Boom Retraction Mechanism as part of Sample Acquisition System from Remote and Hazardous Extra-Terrestrial Sites

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Abstract

This paper discusses the development of a mechanism as part of a comet sampling system. The mechanism, known by the acronym BRAD for *Boom Retraction and Deployment*, is part of a mission proposal to return a comet regolith sample to earth. The mission proposal; CORSAIR for *Comet Rendezvous, Sample Acquisition, Investigation, and Return*, was coordinated by Johns Hopkins Applied Physics Lab in Laurel, MD as a response to the NASA 2017 New Frontiers AO or *Announcement of Opportunity*. BRAD functions as a means to tend and control a deployable boom that connects a sample projectile to the spacecraft.

1. Mission Overview

The mission objective for CORSAIR is to transit to a comet, acquire at least one regolith sample and return that sample to earth. As most any other space flight mission, this proposal would include various sensors to inform the mission in situ. One of the key surveys that the sensors would provide is of the surface for a suitable sampling location. Once the surface has been scanned, there would be many options available to gather the sample.

A conflict arises when selecting a sampling site. The science community would pursuit what has the most scientific value. The mission planning community would seek the lowest risk option to meet the mission objectives. CORSAIR offers a solution to sample locations of high scientific value with no additional risk. This is done by keeping the spacecraft off of the surface and launching a projectile to gather the sample.

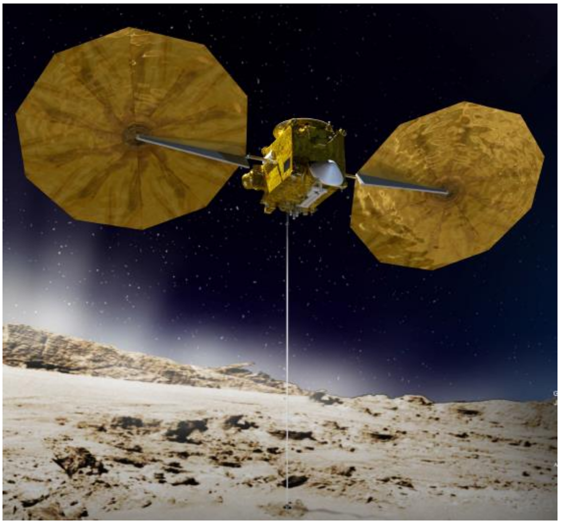

Figure 1 CORSAIR Mission Concept

The sampling technique [1] consists of launching a projectile, known as the SaRP for *Sample Retrieval Projectile*, from a spacecraft with enough kinetic energy to penetrate the surface and collect a sample. Once in the comet, a series of mechanisms in the projectile are timed to close a capture door and release additional mass. In house testing indicates adding projectile mass increases penetration depth more effectively than increasing velocity.

The SaRP is launched from the spacecraft by a pyrogenic device. An expansion chamber captures the pyro generated gas and transfers the energy to the SaRP through an open frame structure, known as the *Bird Cage*. The *Bird Cage* design permits components that attach the SaRP to run down the center of the assembly. Development and testing of this system was carried out at DLR (*Deutschen Zentrum für Luft- und Raumfahrt)* in Munich. [2]

Figure 2SaRP Test Article

BRAD, described herein, controls the connection between the SaRP and the spacecraft. BRAD supplies a means to package and deploy the connection hardware during sampling. Once the sample is gathered, BRAD retracts the SaRP for processing at the spacecraft. Upon return, a robotic manipulator extracts the sample cartridge from the system and then transfers the sample to the Earth Return Vehicle for transit back to earth.

2. BRAD Design and Function

2.1.1 TRAC Boom

The component that attaches the SaRP to BRAD is a deployable boom. Several options were considered for this component and a series of trades were performed. The key features considered were ability to deploy at high speeds, sufficient stiffness when deployed and efficient packaging compatible with surrounding hardware. A candidate emerged that, although not fully optimized, did meet the proposed need for the application. The boom, known as the TRAC boom for *Triangular Rollable and Collapsible Mast*, connects to the SaRP on one end and to the spacecraft via a drum on the other.

TRAC was developed at AFRL (Air Force Research laboratory) in New Mexico [3]. Several options for section properties were tested and for this application it was determined TRAC V5 (*Version 5*) would satisfy the requirements for stiffness and packaging.

2.1.2 Drum

The hardware that packages TRAC V5 and allows deployment at high velocities is known as the drum. TRAC V5 wraps around the drum and provides control at different stages of the sample collection process.

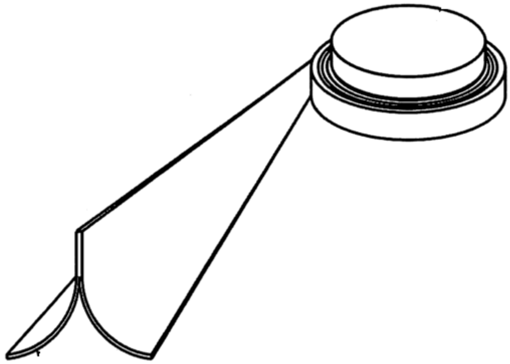

Figure 3 TRAC Boom

The boom is held tightly to the drum with rollers that apply a radial load. TRAC V5 has an inherent property to lift off the drum if not held securely. If gaps are allowed to develop, a whipping action results between TRAC V5 and the drum which could damage surrounding hardware.

The general design of the drum follows the requirements of the TRAC V5 design. A baseline drum design emerges that complies with TRAC V5 needs for width and diameter which was used for testing. Subsequent components are designed commensurate to the drum design.

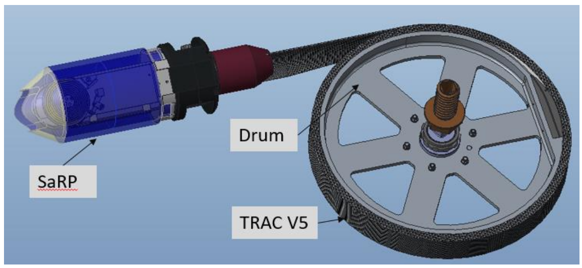

Figure 4 BRAD Components

2.1.3 TRAC V5 to Drum connection

To facilitate assembly, a transition piece is bonded to TRAC V5 boom which sub sequentially bolts to the drum. The TRAC V5 boom cross section is collapsed at this stage and the bond lines are designed to transfer the loads from the TRAC into the transition piece. The transition piece is bolted and pinned to the drum in order to react the loads in shear across the connection plane. Hardware choices are low profile in order to minimize disruptions to the drum rim shape that would otherwise affect the TRAC V5 wrap on the drum.

2.1.4 Retraction Actuator

To prepare for launch, the components in between BRAD and the SaRP need to be preloaded together to eliminate gaps. The SaRP is snubbed against the Bird Cage via preload in TRAC V5. A retraction actuator on the drum applies a torque that pulls the parts together. A clutch, which has a break-away torque feature, is installed between the drum and the retraction actuator. This feature disengages the retraction actuator during launch which reduces drag on the drum once the launch has been initiated. The clutch reengages during retraction.

2.1.4 Shock isolation

The launching system has inherent shocks that are very hard on nearby hardware. The shock due from the pyro firing is minimized to the spacecraft via attenuators isolating the sampling system. The shock at the end of the launcher travel is attenuated by a honeycomb absorber that reduces the impulse created by the harsh deceleration of the *Bird Cage*.

2.1.5 TRAC Length and Brake

The length of TRAC V5 is driven by the resolution of the sensors, quantified at the centimetre level, used to determine the height of the spacecraft at the sample site. The intent is to leave approximately one wrap of TRAC V5 on the drum, at worst case deployment, in order to take advantage of frictional effects known as the capstan effect. This reduces the load at connection of TRAC V5 to the drum as described in 2.1.3.

The TRAC V5 connection must tolerate the loads associated with all three possibilities. Provided the distance to the comet surface is known within a few centimeters, it is possible to select a TRAC V5 length that works for all cases and still permits a one wrap condition.

In the first situation, a brake engages on the drum to arrest all of the momentum in the system. In the second case most of the momentum of the system is absorbed in the penetration of the projectile. This is considered best case scenario in that the projectile cartridge should be full with dense material. The third case is where the surface is so hard that minimal penetration of the SARP happens and more of the TRAC goes into a slack condition. The same nominal amout of TRAC V5 is deployed in every scenario.

Depending on the surface properties at the sample site, three possible scenarios emerge.

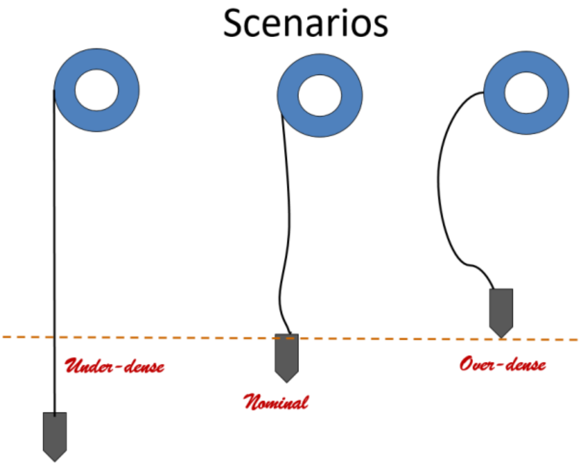

Figure 5 Possible Scenarios

The residual momentum in the drum, TRAC V5 and the SaRP is absorbed by a brake that is triggered by the amount of turns the drum has taken. As the projectile momentum is lost to the comet, a lesser amount is absorbed by the brake reducing the load on all components.

The brake mechanism absorbs the residual energy of the system once the SaRP reaches the comet surface. A device between the brake and the drum allows a nominal number of turns of the drum before engaging the brake. Once engaged, the brake directs the energy in a honeycomb absorber where the system slows down in a gradual fashion.

Once the drum has stopped, on the order of 0.3 seconds, a pause allows the SARP mechanisms to function. After the dwell, the retraction actuator re-engages with the drum and pulls the SaRP back to the spacecraft. The transit back to the spacecraft takes on the order of 10 seconds.

Test Hardware

To expedite development, the test hardware includes a few changes to the conceptual design. A commercial friction brake replaces the honeycomb absorber on the brake mechanism. An expansion chamber using compressed helium, as opposed to a pyrogenic device, was used in the launcher. Using helium allows for the higher velocities needed through a fast acting valve. These changes not only make the original test build faster and cheaper but also allows for much quicker turn around for testing.

SaRP velocity was measured using a captured image from a test run with an oscillating LED mounted on the SaRP. In the photograph, pulses from the LED illuminate one period calculated per Eq. 1:

$$T = 1/ f \qquad (1)$$

T = period (seconds)

f = frequency (cycles per second)

In the image, the distance measured on the tape measure in the background divided by the period gives the velocity.

Figure 6 Velocity Measurement

The SaRP was shot into free space as well as into a material known as foam glass [4]. Foam glass gives a reasonable approximation of the material properties comet scientists expect to see at the comet surface.

A cinder block tower was used at Goddard that facilitated shooting the system towards the ground in a safe manner. The facility was updated with a gas distribution system to keep the operators safe from the fast moving parts of the sampling system. Machine shop and office space were added as the CORSAIR proposal progressed.

Figure 7 Test Tower

Figure 8 Pressure Control Panel

3. Test Results

Various configurations of the test hardware were built up as confidence in the design increased. Testing revealed the velocity needed for a 2 kg SaRP is approximately 35 meters per second. The amount of energy needed to stop the drum was lower than calculated. High speed video revealed a compression wave traveling up TRAC V5 that helps to slow the drum. Changing the drum from aluminium to composite also showed significant reduction in residual energy when trying to slow the drum. This was determined by comparing the amount the brake rotor rotated to stop the drum.

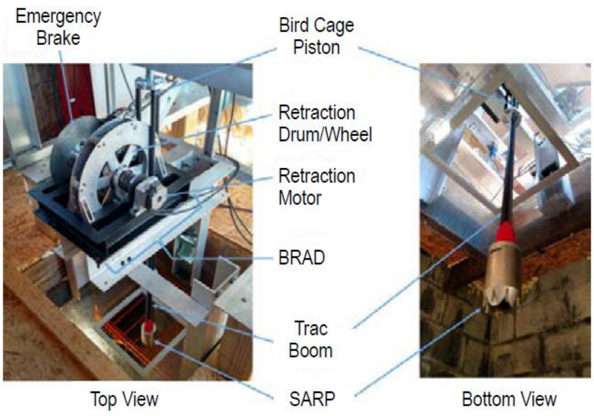

Figure 9 BRAD Test Hardware

4. Summary and Conclusions

BRAD solves the problem of managing a deployable boom at a high velocity. The work done to develop and test this system are described in this paper and provide insight to how various design problems are solved.

References

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[2] Volk, et. al., **Development and testing of a pyro-driven launcher for harpoon-based comet sample acquisition,** 68th International Astronautical Congress, Adelaide, Australia, IAC-17-A3,4B,5,x39772.

[3] Banik and Murphey, 2010, **Performance Validation of the Triangular Rollable and Collapsible Mast**, 24th Annual AIAA/USU Conference on Small Satellites, August 9 – 12, Logan Utah, SSC10-II-1

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List of Acronymns

BRAD: *Boom Retraction and Deployment*
CORSAIR: *Comet Rendezvous, Sample Acquisition, Investigation, and Return*
AO: *Announcement of Opportunity*
SaRP: *Sample Retrieval Projectile*
DLR: *Deutschen Zentrum für Luft- und Raumfahrt*
TRAC: *Triangular Rollable and Collapsible Mast*
AFRL: *Air Force Research Laboratory*
V5: (*Version 5*)