DEPLOYMENT AND CHARACTERISATION OF A TELESCOPIC BOOM FOR SOUNDING ROCKETS: REXUS-11

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1. ABSTRACT

The upper atmosphere continues to be an area of significant interest to the scientific community. A common approach used in obtaining measurements in the upper atmosphere is the deployment of probes from sounding rockets. Payload designers continually strive towards smaller and lighter deployment mechanisms to achieve a lighter and more cost effective payload. Any reduction in the volume and mass of the payload results in a higher apogee and thus longer measurement times.

Currently a range of probes are used to take high resolution and accurate measurements of the upper atmosphere. To achieve these measurements the probes must be extended to distances in the order of metres from the sounding rocket. To meet this requirement folding boom structures are often used to extend one or more probes outside the rocket. While this technique has proven to be reliable it is not without its disadvantages. The folding nature of the boom structure adds considerably to the size, volume, design complexity and cost of the payload. Even in its folded configuration the length of the boom sections take up a considerable proportion of the payload.

The design of the Telescobe experiment yields a low cost novel method of boom deployment using telescopic carbon-fibre poles. The Telescobe experiment aims to reduce the mass, volume and cost required for such probe deployment systems whilst providing structural integrity comparable to those currently in use. This experiment was flown on-board the REXUS 11 sounding rocket in November 2012 from Esrange Space Centre in Kiruna, Northern Sweden. The boom was successfully deployed during the flight and performed nominally during the measurement phase. The success of the experiment was recorded by a camera-based measurement system which was developed to quantify harmonic deflection and determine the final boom deployment length. This approach to sounding rocket boom design showed itself capable of rapidly deploying a stable structure to a known distance with minimal harmonic deflection.

2. INTRODUCTION

Telescobe is an experiment, developed by postgraduate and undergraduate engineering students from the Dublin Institute of Technology (DIT), Ireland. The aim of the Telescobe project was to design, build and fly a telescopic boom system capable of being used to deploy E-Field and Langmuir probes for use in upper atmospheric research. A telescopic boom system potentially makes more efficient use of the available space and mass onboard a sounding rocket when compared with other boom systems.

The Telescobe experiment was first launched in February 2011 on the REXUS 9 sounding rocket. During this flight, the experiment hatch failed to open fully, resulting in the boom deploying against the inside of the hatch. A detailed discussion of this failure was presented in a previous paper [3].

The Telescobe experiment, with a modified hatch system, was subsequently granted a re-flight on the REXUS 11 sounding rocket. REXUS 11 was launched in November 2012 from Esrange space centre in Northern Sweden. During this flight the boom was successfully deployed from the experiment. The performance of the boom during this flight is the main focus of this paper.

The Telescobe experiment was developed as part of the REXUS/BEXUS programme. The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Centre (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through collaboration with the European Space Agency (ESA). Funding for the project was provided by the Dublin Institute of Technology, Enterprise Ireland, ESERO Ireland and Acra Control Ltd.

3. SCIENTIFIC BACKGROUND

Measurements of the Earth's magnetic field and the atmospheric plasma electron density are typically taken using E-Field and Langmuir probes respectively. To take accurate measurements, these probes are extended out from the spacecraft so that they are clear of any wake turbulence or electromagnetic fields created by the rocket. They can be used in single probe and multiple probe configurations. When used in a multiple probe configuration the relative positions of all the probes must be known for accurate measurements to be taken.

There are a number of different systems available to deploy these probes. Probes extended from spacecraft by wires are compact and light weight. However the spacecraft must be spinning as centrifugal force is utilised for deployment. These probes are also prone to oscillation as they extend. Single rigid booms extended from spacecraft can support larger probes and are less prone to oscillation. However, this design does not lend itself to efficient use of the payload volume available. Folded booms are another option. However, they can also require a significant amount of storage space and the addition of hinges and motors also adds further mass and volume. A typical configuration using folded booms is shown in Fig. 1.

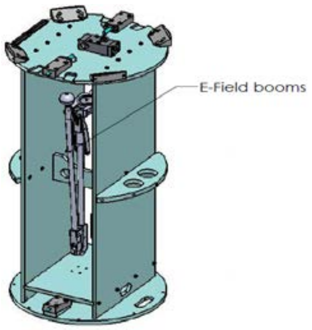

Figure 1: Typical folded boom sections for E-Field probes [2].

An effective telescopic boom system offers a more efficient use of the storage space and potentially a reduction in the overall mass. It can also take advantage of the centrifugal force generated by a spinning spacecraft to deploy, but it does not solely rely on this for deployment. By using a spring loaded configuration, the deployment time of such boom configurations is greatly reduced. This is ideal for short flight sounding rockets.

4. PROJECT AIMS

The primary objectives of the Telescobe project were:

- To design and build a telescopic boom, boom deployment and boom jettison system.
- To safely test this system on a near-space flight aboard the REXUS 11 sounding rocket [1].
- To monitor and record boom deployment length, boom vibration characteristics and boom jettison.
- To collate, analyse and disseminate experiment data via presentations and publications.
- To promote the activities of the Telescobe team, DIT and the REXUS/BEXUS program through an outreach program.

Performing electric field measurements did not fall within the scope of the experiment. Instead the probe fitted to the distal end of the boom housed an accelerometer and six LEDs. This probe was used as the datum point for measurement.

5. EXPERIMENT OVERVIEW

The Telescobe module, shown in Fig. 2, is 220 mm in height and has an internal diameter of 348 mm. An exploded view of the experiment can be seen in Fig. 3. The boom is made from tapered carbon fibre sections and, during the flight it is stored in a PEEK housing inside the module. When it is full extended, the boom is approximately 1700 mm long. A foam cap is used to prevent the boom from being damaged by excessive vibrations during lift-off. Additionally, the experiment consists two measurement cameras for measuring the deployed length of the boom and the magnitude of any boom deflections during the flight, an observation camera for providing real time video feedback of the boom when it is deployed, a hatch in the skin of the experiment module and various electronic and software systems for experiment control and data acquisition. A detailed description of the experiment design was presented in a previous paper [3].

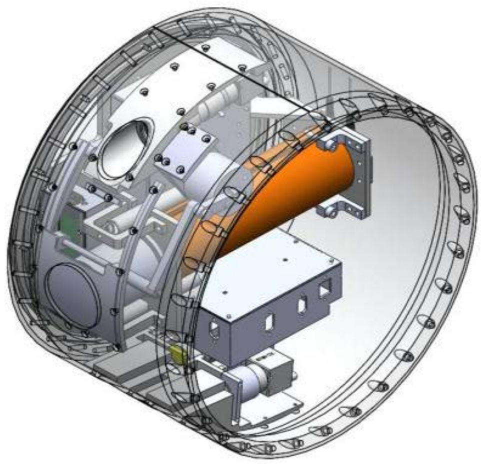

Figure 2: The complete experiment module

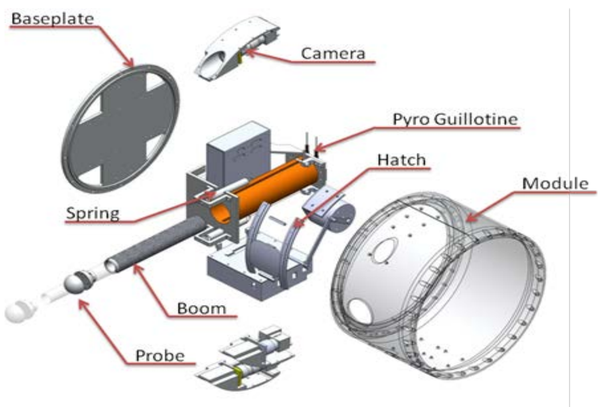

Figure 3: An exploded view of the experiment module with important components labelled.

At a designated time during the flight, the hatch in the skin of the experiment opens. Six seconds later, a pyrotechnic guillotine fires, cutting a nylon cable that retains the boom in its stored position. Two tension springs on either side of the boom housing then deploy the boom out through the hatch. The foam cap is pushed out with the boom and then falls away from it as it is in three sections.

When the boom is deployed, cameras are used to measure its length and an accelerometer is used to quantify any vibrations. After the payload has gone past the flight apogee, a second pyrotechnic guillotine fires, cutting a nylon cable that secures the base of the boom to the experiment. The remaining tension in the two springs then jettisons the boom from the experiment. The boom falls to ground and the hatch closes, preventing hot air from entering the module during re-entry. The timeline for the experiment during the flight is shown in Table 1.

#	Event	Time (s)	Altitude (km) Approx.
1	Lift-off	0	0.3
2	Motor Separation	77	~ 64
3	Hatch Opens	80	~ 67.0
4	Boom Deploys	86	~ 69.0
5	Apogee	139	82.31
6	Boom Jettisons	225	~ 61.0
7	Hatch Closes	232	~ 58.0
8	Power Switched Off	600	~ 35.0

Table 1: Experiment timeline

5.1. The Modified Hatch

The original hatch for the Telescobe experiment was actuated by a solenoid. This failed to open fully during the flight of the experiment on REXUS 9, causing the boom to deploy against the inside of the hatch door. As such, the hatch was modified for the re-flight of the experiment on REXUS 11. An exploded view of this modified hatch assembly is shown in Fig. 4. The hatch design consists of a 12 Watt brushless motor and a planetary gearbox (reduction ratio of 690:1) housed inside an aluminium sleeve. The combination of the planetary gearbox and brushless motor is capable of generating approximately 250 times more torque for hatch actuation than the original solenoid. The planetary gearbox is not back-drivable and its shaft is connected to the hatch through a set of armatures, consisting of a short "S" shape armature and long armature. The short armature is above a pair of inductive sensors, which provide feedback to indicate whether the hatch is opened or closed. An additional printed circuit board (PCB) is also included in the experiment module for controlling the hatch.

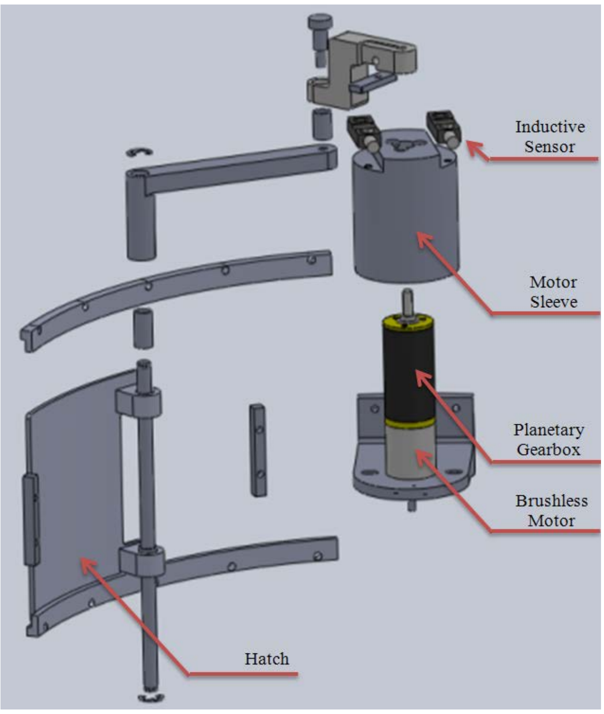

Figure 4: Exploded view of the experiment hatch assembly

6. THE FLIGHT

The Telescobe experiment was launched on the REXUS 11 sounding rocket from Esrange Space Centre in Northern Sweden in November 2012. An image of the experiment ready for final payload integration is shown in Fig. 5.

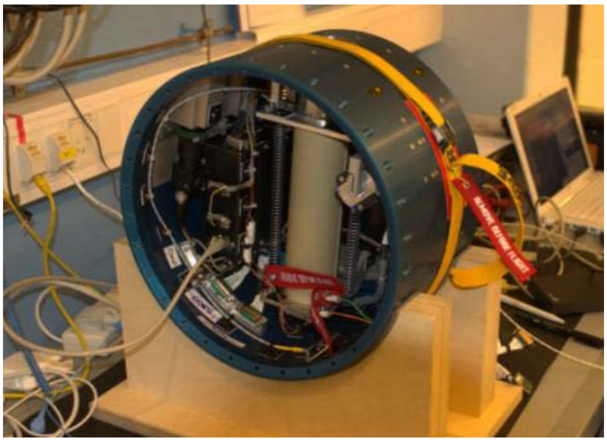

Figure 5: The Telescobe module ready for final payload integration

An issue with the experiments PC/104 flight computer during the flight meant that the telemetry stream to the ground station and the data from the accelerometer in the distal end of the boom were lost. Otherwise, the flight was nominal.

7. RESULTS

The boom was deployed successfully from the experiment module, as shown in Fig. 7 and Fig. 8. The video file recorded from the measurement cameras during the flight was recovered from the experiment and analysed to determine the deployed length of the boom and the magnitude of any boom deflections. A sample frame extracted from this video file is shown in Fig. 6. From analysis of this video file the boom was found to have deployed in less than 1 second to a length of 1708.3 mm during the flight and remained within the confines of the measurement resolution (±6mm) for as long as it was possible to verify (i.e. until 100s after boom deployment). This indicates that all of the boom sections locked out correctly and that the boom was rigid.

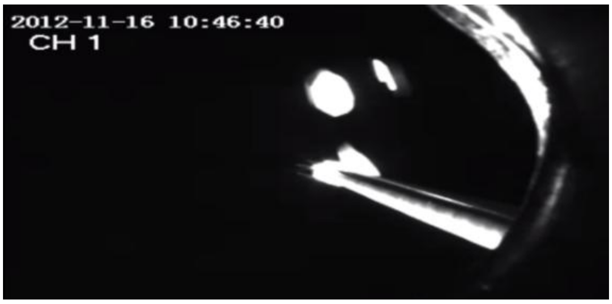

Figure 6: The boom deploying at T+86s. The image shows that the three section of the probe protector were successfully thrown clear of the boom deployment.

Figure 7: The telescopic boom deployed from the experiment module 12 seconds after boom deployment.

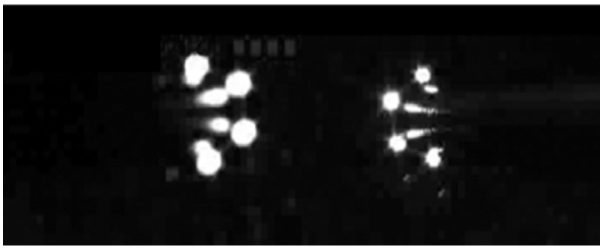

Figure 8: A frame extracted from the measurement camera video file.

Boom deflection data was also extracted from the measurement camera recordings. Fig. 9 shows the deflection of the distal end of the boom in an axis parallel to a plane between the X-axis and Y-axis of the payload (i.e. left-right). Fig. 10 shows the deflection of the boom in an axis parallel to the Z-axis of the payload (i.e. up-down). From both graphs it can be seen that the maximum deflection of the probe at the distal end of the boom did not exceed 5mm in any direction during the first 90s after boom deployment. In fact, for most of this period boom deflection did not exceed 2mm. There are small gaps in both graphs between 20.0s and 22.4s and between 26.1s and 27.5s. These were periods when the measurement cameras were pointing towards the sun and no clear picture was available. It was not possible to obtain deflection data for these periods.

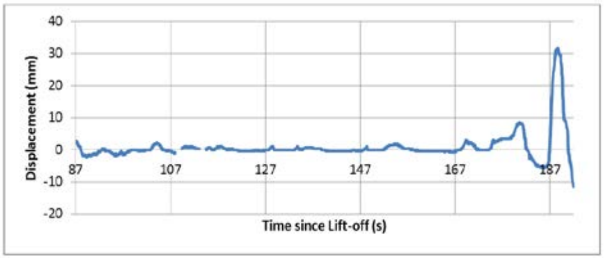

Figure 9: Displacement of the distal end of the boom in an axis parallel to a plane between the payload X-axis and Y-axis during the first 105 seconds after boom deployment.

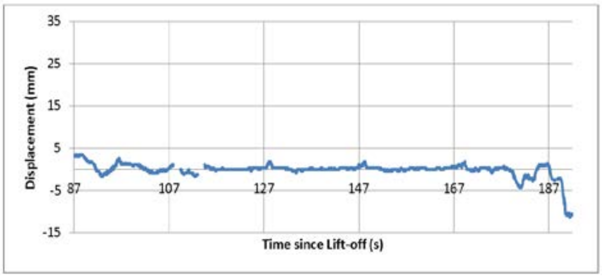

Figure 10: Displacement of the distal end of the boom in an axis parallel to the payload Z-axis during the first 105 seconds after boom deployment.

From ~T+175s onwards it can be observed from both graphs that the magnitude of boom deflection began increasing significantly. This deflection was such that the probe began to move outside the field of view of the measurement cameras after T+192s, hence making it impossible to measure boom deflection after that point. However, it is known that boom deflection eventually increased to such an amount that the boom finally fractured three seconds before it was due to be jettisoned at T+225s. Fig. 11 and Fig. 12 depict images taken from the observation camera feed during this time.

Figure 11: The boom deflecting at T+221s

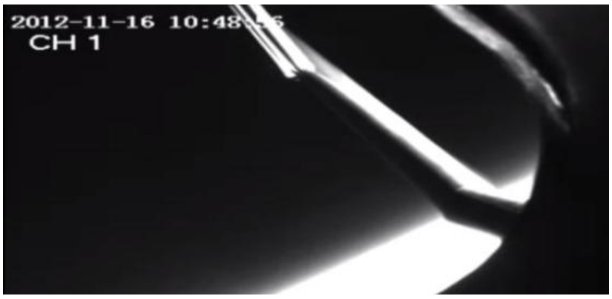

Figure 12: The boom breaking at T+222s

8. CONCLUSION

Overall the experiment can be deemed a success. The problem encountered during the launch of the original Telescobe experiment on REXUS 9 (namely the non-functional hatch) was overcome and the boom was successfully deployed from the experiment module. While some problems with the flight computer were experienced during the flight, measurement camera data was recovered successfully for post flight analysis. The carbon fibre, telescopic boom performed well during the flight. It deployed and settled quickly at T+86s and remained stable until T+177s, a period of time that took it through the apogee of the flight. The boom broke then due to the aerodynamic froces acting on it three seconds before it was due to be jettisoned at T+225s. However, had the boom been jettisoned earlier, closer to the apogee of the flight, this eventual breaking of the boom would have been avoided. Overall, this boom system has shown itself to be particularly suited for use on sounding rockets where the fast deployment time lends itself to the short payload flight time.

9. REFERENCES

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