Novel Ice Mitigation Methods

2006 Center Director's Discretionary Fund Project

Propellant Loading/ Servicing/Storage

After the loss of Columbia, there was great concern in the Space Shuttle program for the impact of debris against the leading edges of the Orbiter wings. It was quickly recognized that, in addition to impacts by foam, ice that formed on the liquid-oxygen bellows running down the outside of the External Tank could break free during launch and hit this sensitive area. A number of possible solutions were considered, and eventually heaters were installed in this area. This allowed Shuttle launches to resume, but adding heat to the cryogenic flow system was not an optimal solution. Consequently, the Shuttle program requested that a Center Director's Discretionary Fund (CDDF) project explore possible alternatives.

Previously both the Shuttle program and the NASA Engineering and Safety Center had funded extensive efforts for ice mitigation. Many concepts were examined in detail, such as encapsulating the area, projecting heat, using flexible insulation, and applying innovative coatings, but all had drawbacks that prevented them from being used. So it was decided that the CDDF project would not devote resources to concepts that had already been heavily explored, and instead would concentrate on novel ideas that were potentially applicable. Patent and literature searches, as well as brainstorming sessions, resulted in a number of interesting concepts to be considered.

The resulting list of ideas was further filtered to remove ones that, while not considered for Discovery's return to flight, were already well developed and understood (for example, electro-expulsive ice removal). In the end, four concepts were chosen for testing and possible development: (1) adding compounds to the ice to affect its hardness, (2) using dark coatings to increase infrared absorption, (3) using shape memory alloys to break ice free, and (4) applying a high electric field with low-adherence coatings to repel ice.

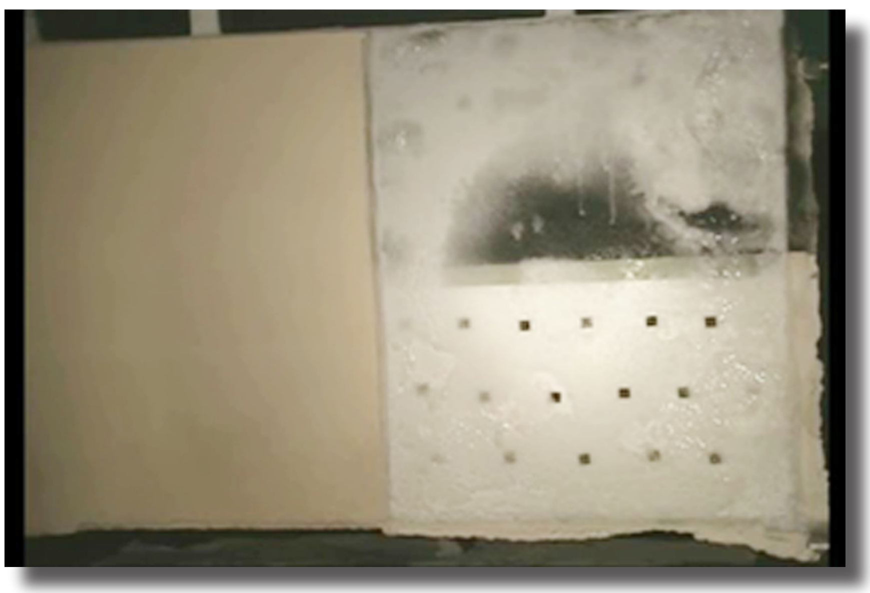

Figure 1. Ice sheet construction involved clamping a sheet of aluminum to a flat, liquid-nitrogen dewar and then spraying the surface with a water mist. The aluminum sheet had both white and dark surfaces, the idea being that the dark surfaces would absorb more radiation and melt the ice more quickly. In the picture, radiative heat has been applied to the panel for some time, warming the center region of the panel and melting the ice.

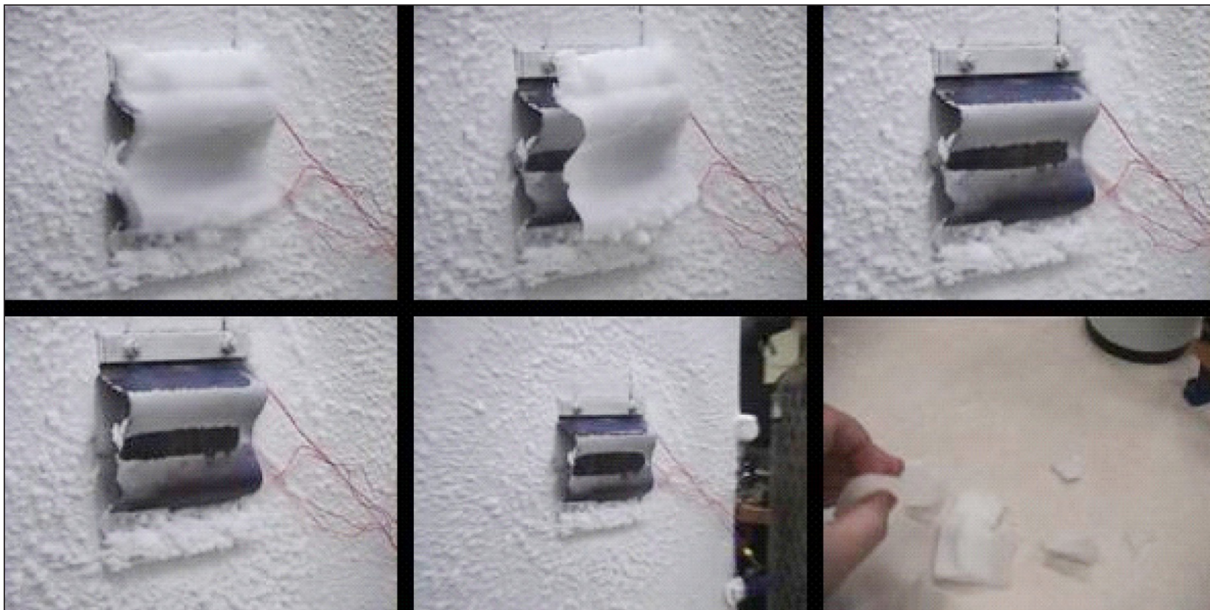

Figure 2. A corrugated NiTi sheet exhibiting a shape metal alloy effect was used in this experiment. As the timeline evolution from the upper left to the lower right shows, heating causes the corrugated pattern to return back to its bowed shape, ejecting the ice. The thick ice chunks shown in the last frame demonstrate the enormous stress force that the NiTi can exert.

Adding compounds to affect the hardness of ice could proceed in two directions; one idea was to form weak ice, which factures easily and into small pieces, whereas a second idea recommended forming strong ice, thus minimizing ice shedding during launch. Various additives were shown to affect ice hardness, but significant amounts of these additives were required to achieve the desired goals, precluding this as a viable approach.

Infrared radiation tests were performed on 2-ft-square aluminum sheets on which ice had been grown (Figure 1). These sheets were painted with white and black regions so that the dark areas would absorb more heat from the radiation and melt the ice more quickly. In testing, though, this did not happen, probably because the ice itself reflected and absorbed much of the radiation before it reached the underlying coating.

The most successful of the new concepts for ice mitigation involved shape memory alloy materials. These materials can be bent into a given shape and, when heated, will return to their original shape. Figure 2 shows a piece of nickel titanium (NiTi) bent into a corrugated pattern and then chilled until a thick layer of ice formed on it. Then, after being heated, it returns to its original shape, throwing off the ice. This approach proved repeatable and, if further development were requested, would be our primary recommendation.

Our final concept explored how to use very high-voltage electric fields to eject ice as it is being formed. Very high-voltage fields were observed to cause ice to form in fine fingerlike structures and fly off. Special coatings minimized the attachment of the ice to a surface, and then high voltages were applied to see if they could repel the ice from the surface. This approach did not work consistently and, after several tries, was dropped.

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