reports of well-briefed pilots, flying research missions through squall line cloud tops, who describe rapid accumulations of ice on the windshield and structural members of the aircraft as intense convective cells were penetrated. There have been some documented cases in which icing was observed at temperatures as cold as −70C (e.g., Shaw, 1954). There is no question that ice forms on aircraft at temperatures much colder than −40C. There is a question as to the source of the icing.

A number of arguments have been advanced to explain how such icing may occur without requiring liquid water at temperatures colder than −40C. The most popular of these arguments is that liquid water is transported upward so rapidly that its cooling cannot keep pace with the atmospheric lapse rate. The purpose of the paper (Simpson, 1962) referred to by Schaefer was to demonstrate that within practical limits this argument is not valid.

A more attractive possibility suggested by the work of List (1960) is that the freezing process in large drops begins with the formation of an outer shell of ice which retards the progress of freezing in the core of the drop. The rupture of ice shells with liquid cores as they impinge on an aircraft could cause rapid accumulations of ice.

On the other hand, some careful laboratory experiments (e.g., Weickmann, 1947) have succeeded in lowering the temperature of liquid water drops to −50C and colder.

In any event, our knowledge of the physical process of freezing is sufficiently limited that there is reason to maintain an open mind concerning the validity of a critical temperature for homogeneous nucleation of liquid water.

It is important, however, that this open-mindedness be coupled with a determined effort to establish experimentally the structural character and the sizes of the precipitate which causes this icing.

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Reply

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In his comments on my paper relative to the state of condensed water at temperatures colder than −40C, I am pleased that Simpson agrees that we should mount a determined effort to establish the cause of aircraft icing reported to occur at very cold temperatures. I agree that several mechanisms such as the one reported by List could account for ice forming on the windows and other parts of aircraft at temperatures colder than −40C. The main point I wished to convey is that I know of no quantitative experiment which demonstrates the presence of the liquid phase of water having its internal temperature colder than −40C. With water enclosed in an ice sphere suspended in very cold air, the liquid phase is very much warmer than that temperature.

Ice-like structures can be formed from dry powder if impacted even at velocities less than 100 mph as we found in some of our early studies of precipitation static. Similarly, watery splashes can be observed on heated windows such as are used in the cockpit of multiengine aircraft when snowflakes or graupel contact their hot surfaces.

During our 1963 Yellowstone Expedition we again had two periods of weather when the free air temperature was colder than −40C. All of the phenomena reported in my paper describing the observations made in 1962 were confirmed, including the formation of ice particle clouds, the absence of optical effects and the transition back to supercooled clouds as the temperature became warmer than −40C.

I hope a practical method can be devised for studying super-cooling from high speed aircraft which will remove the ambiguity that seems to be an inherent feature of observations made under flight conditions. I shall be glad to cooperate in any effort made to develop an acceptable procedure.