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DESIGN AND TESTING OF A DEPLOYABLE, RETRIEVABLE BOOM FOR SPACE APPLICATIONS

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ABSTRACT

The Deployable Retrievable Boom (DRB) was developed by Piaggio under contract to the Italian Space Agency (PSN/CNR) as part of the joint U.S.-Italian program Tethered Satellite System (TSS).

The design mission of the boom, two of which will be carried by the TSS satellite during its first mission (scheduled for launch in January 1991), is to support, deploy, and retrieve an experiment package for the study of the electromagnetic field surrounding the satellite. The mechanism includes a jettisoning provision and deployable harness for the supported payloads connection.

The design was conceived for missions requiring launch and re-entry with the NASA Space Transportation System (STS).

This boom is based on a tubular telescopic concept as are other existing European boom designs. Particular emphasis has been given to payload harness connection capability and safety provision in order to meet STS requirements.

In this paper, the design and development of the boom will be presented and discussed, with particular emphasis on trade-offs and on techniques developed to overcome specific design or manufacturing problems. Major results of qualification testing will be presented and compared to the original requirements of the TSS mission. Finally, development potential of the design concept and its limitations will be discussed.

INTRODUCTION

PSN has requested R. Piaggio to design two booms for the TSS1 mission scheduled in January 1991. Piaggio is undertaking design, manufacturing, and qualification of a DRB for the TSS1 mission which will support the RETE experiment.

The project was begun in January 1987. Initial development tests were performed in ESTEC IN April 1987. Qualification is now almost completed and delivery is planned for March 1989.

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The reason for developing a new boom design for an important application came from a number of peculiar requirements that became the design goals of the contract:

- Be capable of deployment and restowage in agreement with STS safety rules
- Provide an inherent jettison capability to be used to improve mission success
- Provide support and deployment of high voltage harness for payload probes
- Be capable of partial deployments necessary for payload measurements
- Reduce as much as possible the number of electromagnetic drive motors necessary for deployment, retrieval, and off-load
- Use a simple and reliable mechanical design.

The following sections will show how the above criteria have been met, creating a new and unique multi-purpose mechanism. Qualification test results will be presented with emphasis on safety and performances, in particular, in comparison with predicted analytical results.

DESCRIPTION OF R. PIAGGIO CONCEPT

The DRB qualification unit is shown in Figure 1. The figure shows an assembly drawing of the complete unit with a section showing the tubular elements in stowed position and the drive motor. It also shows the folded payload harness, the pyro cutters, and the Marman clamps.

The design performs five basic mechanical functions that will be discussed separately in order to simplify the description. These are:

- A tabular telescopic boom with its deployment mechanism
- Latch mechanism to support launch and re-entry loads
- Deployment and support for high voltage harness
- Jettisoning mechanism capable of disconnecting payload harness
- Jettison prevention latch to avoid jettison of a stowed boom.

BOOM AND DEPLOYMENT MECHANISM

The boom structure consists of seven tubular elements nested inside each other, with a length of 400 mm and diameters ranging from 50 to 120 mm. When deployed, each tube overlaps the nearest one by a length of 1 diameter to provide sufficient stiffness at the joints. The length and number of tubes have been adjusted to the mission requirements, in particular for the reduced stowage envelope available due to the position on the upper satellite floor. The material used for the tubes is a 2024 aluminum alloy mechanically milled down to a thickness of 0.4 mm. The tolerance in thickness can be 0.02 mm with a maximum roundness error of 0.05 mm. Quality and tight tolerances are fundamental requirements for the achievements of required performances. The tubes slide one against the other over vespel pads. Consequently, tight tolerances mean low friction and high stiffness.

Flanges at both ends of each tube support the pulleys and distribute the concentrated loads for deployment and retrieval operations. These flanges also support the sliding pads. The stiffness and strength of the boom depend primarily on tube overlap and, consequently, on the deployed length so that a minimum frequency of 40 Hz can be met in stowed condition without the need for an off-load device. When fully deployed, the frequency will be around 2 Hz.

The deployment mechanism concept is shown in Figure 2.

The system provides a parallel and simultaneous deployment of all tubes.

The first tube (n.1) is pushed directly by a worm-screw nut mechanism connected to the drive motor that provides the power during the whole deployment phase.

The second tube (n.2) is connected by two steel wires to the fixed tube (n.0) passing through two pulleys mounted at each end of the tube (n.1).

The motion of the first tube relative to the fixed one (n.0) determines the motion of the second tube (n.2).

All the other tubes are connected sequentially in a similar manner as shown below:

- Tube n.2 connected to tube n.0 pulley on tube n.1
- Tube n.3 connected to tube n.1 pulley on tube n.2
- Tube n.4 connected to tube n.2 pulley on tube n.3
- Tube n.5 connected to tube n.3 pulley on tube n.4
- Tube n.6 connected to tube n.4 pulley on tube n.5
- Tube n.7 connected to tube n.5 pulley on tube n.6.

The first tube is driven by the spindle where the stepper motor is mounted. The stepper motor gives a 0.36 Nm torque transformed to deployment thrust by the spindle-nut. Low detente torque and high efficiency of nut-spindle due to use of a recirculating satellite nut made necessary the conception of a retention device for resisting launch accelerations.

LATCH MECHANISM

To prevent deployment during accelerations and vibration, an additional latch mechanism was required. This mechanism was not present on initial design but was added when a recirculating nut was selected in place of a conventional nut. To reduce the complexity of adding a new independent mechanism, we have elected that latching be performed by the same actuator utilized for the deployment. This has been possible utilizing the sequential position characteristics of our mechanism. In this way the first revolution of the spindle is utilized to release the two hooks that latch the last tube.

During restowage when the last tube reaches its completely stowed condition, the hooks latch by action of a spring, preventing deployment in re-entry. The motion of each hook is connected to two microswitches that monitor and control completion of restowage (Fig. 3). In this way there is a completely redundant monitor of this safety device. If the boom does not retrieve enough or the hooks fail to engage properly, the booms will be jettisoned, saving the satellite and the remaining scientific missions.

To add additional safety to the mechanism, a retention device was added to the latch system so that in case of successful restowage the boom cannot be jettisoned. This retention consists of two hooks that become engaged at the same time as the latches, preventing the jettison of the booms when they are completely stowed. This reduces greatly the risk of unwanted jettison near the orbiter or in the cargo bay. All those mechanical interconnections should increase the reliability and safety of the mechanism.

JETTISONING MECHANISM

According to safety requirements of the STS, a jettisoning mechanism has been studied for the ejection of the boom in case of failure to retrieve.

The fixed part of the boom structure (tube n.0) is connected to the external shroud through a Marman clamp mounted at the outer end. In addition, rollers support the other end of the tube (n.0) and are connected with three tension springs to the external shroud.

As shown in Figure 4, release of the Marman clamp by pyro-cutters allows deployment of the mechanism and disconnection of the harness by two separable connectors. The rollers guide the initial phase of the ejection, providing a well-defined trajectory and preventing possible contacts with other spacecraft subsystems.

This mechanism is designed with simple and already tested components and with enough elastic potential energy to ensure a safe ejection. All the single point failure elements have been doubled to provide complete redundancy. Jamming or cold-bonding risk is minimized using special coating and dry lubrication materials. Pyro and their control units comply with NASA Safety Requirements.

HARNESS DEPLOYMENT AND SUPPORT MECHANISM

The harness of the payload is stored in two symmetric fanfold configurations as shown in Figure 5. The conductors are divided into two cables containing coaxial and twisted conductors. The two cables are held by brackets pivoting on the tube tip flanges. In the stowed configuration, the harness is packed by holding the supports perpendicular to the boom axis. The mechanism concept is simple and does not require high torque drawn by the drive motor.

QUALIFICATION TEST RESULTS

In January 1987, we started the so-called first phase of the contract, and successfully tested one prototype of the DRB in the ESTEC vacuum chamber HBF3 in April 1987.

The design of the proto unit was simplified (only five tubes and 1.5 m deployment length) but it was representative of some critical design features:

- Tube dimensions and thicknesses
- Pads materials
- Thermal finishing
- Deployment mechanism design and materials.

A photograph of the proto-DRB is shown in Figure 6.

The test, organized and set-up with the cooperation of ESTEC personnel, was performed with the following scope:

- Performing a thermal balance test with temperature measurement along the boom
- Showing the capability of deployment and retraction in the worst thermal condition obtained during the orbital simulation of the thermal balance test.

In October 1988 we started qualification tests using the experience gained in proto testing. A photo of the qualification model is shown in Figure 7. The test sequence was of course a complete set of environmental tests followed by a performance and life test in the solar simulation chamber HBF3. The qualification thermal vacuum test was very similar to the jettison mechanism. The improvement over the prototype manufacturing tolerances is so good that obtained performances are well beyond the prototype ones.

After this we performed a jettison test to show performance of the jettison mechanism. The improvement over the prototype manufacturing tolerances is so important that obtained performances are well beyond the prototype ones. In particular, we have shown a very good correlation between finite elements with calculated fundamental frequencies, and the one measured during vibration test. This meant that at each joint, backlash and free play are eliminated to the extremely good manufacturing results.

During thermal vacuum testing we have shown the capability to deploy, restow, and latch in all thermal conditions, including the qualification temperature margins. Temperatures observed on the boom vary from a maximum of 60°C at the satellite interface in the orbital hot case to a -85°C at the payload interface in the deployed cold case.

We have, nonetheless, experienced some problems in performing the requested number of 50 orbital-complete deployment and retractions. This is due to the lubrication system selected for the spindle, where the molybdenum disulfide was very easily worn out by the nut. We will repeat this test after spindle refurbishment for a verification of the allowable number of deployments.

PERFORMANCES AND RESULTS FOR FUTURE UTILIZATION

The DRB design is based on the use of tubular elements built using commercial aluminum alloy tubing. We have defined a manufacturing procedure that can produce tubes with minimum thickness as low as 0.3 mm, keeping the external and internal surface tolerances below 0.05 mm. We are also investigating the possible use of a high performance material like CFRP, but we feel that the achievable tolerances will not be significant over aluminum with minimum thickness.

We have evaluated the possible performance of aluminum DRB in a range that we consider optimum for its characteristics:

- Length - 5 to 25 m
- Stiffness - 1000 to 100000 $(N*m)^2$.

Those studies are contained in Reference 4.

Some of the possible applications reviewed there are summarized here:

- Support antennas of up to 40 kg to a distance of 10 m from spacecraft
- Support an experiment of 10 to 20 kg at 15 m from spacecraft.

CONCLUSIONS

The R. Piaggio DRB shows good performance, with reasonable design complexity and cost. The Italian space authority, PSN, has given R. Piaggio the opportunity of applying this concept and showing its capability in a complex configuration and complete design.

Although the requested sizes were not the optimum for the best performance of a tubular telescopic boom, the results of the tests performed up to now are very promising. R. Piaggio is looking forward to the opportunity of showing the capability of the DRB in an application where the required dimensions are more consistent with boom optimal performance, as shown in the above examples.

REFERENCES

1. Becchi, P.: Tubular Telescopic Mast. Estec Working Paper No. 1288.
2. EASTP for LHSA, "Mechanism Phase 2 Report," Esa Contract 3787/78/NL/HP.
3. FASTP for LHSA, "Tube Study Phase 2 Report," Esa Contract 3787/78/NL/HP.
4. Becchi, P., and Miranda, D.: Deployable/Retrievable Boom; One Application to Tethered Satellite. Proceedings of 3rd European Space Mechanism Technology Symposium.

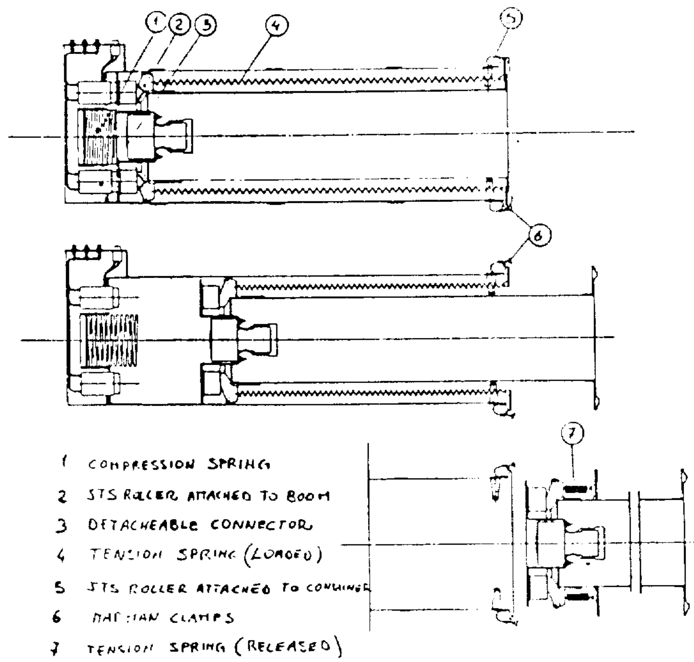

Figure 4. Jettison release system.

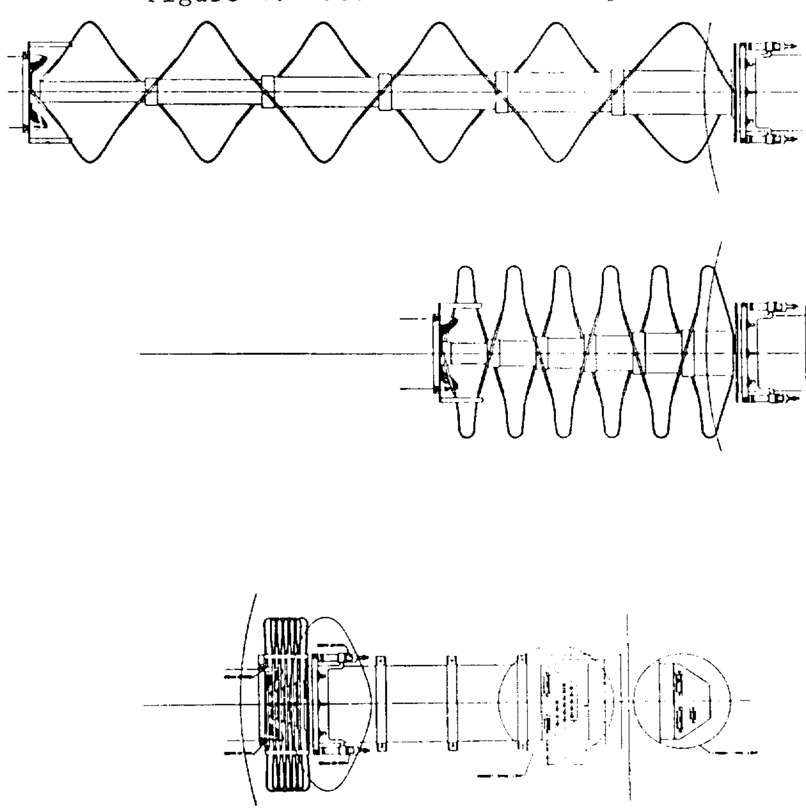

Figure 5. Payload harness system.

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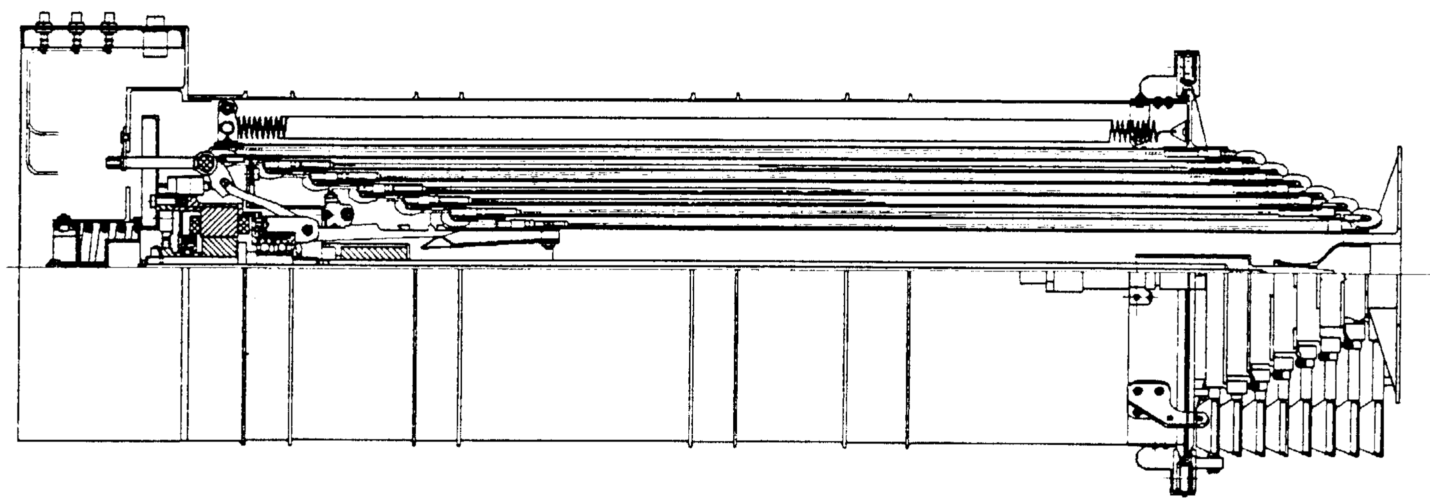


Figure 1. Assembly drawing of DRB.

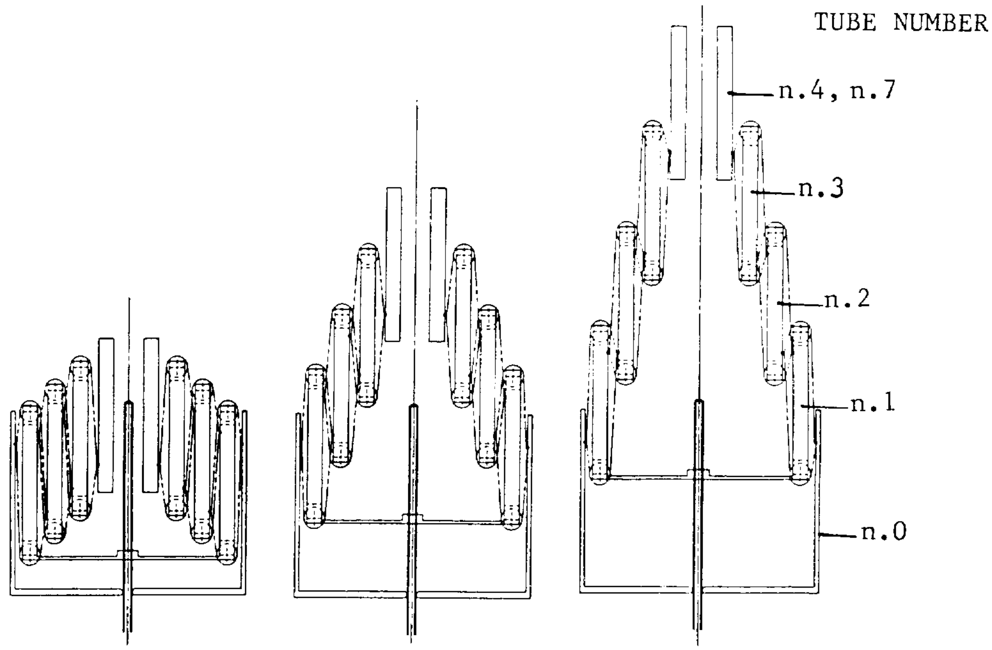


Figure 2. Deployment mechanism concept.

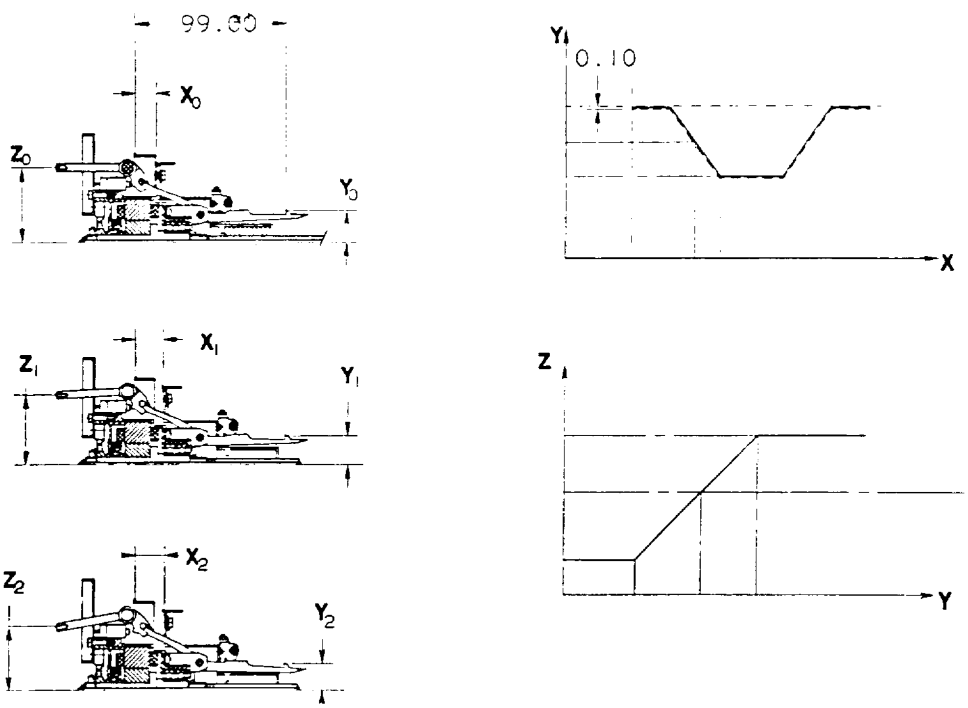
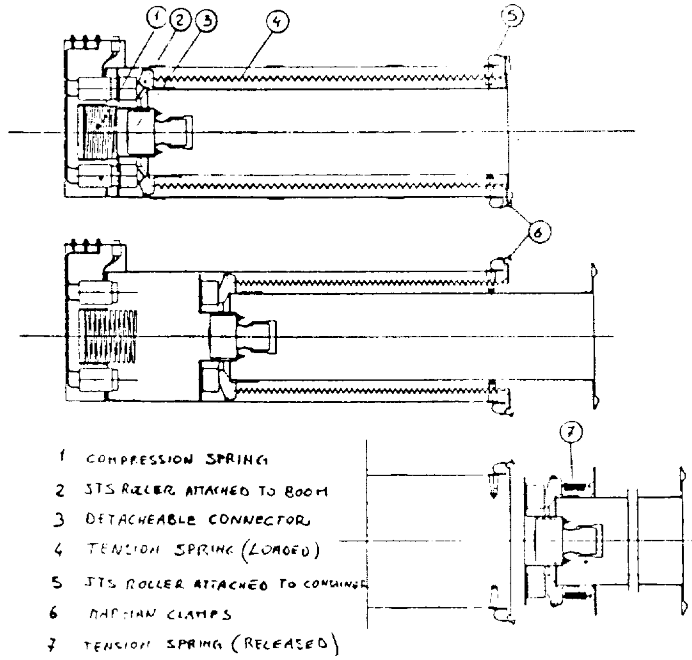


Figure 3. Latch mechanism concept.



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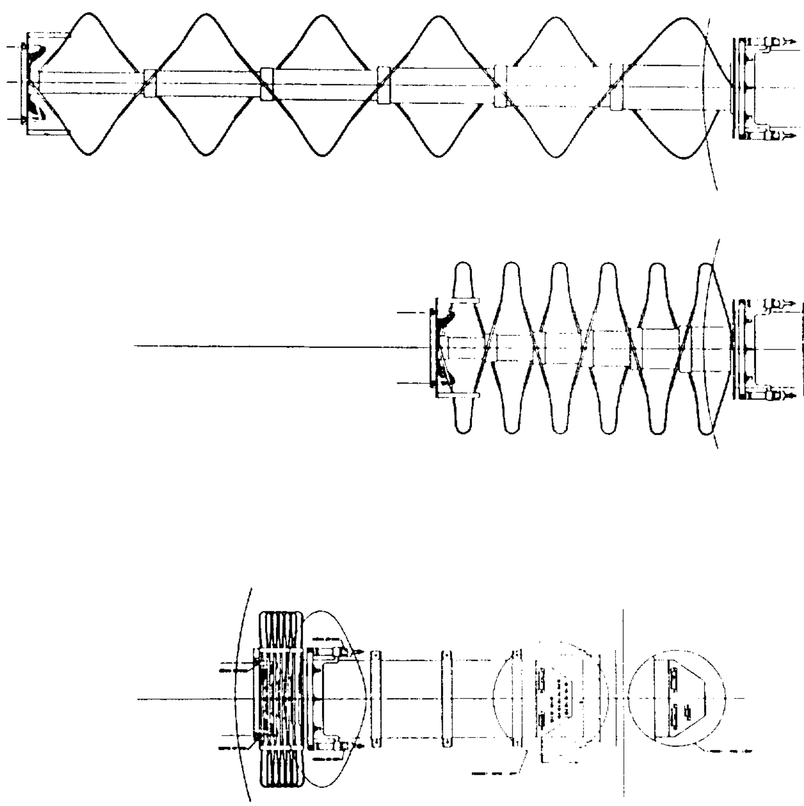

Figure 5. Payload harness system.

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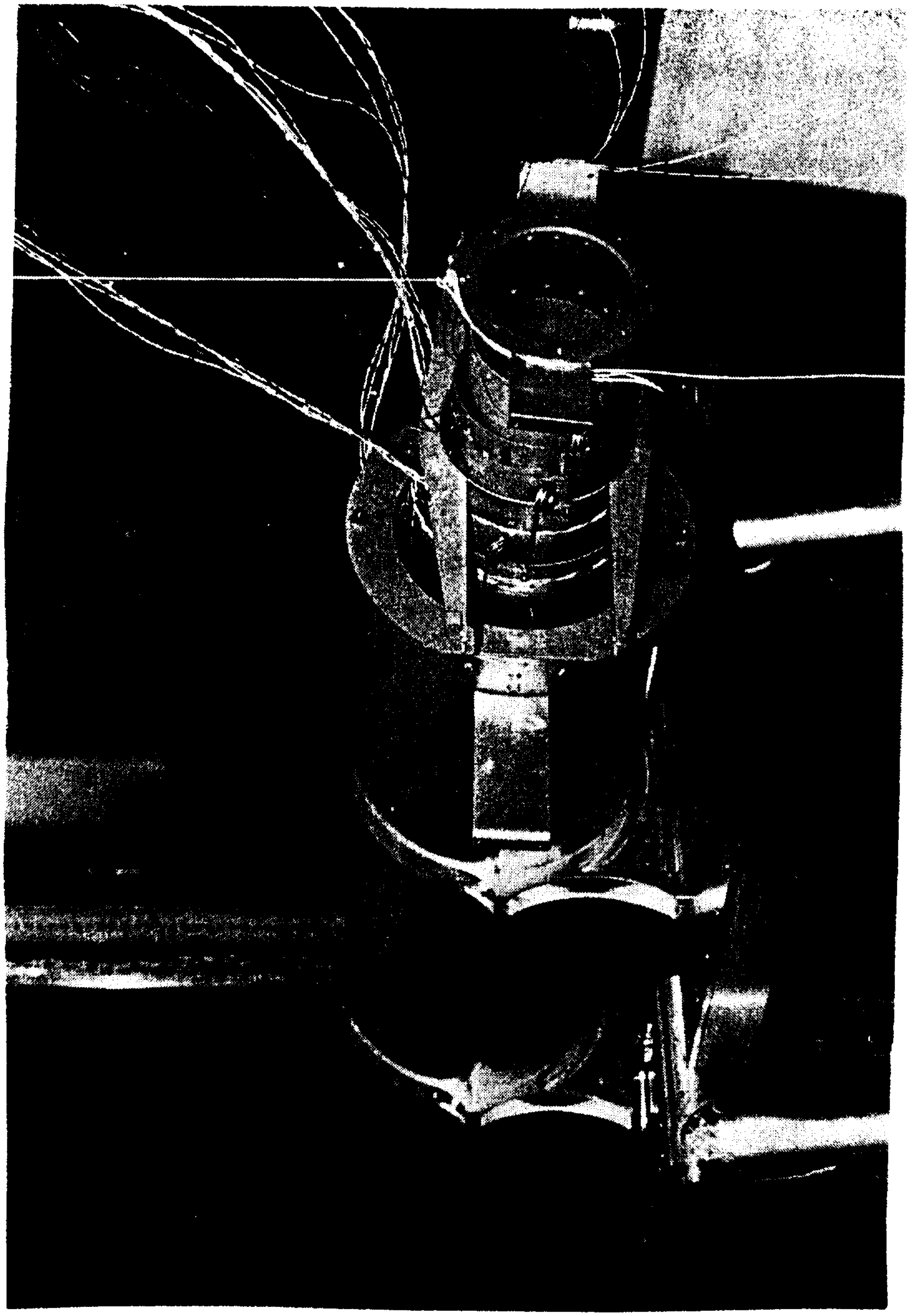

Figure 6. Prototype during testing.

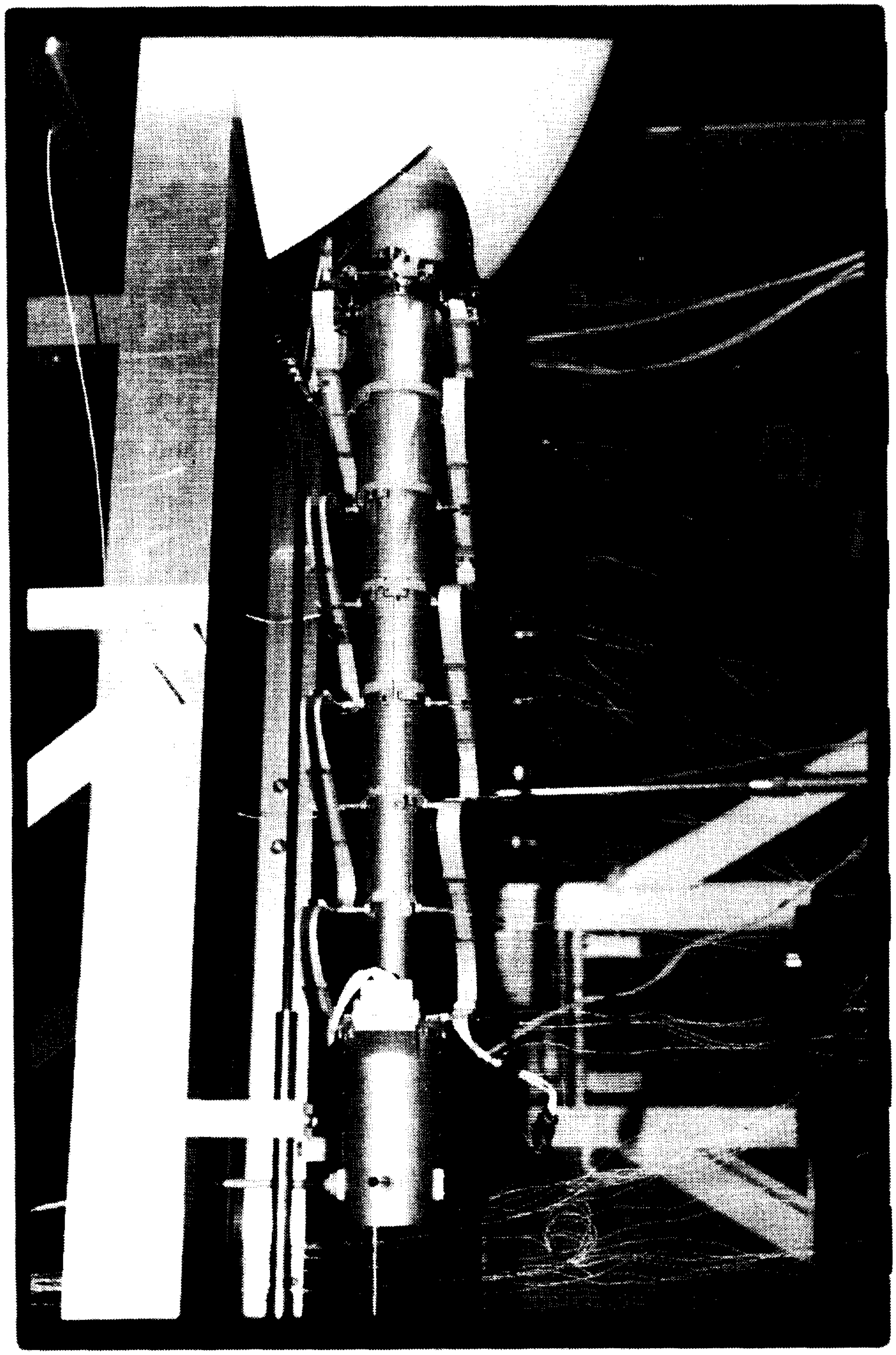

Figure 7. DRB qualification model.

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