Unique Telemetry Requirements for a Hypersonic Telemetry System

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Abstract

With the various hypersonic vehicle developments happening today, there are several unique Telemetry requirements that differ from the ones used in everyday flight test that migrates from the standard products offered in our industry. This paper discusses the unique requirements based on the hypersonic use case, what and whys behind the list, and why are these unique from the airborne perspective and drive new design to full fill the requirement.

Keywords

Hypersonics, Telemetry, Requirements

Introduction

With the recent interest in hypersonic vehicles along with increased funding, many new programs are moving into flight test and procuring Telemetry equipment to obtain the critical flight data. This paper examines the hypersonic use case compared to the traditional telemetry applications, uniqueness of the hypersonic application, and the limitations of testing a vehicle that can travel 10 times the speed of sound.

Background information

The development of hypersonic vehicles has produced several variants that are tested to demonstrate the Mach 10 capability. Piloted as well as internal guidance vehicles has successfully demonstrated speeds of Mach 10 using commercial off the shelf (COTS) telemetry equipment to gather the flight data for many years. The author of this paper provided telemetry equipment on early development programs using standard Data Acquisition Units (DAU) both to record and transmit the telemetry data for post flight analysis. Today's telemetry requirements have changed in areas where the technology has matured that specifically supports the hypersonic use case.

Why COTS?

Hypersonic programs use a high degree of (COTS) products where possible due to their mature product status. COTS products are generally lower cost and have shorter deliveries as compared to a custom design. From the signal conditioning perspective, the hypersonic requirements are fairly standard, and the sensors used are consistent with most other applications. These are the typical sensor requirements for temperature, strain gauge, an accelerometer, a radiometer, and several pressure measurements used on many aircraft and missile applications today.

Stages of vehicle development

There are three major stages to development most vehicles, propulsion, control, and guided stages. The first stage is a propulsion or rocket motor test where the telemetry requirements follow the sensor selection. Much of the telemetry data consists of temperature, strain, and pressure measurements. The second stage, sometimes referred to as the control phase, changes the requirements to monitor the actuated surfaces for level flight of the vehicle while directing the flight in the desired direction.

Figure 1 AXON field configurable DAU

In this phase the telemetry requirements change slightly from the first stage by reducing the number of temperature sensors and adds new high current measurements to evaluate the stress to the flight structure. The last stage of the development includes a guided flight that generally reduces the signal conditioning even further while introducing a flight computer data to gather the overall status of the vehicle. To compensate for the varying requirements the COTS DAU is designed to be configurable to remove and replace signal conditioning modules as needed to match the phase of the development. Most of the customer base performed their own reconfiguration of the DAU after factory technical training. The technical training, generally performed at the factory assures decrease reconfiguration risk while reducing the schedule.

Current procurement trends

It's becoming problematic for vehicle developers to customize their telemetry system design due to the time it takes to create the requirement list, generate proposal packages, and obtain delivery of the products. The focus on COTS product solutions is favored over custom designs due to the shorter deliveries and familiarity of the recurring customers with the COTS product. Also COTS equipment has been previously environmentally tested that ultimately reduces the need for a qualification campaign. This puts the program in a better position to meet the aggressive goals.

Environmental considerations

There are two common and well documented methods to obtain higher Mach speeds. The first is a reentry vehicle to gain the velocity need to accelerate to the desire level in an arcing or ballistic trajectory. This approach has several unique environmental requirements including high altitude as well as a phase of high aero heating. As discussed in the previous section for a COTS Data Acquisition solution, the high altitude and high temperatures may limit a COTS solution depending on the vendors product offering.

The other common approach is the scramjet based solution that is still being developed further today. This solution is much more likely to use a COTS products due to the lower altitude environment. This in turn, requires additional sensors measurements for the DAU which are widely support by COTS products.

What is important here is the COTS past qualification test reports that supports utilization of these devices in the intended application. Many of the COTS products are current used in Launch programs of which the environments are similar in levels to both the arcing ballistic technologies as well as the scramjet applications

Figure 2 COTS DAU

Vibration levels, duration, and concern of mechanical stresses all work in favor the COTS solution primarily due to the lower cost of the COTS DAU. Since the vehicles often end in a destructive landing, expensive and long lead DAU systems are not generally selected for the program due to cost priorities.

Transmission of the Data

The data during these test flights have various levels of security but certainly data privacy is a key one. These development programs require the data to be encrypted. As a COTS solution for data privacy encryption, AES-256 is the algorithm of choice to provide the privacy with out the burden of the government oversite. This concept to transition to the commercial solutions for classified CSfC is not new and found to be a good choice for protecting data at rest but not designed specifically for Telemetry data in transit.

Figure 3 MESP

AES-256 is certified through National Institute of Standards and Technology (NIST) via a FIPS-140 process Level 2 and is suitable for Suite B applications while the Commercial Solutions for Classified is certified through the US National Security agency.

The modern implementations of AES-256 in a streaming telemetry application implement the algorithm with a small amount of forward error correction (FEC) to minimize the link loss when data is randomized. The FEC does add a small amount of overhead resulting in an equally small amount of data rate expansion. Bit error rate tests have shown that the FEC improves the bit error handling and eliminates the typical loss when randomizing. In these use cases where the distances are great and the link error margin is small, the link improvement is major when the telemetry data is most important in the hypersonic test flights post analysis.

Data latency

Data latency or the time through which the data is processed through the Data Acquisition Unit (DAU) should be analyzed in a Hypersonic application as events happen very quickly. Flying the speed these vehicles travel at Mach 10, cover 2.1 miles per second creating a concern about latency and the ability of getting the critical end game data to the ground station before the vehicle impacts the target.

Data latency includes the DAU analog to digital processing time, the word length, the length of the PCM format, the PCM bit rate, the time it takes to output the IRIG-106 chapter 4 formatted data, the time delay to encrypt the data, the transmitter to shift the data into its modulator, then finally transmit it all before the vehicle crashes into its test target. Minimizing the latency through the system may be critical for the end of flight data and whether is has time to be transmitted. Many programs have requested modifications to the transmitter to minimize the latency in the serial stream of data to get as much of the end of flight data as possible.

To illustrate the effect of data latency the time it takes to transmit the, the result of an example model is tabulated below. The model calculated the minimum distance to transmit a frame of PCM data before the vehicle impacts the target. The assumption is that any data in transit within the telemetry system, whether the DAU, encryption, or in the transmitter will be terminated by the impact and not transmitted in full. The point here is that any end of flight data may not be transmitted due to the time it takes to be moved through the system. Equipment being arranged in a serial fashion and their additive latency is a direct impact on if the critical data is transmitted in time.

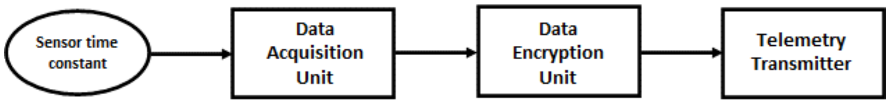

Figure 4 Latency Pipeline

Table 1 Model Feet from Impact

Speed (Below)		10	5	1	Mbps (Across)
Mach	10	25	43	187	Feet away from EOF
	8	20	35	150	
	6	15	26	112	
	4	10	17	75	
	2	5	9	37	

EOF: End of Flight

Link Margin

Telemetry Transmission distances for the hypersonic applications are very long, the curvature of the earth and the ability to acquire lock and tracking using the traditional methods seem to support a high risk that much of the data could be lost in transmission just from the distance perspective. From the industry inquiries transmitter RF output power are in the 25 Watt or higher range to transmit the distance as well as to compensate for plume attenuation, multipath, tracking, and other error sources. Also with the adoption of Low Density Parity Check (LDPC) or Forward Error Correction (FEC), the benefit of using this technology is closing the line of site (LOS) link margin.

The use of Forward Error Correction is also prevalent in the requirement list for these applications to provide the additional gain to close the RF link. The use of FEC is not a cure all, meaning the use of LDPC needs line of sight reception and is a good choice for tests performed at the properly equipped US test sites.

The use of FEC is also prevalent in applications where the telemetry down link is transferred from the vehicle to a string of ground installations or airborne chase planes, in a re-radiation daisy chain to support beyond line of site applications.

Arranging multiple sites along the flight path requires many assets along with a flight plan. Future range capabilities are not being well advertised for the right reason, so for time being the current technology is being requested from the prime developers based on sound and proven methods to obtain the flight data on existing, well equipped test ranges.

Doppler shift

Due to the high speed of the vehicle and the distances it flies, doppler shift if a concern. With modern implementation of both the transmitters as well as ground receivers with active compensation can manage the shift in frequency. Transmitters today use very stable reference oscillators that were not available in a usable form factor until recently. Low cost but highly stable PLL references are available that provide 1 PPM of stability that enhances the telemetry link to ease the burden on the ground receiver in the test flights. Yet additional development is required to fulfill he long term path for hypersonic programs and the new interest in the enhancing era we are in today.

Conclusion

The use of COTS products is being sought for new Hypersonic development provides a quick response lower cost solution for the immediate data acquisition needs. Transmitting the telemetry data is adequate for shorter range test flight, taking advantage of FEC as well as higher RF power transmitters. Hypersonic vehicles have been around for many years, with the new development happening today no doubt will drive our industry for new advances in our telemetry technology for current and future applications.

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References:

IRIG-106-23, Range Commanders Council, Telemetry Standards

Glossary:

COTS	Commercial off the Shelf
DAU	Data Acquisition Unit
EOF	End of Flight
FEC	Forward Error Correction
Rf	Radio Frequency
PCM	Pulse Coded Modulation

Export Control:

This document was reviewed on 02/05/23 and does not contain technical data.