2D ANAYLSIS OF IN-FLIGHT PARTICLES

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One of the primary uses of the in-flight icing research performed aboard NASA Glenn's DHC-6 Twin Otter is for Icing Research Tunnel (IRT) and icing prediction code (Lewice) validation. Using the in-flight data to establish the IRT and Lewice as accurate simulators of actual icing conditions is crucial for supporting the research done in the Icing Branch. During test flights during the 2003 and 2004 flight season, a Natural Ice Shape Database was collected. For flights where conditions were appropriate, the aircraft is flown in an icing cloud with all ice protection systems deactivated. The duration of this period is usually determined by the pilot's ability to safely control the aircraft. When safe flight is no longer possible, the aircraft is maneuvered into clear air above the cloud layer. At this point several photographs are taken of the ice shape that was accreted on the wing test section during this icing encounter using a stereo photograph system (Figure 1). The stereo photograph system utilizes two cameras located at different locations on the fuselage that are both pointed at the same location on the wing. When both cameras take photographs of the same location at the same time, the negatives can be combined digitally to generate a two dimensional plot describing the cross-section of the ice shape. After these photographs are taken, the wing de-icing boots are activated and the ice shape is removed.

In addition to the stereo photographs documenting the ice shape, many different channels of data are recorded by the aircrafts data acquisition system. Many probes and sensors record airspeed, temperature, ice presence, liquid water content, and droplet size. During post-flight data processing, the start and end times each icing encounter are identified from the flight notes. At this point, the pertinent data collected during the icing encounter can be used to generate the necessary settings for re-creating this flight using the IRT or Lewice. In the IRT, an actual Twin Otter wing section will be used with the determined conditions to accrete an ice shape which should be similar in shape to the in-flight shape documented by the stereo photographs. The accuracy and likelihood for success of these wind tunnel tests relies heavily on the accuracy of the input data. If the data acquired in-flight is not processed correctly, these input conditions will not produce a duplicate ice shape.

Temperature, airspeed, liquid water content, and drop size are all critical inputs for any IRT test. Each of these parameters is collected by probes on the aircraft, and can be analyzed after the normal post-flight processing. Droplet size, however, is especially important for ice cloud simulation, and requires extra post-flight analysis to correctly report. Nearly all meteorological testing agencies in the United States and elsewhere use Particle Measuring System (PMS) probes to acquire the size of cloud droplets. The Twin Otter primarily uses two PMS probes drop size acquisition. For sensing drops between roughly 0-50 microns, a Forward Scattering Spectrometer Probe (FSSP) is used (Figure 2). This probe measures drop diameter from the forward scattering of laser light by the droplets passing through the probe. Larger drops, up to over a millimeter in diameter, require a different type of probe called a PMS Optical Array Probe (OAP) 2D-C Grey (Figure 3). This probe finds drop size using an array of diodes that are shadowed when droplets interrupt a laser beam exposed to the cloud. When it is determined by the flight test researchers that drops greater than 50 microns were present during an icing encounter, analysis of the 2D data from the 2D-C Grey is necessary to accurately determine the average drop size in the cloud.

This analysis process was one of my multiple tasks during this summer work session. While the data collected by the FSSP probe directly reports a distribution of drop sizes present in a cloud, the 2D Grey instead stores thousands of two-dimensional images recorded during flight. When a particle passes through the laser beam and shadows the diodes, the 2D image is presented real-time to the flight researchers, and stored for later 2D analysis. This processing requires specially authored software to interpret the 2D images and convert them into a distribution of drop sizes. Although the software is capable of analyzing the images in an automated fashion, the errors associated with such processing are very undesirable. It is important to remember that the probe records images of all particles passing through the air, and not just water droplets. Ice plates, rods, and snowflakes are all common particles that skew the droplet distribution if processed automatically due to the inability of the software to distinguish between them and droplets. These particles do not pose a problem for the FSSP probe because in general they are much greater in size than 50 microns. In order to minimize the error for these cases, the software must be used interactively with human judgment to discern between particle types.

Each icing encounter is analyzed in one minute increments, and the distribution of drop sizes over that period is averaged to report one Median Volumetric Diameter (MVD) representing that minute. The software can be configured to aid in the interactive process by eliminating some particles automatically (Figure 4). Different calculations are made on each 2D image to determine how close to circular it is, as well as how focused. Some particles are automatically filtered by cut-offs input for these parameters. Before any particle is accepted and added to the distribution, the user is asked to verify that it is in fact a water droplet (Figure 5). Depending on probe resolution, there is still a certain amount of error in the user judgment of particles. After all particles for a particular minute increment are counted, an output file is written for later use.

Because the FSSP and 2D Grey have a certain amount of overlap in their effective size ranges, the newly processed 2D data must be blended with the FSSP to generate a representative MVD for the entire droplet spectra. A complicated series of formulas is used in Microsoft Excel to accomplish this task. Since FSSP MVD is recorded every second, a block of sixty seconds must be combined for use with the 2D data. Both probes count the number of droplets and sort them according to size in different bins. An imaginary bin is interpolated between the size ranges of each probe, with the bins closest to this interpolated bin being discarded. With the droplet distribution of each probe effectively blended together, the spectra MVD value can be reported for the one minute segment. When all one minute periods in a specific icing encounter are processed, the conditions are now ready for IRT testing.

Accurate droplet size is essential for re-creating the in-flight ice shape and validating the IRT testing conditions. Drop size has an enormous impact on the shape and size of accreted ice shapes, and ignoring drops larger then 50 microns would certainly cause differences to arise between ice shapes. With the properly processed spectra MVD data, valuable IRT testing time will not be wasted. The conditions input into the tunnel will be an accurate representation of in-flight icing.

APPENDIX

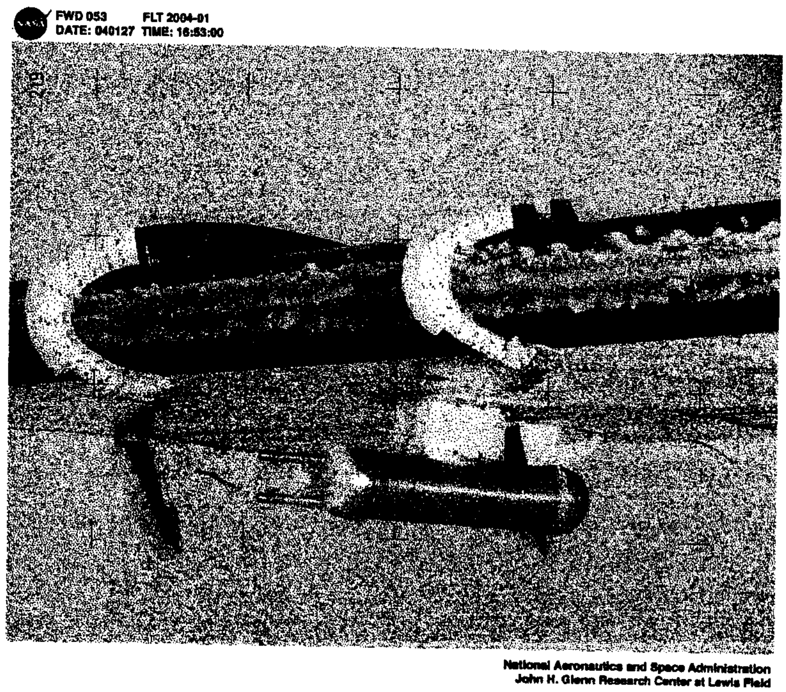

Figure 1: Stereo photograph of wing test section

Figure 2: FSSP Probe mounted on wing hardpoint

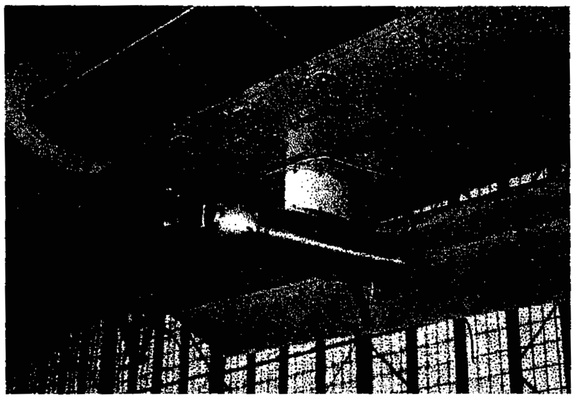

Figure 3: 2D Grey probe mounted on wing hardpoint

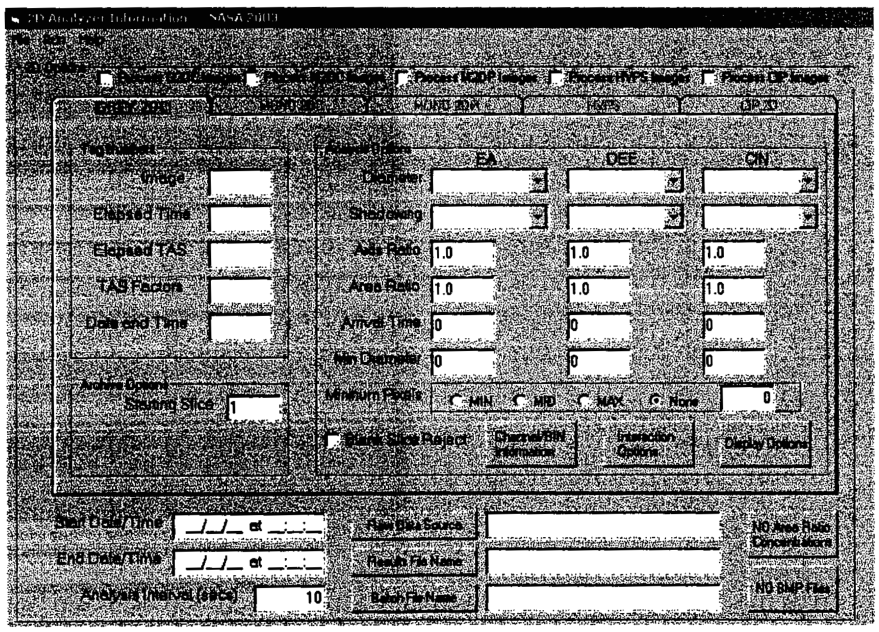

Figure 4: 2D Analyzer configuration screen

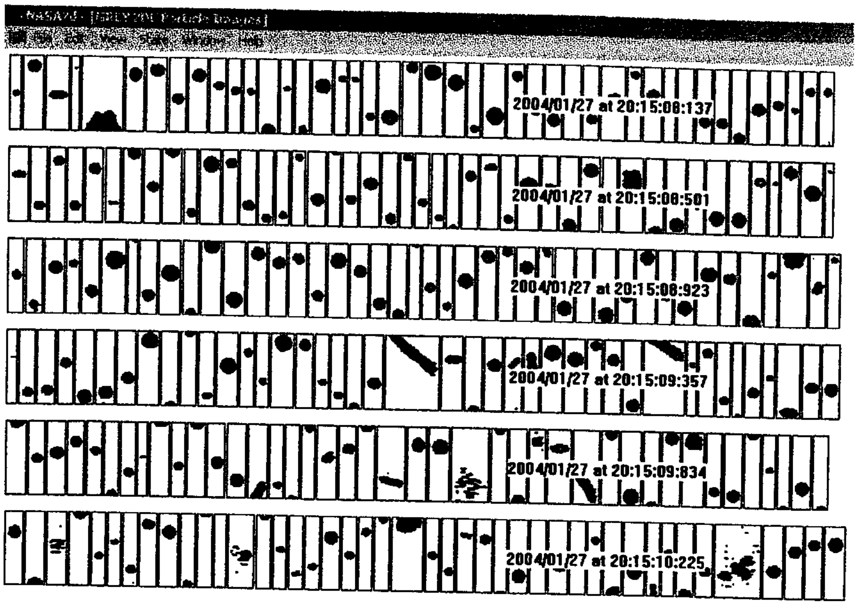

Figure 5: 2D particle images