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CONTAMINATION OF SPACECRAFT BY RECONTACT OF DUMPED LIQUIDS

by

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Liquids partially freeze when dumped from spacecraft producing particles which are released into free space at various velocities. Recontact of these particles with the spacecraft is possible for specific particle sizes and velocities and, therefore, can become contamination for experiments within the spacecraft or released experiments as a result of waste and potable water dumped from Space Shuttle. An examination of dump characteristics was conducted on STS-29 using both on-board video records and ground based measurements. A preliminary analysis of data from this flight indicates particle velocities are in the range of 30 to 75 ft/sec and recontact is possible for limited particle sizes.

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INTRODUCTION

Several times during a mission, the Space Shuttle Orbiter has to release water which has accumulated from the fuel cells. Due to the vacuum environment into which they are being released, the water flash evaporates, leaving small ice particles. There has been some concern that the motion imparted to these particles could return them to the orbiter during subsequent orbits. This could lead to contamination of experiments in the payload bay and in the extreme, damage to materials such as the thermal protection system tiles. It has been reported that particles contacted the orbiter on STS-8 and STS-61A during subsequent orbits after water dumps (1). As a consequence, water dumps are being planned more carefully with respect to the orientation of the orbiter during the dump. Judicious angles at which the water is released can lead to the water reentering (7) the earth's atmosphere prior to recontact with the vehicle.

A Detailed Test Objective (DTO) was formulated for STS-29 where the water dumps were planned around the viewing opportunities from both the orbiter and ground cameras. The idea was to release the water as the orbiter was first coming into light over the event horizon yet still against a black background for better viewing. Such observations would provide general plume shape and therefore velocity vector information for the released particles. The video images from the orbiter provided the means to analyze the particles' trajectories and velocities in the near field. With this information, it was possible to analyze the orbit of the particles and determine if recontact was possible. With this information, a model could be developed for use in detailed mission planning.

ICE PARTICLE ANALYSIS

The first step to the analysis of the recontact problem involved understanding the ice particle flow including velocity distribution as well as the mass of the particles. The stream of water released from the orbiter is very collimated up to the burst zone (2,3). The burst zone is mostly regulated by the vapor pressure of the liquid, in this case water, as the liquid begins to boil (3). Adding dissolved gasses can decrease the length of the collimated stream (4-6) due to the expansion of the gases in vacuum. Other factors involved include the orifice diameter, temperature of the liquid, and initial pressure of the stream before release (2-6). In this case, the burst zone is approximately 1-2 ft away from the orbiter.

The size of the ice particles formed can be estimated (4) by using a force balance on the water droplet before evaporation occurs

$$D = 30\gamma/P_v \qquad (1)$$

where D is the diameter in microns, γ is the surface tension of the liquid in dynes/cm, and P_v is the vapor pressure. Table 1 gives typical diameters for water

Table 1 Ice particle size vs temperature

Temperature °C	D (μ)
0	479
10	238
25	92.3
30	68.9
50	23.7

at various temperatures. These values are only estimates as they use the surface tension of pure water in air at 18°C. A typical potable water dump is made at temperatures between 25 and 30°C and approximately 15-20 psia at the nozzle, and consists of pure water. Waste water releases also occur under the same conditions..

The velocity of the particles was determined from the video tape taken on board of the dump which occurred on orbit 49 (March 16, 1989). While time consuming, the method was relatively straight forward. A particle was first found that could be differentiated from the flow through several fields of the video image (there are 2 fields per frame). If a part of the orbiter structure was in view, the dimensions of the structure were used as a reference in order to find the distance traveled by the particle. Simple geometry is used to estimate the flight of the particle over a given number of fields (one field = 1/60 sec.). In other cases where the orbiter was not in view, the downlinked data on the movement of the camera about a pivot allowed the same calculations to be made.

From these calculations, the relative velocity of the particles were found to be between 30 and 75 ft/sec. The angle at which the particles left the orbiter were not completely definable with the video images available, but for this analysis will be assumed to be perpendicular to the orbiter out the port side, parallel to the y-axis of the orbiter. The actual plume is roughly conical in form. It should also be noted that the actual size of the particles could not be determined with any accuracy in the video images but appear to be larger than the theoretical. This might be possible if the structure of the ice particles were more porous like snowflakes than solid ice spheres. Trapped gasses and vapor expanding in the particles could account for larger than theoretical sizes.

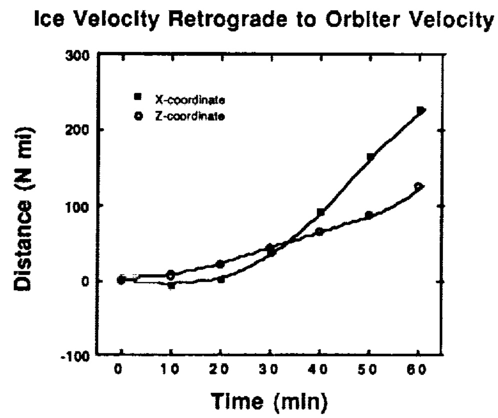
ORBITAL ANALYSIS

All of the orbital mechanics analysis of the ice particles was performed using software developed at the Johnson Space Center called High Accuracy Relative Motion Processor (HAREM). The HAREM program takes the atmospheric model for the date that is specified, the shuttle weight, altitude and orbit, along with the particle parameters such as relative velocity vector to the orbiter, weight, center of mass, and moments of inertia, and predicts the orbit of the particles with respect to the orbiter. A parametric study was made of such parameters as ice mass and velocity vector in order to determine if recontact was possible for the water dump of STS-29.

Table 2 Particle size and weight

Diameter (cm)	Weight (mg)
0.01	5.24×10^{-4}
0.1	0.524
1.0	524

Table 2 describes the particles of interest for this study. The particle sizes were chosen to encompass the theoretical particle sizes plus a larger particle which might be formed due to vapor expansion in accordance with the video tape images. The relative speeds used for this study were 12, 30 and 75 ft/sec. The orbiter was positioned in such a way as to release the particles in several directions; retrograde, posigrade, 90° pure out of plane, 90° radially up and down, and 45° out of plane relative to a local vertical, local horizontal (LVLH) reference plane. The orbiter was considered to be in an orbit 160 x 160 nautical miles. The date was taken to be March 1, 1989, or roughly the date of STS-29, unless otherwise noted.



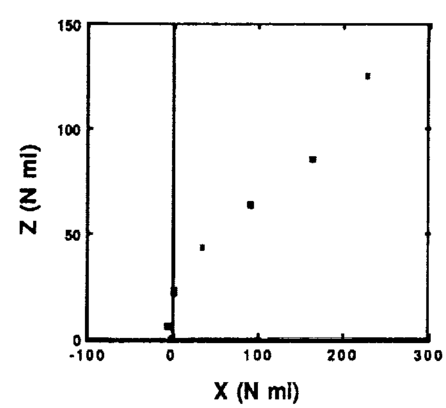


Figure 1 One mm particle in retrograde motion release at 30 ft/sec

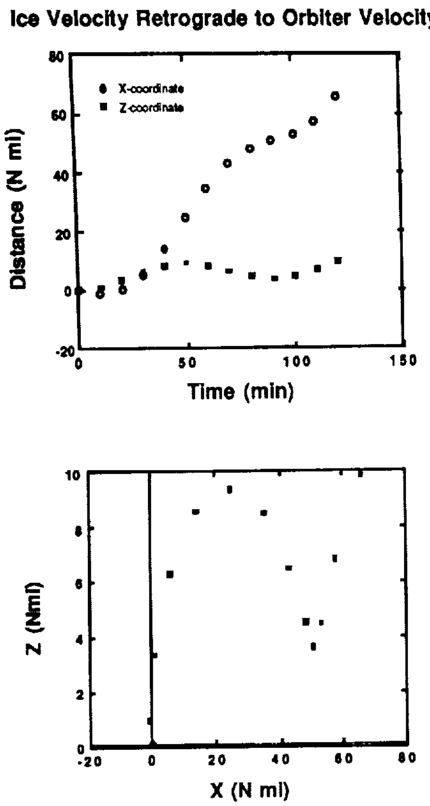


Figure 2 One cm particle in retrograde motion released at 75 ft/sec

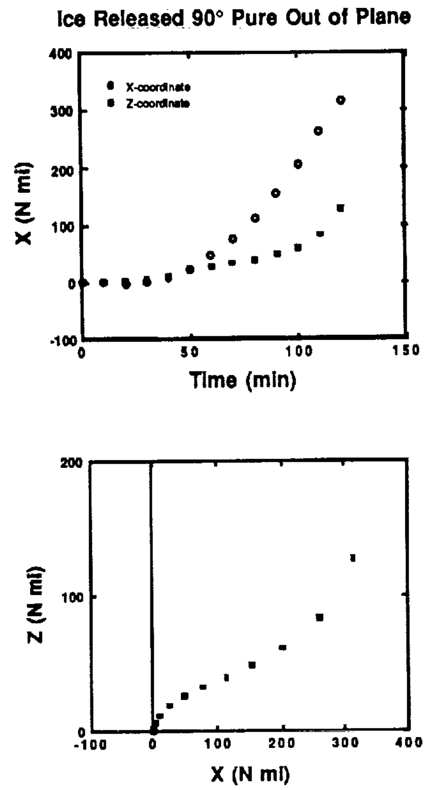


Figure 3 One mm particle released 90° pure out of plane at 75 ft/sec

In Figures 1 and 2, two different graphs are used to show the relative motion of the ice particles with respect to the orbiter. The first figure plots the X- and Z- coordinates with respect to the orbiter centered LVLH coordinate frame as a function of time. The second plots the Z- coordinate as a function of the X-coordinate in the LVLH reference frame. In the LVLH reference frame, +Z is down toward the earth, and the origin of this plot is therefore the orbiter. As can be seen in these two figures, a retrograde release of the ice particles, regardless of the size of the particle, results in deorbit of the particles in a timely fashion, posing absolutely no threat to the orbiter. This should not be surprising since a retrograde velocity slows the particles, causing them to fall to a lower orbit, where drag forces cause further decay of the orbit. It should be noted that the larger particle stays in orbit longer than the smaller particle, and can be explained in terms of the energy of the orbit. Given the same relative velocity, the energy of the particle is determined by its mass, thus the larger particle has more energy and stays in orbit longer. This poses interesting possibilities for decreasing the orbit time of the particles by decreasing their size.

Figures 3-5 represent the orbits of particles of 1 mm in diameter which are 90° pure out of plane, 90° radially up and 90° radially down to the orbiter in LVLH. As can be seen in these figures, recontact does not seem to be possible before reentry. As a check, a 1 cm particle was released at 90° pure out of plane at 30 ft/sec and 75 ft/sec and are depicted in figures 6 and 7 respectively. In both cases, the particles are well on their way to reentry within two orbits. This is not meant to imply that no conditions for these particular release angles will ever cause recontact, but this limited evidence is promising.

Trajectories for a 1 mm particle released in a posigrade trajectory at 30 ft/sec are shown in figure 8. This particle, due to its small diameter does not recontact the orbiter. Its orbit decays below that of the orbiter after two orbits. Figure 9 represents the case of a 1 cm particle traveling at 75 ft/sec when it leaves the orbiter. As can be immediately seen, this particle stays in orbit much longer than the previous cases, traveling in an orbit above the orbiter initially. While recontact is not observed, it shows that

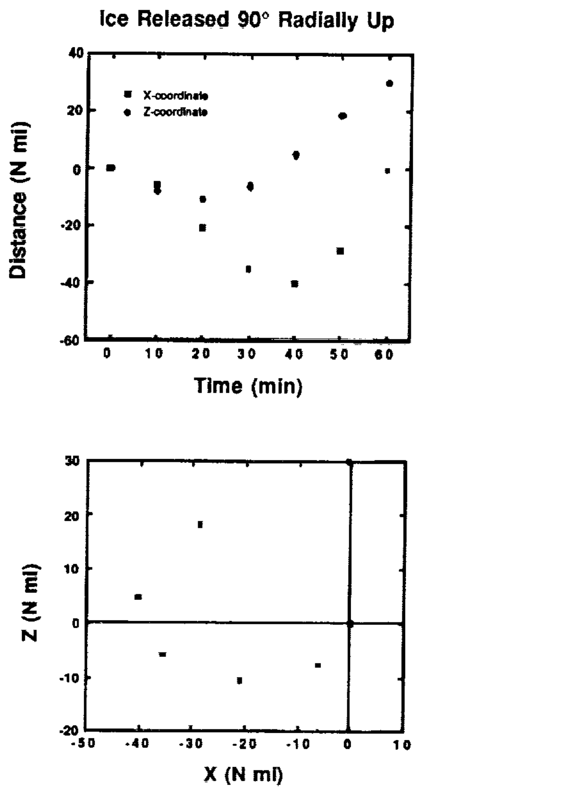


Figure 4 One mm particle released at 30 ft/sec away from the earth

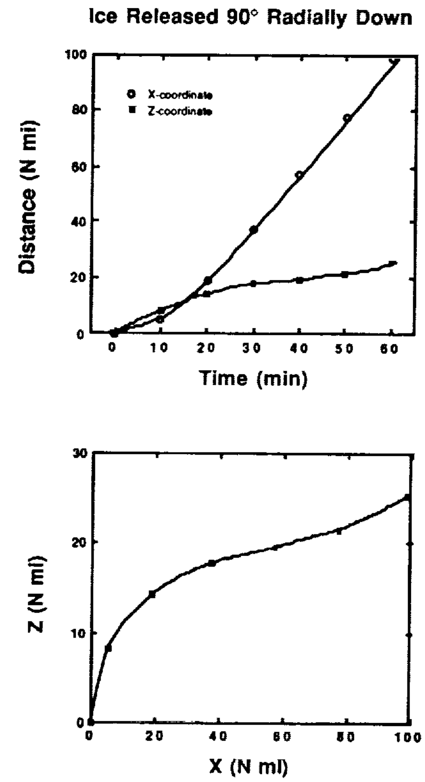


Figure 5 One mm particle released at 75 ft/sec toward the earth

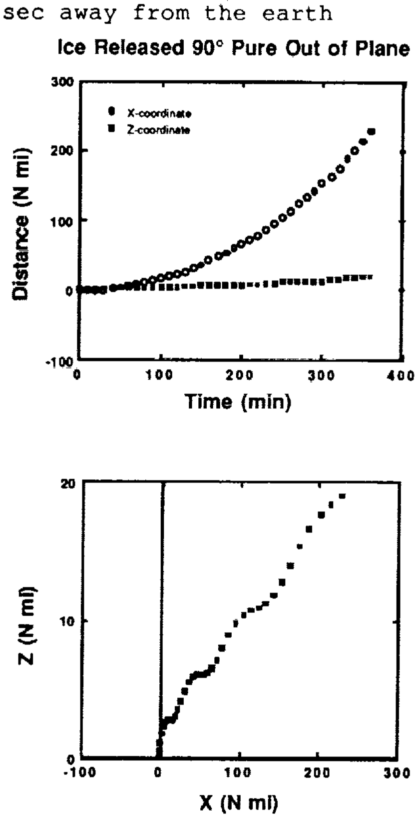


Figure 6 One cm particle released 90° pure out of plane at 30 ft/sec

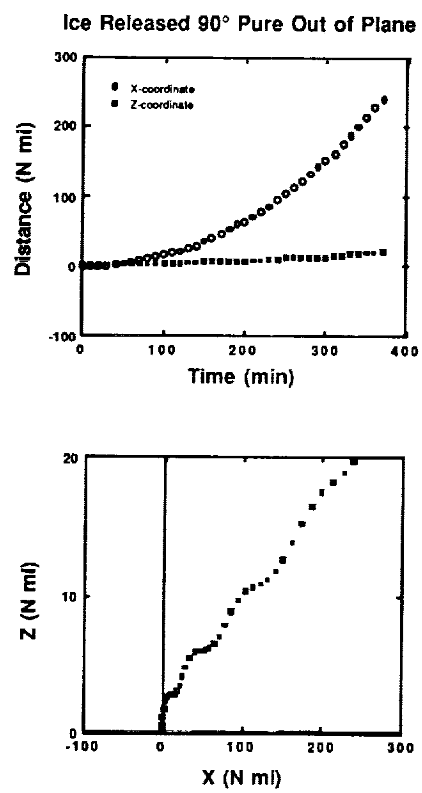


Figure 7 One cm particle released 90° pure out of plane at 75 ft/sec

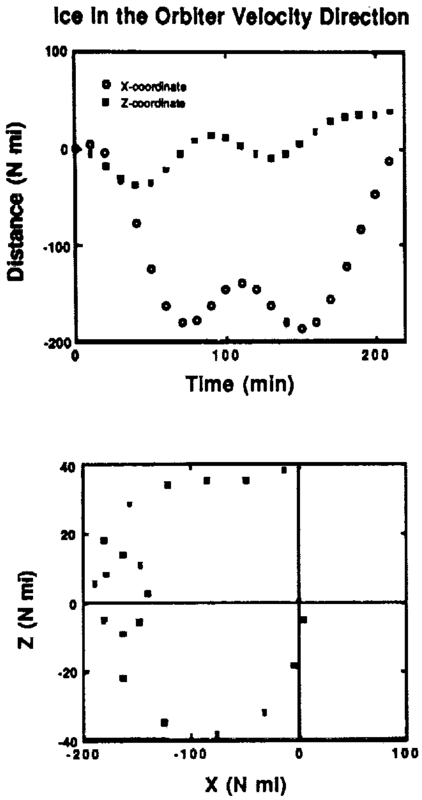


Figure 8 One mm particle in posigrade motion at 30 ft/sec

there are orbits which could cause problems. Given that recontact was observed for STS-61A, the same particle and trajectory was analyzed for the November time frame of 1985, or the approximate time of STS-61A. The atmosphere should have been less dense at this altitude for this time frame since the solar cycle is just now reaching its peak in the 1989-1990 time frame. The trajectory results are found in Figure 10. At 75 ft/sec, a 1 cm particle stays in orbit, generally at an X-coordinate many miles from the orbiter. The ice particles, however, oscillate in the Z-coordinate around the orbiter's orbit. Somewhere around the tenth orbit after release, recontact becomes possible as the ice particles begin to catch up to the orbiter. Apparently, the higher density of the atmosphere of 1989 creates enough drag to deorbit the particles faster.

With this in mind, it follows that other combinations of speed and mass would produce recontact given a posigrade trajectory. Figure 11 illustrates recontact for the case of a 1 cm particle with an initial velocity of 12 ft/sec in a posigrade motion with the 1985 atmospheric model. In this case, recontact is possible much sooner, with opportunities twice in the first 2 orbits. Slight angles to the pure posigrade trajectory may also facilitate recontact.

While this study covers only limited particle size and velocity distributions, it points out the possibilities for recontact given the right conditions. Retrograde trajectories appear to preclude particle recontact.

CONCLUSIONS

It was found that a larger particle has a longer time in orbit. Breaking up the particles into smaller spheres will have some effect on the decay time and therefore provides another means by which recontact can be avoided.

The atmospheric density also plays a key role in the decay of the particle orbits. It was shown that the 1985 atmosphere had less of an effect on the orbit of the particles than the 1989 atmosphere. Since density of the atmosphere is a changing function of time, it is another parameter to take into account for the entire problem.

Release of water in posigrade trajectories was found to recontact the orbiter and could cause problems for experiments

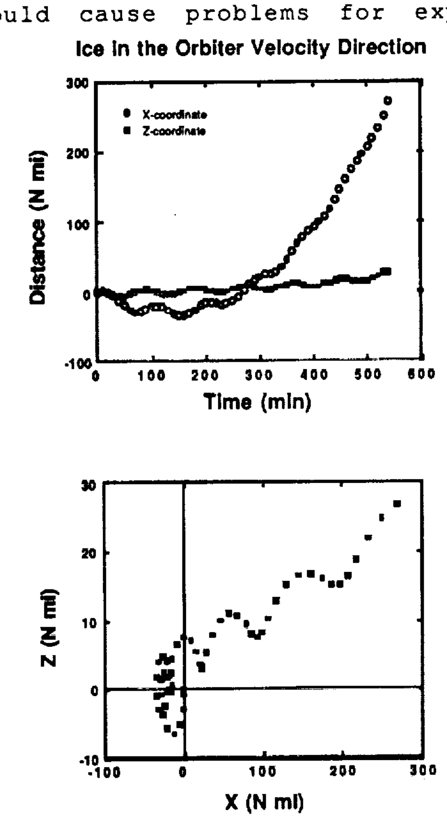


Figure 9 One cm particle released at 75 ft/sec in a posigrade motion

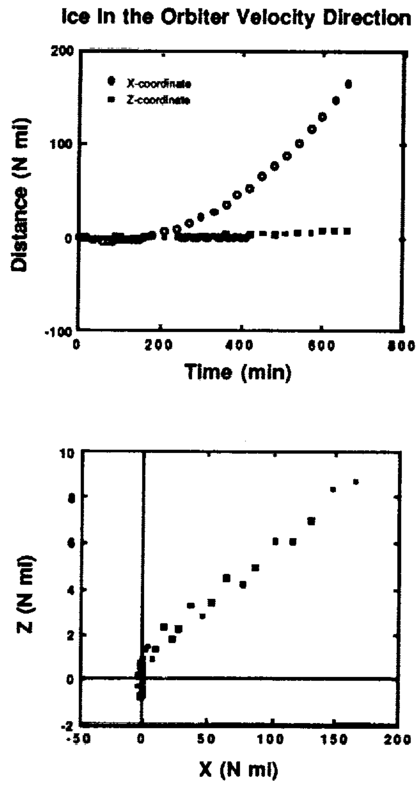


Figure 11 One cm particle (12 ft/sec) in a posigrade motion for the 1985 atmosphere

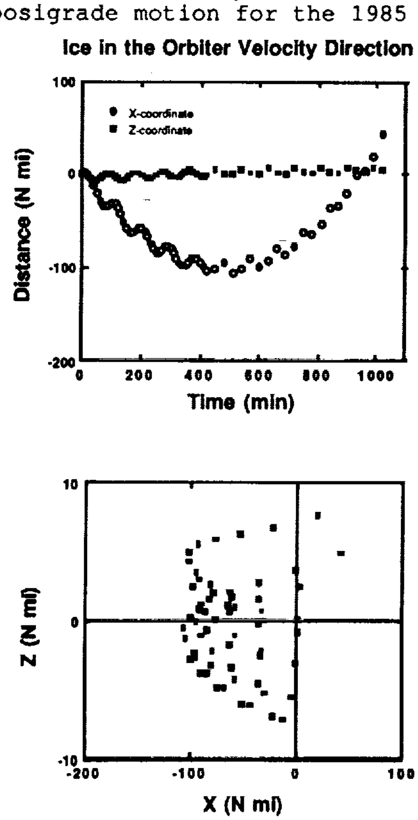


Figure 10 One cm particle released in a posigrade motion at 75 ft/sec (1985)

operating in attached payload mode or even for certain cases of release payloads.

Additional study of particle characteristics is needed to preclude deposition of material (residue from impact) on experiment surfaces and field-of-view interference.

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