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Project High Water - A Test of an Abort in Space

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The two Project High Water experiments have produced optical, ELF, radiofrequency, and radar data essential to understanding the effects of data releases of large quantities of water in the ionosphere. Extensive cross correlations were found between the various frequencies of acquired electromagnetic data. These data have been analyzed and a physical model of the expansion process has been developed. Results of the analyses demonstrate that:

1. Extremely low temperatures will be generated by the evaporation-condensation-sublimation processes. These temperatures will depend upon the type, and quantity of liquid released, and upon the ambient conditions into which the release is made.

2. The maximum velocity of the expanding ice-water cloud approximated 1.83 km/sec. However, a perturbation wave associated with the liquid release possessed a velocity as high as 3.60 km/sec.

3. Considerable turbulence is associated with the sudden release of liquids into space.

4. Telemetry attenuations can result from inhomogeneous regions within the ionosphere.

5. Considerable doubt was raised concerning the possible existence of ice in space.

The attenuation effects were found to be both frequency and directionally sensitive. Thus, electromagnetic observations provide a technique for investigating inhomogeneous regions in the ionosphere.

Introduction

In two of the early test flights of Saturn launch vehicles, water was used for ballast in the upper stages to simulate expected future payloads. The second and third stages included one tank each containing 44,000 and 42,000 kg of water, respectively. The tanks were designed to simulate boost phase flight characteristics expected in future missions. In the SA-2 flight, the second stage tank was split longitudinally at an altitude of 105.3 km. The third stage had a series of ports one foot in diameter opened up by primacord discharge. This differed from the SA-3 flight only in the altitude at which the water was released, which was at 165 km.

Several scientific objectives were considered possible with a High Water experiment. These objectives were:

A. Investigate the effect of a large perturbation in the ionosphere.

B. Investigate noctilucent cloud effects.

C. Investigate the behavior of ice in space.

D. Investigate ionospheric wind.

The SA-2 flight occurred on April 25, 1962, from Cape Canaveral, Florida. The SA-3 flight occurred on November 16, 1962, from Cape Canaveral, Florida. On this second High Water operation the water was released at an altitude of 165 km.

Observations

During the High Water operation observations were attempted by:

(a) Direct observation

(b) B.C. 4 cameras

(c) Motion-picture camera

(d) Optical spectrometer

(e) Radiometers

Many of the instruments obtained no data or only partial data. However, some of the motion picture cameras obtained excellent data of the expanding ice-water cloud. The data gathered with the optical spectrometers or radiometers has not been made available.

Analysis of the photographs obtained from three different locations showed the time development of the structure of the ice-water cloud. The locations of the stations used for this study of the cloud development, relative to the point of water release are shown in Figure 1. The "y" direction is along the trajectory of the vehicle.

Figure 1 shows that the planes of the observations are nearly perpendicular to each other for the False Cape and Melbourne.
Laboratory experiments show that these are offset nearly 30° from the rays. Both are also four cloudlets visible within the motion picture film that was exposed 2144,000 + kg of water, 3,000 kg of fuel very interesting aspects can be noticed milliseconds after the explosion. Several are considered to be results of the explosion the nearly circular cloud. These rays are distributed uniformly around the cloud. Careful inspection shows a slight haze distributed between these rays. There are also four cloudlets visible within the cloud structure. The cloudlets are also uniformly distributed around the cloud but are offset nearly 30° from the rays. Both the rays shown in Figure 2 and the haze are considered to be results of the explosive charge. The denser ring and the system of cloudlets consist of the expanding liquid. This liquid was composed of 44,000 + kg of water, 3,000 kg of fuel (RP-1) and 4,600 kg of liquid oxygen. Laboratory experiments show that these other constituents of the released liquid behave very similarly to water.

Figure 3 shows the cloud as it appeared 221 milliseconds after the water was released. Considerable structure is observed within the cloud. The four cloudlets that were discernible in the cloud 21 milliseconds after the water release can be observed as bulges in the outer parts of the cloud in Figure 3.

At 722 milliseconds after the water release the cloud appeared as shown in Figure 4. The filament structure of the cloud was strikingly evident at the time of this picture. Also an anti-symmetrical expansion can be observed. The cloud appears to bulge toward the lower right-hand side of the picture. This bulge expanded outward much more rapidly than the inner, more reflective portion of the cloud. In both Figure 2 and 3 the effect of turbulence and the condensation-evaporation processes are evident.

Expansion Rate Analysis

The expansion of liquids under reduced pressure is a complex phenomenon because of the phase changes that occur. A mathematical theory has been developed utilizing hydrodynamic-thermodynamic considerations.7 Utilizing these considerations an equation can be developed for the density of the expanding liquid. However, in the cases where rapid changes occur experimental data are required to determine the changes that occur in the expansion model.

Cloud expansion velocities were obtained by measuring the actual displacement of the cloud edge, or the center of a particular cloudlet, on a series of frames. The actual distance moved was calculated from the known focal length of the camera, frame size, and distance from the camera location to the cloud.

Expansion velocities of the spikes that appeared on the first picture obtained after the explosion (740.021 sec.) are 3.3 km/sec. This velocity is, of course, an average velocity over the first 21 milliseconds. However, this may be a good estimate of the initial perturbation wave velocity.

Expansion velocities were measured for the outer and inner cloud systems and the radial velocities were measured for six distinctive cloudlets. The velocities of the various cloud forms are shown in Figure 4. Fluctuation in the velocities with time are due to turbulence and condensation-evaporation dynamics within the cloud. It is of interest to note that the outer ring had an average velocity considerably greater than the inner ring. When the bulge developed in the inner ring, its average velocity was greater than the cloud region from which it developed, but not as great as the outer ring velocity. Fluctuations in the velocity of this bulge appeared to damp out as it expanded beyond the field of view of the camera. However, the fluctuations in the velocity of the inner ring continued.

Model of Liquid Release in Space

Results from the two High Water experiments and from laboratory experiments show a definite model for the physical processes that occur when liquids are released into a region of reduced pressure.

Two critical factors involved in determining the physical processes involved are:

1. The temperatures of the released material, and
2. the difference between the vapor pressure and the actual external pressure.

From basic physics, the boiling point of a liquid is the temperature at which the vapor pressure of the liquid is equal to the external pressure.9 When the vapor pressure exceeds the external pressure, the liquid immediately starts boiling. Since boiling generates vapor, the vapor pressure in the vicinity of the liquid (within the cloud) increases rapidly with time. This change in phase produces a correspondingly rapid reduction in the liquid temperature. This cooling causes the liquid droplets to freeze at rates which are functions of the droplet diameters.10 The internal temperature of a frozen droplet changes comparatively slowly because the heat conduction is poor in the solid state. At these reduced temperatures, the saturation vapor pressure of the super-
cooled droplets is greater than the saturation vapor pressure of a frozen particle at the same temperature. Following such an explosive boiling regime, the ice particles are surrounded by environmental vapor pressures greater than their own saturation vapor pressures. Therefore, condensation from the gaseous to the solid state occurs, and the ice particles grow at the expense of the surrounding vapor. Also, as the ice particles grow, the entire cloud continues to expand, resulting in a continuously decreasing environmental vapor pressure. The vapor pressure of the system decreases until the particles experience pressures below their saturation vapor pressures. The particles then sublime directly to the vapor state.

The initial physical conditions described above were evident in the High Water I data. During the first 400 milliseconds following the release, the released water was boiling and cloud particles were accelerating outward. As the ice particles formed, the cloud acceleration decreased with time. At the same time, the original boiling generated violent dynamic conditions within the cloud. The resulting internal turbulence tended to mask the increases and decreases in radial accelerations. By combining data from two locations some of the turbulence effects can be eliminated and the radial acceleration components can be observed more clearly. Data from the High Water II test was not acquired for a sufficient length of time to determine the effects of freezing on the cloud motion.

Laboratory experiments have shown that liquids released at very low pressures follow the above described regime of physical processes. Laboratory experiments have disclosed evidence of a perturbation wave that travels outward with the velocity of the initial liquid expansion. The fact that retardation of the ionospheric E condition was observed at the time of water release is considered to be evidence of such a perturbation.

Maximum expansion velocities of the ice-water cloud for the High Water I and the High Water II experiments are shown in Table 1.

<table>
<thead>
<tr>
<th>Structure</th>
<th>High Water I* (km/sec)</th>
<th>High Water II* (km/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sideward Spike</td>
<td>2.53</td>
<td>3.60</td>
</tr>
<tr>
<td>General Cloud</td>
<td>1.83</td>
<td>1.83</td>
</tr>
<tr>
<td>Cloudlet</td>
<td>1.83</td>
<td>1.83</td>
</tr>
</tbody>
</table>

* 105 km above sea level
** 165 km above sea level

In comparing the expansion velocities of the two clouds it must be remembered that the ambient conditions into which the water was released were quite different in the two experiments, as shown in Table 2.

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Pressure (mm Hg)</th>
<th>Number Density (n/m³)</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>105</td>
<td>10⁻⁴</td>
<td>5x10⁻¹³</td>
<td>28.85</td>
</tr>
<tr>
<td>165</td>
<td>2.5x10⁻⁶</td>
<td>2x10⁻¹⁶</td>
<td>27.90</td>
</tr>
</tbody>
</table>

Consideration of these facts explains why the water released at 165 km dissipated much more rapidly than that released at 105 km. This result was observed when data from the two operations were compared. The cloud formed in High Water I required about ten (10) seconds to optically disappear, while the High Water II cloud was visible for only approximately five (5) seconds.

Conditions associated with a potential abort were demonstrated by the High Water project. If an astronaut were enveloped within the expanding cloud from an abort he would experience an environment similar to that produced by the High Water experiment. During the evaporation and sublimation regimes, the temperature of his environment will be suddenly and drastically reduced. If he were outside the vehicle at the time of a release, he would experience a perturbation wave such as was evident in the laboratory experiments. A similar perturbation wave appeared to be associated with the High Water I operation. The cloud resulting from an abort would also cause telemetry and radio dropouts. If an abort should result in the release of fuels and oxidizers, the ensuing turbulence would produce mixing and would therefore increase the fire hazard.

Results from the High Water experiments also raise some interesting aspects concerning the theories proposing the existence of accumulations of ice on the moon. For any quantity of ice to exist, one of two improbable conditions would be required: 1) extremely low ambient temperature at the space location when the formation occurred, or, 2) formation in a high gravity environment, followed by cooling to an extremely low temperature prior to release to a low pressure environment.

It has been proposed that bulk water may exist on the moon within a porous structure. Project High Water results provide particularly convincing reasons to doubt this concept. Numerous efforts have been made to evaluate the density of the lunar atmosphere. One of the widely
accepted values is some $10^{-13}$ of the sea-level density of the earth's atmosphere. It follows that the equilibrium temperature at the ambient pressure of the lunar surface is much lower than the measured temperatures existing there, and any lunar water not chemically bound would dissipate as rapidly as, and in a manner analogous to, that observed with Project High Water releases. In order for any bulk lunar water exposed to the lunar atmospheric conditions to remain for any appreciable period of time, its temperature would have to be maintained at about $-150^\circ$C ($123^\circ$K). The minimum observed night time temperature of the moon's surface is barely below the required value (d.h., $-157^\circ$C or $116^\circ$K), while the day time temperature is very much higher (d.h., $101^\circ$C or $374^\circ$K). Even if the lunar age is taken to be less than that of the earth, the prospects of finding bulk water on the moon are considered to be remote.

References


3. A. E. Potter, Jr., Memorandum to Aeronautics Subcommittee of the Space Science Steering Committee, "Remarks on proposal to release 200,000 lbs of water at 150 km." (February 14, 1962).


Fig. 1  Camera Direction from the Ice-Water Cloud

Fig. 2  Ice-Water Cloud 21 Milliseconds after Explosion
Fig. 3 Ice-Water Cloud 221 Milliseconds after Explosion

Fig. 4 Ice-Water Cloud 722 Milliseconds after Explosion