ABSTRACT
Since the early days of NASA/Marshall Space Flight Center (MSFC), there has been a rigid protocol regarding business processes. Procurement of flight hardware was done a certain way, monitoring contracts was done a certain way, and test support was done a certain way. There was little flexibility to support those small, quick turn-around experimental programs where cost and schedule were paramount to rapid prototyping success. When the Delta Clipper Experimental (DC-X) space flight test vehicle was being upgraded to the Delta Clipper Experimental Advanced (DC-XA, later called the Clipper Graham), the opportunity to enhance the way MSFC did business presented itself. The development of the flight test telemetry system (FTTS) for the Clipper Graham presented the perfect opportunity for the MSFC business community to embrace the "better, faster, cheaper approach."

BACKGROUND
The Delta Clipper Experimental (DC-X) space flight vehicle was originally developed for the United States Air Force by McDonnell Douglas Aerospace (MDA). After a series of flights for the Air Force, the DC-X was transferred to NASA for use as a technology test-bed. The vehicle was re-named the Delta Clipper Experimental Advanced (DC-XA). The vehicle was later re-named after General Graham, a leader of single stage to orbit technology, to the Clipper Graham. The Clipper Graham's flights provided a test-bed to verify the feasibility of advanced technology components and systems operating under flight conditions at the United
States Army's White Sands Missile Range, New Mexico.

PROCUREMENT

When MSFC took possession of the DC-X vehicle from the Air Force, various upgrades were undertaken. Towards this end, MSFC entered into a cooperative agreement with McDonnell Douglas Aerospace (MDA). In this agreement, both MSFC and MDA contributed in-kind support. One task was the development of a flight data acquisition system to collect environmental data from new technology on the vehicle. MSFC's Astronics Laboratory was given the task of developing, fabricating, testing and supporting the flights for a new Flight Test Telemetry System (FTTS). The FTTS consisted of a pulse code modulation (PCM) unit, a S-Band telemetry transmitter system and a ground based decommutation system. In the DC-X rapid prototyping spirit, the FTTS was to be done on a very tight schedule. The concept stage through the first use of the FTTS spanned fifteen months. Utilizing MDA technical support personnel, MSFC was able to write the FTTS specification and statement of work and have the procurement advertised on the Internet and in the Commerce Business Daily in four months. At MSFC, it is extremely rare that a task of this significant technical magnitude can be accomplished in such a short time period. MSFC was able to do this by organizing all associated parties into an integrated product team, with daily written and verbal communication. Additionally, statusing with program chiefs at the contractor and MSFC occurred daily via early morning telecons. The procurement office is normally a sticking point in most large procurements simply because of public law. However, in the procurement of the FTTS they were an asset.

Procurement personnel were involved in the procurement from the first day and they gave valuable insight on the processes their participation was in parallel, not series. While writing the specification and statement of work a decision was made not to impose MSFC workmanship and fabrication requirements on the FTTS vendor. The vendor was allowed to develop the FTTS according to their own in house standards. This is in keeping with total quality management system in which each qualified supplier takes full responsibility for their own product. No MSFC quality personnel/requirements were involved in the procurement. However, MSFC did require that the vendors provide their workmanship manual and a description of their in house quality procedures for review. This was essentially an engineering skunk works show. During the development of the FTTS specification, trips were made to some of the possible vendors of the FTTS hardware. The trips were made to determine the ability of the vendors to meet the tight program schedule and to determine if potential suppliers had a total quality management system process in-place. Also, some vendors came to MSFC and gave a presentation on their companies capabilities. Six weeks after the procurement was advertised, proposals were submitted. Five proposals were returned and they were evaluated in two weeks. A MDA technical person was allowed to observe and lend technical expertise in the evaluation of the FTTS proposals. The contract for the FTTS was awarded to Gulton Data Systems, Albuquerque New Mexico. Gulton provided a PCM unit, the transmitter, and a decommutation system. Gulton developed the PCM unit in house and went to other vendors for the RF transmitter, and the decommutation system. MDA provided the power divider and the vehicle antennas.
The Clipper Graham was developed to be a technology test-bed for new advanced components and systems. The vehicle was 43 feet high and 13.5 feet across the base of the heat shield. The vehicle was launched from and landed in a vertical position. New technologies that were on the Clipper Graham included a cryogenic composite liquid hydrogen tank, an aluminum-lithium liquid oxygen tank, a composite intertank structure, an oxygen and hydrogen powered auxiliary power unit and cryogenic lines and valves constructed of composite material. This was the first time many of these technologies had been exposed to the flight environments. To measure these environments, the Flight Test Telemetry System was developed.

**Flight Test Telemetry System (FTTS)**

The FTTS consisted of a pulse code modulation (PCM) unit, a radio frequency (RF) system and a ground based decommutation system. The FTTS was designed to sense and transmit to the ground special purpose diagnostic and flight test developmental instrumentation for various parameters of the Clipper Graham vehicle. To accomplish these functions, the FTTS consisted of the necessary sensors, cables, signal conditioner, multiplexer, transmitter, antennas, associated mounting hardware and a ground based decommutation system. The PCM also received data from two on-board experiments via asynchronous serial digital interfaces. The experiments were the Hydrogen Leak Detection System (HYLEDS) and the Optical Plume Anomaly Detection System (OPADS). The HYLEDS consisted of 32 hydrogen sensors, which were strategically located in the vehicle to sense hydrogen leaks. The OPADS consisted of four optical spectrometers and a computer. The four engine plumes were scanned for metal signatures which could be an indication of engine breakdown. Figure 1 shows a block diagram of the FTTS. The FTTS
telemetry data was transmitted from the RF system to the White Sands Missile Range (WSMR) ground station via a two watt S-Band carrier. The telemetry data was then sent to the decommutation system for storage and analysis. In those instances where RF open loop testing could not be accomplished because of schedule conflicts with WSMR frequency clearances, the serial output of the PCM multiplexer was transmitted hardwire via the umbilical to the associated ground decommutation system over a fiber optics transmission cable.

**Pulse Code Modulation (PCM) Unit**

The PCM unit collected analog and serial digital data, multiplexed it, and formatted it into a 2.112 Mbps serial digital data stream. The PCM had the capability to signal condition pressure, temperature, acoustic, vibration and strain transducers. Table 1 shows the selection of measurements and sampling rates. The gains and offsets of the analog sensors could be changed interface when the PCM was mounted on the vehicle. This in essence allowed the procurement of catalog "off-the-shelf" transducers. Thus, the effects of mounting torque offsets, temperature drift and other analog errors could be mitigated subsequent to installation making for highly accurate end-to-end calibration scale factors. This was a significant cost saving from a transducer procurement point of view, it enhanced transducer delivery schedules and most importantly, enhanced end-to-end channel accuracy. The programmable output format control was implemented with user friendly loader/verifier software that resided in the decommutation system. All sampling format, channel offset, and channel gain information was stored in EEPROMS. The EEPROMS

<table>
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<tr>
<th>Sensor</th>
<th>Provided</th>
<th>Spares (Format)</th>
<th>Total</th>
<th>Sample Rate</th>
</tr>
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<tbody>
<tr>
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<td>17</td>
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</tr>
<tr>
<td>Vib</td>
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<td>12000 sps*</td>
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<td>32</td>
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<tr>
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<td>0</td>
<td>3</td>
<td>800 sps*</td>
</tr>
<tr>
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<td>17</td>
<td>400 sps*</td>
</tr>
<tr>
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<td>32</td>
<td>2 sps</td>
</tr>
<tr>
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<td>0</td>
<td>4</td>
<td>2 fps**</td>
</tr>
</tbody>
</table>

* Samples per second
** Frames per second

**TABLE 1. FTTS CHANNEL ALLOCATION**
were programmable via a RS422 interface to the decommutation system. The PCM unit had two additional RS422 interfaces, which were used to receive data from the HYLEDS and the OPADS. The PCM unit consisted of four double ended low level (DELL) analog boards, 2 resistive temperature device (RTD) analog boards, four vibration/acoustic analog boards, and two serial digital RS422 boards. The greatest challenge for Gulton to meet was the vibration environment. The PCM unit was mounted in the engine section of the vehicle and expected to encounter a 50.2 grms random vibration environment. This was the most severe environment of the vehicle. To mitigate the effects of the environment, the PCM could have been located in various other locations in the vehicle where the environment was far less benign, however by design, the PCM was purposely placed in this environment. The reason being to demonstrate that a highly complex piece of avionics could be rigidly (no shock absorbers) mounted in this environment and operate successfully. As vehicle systems become more complex, distributed avionics, connected via bus systems will have to be employed. For this to be successful, avionics needs to perform in very severe engine section environments. A PCM, mounted in the DC-XA engine section would demonstrate that a carefully designed avionics suite could meet this challenge.

Radio Frequency System

The RF system consisted of a RF transmitter, a power divider, and antennas. Gulton purchased the transmitter from Southern California Microwave. The output frequency of the transmitter was 2216.5 MHz. The output power of the transmitter was 2 watts. The power divider was provided by the government and the antennas by MDA. The power divider was rated for 5 watts. The antenna frequency range was also 2.2 - 2.3 GHz. The antenna polarization was linear. The RF system was mounted in the avionics rack on top of the vehicle.

Ground Support Equipment

As shown by Figure 1, the GSE essentially consisted of a tracking antenna, RF receiver, analog tape recorder and a portable PCM decommutation system.

TTAS

WSMR had previously supported the DC-X program telemetry downlink using their Transportable Telemetry Acquisition Station (TTAS). WSMR continued to provide this same support for the DC-XA flight test. In addition however, they agreed to add a second S-band receiver to the tracking antenna (8 foot dish) via a standard RF multicoupler. The discriminated output from this FTTS dedicated receiver was hardwired from the TTAS trailer to an adjacent small building where the portable decommutation system was housed. It was agreed early in the design phase that the flight transmitter and PCM adhere rigidly to the range IRIG 106 standards, without exception. As the result, there were no interface problems or start-up issues with the TTAS. It worked the first time. The integration time was essentially zero. There was only a brief pre-integration meeting with range personnel regarding the specifics of the downlink. The system was designed to be compliant to the range required parameters in total and no modifications were required by the range prior to power on testing. Clearly this approach greatly mitigated what could have been significant delays in integrating the flight system with the WSMR ground based resources.
Decommutation System

A ground based decommutation system (bit synchronizer, decommutation, display and PCM simulator) was procured by Gulton from Terametrix Systems International located in Las Cruces, New Mexico. This system was required to receive the 2.112 Mbps NRZ-L bit stream, convert each word to engineering units and to display the vehicle data in near real time. The engineering team (MSFC, MDA and Gulton) made a conscience decision to select Terametrix as the supplier for this product. Not only was Terametrix clearly qualified for the manufacture and test of this unit, but equally important they were located at the doorstep of WSMR. This mitigated the need for procurement of spare boards and allowed essentially one hour factory service if required, in any 24 hour day of the week. This proved to be a valuable asset simply because of the overwhelming negative WSMR environment to which this portable unit was subjected. It was remarkable it stood up as well as it did and also fortunate that we wisely selected the vendor whose factory was in Las Cruces. The decom also had the capability to receive IRIG-B time and time mark the data. The decom had an ethernet card that allowed the flight data to be transmitted to MSFC for post flight processing.

SYSTEMS INTEGRATION

Sub Assembly Integration

A key decision made early in the design and procurement of the FTTS was to have Gulton interconnect the PCM to the transmitter and hardwire the output to the Terametrix portable decom via a S-Band receiver at their facility. Analog inputs were simulated in most cases and in others, actual flight sensors were borrowed and connected to the PCM input. Essentially the entire FTTS system was powered on as part of the FTTS acceptance testing at Gulton. All elements of the FTTS, except for the actual vehicle cable harnesses were in place at the Gulton facility. The entire acceptance testing of the PCM and transmitter, including acceptance vibration and thermal cycling was accomplished using the GSE intended to support the flight. Therefore, well before the units were shipped to MDA for vehicle integration and test, the FTTS system had been fully checked out and the learning and system familiarity was well up the curve. When power was first applied at the MDA integration facility at Huntington Beach, CA, there were no surprises. Compatibility issues had long been worked and well understood. There were no delays associated with FTTS incompatibility when this system was installed on the vehicle. Since the associated wire harnesses was been thoroughly rung out as individual subassemblies at the MDA St. Louis facility, the FTTS turn on was nearly flawless.

Vehicle Integration

Four MSFC personnel traveled to MDA, Huntington Beach to assist in the integration and checkout of the FTTS with the Clipper Graham. MDA personnel installed the all of the flight hardware on the vehicle. The MSFC personnel assisted MDA personnel with the sensor checkout and programming the PCM unit's gains and offsets as a function of sensor supplier calibrations. Near the conclusion of vehicle testing at Huntington Beach a major power transient in the integration building (potentially lighting related) was transferred to the vehicle GSE power supply. This caused a significant overstress failure with several key
avionics flight and GSE units that were powered on at the time. The PCM and the decom were among the units affected. These units were removed and concurrently while the vehicle was shipped to WSMR in preparation for preflight testing, the PCM and the decom were returned to their respective suppliers for repair. Working closely with MSFC procurement, repair contracts were issued and both units were ready and in-place when FTTS sensor installation and checkout resumed at WSMR. A large spreadsheet that tabulated the ambient readings of all the sensors was initiated. Sensor readings were taken each time the vehicle was powered, and/or there was an unique test that effected sensor performance. This recording continued throughout the entire flight test program. This information was invaluable in that it provided trend performance of each sensor during various phases of pad testing. Correlation of this data with sensor performance during flight greatly enhanced the understanding of flight data.

FLIGHT EXPERIENCE

The FTTS was operational on every Clipper Graham flight. Data was collected from the time that the fuel tanks were being filled through flight and post flight vehicle shutdown. Data gathered via the FTTS was instrumental in allowing very rapid, near time vehicle health and status to be determined.

Flight 1

During the first flight, the FTTS performed nominally during the prelaunch and post landing phases. However, during the flight, the downlink telemetry signal experienced a significant number of dropouts, rendering the data essentially non-recoverable. Subsequent troubleshooting revealed that the RF coaxial terminations at the power divider had failed. At the power divider, the crimped shields of the interfacing coaxial cables were loose. This caused exceedances in the voltage standing wave ratio (VSWR) of the link, resulting in excessive attenuation of the signal. The vibration environment of the flight thus apparently caused the observed high rate of dropouts (similar to chattering) as the result of these bad crimp terminations. As the dynamic environment ceased, the dropouts subsided and valid data was again recovered. It was determined that the crimp approach for terminating the coaxial cables was unacceptable. The coaxial cables were re-terminated such that each center pin was soldered to its center conductor and the braided shields were soldered to the connector housing. There was also the suggestion that the WSMR Transportable Telemetry Acquisition System (TTAS) had experienced difficulties in the auto-track mode although this could not be verified and it certainly did not cause the dropouts. However as a backup to the TTAS for the FTTS downlink, it was planned to provide a secondary RF ground station. This secondary RF receiver was provided by MSFC.

Flight 2

During the second flight, the FTTS performed nominally during the prelaunch and post landing phases. However, during the flight there were a large number of bit dropouts in the data supplied by the TTAS. There were virtually no dropouts in the data stream provided by the MSFC system. The TTAS again relied on the auto-tracking mode although it appeared as if the TTAS was tracking an antenna sidelobe.
Flight 3

The FTTS performed nominally during all phases of the mission. The TTAS used the optical slave aided mode. This negated the effects of the side lobe tracking interference. One hundred percent of the data was recovered and no dropouts were observed in the data stream.

Flight 4

For the fourth flight, the TTAS pointing was accomplished exclusively in the optical aided mode for the entire duration of the flight. One hundred percent of the data was recovered with no dropouts in the data stream from the TTAS data stream. During the landing phase, one of the four landing gears did not deploy, resulting in catastrophic loss of the vehicle.

SUMMARY

The Clipper Graham’s Flight Test Telemetry System gave Marshall Space Flight Center an opportunity to do a project better, faster and cheaper. By coordinating the project tasks with all required organizations early in the project, problems were detected and solved before they become major impacts. Having a cooperative agreement with McDonnell Douglas Aerospace gave the program the opportunity to pool the resources of two organizations. This collective effort made the program much stronger throughout its life. The systems test before integration was also a key milestone of the program. This test helped drive out integration and installation problems that could have occurred.

Acknowledgments

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