7/30/2010
I.A.2	Both displays shall contain the MSID for each telemetry signal.	✓				✓			7/23/2010	7/30/2010
I.A.3	Both displays shall contain the IRIS description for each telemetry signal.	✓				✓			7/23/2010	7/30/2010
I.A.4	Both displays shall be compatible with East and West coast NASA telemetry labs.	✓		✓		✓	✓	✓	7/23/2010	7/30/2010
I.A.5	Both displays shall contain RIFCA telemetry data.	✓		✓		✓	✓	✓	7/23/2010	7/30/2010
I.A.6	The Upper Stage display shall contain a quick view of the CBC display.	✓		✓		✓	✓		7/23/2010	7/30/2010
I.A.7	The Upper Stage display shall contain 2nd stage flight events.	✓		✓		✓	✓		7/23/2010	7/30/2010
I.A.8	The CBC display shall contain a quick view of the upper stage display.	✓		✓		✓	✓		7/23/2010	7/30/2010
I.A.9	The CBC display shall contain first 1st stage flight events.	✓		✓		✓	✓		7/23/2010	7/30/2010
I.B.1	Both displays shall contain 4 independent cells within each event block.	✓		✓		✓	✓		7/23/2010	7/30/2010
I.B.2	Both displays shall contain formulas for conditional formatting.	✓				✓			7/23/2010	7/30/2010
I.C.1	The displays shall use Sun OpenOffice Macros for latching.	✓				✓	✓		7/23/2010	7/30/2010
II.A.1	Each cell in OpenOffice shall be referenced to Iris.	✓				✓			7/23/2010	7/30/2010
II.B.1	The toolbox shall be developed using OpenOffice Spreadsheet	✓				✓	✓		7/23/2010	7/30/2010
II.C.1	The toolbox shall read telemetry from the Delta IV.	✓		✓		✓	✓	✓	7/23/2010	7/30/2010
III.A.1	The toolbox shall use buttons to set and reset the ordinance events latch.	✓		✓		✓	✓		7/23/2010	7/30/2010
III.B.1	The displays for the IRIS software shall be designed using black for the background.	✓				✓			7/23/2010	7/30/2010
III.B.2	The displays shall use dark grey to indicate the disabled state of a component.	✓		✓		✓	✓		7/23/2010	7/30/2010
III.B.3	The displays shall use light green to indicate the active state of a component.	✓		✓		✓	✓	✓	7/23/2010	7/30/2010

Note: Testing for prototype 2 and 3 was done at Hangar AE by running a playback of GPS2F1 and comparing the telemetry to other mission constants.

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USRP Internship Experience

I am an Electrical Engineering student working as a NASA intern at KSC this summer, and will be entering my senior year at Arkansas Tech University this fall. During this internship, I had the opportunity to work for the NE Avionics branch through the USRP program which provided me with a broad range of activities. I was provided with an excellent introduction into researching and analyzing engineering issues. Through this experience I acquired a great amount of knowledge in launch vehicles avionics/GN&C, programming, SE techniques, and telemetry. I was also introduced to the NASA's fleet of launch vehicles: Shuttle, Delta II/IV, AtlasV, Pegasus, and Taurus. My communication and oral presentation skills greatly improved through my experience with SE reviews, and I enjoyed the networking opportunities that were created by a very diverse work environment. My internship also taught me about the history of NASA, the role of each Space Center, and how each facility operates through very interesting and informative tours. It was an amazing experience to be a part of such an inspirational program, and I know that the knowledge I acquired this summer will be useful for the rest of my life.

References

[1]Blanchard, B., Systems Engineering Management, 3rd ed., John Wiley & Sons, Inc., Hoboken, New Jersey, 2004 Chaps, 2-3

[2]Clausing, D., and Hauser, J.R., "The House of Quality." Harvard Business Review, 1988. URL: http://www.csuchico.edu/~jtrailer/HOQ.pdf [citied Aug 5, 2010].

[3]NASA's Launch Services Program. NASA., 2005. URL: http://www-pao.ksc.nasa.gov/kscpao/nasafact/pdf/LSP2005.pdf [citied Aug 5, 2010].