SOAREX-VI RE-ENTRY FLIGHT TEST EXPERIMENT - ELECTRONIC SYSTEMS OF THE SLOTTED COMPRESSION RAMP (SCRAMP) PROBE

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ABSTRACT

The Sub-Orbital Aerodynamic Re-entry Experiments (SOAREX) VI project is scheduled for launch from NASA Wallops Flight Facility, VA, USA in late 2007 on a 500 km altitude, 4 km/s sub-orbital flight. The primary payload of this experiment is the Slotted Compression RAMP (SCRAMP) probe. Developed as an alternative to the ubiquitous Newtonian sphere-cone re-entry body, the SCRAMP is uniquely self-stabilizing. Traditional re-entry methods require precise pointing of the craft, inflexibility in center-of-mass placement (sometimes requiring ballast and its associated mass penalty), and spin stabilization or active attitude correction systems. The SCRAMP has none of these requirements. Full characterization of this probe requires a simple yet powerful sensing suite coupled with unique telemetry & data return solutions. Velocity, position, acceleration, rotation, pressure, temperature, and heat shield recession data are all recorded and redundantly transmitted in real-time to ground and space-based telemetry assets. The full aerophysics of the craft will only be described here inasmuch detail to permit a rationale for all onboard systems.

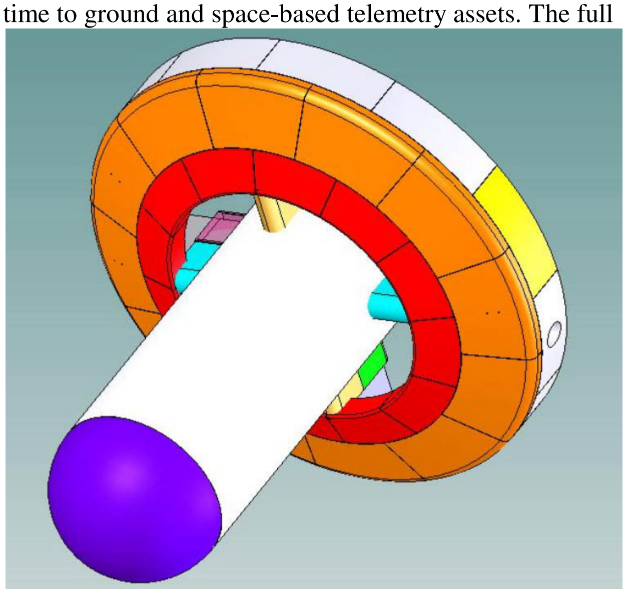

Figure 1. The SCRAMP

1. AEROPHYSICS

In the simplest terms, the SCRAMP can be loosely thought of as a hypersonic badminton shuttlecock, always coming down nose-first. A probe with its heat shield located behind the payload, the SCRAMP consists of a cylindrical forebody with hemispherical nose cap, and 70° slotted aft flare (Fig. 1). It is this flare that generates most of the drag (causing a 'classical' compression ramp) and places the aerodynamic center well to the rear of the probe. In order to alleviate the flow recirculation caused by the compression ramp, a series of slots are located at the compression ramp corner. By minimizing this recirculation, the drag efficiency of the aft flare is increased [1]. On re-entry, a pressure shock forms at both the nose cap and aft flare. Above approximately 3.5 km/s velocity, the angle of the bow shock converges to the aft flare creating an Edney Type IV shock-shock interaction.

A small SCRAMP design was tested previously in the SOAREX I suborbital flight, successfully demonstrating the self-stabilizing properties of the probe. SOAREX IV will attempt to further characterize this unique shape with a much larger probe (66 cm total length and 56 cm diameter aft flare) and greatly expanded complement of sensors.

2. ELECTRONIC SYSTEMS

The SCRAMP is composed of four basic electronic subsystems: initiation, sensing, data handling, and telemetry (Fig. 2). The initiation system powers on the other subsystems at specific times during the flight. The sensing system collects probe motion and environment data, which are then provided to the data handling system in preparation for transmission by the telemetry system.

2.1. Initiation

The SCRAMP initiation system turns on various subsystems at two points during the flight. The SCRAMP is powered by a 24-cell 28V/3Ah NiCd battery pack, which affords a 29 minute margin for the 10.5 minute mission. At launch T=0, all subsystems are off. Power is only available to the probe after two altitude switches activate at 1.5 km altitude (T=17s). This prevents any battery drain while still on the launch pad. The sensing and data handling systems are powered up at this time. At 252 km altitude (T=163s) an umbilical containing a breakwire separation loop is severed by a pyrotechnic cable cutter (part of the ejection system not covered here). The voltage of the separation loop is grounded until cut, at which time a pull-up resistor at the node activates a relay, allowing power to flow to the telemetry system. This delay is to prevent any RF emissions from interfering with the launch vehicle telemetry and/or flight termination system. At the time of SCRAMP telemetry system turn-on, the launch vehicle telemetry (with the exception of a single camera to monitor probe ejection) is no longer in use.

2.2. Sensing

Motion and environmental data from the SCRAMP are obtained using a mix of commercial and advanced prototype sensors. Placement is both internal and external at strategic locations on the probe nose and aft flare (Fig. 3). Mounting is in Teflon thermal protection system (TPS) coupons on the nose, and variously in Teflon and SIRCA TPS on the aft flare. Cabling for aft flare sensors is routed to the body through two hollow flare struts.

Probe motion data are collected via various means. The anticipated 22g deceleration is monitored in three dimensions by a Crossbow CXL25LP3 triaxial accelerometer (±25g, 10mg RMS accuracy), rotation in three dimensions by three Systron-Donner QRS-11 angular rate sensors (±0-1000°/sec, 2.5mV/°/sec accuracy), and a Herley MD-50c C-band radar transponder is used in conjunction with ground telemetry assets to characterize probe altitude, velocity and position. A Supercircuits PC169XS color video camera (70° FOV, 480 line resolution) is located behind a protective quartz window on the outer edge of the aft flare. This provides a real-time view of successful SCRAMP ejection, as well as probe stability and entry angle.

Pressure is recorded at four ports on the nose and the aft flare of the SCRAMP using GP50 model 242 transducers (0-30 PSIA, ±0.5% FSO accuracy). Two ports on the nose are at 0 and 45° from the center to characterize the bow shock, while two aft ports are located radially on the edge of the flare to characterize the shock-shock interaction.

Two Hollow aErothermal Ablation Temperature (HEAT) sensors (24.13–0mm, ±0.5mm accuracy) developed at NASA Ames Research Center by Martinez, Fu, Oishi, et

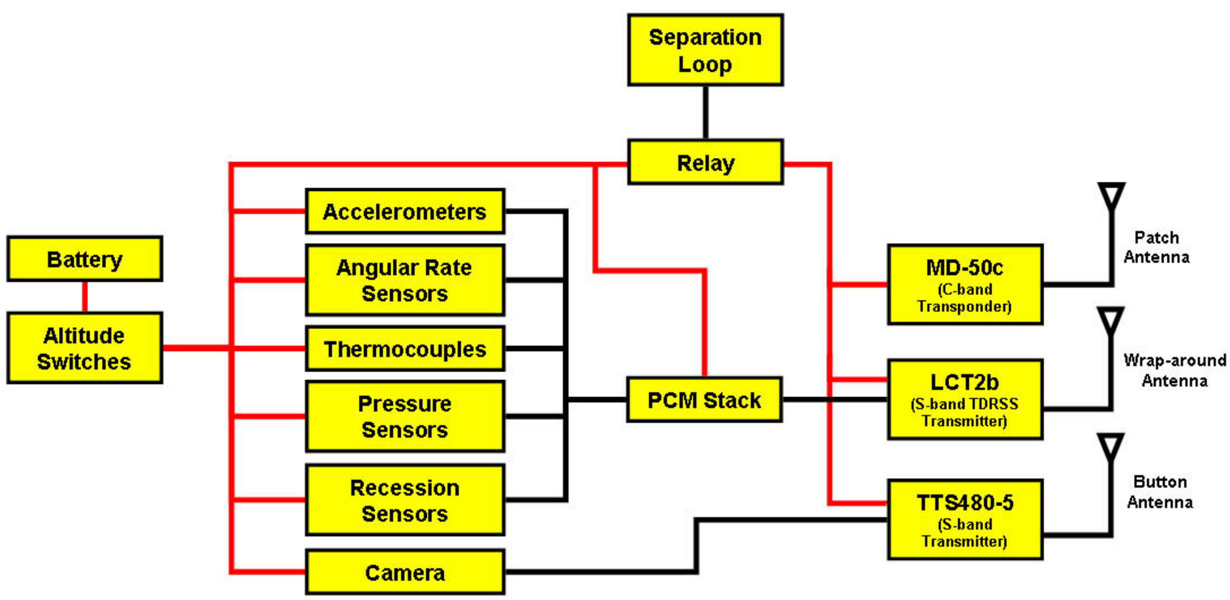

Figure 2. SCRAMP Block Diagram

al, are mounted in a Teflon coupon on the aft flare. These sensors track the progression of a 700° C isotherm in the TPS, effectively measuring ablation rate and amount in in the case of Teflon, a non-charring pure ablator. Each sensor head is composed of a non-conductive polyimide tube wrapped with two Pt-W wires, and has a known resistance per unit length. Mounted flush with the exposed TPS, a constant current powers each. On re-entry, the sensor ablates with the surrounding Teflon. The polyimide chars to a conductive carbon structure and completes the circuit between the two Pt-W wires. The voltage measured at the sensor is linearly proportional to the remaining sensor length and TPS thickness.

12V supplies for pressure transducers 1&3, pressure transducers 2&4, recession sensors, and video. All other components are internally regulated and are powered directly from the 28V battery.

2.3. Data Handling

All SCRAMP sensor outputs are analog, and, with the exception of the video camera, which is transmitted as an analog signal, must be converted to a digital signal for transmission. This is accomplished via a Pulse Code Modulation (PCM) stack built by NASA Wallops Flight Facility. The PCM stack analog-to-digital converters are

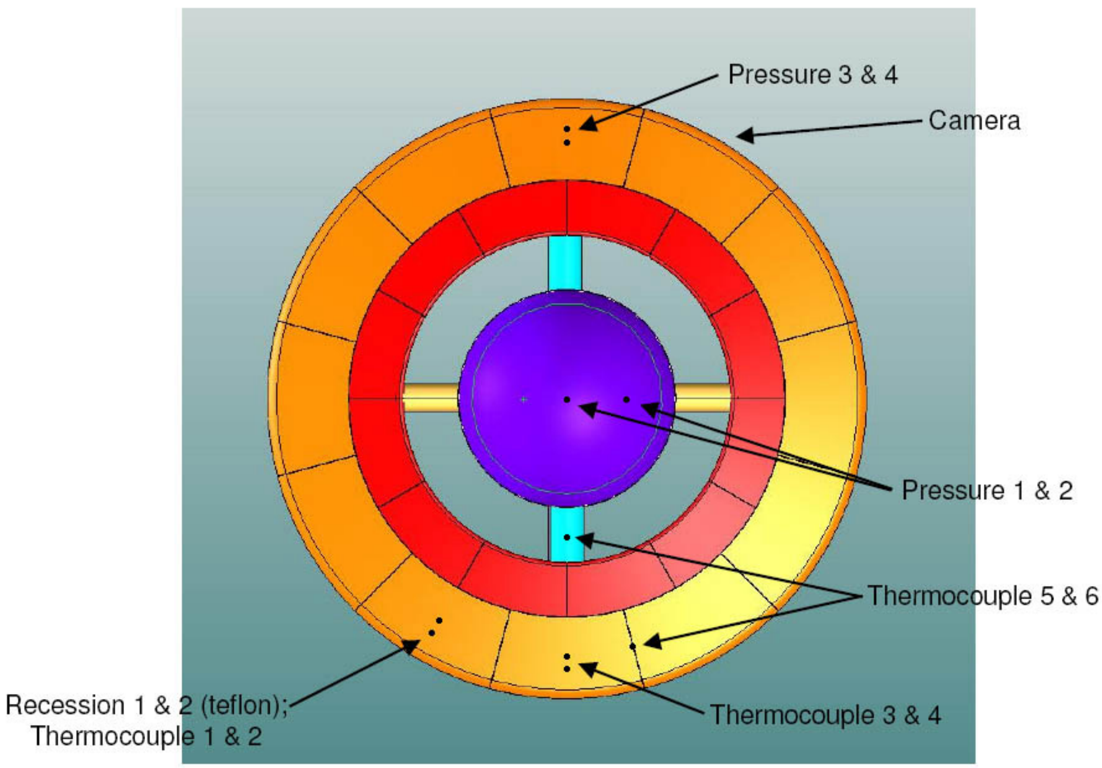

Figure 3. External Sensor Placement

Finally, eight K-type thermocouples are placed variously throughout the probe, six of them on the aft flare to measure shock-shock interaction heat flux, strut heat flux, tile bond line temperature, as well as two for recession sensor calibration. The final two thermocouples record internal pressure transducer and deck plate calibration temperatures.

Sensor power is regulated to separate 5V supplies for the angular rate sensors and accelerometers, and separate

calibrated for a 0-5V input, and as such any sensors that do not output this range have been outfitted with amplification circuits. The PCM stack outputs data at 10 kbits/second, in a bi-phase level, five-'pass', 750-word, 10-bit word cycle. Some sensors are read more frequently than others within this cycle depending on the dynamic nature of the sensor reading. The beginning of each pass contains two sync words and one subframe ID word, followed by various sensor data (Fig. 4). In this configuration, pressure, angular rate & acceleration are

Word 0	Word 1	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8	Word 9	Word 10	Word 11	Word 12	Word 13	Word 14
Sync	Sync	SFID	Press 1	Press 2	Press 3	Press 4	Accel x	Accel y	Accel z	Gyro x	Gyro y	Gyro z	Temp 1	Temp 2
Sync	Sync	SFID	Press 1	Press 2	Press 3	Press 4	Accel x	Accel y	Accel z	Gyro x	Gyro y	Gyro z	Temp 3	Temp 3
Sync	Sync	SFID	Press 1	Press 2	Press 3	Press 4	Accel x	Accel y	Accel z	Gyro x	Gyro y	Gyro z	Temp 5	Temp 4
Sync	Sync	SFID	Press 1	Press 2	Press 3	Press 4	Accel x	Accel y	Accel z	Gyro x	Gyro y	Gyro z	Temp 7	Temp 5
Sync	Sync	SFID	Press 1	Press 2	Press 3	Press 4	Accel x	Accel y	Accel z	Gyro x	Gyro y	Gyro z	HEAT 1	HEAT 2

Figure 4. PCM Matrix Optimized for TDRSS

read at a sample rate of 66.6 Hz, while temperature and recession are read at 13.3 Hz.

2.4. Telemetry

The launch vehicle scheduled to carry SOAREX VI will travel on a ≈135° azimuth toward Antigua with a downrange splash 1079 nautical miles out into the Atlantic Ocean. Space constraints prevent the inclusion of a flotation device and locator beacon, so data must be retrieved remotely. As such, the SCRAMP contains three transmitters utilizing telemetry assets on the east coast of the United States, Antigua, as well as the TDRSS space communications satellite network.

As the 135° launch azimuth is not guaranteed, TDRSS was chosen as an azimuth-independent option to reduce risk of data loss. The disadvantage is that all data must be sent at 10 kbits/s, much lower than the typical 1 Mbit/s rate afforded by ground telemetry assets. A Herley MD-50c radar transponder and patch antenna transmit velocity, altitude, and position to NASA Wallops and Antigua. A TTS480-5 S-band transponder and custom Haigh-Farr button antenna located in the nose transmit analog video signal, again, to Wallops and Antigua. Probe sensor data are transmitted to either Antigua or one of two TDRSS satellites via an LCT2-b S-band BPSK TDRSS transmitter and custom Haigh-Farr wrap-around antenna located partway down the cylindrical probe body. All antennae are protected by Teflon TPS, an RF transparent material. Extensive link analyses have been done to ensure low bit error rate (at least 10^{-5}) transmissions to all telemetry assets during the flight. NASA Wallops link margin decreases continuously after ejection until loss of signal at approximately 182 km altitude. TDRSS link margin stays consistent during the flight, and loss of signal occurs at splash. The Antigua link margin continuously improves as the probe approaches, until loss of signal at approximately 50km altitude.

3. CONCLUSION

The SOAREX VI project aims to further characterize the innovative SCRAMP shape with a simple yet effective suite of sensors and novel telemetry solutions. The coming flight will provide a wealth of further detail regarding the hypersonic behavior of this craft. It is the hope of the project that the SCRAMP will simplify entry, descent and landing for future planetary probes, and will be a practical method for delivery of high-risk, small form factor ‘companion’ missions accompanying larger vehicles to Mars or other planetary bodies [3].

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