the result is increasingly favorable with an increasing size of auxiliary propulsion unit. At the same time the greater inertia and the rearward displacement of the center of gravity due to the weight of the propulsion unit located at the nose-cone rear do not make the working of the Cassiopee system any easier. This sets the necessary restriction of using a propulsion unit of 100 kg propellant capacity, which enables the loss in the useful flying time of approximately 450 sec to be kept down below 15 sec in 50% and 45 sec in 95% of cases.

Control efficiency in the propulsion phase

In the propulsion phase, the nose cone is perturbed by the misalignment of the propulsive jet. For the projected propulsion unit (thrust 16,500 N), the standard deviation on this unwanted moment is three times as high as the Cassiopee control moment. All the same, the average direction of the nose cone hardly deviates from the assigned direction and with the cone made to spin at a speed of over 0.5 rps the disturbance in lateral velocity stays below 4m/sec. Nitrogen consumption in the propulsion phase is 0.750 kg.

Accuracy of Impact

Impulse trajectory correction following combustion in the two main rocket stages obviates previous errors, but introduces new, though fortunately slight, ones. The residual scatter of impact results from a combination of them; they are summarized in Table 1, together with their standard deviations and respective effects, for the projected propulsion unit containing 100 kg propellant and having a correction capability of 480 m/sec.

The effects of 2, 4, 5, and 7 on the impact point depend on the correction to be applied, and are computed in mean square value terms for all trajectories capable of correction.

The uncertainty factor in the impulse of the auxiliary propulsion unit has a more important effect than the rough-aiming errors, 2 and those of attitude control during the propulsion-unit combustion phase 4. Accordingly, the Cassiopee system appears to measure up in accuracy (0.5°) to the new mission expected of it.

Errors 2, 4, and 5, which are bound up with the corrective capability of the propulsion unit, could be lessened by the use of a propulsion unit with a corrective capacity of 380 ms^{-1} only. The resultant deviation of the correctible trajectories could be brought down to 2.6 km, but the penalty to pay for this gain would be more trajectories unamenable to correction (5% instead of 0.1%).

The use of a linear corrective algorithm is justified by the slight error so introduced.

Conclusions

An accurate correction of the trajectories of Beridan sounding rockets after completed combustion in the two propulsive states has been made possible by the Cassiopee system installed aboard observation nose cones and by the use of CSG equipment.

The result is a reduction of impact scatter to 3.1 km (instead of 39 km as before), with the recovery area brought within 5 km of the coast (instead of a former 100 km).

To achieve this improvement, the base of the nose cone (of 400 kg initial weight) must be equipped with a corrective propulsion unit containing 100 kg propellant, and be able to impart to the cone a velocity variation of 480m/sec. This enables practically all (99.9%) of the deviating trajectories to be corrected at no great sacrifice of time available for subsequent scientific observation.

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Churchill Research Range Auroral Launcher Facility

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Background

OUT of a total of 630 scientific rockets launched at the Churchill Research Range since its inception in 1957, 350 were fired under subzero temperature conditions. The most favored time for rocket launching at Churchill is during the winter months when clear skies and long nights prevail. The existing subarctic conditions in northern Manitoba provide an excellent opportunity for the study of geophysical events such as the aurora borealis, but they also create deplorable working conditions. This situation requires continued efforts to improve the environmental control systems of the launcher facilities. When a new launcher was constructed in 1968, it incorporated design features based on considerable experience in operating in the north. This facility, which was designated the "Auroral Launcher," has proven to be the most favored of all launchers in use at Churchill because of the superiority of its temperature control system.

Design Requirements

The basic requirement was to provide reasonably comfortable conditions for the launch crew during loading operations and the maintenance of the rocket at a satisfactory temperature during prolonged periods when it would be held in an upright position in readiness for launching at the onset of a desired geophysical event. In the earlier facilities, such as the Universal Launcher, these requirements were met by enclosing the launcher in its lowered position (Fig. 1) in a building with large roof doors. When the roof doors were open and the rocket elevated, temperature control for the rocket was provided by forcing heated air through clam-shell heat shields which encased the vehicle.

This arrangement had several serious drawbacks. The large roof doors were of necessity slow acting and, as a con-

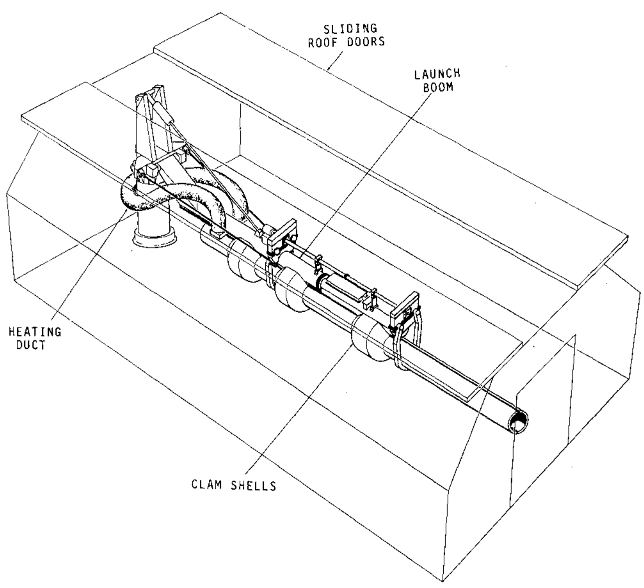

Fig. 1 Universal launcher.

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sequence, turn around times were lengthy. It took an excessively long period to close the roof doors after a launch had taken place and to bring the temperature in the building back to a reasonable working level. Further, repairs to the rather fragile heat shields were frequent and costly. Additionally, installation costs for this type of launcher were high because of the need to provide a large concrete pad to counteract the overturning moment of the cantilevered boom-type launcher. This was a particularly significant problem at Churchill where perma-frost soil conditions exist. It was therefore decided that the new launcher should incorporate design features to overcome these difficulties.

The design specification included the following: the building was to be as small as possible to facilitate rapid recovery to a suitable working temperature, heat shields around the rocket were to be eliminated, and blast relief and roof doors were to be fast acting to allow quick response when firing into required geophysical events. The largest rocket to be accommodated on the launcher was a Black Brant IV—a solid-propellant two-stage vehicle weighing 3600 lb and having an over-all length of 36 ft.

The elimination of the heat shields meant that the launcher elevating and aiming maneuvers would have to be contained within a building. This ruled out the use of a conventional boom launcher since the large building required to house it would be costly to build. Further the requirement for fast building reheating could not be achieved.

Initial Design

In searching for a solution, a launcher configuration was devised which could be enclosed by a relatively small structure. To minimize the size of both the building and the roof doors it was proposed that the launch boom be pivoted at the upper end rather than the lower end as was the case with the Universal Launcher.

The proposed design, as shown in Fig. 2, incorporated two major assemblies. The first consisted of a fixed mast at an elevation of 75° with side bracing in the form of a tripod, all mounted on rollers running on a circular track. The entire assembly would be rotated to obtain required launch azimuth bearings. This assembly would act as a hoist for the second assembly which would consist of a 30-ft boom with launching rails mounted on one side and rollers on the other. The idea was to provide several transportable booms so that rockets could be assembled in advance and mounted on the booms in readiness for launching. When required, the boom complete with rocket would be moved into position for hoisting into the launch attitude by means of a fixed mast. The top of the launching boom would be restrained at the apex of the mast and the bottom held by the elevation gear at the base of the mast. Required elevation adjustments would be achieved by moving the bottom of the launching boom to obtain any desired setting from 75° to 90°.

During the detailed design work on the new launcher several potential operational hazards were revealed. Because of the weight and size of the loaded transportable boom, it would be difficult to maneuver it into position for mating to the launcher mast. Further, to ensure safety in the mating and elevating operation, time-consuming check-tests would be necessary. Also the umbilical cables and firing lines would have to be installed when the rocket was in the elevated position. This would require the provision of removable platforms midway up the launcher structure. It was felt that these factors would largely negate the potential fast turnaround advantage resulting from the use of preloaded booms.

Final Design

To overcome these problems, the design of the launcher was modified to incorporate the desirable features of both the transportable boom launcher and the conventional hinged-boom launchers. The modified design retained the mast

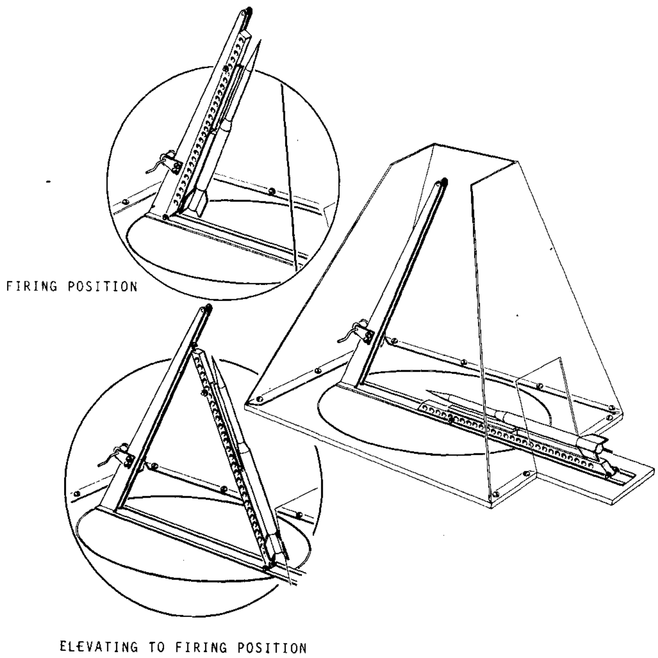

Fig. 2 Design concept for a transportable boom launcher.

structure mounted on a circular track. The boom, however, would be an integral part of the launcher. Elevation adjustments would be achieved in the same manner as in the original design. Loading would be accomplished by employing a split-boom arrangement of two major subassemblies; i.e., an elevation and a rail boom. As shown in Fig. 3, the elevation boom would be pinned to the top of the supporting mast and mounted on rollers at its base for elevation adjustment. The rail boom would be hinged at a point approximately 6 ft from the lower end of the elevation boom and could be lowered on cables to a horizontal position. This would place the rails on the lower side of the boom approximately $5\frac{1}{2}$ ft from the floor in a convenient position for rocket loading.

The design of the operating mechanisms and controls was quite straight forward. Adjustment in azimuth was accom-

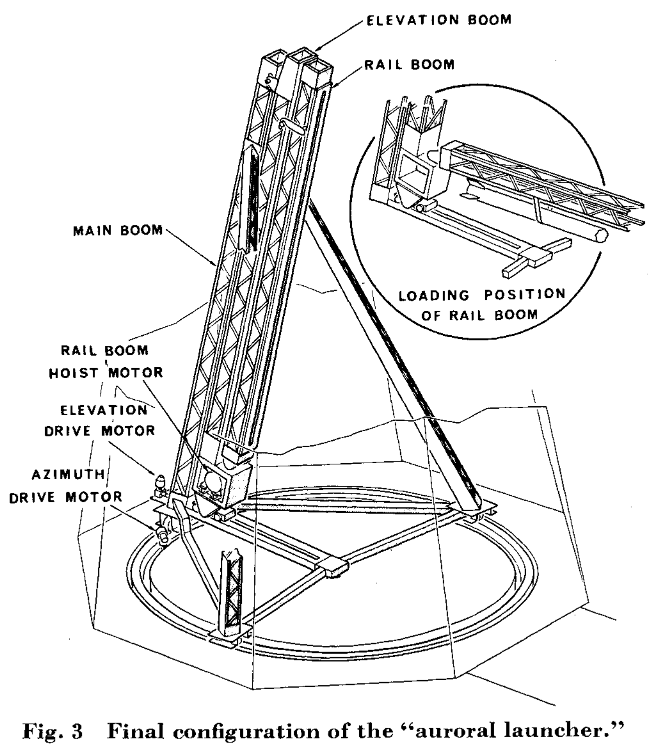

Fig. 3 Final configuration of the "auroral launcher."

plished by a $\frac{3}{4}$ hp electric motor driving a sprocket that engaged a drive chain secured to the circular track.

Adjustment in elevation was provided by a 2 hp electric motor that operated a drive screw which engaged with a travelling nut on the underside of the elevation truck to move it along a track mounted radially between the launcher pivot and the base of the supporting mast.

The hoist motor for raising and lowering the rail boom was located in the lower end of the elevation boom driving two single falls of $\frac{1}{2}$-in. wire rope attached to the end of the rail boom. Limit switches were incorporated to prevent overdriving of any of the motor-operated mechanisms.

Building Construction

To obtain a minimum volume building, as permitted by the launcher design, a conical shape was adopted. The basic structure was a truncated octagonal pyramid 48 ft high on a 42-ft-diam base. A 12-ft × 12-ft hinged roof hatch was provided for passage of the launched rockets. Blast relief doors were located around the base and midway up alternate walls of the structure.

One of the major problems anticipated in the construction of the building was the installation of a stable foundation on the perma frost soil. One solution was to excavate to bedrock and fill with granular material as was done for the Universal launcher. However, the cost of this method would be extremely high and it was felt that an acceptable alternate would be to spread 6–7 ft of compacted fill on the site early in the spring when the ground was still frozen. The building would then be constructed on footings placed in the fill and the floor structure elevated above the grade level to provide ventilation underneath. It was felt that this depth of granular fill would be sufficient to provide permanent insulation against future freeze/thaw cycles. The fill would be high enough to ensure that no appreciable amount of moisture would be retained.

Design and construction of the building and launcher proceeded in parallel. The launcher was produced and installed by a Montreal-based steel company. The building was erected by the Range Staff with the aid of a supplementary work force.

Construction of the auroral launcher facility was completed in August 1968 and operations were commenced shortly thereafter. Satisfactory launcher performance has been demonstrated in launches up to the end of March 1971.