NASA/TM–2017-219018/Supplement

Development and Testing of Harpoon-Based Approaches for Collecting Comet Samples

Video Supplement

Compilers: Lloyd Purves, Joseph Nuth, and Edward Amatucci

Contributing Authors: Donald Wegel, Walter Smith, Joseph Church, James Leary, Lake Kee, Stuart Hill, Markus Grebenstein, Stefan Völk, and Peter Lell

April 2017

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GSFC Development and Testing of Harpoon-Based Approaches for Collecting Comet Samples

Video Supplement

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Development and Testing of Harpoon-Based Approaches for Collecting Comet Samples

Video Supplement

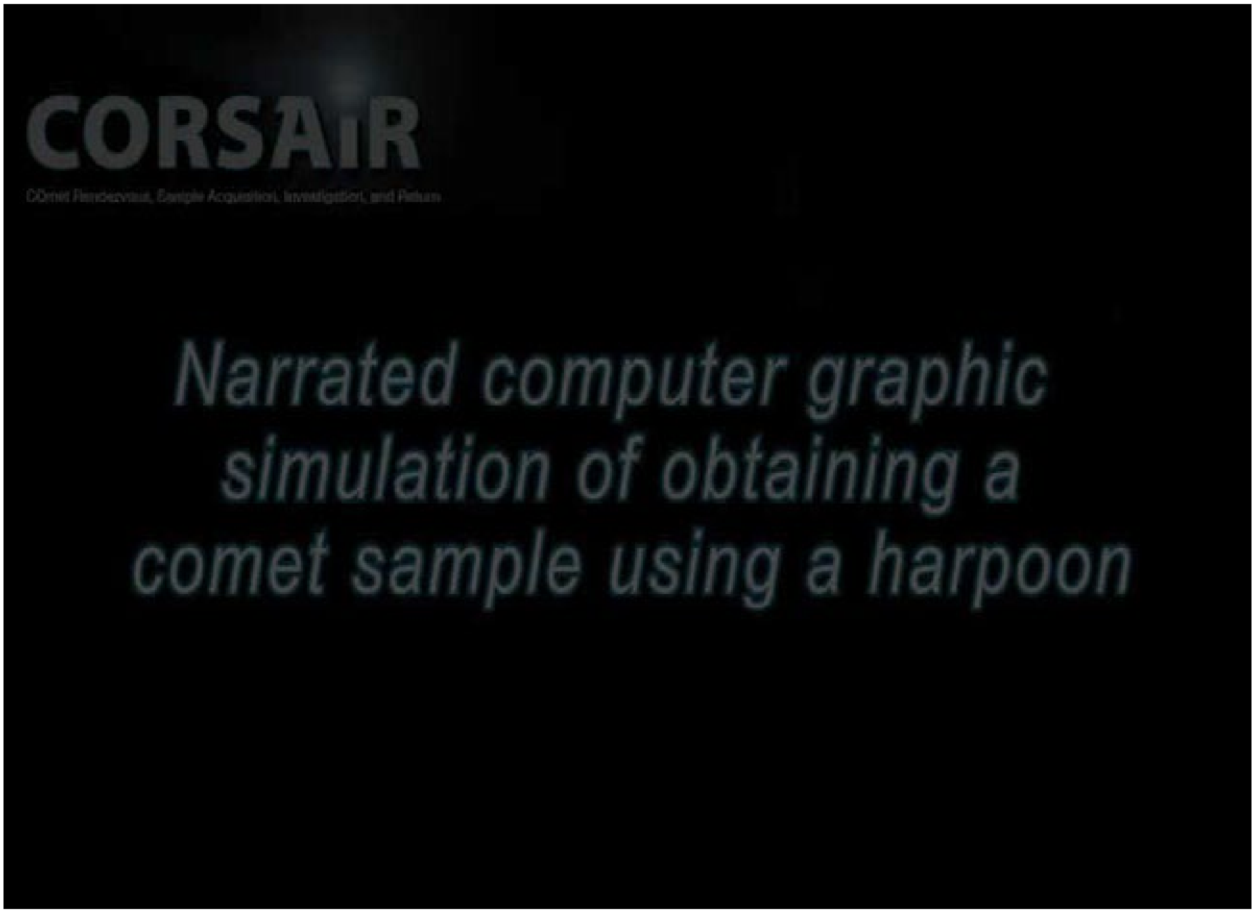
1. Introduction

This video supplement contains a set of videos created during the approximately 10-year-long course of developing and testing the Goddard Space Flight Center (GSFC) harpoon-based approach for collecting comet samples. The purpose of the videos is to illustrate various design concepts used in this method of acquiring samples of comet material, the testing used to verify the concepts, and the evolution of designs and testing.

To play the videos this PDF needs to be opened in the freeware Adobe Reader. They do not seem to play while within a browser.

While this supplement can be used as a stand-alone document, it is intended to augment its parent document of the same title, Development and Testing of Harpoon-Based Approaches for Collecting Comet Samples (NASA/CR–2017-219018; this document is accessible from the website: https://ssed.gsfc.nasa.gov/harpoon/SAS_Paper-V1.pdf). The parent document, which only contains text and figures, describes the overall development and testing effort and contains references to each of the videos in this supplement. Thus, the videos are primarily intended to augment the information provided by the text and figures in the parent document. This approach was followed to allow the file size of the parent document to remain small enough to facilitate downloading and storage.
Some of the videos were created by other organizations, Johns Hopkins University Applied Physics Laboratory (JHU APL) and the German Aerospace Center called, the Deutsches Zentrum für Luft- und Raumfahrt (DLR), who are partnering with GSFC on developing this technology. Each video is accompanied by text that provides a summary description of its nature and purpose, as well as the identity of the authors. All videos have been edited to only show key parts of the testing. Although not all videos have sound, the sound has been retained in those that have it. Also, each video has been given one or more title screens to clarify what is going in different phases of the video.

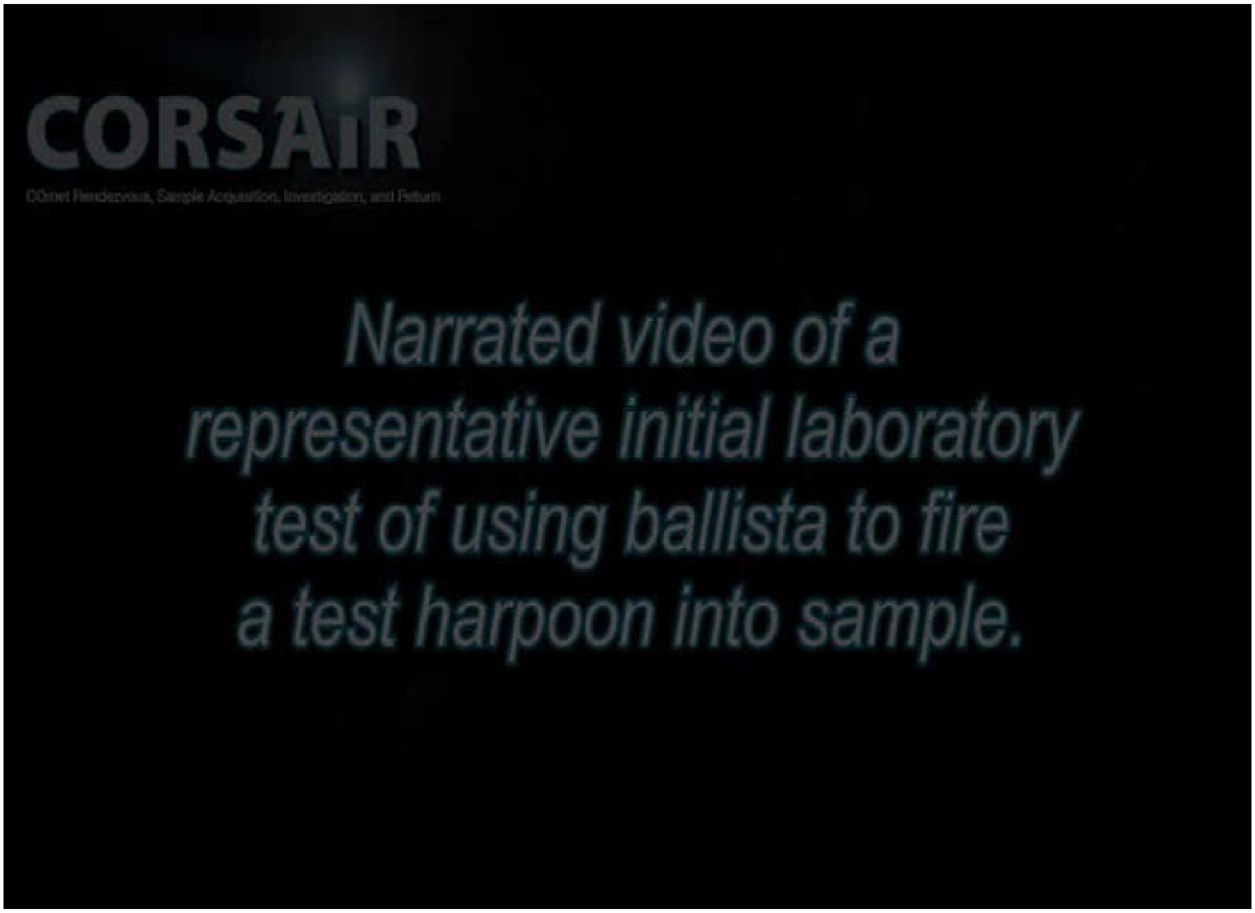
2. Computer Graphic Simulation of Using a Harpoon to Acquire a Sample from a Comet



This video demonstrates how a comet sample could be obtained using spacecraft and a sample-gathering harpoon. This video is a computer graphics simulation that was made in the 2006 time-frame and was intended to provide a fairly simple end-to-end summary of how the harpoon system would gather a comet sample. Because a great deal of design evolution has taken place since making this movie, the harpoon system shown in this video is different in many ways from its current configuration.

This computer graphic simulation was produced by the GSFC video department, and was laid out by GSFC aerospace engineer Donald Wegel, who narrates the video.

3. Laboratory Firing of a Test Harpoon into Sand



This video demonstrates the laboratory firing of a test harpoon into sand. Like the previous video, this one was also made in the 2006 timeframe and was intended to show a representative example of using a custom built ballista to fire a test harpoon into a container of sample material, in this case sand. This video illustrates the operation of the ballista and the overall laboratory set up. Many of these tests were performed using a variety of ballista velocities, harpoon geometries, harpoon masses, and sample materials.

Like the previous video, this one was also produced by the GSFC video department, and was narrated by GSFC aerospace engineer Donald Wegel, who appears in the video.

4. Using Ballista with Dual Carpenter's-Tape Tether to Fire Harpoon into Various Materials

This video demonstrates the next stage of testing the harpoon approach after the laboratory tests shown in the previous video. The first part of the video shown here illustrates the GSFC Tower Test Facility (TTF) in which these tests took place.

The TTF consists, in part, of a tower about 6 meters high originally built to support Apollo-era laser ranging experiments. A shed was placed on top of this tower to protect test equipment. The ballista was then moved from its indoor laboratory to the shed and integrated with the first test version of a harpoon retraction system, which consisted of a Dual Carpenter's-tapes Tether (DCT) along with mechanisms for spooling, drag, and retraction. Harpoon targets consisted of barrels of various materials sitting inside the tower at ground level, which allowed the harpoon and tethers to travel about 6 meters downward after firing and before hitting the target material.

5. End-to-End Sample Acquisition with Test Harpoon and Mechanisms

This video demonstrates one of the first TTF end-to-end tests of the GSFC Sample Acquisition System (SAS), which is the designation for the combination of the Launcher (Ballista in this test), the DCT retraction system, and the Sample Acquisition and Retrieval Projectile (SARP) with its sheath release. For this test, the TTF provides an environment representative of a spacecraft, located some meters above the surface of a comet, firing a SARP into the comet and retrieving the filled sample cartridge.

This video was produced by GSFC engineers Walter Smith and Donald Wegel.

6. Test of Firing of Harpoon into 800 kPa FOAMGLAS

This video demonstrates the higher speed firing of the SARP by the Variable Impulse Pressure (VIPr) Launcher into FOAMGLAS.

As testing experience was gained in the TTF, it was discovered that the Ballista lacked the ability to give the SARP a penetration velocity of much over 20 meters per second. Computer modeling indicated that a SARP velocity of around 50 meters per second seemed necessary to adequately penetrate the hardest expected comet material. This led to two changes. First, the Ballista was replaced with a much higher performing gas-driven Launcher called the VIPr Launcher. The second change was to use FOAMGLAS, a commercial building insulation material manufactured by the Pittsburgh-Corning Corporation, for the comet surface simulant. FOAMGLAS had the advantages both of being available in a variety of compressive strengths of up to 2.4MPa, and having consistent (+/- ~10%) material properties.

This video shows the results of an early penetration test into a horizontal slab of 1-MPa FOAMGLAS. As shown by the video, the test was only a partial success for, while the SARP did penetrate the FOAMGLAS, the VIPr laucher, which was still being debugged, had its piston break off due to inadequate performance of the first shock absorbing system used in VIPr. This problem was later fixed.

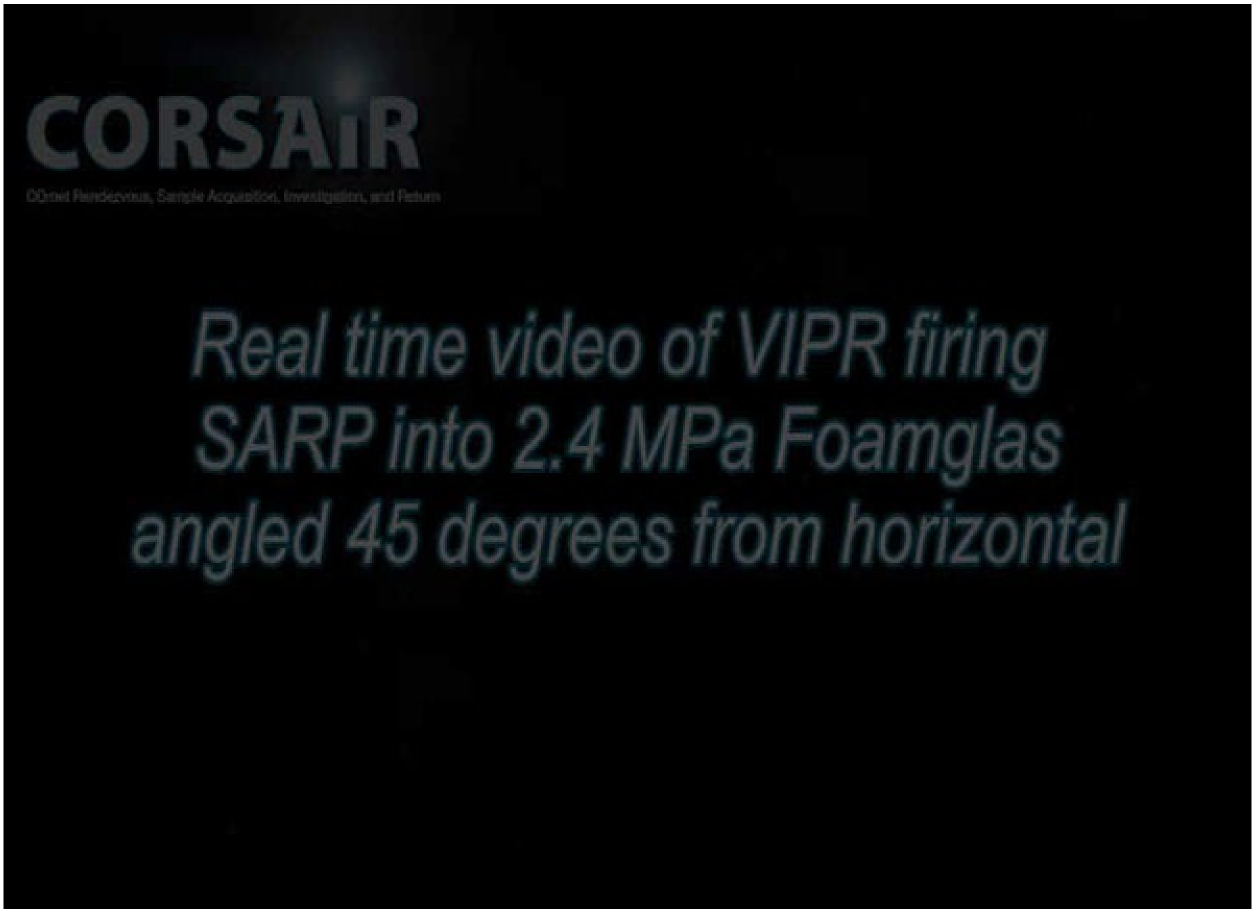
This video was made by Walter Smith and Donald Wegel.

7. SARP Being Fired into 1 MPa FOAMGLAS

This video demonstrates the results of a more successful penetration test by the VIPr-Launcher SARP into a horizontal slab of 1-MPa FOAMGLAS.

This video and the still images were made by Walter Smith and Donald Wegel.

8. SARP Being Fired into 2.4 MPa FOAMGLAS



This video demonstrates the successful results of a very challenging penetration test consisting of the VIPr-launcher firing the SARP into a slab of 2.4-MPa FOAMGLAS angled 45 degrees from horizontal.

This video was made by Walter Smith and Donald Wegel.

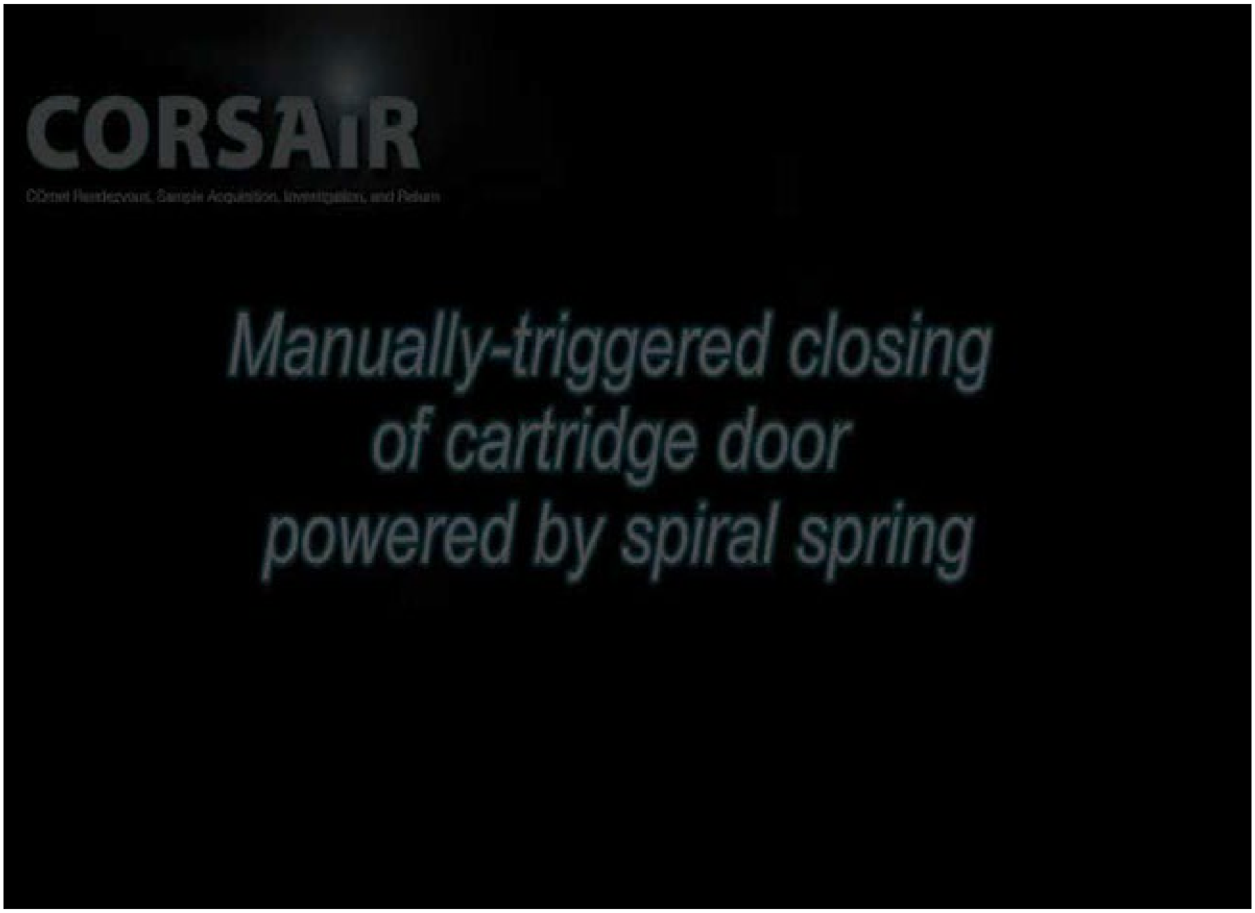
9. Operation of Bi-Stable Pin Puller in SARP

This video demonstrates an early test of using the bi-stable pin puller to trigger the closing of the door of the SARP sample cartridge. Not shown in the video is the coil spring (because it was on the back side of the cartridge), which was initially used to power the door closing after the door was released by the pin puller.

In a work effort that paralleled the testing of SARP penetration into FOAMGLAS, GSFC developed more flight-like mechanisms for the SARP. Part of this work resulted in the “bi-stable pin puller”, which is a compact, powerful, and fast-acting device to trigger mechanisms within the SARP.

This video was produced by Joseph Church and Donald Wegel.

10. Closing Door of Sample Cartridge Using a Custom Spiral Spring



This video demonstrates an early and successful test of closing the door of the SARP sample door as it cuts through a sample of FOAMGLAS. In this video, the spiral spring is manually-triggered.

The reason for the spiral spring is that earlier tests had shown that the coil spring being used did not have sufficient strength to pull the cartridge door through the hardest FOAMGLAS. After analysis showed that it would be difficult to find enough room in the SARP for a coil spring of sufficient strength, GSFC designed a custom spiral spring that could close the door on FOAMGLAS and still fit within the SARP.

This video was produced by Joseph Church and Donald Wegel.

11. Closing Door of Sample Cartridge Using the Spiral Spring at a Cryogenic Temperature

This video demonstrates the spiral spring could still function as intended when cooled to the 77 K temperature of liquid nitrogen.

This test was made because it is planned to allow the flight SARP to passively cool to a low enough temperature before being firing by keeping it on the shaded side of the CORSAIR SC where its heat can be radiated to deep space. This will be done to avoid allowing the sample cartridge reach a high enough temperature for aqueous or other alteration of the comet sample to take place.

This video was made by Joseph Church and Donald Wegel.

12. Test Firing of Single Piston Rod DLR Launcher

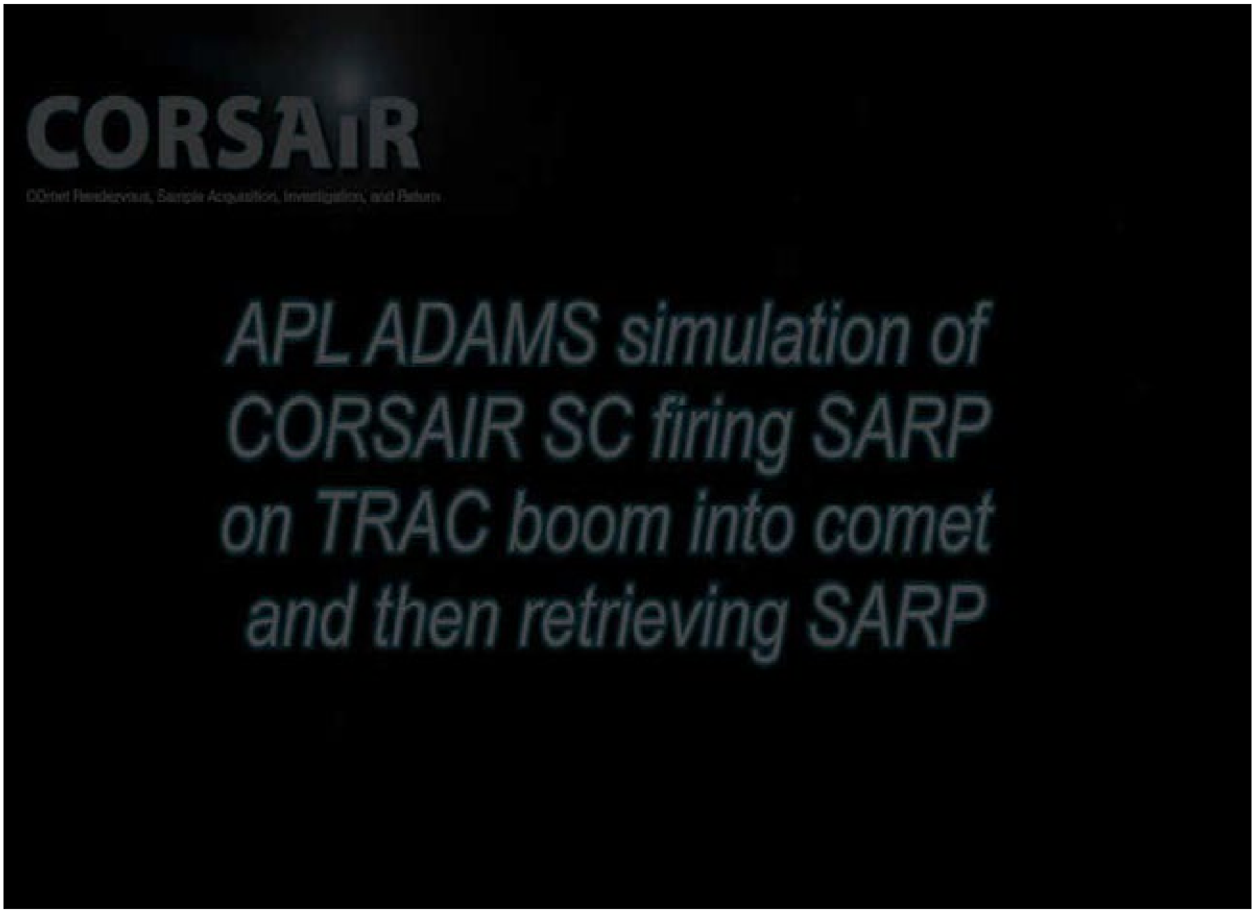
This video demonstrates a test firing of the DLR Launcher with a single piston rod, which was used in its initial design.

The DLR developed this Launcher when it became a partner of the broader APL-led CORSAIR effort. The DLR role included, among other things, the design and development of a Launcher for the flight SAS. The DLR Launcher was intended to make maximum use of what DLR had learned from developing the Launcher for the harpoon anchoring system employed on the Philae lander, which in turn was part of the overall ESA Rosetta mission, the first spacecraft to rendezvous and orbit a comet.

This video shows a test of the Launcher version compatible with the initial concept of a dual tether retraction system. Since the harpoon, called the SARP would have been attached to two tethers positioned on opposite sides of the Launcher tube, a piston with a single center rod sufficed to push the SARP towards the comet.

This video was produced by Stefan Völk of the DLR and Peter Lell of the PyroGlobe GmbH.

13. Computer Graphic Simulation of Firing SARP attached to TRAC Boom



This video demonstrates the simulated results of firing and retrieving the SARP when it is attached to the CORSAIR SC via a Triangular Rollable and Collapsible (TRAC) boom.

This switch from the Dual Carpenter's-tape Tethers (DCT) to the TRAC boom was the result of the CORSAIR team modeling the SC trajectory and velocities relative to the comet surface at the time of firing the SARP. This modeling showed that the DCT lacked sufficient stiffness to ensure that SARP would not swing around and hit the CORSAIR SC during the retraction phase. To address this issue, a new SAS concept was developed to accommodate a single, but much stiffer tether consisting of a TRAC boom.

To verify that the TRAC boom would have sufficient stiffness, APL developed used the Automated Dynamic Analysis of Mechanical Systems (ADAMS) software to simulate the behavior of the TRAC boom SAS during firing and retrieval of the SARP. This movie was made from the ADAMS simulation and shows how the TRAC boom first keeps playing out and bending after the SARP hits the comet and comes to a sudden stop. Then this bend and any relative horizontal motion of the SC with respect to the comet surface causes the SARP to start moving sideways with respect to the SC immediately after being extracted from the comet surface. While the SARP begins swinging around towards the SC, the stiffness of the TRAC boom is sufficient to arrest this sideways motion and to keep the SARP well away from the SC during the entire retrieval phase.

This video was produced by the APL team of James Leary, Stuart Hill and Kee Lake.

14. Test Firing of Triple Piston Rod (“Birdcage”) DLR Launcher

This video demonstrates a test of Launcher version 2.0, which used the three-rod (“birdcage”) piston.

The background of the Birdcage Launcher is that DLR needed to redesign the pyro-powered DLR launcher to accommodate the TRAC boom instead of the DCT. This version of the Launcher is compatible with the latest Boom Retraction and Deployment (BRAD) system where the TRAC boom will be deployed centrically aligned with the Launcher axis. In order to conform with this modification, this Launcher version uses three piston rods —referred to as “birdcage”—which provide enough clearance for the TRAC boom feed-in in the radial and axial directions. A steel body implements a dummy mass sufficient to account for the higher rotational inertia of the boom reel. The dummy mass is plugged in a ring-link interface at the end of the birdcage.

This video was produced by Stefan Völk of DLR.

15. Low-Speed Deployment and Retraction of SARP from Transfer Stand

This video demonstrates a test device called the “Transfer Stand” being used to deploy at low velocity a SARP attached to the TRAC boom. After the short deployment, the Transfer Stand retracts the SARP back to its initial and stable position. Then the SARP “flip hinge” is manually triggered to rotate the sample cartridge enough that its clean backside is made accessible for cartridge removal, which is accomplished manually in this video.

The video was made at GSFC by Walter Smith and Donald Wegel.

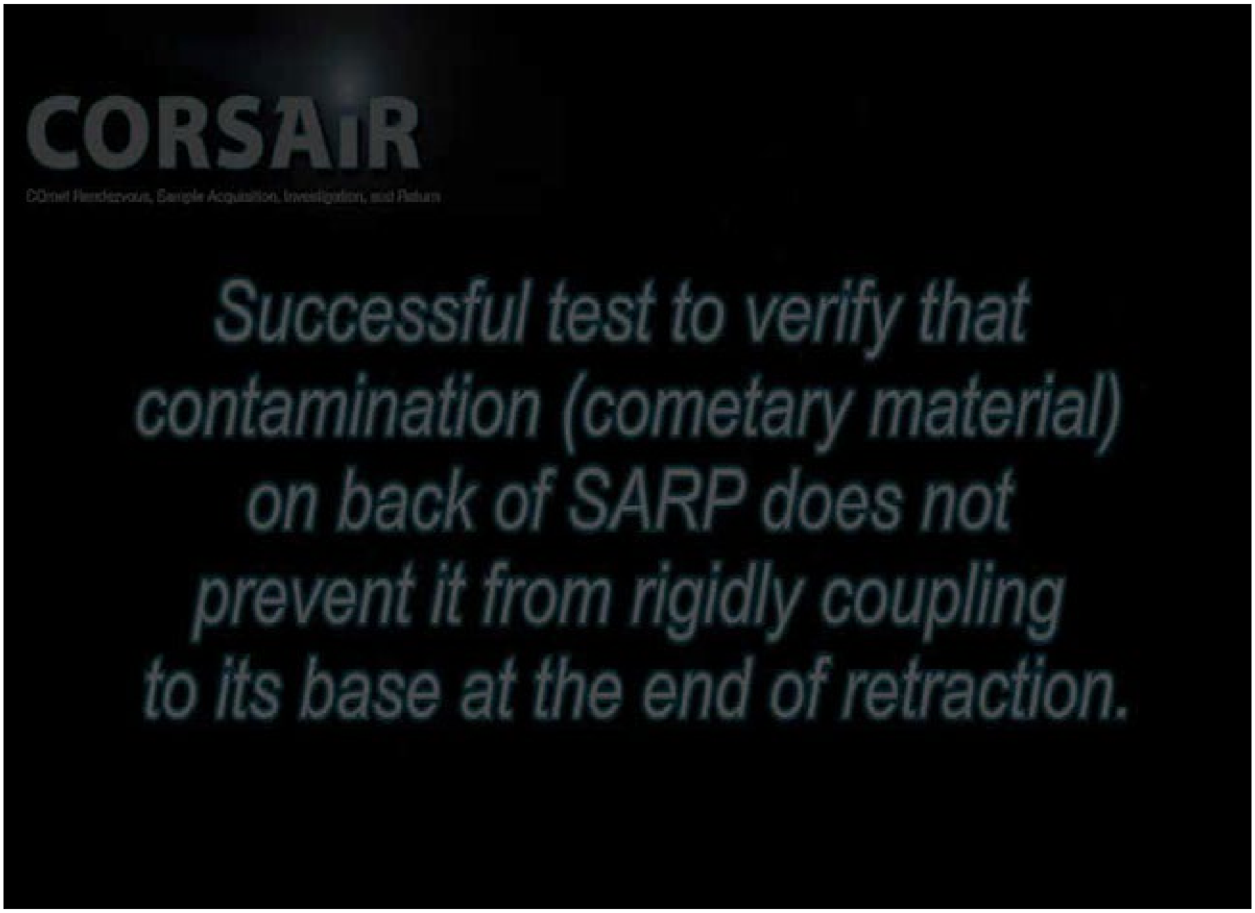
16. DLR Robot Extracting, Moving, and Inserting Sample Cartridge

This video demonstrates a DLR end-to-end test of a test version of the robotic Sample Transfer System (STS).

The robot target position is intentionally offset by about 10 mm from where the robot expects it to be in order to demonstrate the robot’s capability to deal with uncertainties of the target positions using torque control. Torque control enables the robot to sense the position of the mating surfaces like humans do. Hence, the robot is robust against errors in the target positions. Also, due to normally expected positioning errors, a rigid robot without torque control capabilities would impose very high reaction forces on rigidly mounted components in particular and thus could damage the Sample Acquisition System or the Sample Handling Station. The end-to-end test fully integrates hardware of GFSC, APL and DLR.

The video was made by Markus Grebenstein of DLR.

17. Retraction of SARP Covered with Cometary Material

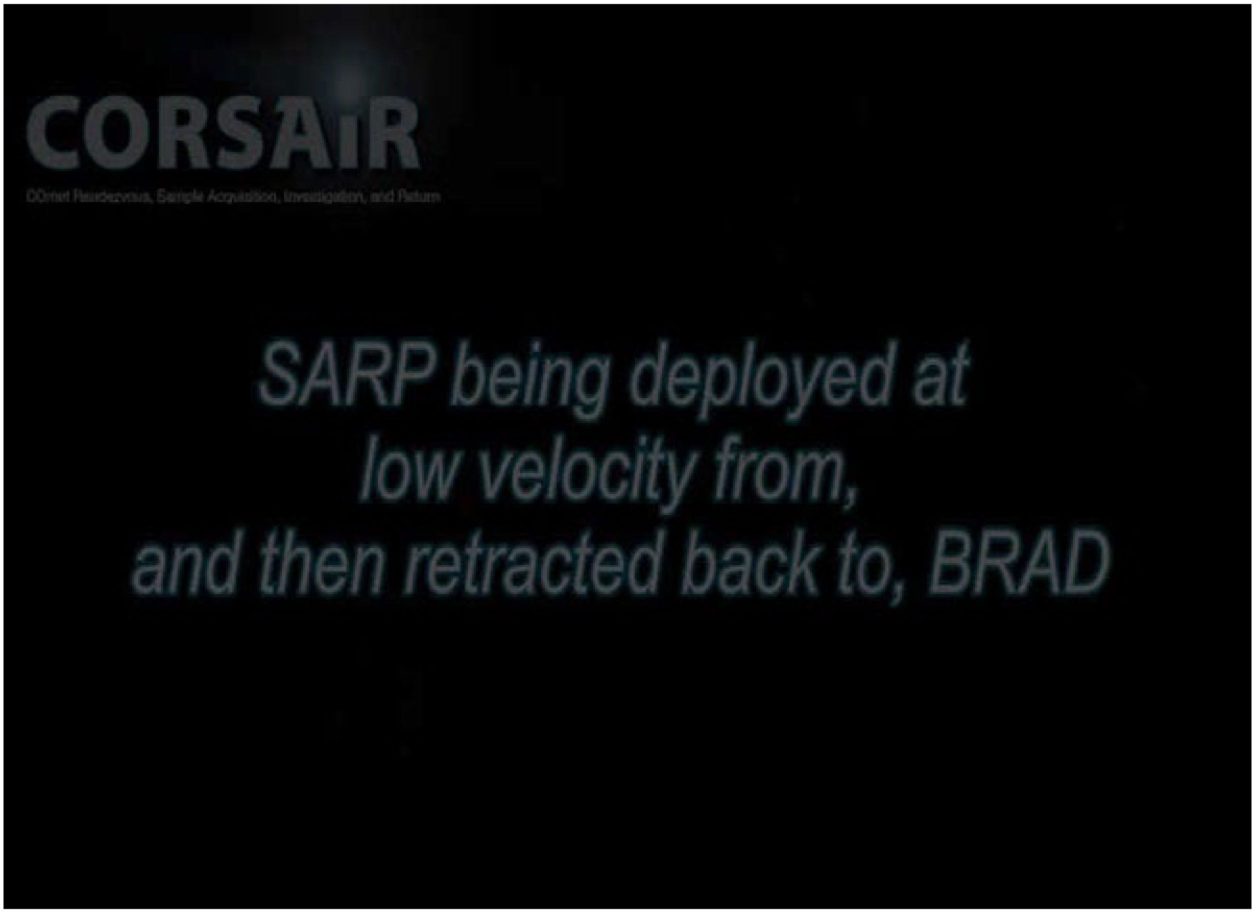


This video demonstrates the results of a successful test to verify that the SARP, even with a large amount of cometary material adhering to its back side, could still achieve a sufficiently rigid coupling with the interface plate at the end of the birdcage piston, which serves as the mechanical ground for the SARP at the end of its retrieval.

Note that the axial stiffness of the TRAC boom forces the “clocking” angle of the SARP to be within a narrowly defined range at the end of its retrieval, which means that it will be close enough to where the DLR robot expects it to be. The compressive force exerted by the retrieval motor, and the cogged mating surfaces of the birdcage piston and SARP, mean that the SARP, even if separated by a significant amount of cometary material contamination on the rear of the SARP, will become rigidly enough connected to the piston interface plate to allow the DLR robot to extract the sample cartridge.

This video was produced by Walter Smith of GSFC.

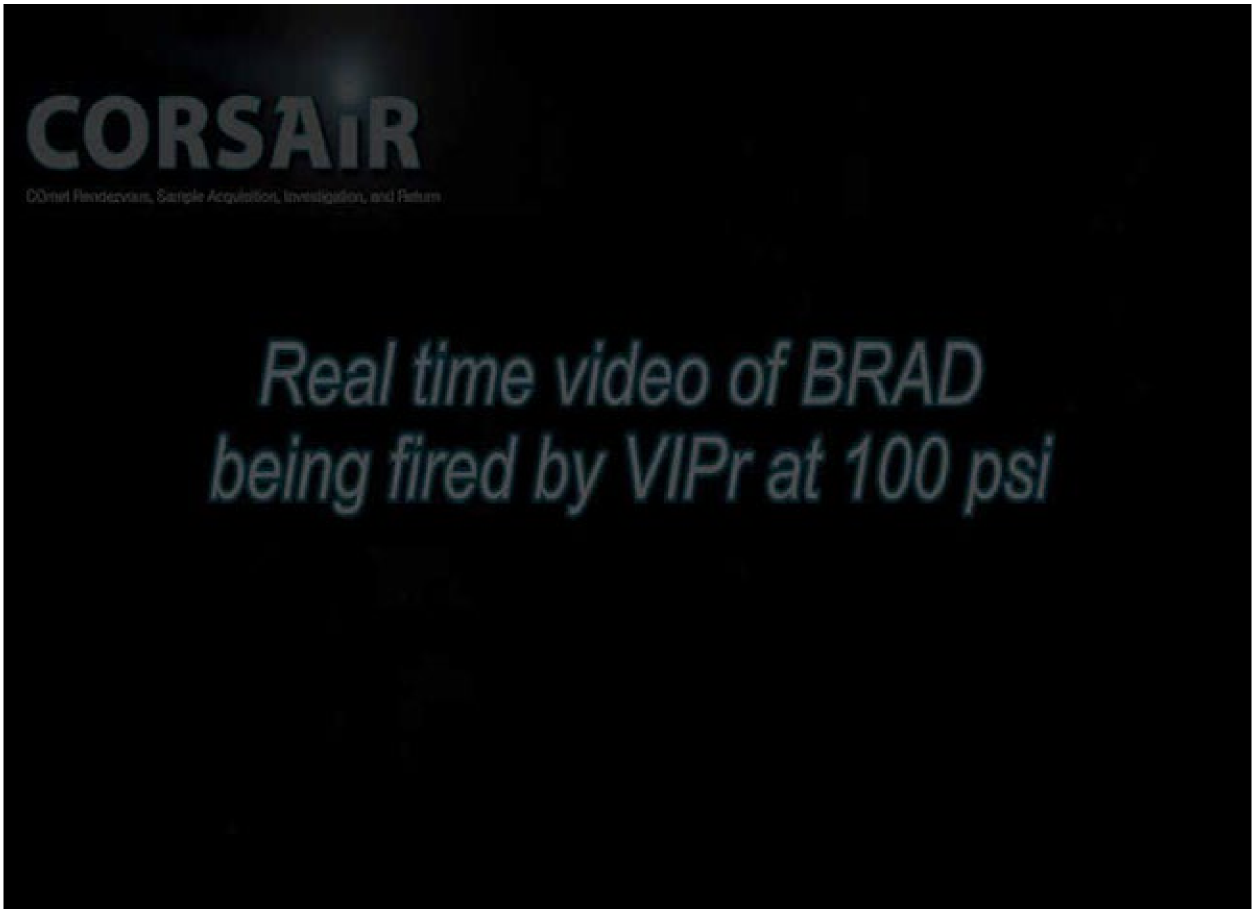
18. SARP on TRAC Boom Being Dropped From and Retrieved Back to BRAD



This video demonstrates a test in the TTF of the SARP (attached to a TRAC boom) being dropped and then retrieved using the Boom Retraction and Deployment (BRAD) device. In this video, the SARP is not fired using the VIPr, but drops down due both to gravity and to the compressive energy stored in the stowed TRAC boom that would cause the boom to naturally deploy if it were not held in place. The video also provides a useful view of BRAD and its operation during the SARP retraction phase.

This video was produced by Walter Smith and Donald Wegel at GSFC.

19. Upper View of SARP Being Fired from BRAD with VIPr at 100 Psi

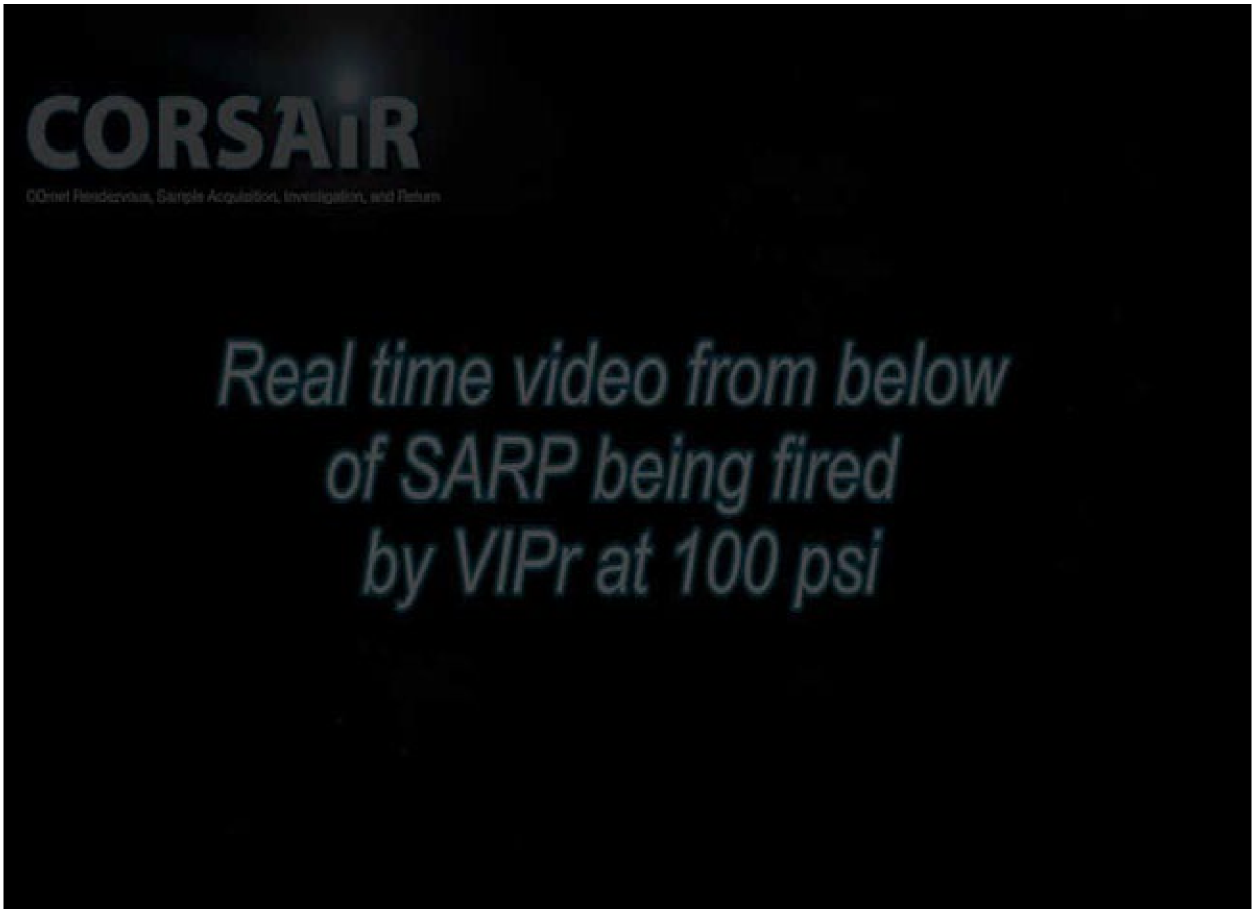


This video demonstrates the SARP, attached to a TRAC boom, being successfully fired in the TTF by the VIPr pressurized to 100 psi.

This video shows a structure representing the DLR birdcage piston attached to the VIPr, the BRAD drum for the TRAC boom (along with the rollers that keep the TRAC boom evenly rolled on the drum), and (to the left of the drum) the brake that brings the TRAC boom and SARP to a controlled halt.

This video was produced by Walter Smith and Don Wegel at GSFC.

20. Lower View of SARP Being Fired from BRAD with VIPr at 100 Psi



This video demonstrates a lower camera view of the SARP being fired by the VIPr from the BRAD.
The test is essentially the same as the one in the previous video, except that the camera position is different, being placed lower in the TTF in order to show the behavior of the SARP during deployment and retraction.
This video was produced by Walter Smith and Don Wegel at GSFC.

21. SARP on TRAC Boom Being Fired into FOAMGLAS from BRAD with VIPr at 300 Psi

This video demonstrates a SARP being fired into horizontal FOAMGLAS by the VIPr pressurized to 300 psi.

The video shows an initial test of using the VIPr to first a SARP attached to a TRAC boom at a high enough velocity to penetrate FOAMGLAS. The TRAC boom is attached to the BRAD, so this test approaches being an end-to-end test of the SAS configuration being considered for the CORSAIR flight system.

This video was produced by Walter Smith and Don Wegel at GSFC.

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