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Effective Training for Flight in Icing Conditions

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Abstract

The development of a piloted flight simulator called the Ice Contamination Effects Flight Training Device (ICEFTD) was recently completed. This device demonstrates the ability to accurately represent an iced airplane's flight characteristics and is utilized to train pilots in recognizing and recovering from aircraft handling anomalies that result from airframe ice formations. The ICEFTD was demonstrated at three recent short courses hosted by the University of Tennessee Space Institute. It was also demonstrated to a group of pilots at the National Test Pilot School. In total, eighty-four pilots and flight test engineers from industry and the regulatory community spent approximately one hour each in the ICEFTD to get a "hands on" lesson of an iced airplane's reduced performance and handling qualities. Additionally, pilot cues of impending upsets and recovery techniques were demonstrated. The purpose of this training was to help pilots understand how ice contamination affects aircraft handling so they may apply that knowledge to the operations of other aircraft undergoing testing and development. Participant feedback on the ICEFTD was very positive. Pilots stated that the simulation was very valuable, applicable to their occupations, and provided a safe way to explore the flight envelope. Feedback collected at each demonstration was also helpful to define additional improvements to the ICEFTD; many of which were then implemented in subsequent demonstrations.

About the Authors

Billy P. Barnhart is the Vice-president of Bihrle Applied Research, Inc., and has been with the company since 1976. He has participated in or overseen many of the innovations that the company has developed in dynamic data acquisition and utilization in simulations of aircraft motions. He also served as the lead engineer in the development of NASA's ICEFTD described in this paper, developing and implementing the math models and the device hardware, as well as validating the results and assisting in developing the training scenarios described here.

Thomas P. Ratvasky is an aerospace engineer at the NASA Glenn Research Center's Icing Branch. He was the NASA lead in development of the ICEFTD training device and devised the training scenarios discussed herein, as well as serving as the test administrator for the training sessions at the various discussed venues where the ICEFTD was featured. In addition to these, he also served as the on-board flight test engineer during the icing flights of the Twin Otter Icing Research Aircraft.

Introduction

NASA's Aviation Safety and Security Program (AvSSP) and the Commercial Aviation Safety Team (CAST) Loss of Control Joint Safety Analysis Team identified icing as a contributing factor in a significant number of recent fatal accidents (Russell, 2000). Several highly-ranked interventions and research recommendations addressed the need for upset recovery training with high-fidelity simulation and the requirement for improved aerodynamic modeling at the stall and post-stall region of the envelope.

Through the sponsorship of AvSSP's System Wide Accident Prevention Project (SWAP), NASA Glenn's Icing Branch teamed with Bihrle Applied Research and the Wichita State University in 1998 in a program to develop an icing effects flight training device concept demonstrator. The objective of the program was to develop a methodology for deriving and validating icing effects simulation models, and to demonstrate the utility of using this device for training pilots to recognize and recover from the hazardous flight characteristics caused by aircraft icing. These led eventually to the development of NASA's Ice Contamination Effects Flight Training Device (ICEFTD).

The capability for including icing effects into flight training simulators used for initial and recurrent training will allow pilots to experience representative icing-induced aircraft handling characteristics, especially in failure case training scenarios. Presently, icing effects in even the most sophisticated flight simulators are simple models that do little more than increase aircraft weight to simulate in-flight icing. Realistic icing simulator models however, based on aerodynamic effects of airframe icing, will enhance safety by allowing pilots to recognize important visual and tactile cues associated with an icing event. Currently, pilots only experience the effects of an ice protection system failure for the first time in a real flight situation. As in stall and windshear training, improved icing flight simulation will better equip pilots to employ the correct procedures and techniques to effect a recovery to a safe flight condition.

The process that was used to develop the icing flight training device will be briefly outlined here. More detailed aspects of the steps taken during the development have also been reported in various reports, for example: Papadakis, Laflin, Youssef, and Ratvasky (2001), Gingras, Dickes, Ratvasky, and Barnhart (2002), Barnhart, Dickes, Gingras, and Ratvasky (2002), Ratvasky, Blankenship, Rieke, and Brinker (2002), and Ratvasky, Ranaudo, Barnhart, Dickes, and Gingras (2003).

The airplane chosen for this activity was a DeHavilland DHC–6 Twin Otter since NASA had extensive operational experience in icing conditions with this airplane and the Twin Otter has a known sensitivity to ice contaminated tailplane stall.

This paper also describes how the ICEFTD is being used to demonstrate these icing effects at three recent icing short courses held at the University of Tennessee's Space Institute (UTSI) and one demonstration at the National Test Pilot School. Specifically, the training syllabus elements and how they were implemented are discussed. Pilot feedback on the value of the flight training device is also discussed. Lastly, remarks on potential future directions are shared.

Development

One of the primary goals in the development of the ICEFTD was to develop a methodology to be used in future development of other icing effects simulations for different airplane configurations. In order to do this, it was necessary to demonstrate that subscale wind tunnel testing of iced airplane models could yield aerodynamic data of sufficient fidelity that a simulation math model that replicated the icing effects could be produced. Consequently, one of the first steps was to undertake a series of wind tunnel tests to look at scaling of the ice effects. These examined the wind tunnel results for full-scale and sub-scale Twin Otter wing and tail sections with geometrically-scaled ice shapes, as well as a series of similar shapes in order to identify equivalent ice shapes that would produce the correct effects in subsequent sub-scale total airplane wind tunnel tests. These tests did, indeed, identify equivalent simpler shapes that were then used for the total airplane tests.

In the case of the chosen Twin Otter airplane, we did not have access to a high fidelity simulation model of the un-iced aircraft, so wind tunnel tests included the un-iced airplane, as well as two icing conditions. The first condition was tail-plane icing alone and the second was the all-ice configuration that included ice on the wing and both the horizontal and vertical tails. The model was a 6.5 percent-scale model of a Twin Otter.

The data from these tests were subsequently used to produce simulation math models of the un-iced and the two iced configurations. The models were hosted in D–Six, (Bihrle Applied Research, Inc.) a commercial off-the-shelf PC-based simulation environment for further development and validation.

In order to validate the model, a series of flights of NASA's Twin Otter Icing Research airplane were made with the same ice shapes and conditions that were simulated in the wind tunnel test. Using the data from these tests, the models were validated and modified when areas of disagreement were found.

The final step in the development was to construct the actual training device.

ICEFTD Device

The device that was subsequently produced was a stand alone training device (fig. 1) that consists of a raised platform and framework that supports a pilot seat, a control yoke, rudder pedals, a twin turbo-prop throttle quadrant, three flat panel monitors for out-the-window graphics, and two additional flat panel monitors for instrument panel graphics.

Figure 1.—Ice contamination effects flight training device.

Figure 2.—Ice contamination effects flight training device setup with instructor workstation.

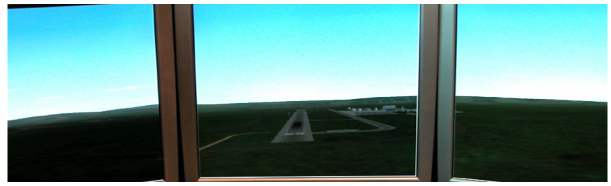

Figure 3.—Out-the-window graphics.

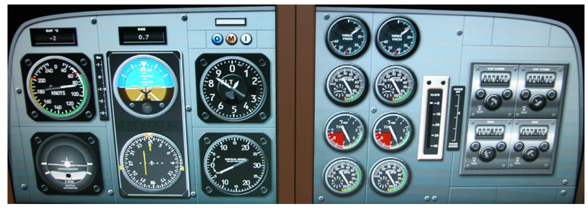

Figure 4.—Instrument panel graphics.

The control column is connected to a programmable loader for longitudinal force feedback, whereas the yoke (lateral) and rudder pedals force gradients are provided by spring resistance. A curtain surrounds the ICEFTD to isolate the pilot from external visual distractions. An instructor station is set up on a table directly behind the ICEFTD (fig. 2). The instructor station consists of a laptop computer to provide control of the simulation (initial conditions, start, stop, etc.), video recording and monitoring devices, and an intercom system for communications between the training pilot and the instructor. A second laptop computer is used to transcribe pilot comments and relevant notes during the simulation sessions.

The D-Six simulation software that was used for math model development also serves as the host for the ICEFTD simulation and for the graphics displays. The out-the-window view (fig. 3) is generated from a generic terrain model and includes features such as an airport, buildings, trees, and varied terrain elevations. Also sky conditions, based on time of day and cloud bases and tops, are fully programmable. The cloud functions are a key feature used in the scenario-based training module. Winds, turbulence and wind shear are also configurable within D-Six environmental settings.

The instrument panel graphics (fig. 4) were designed to represent traditional round dial instrument displays typically found in general aviation airplanes with airspeed, attitude, altitude, vertical speed, heading, and turn/bank indicator instruments. Torque pressure, flap position, and elevator trim tab position indicators are also provided.

A horizontal situation indicator (HSI), distance measure equipment (DME) indicator, and marker beacon indicators were also represented to enable precision approaches to be executed as part of the scenario-based training module. An instrument landing system is modeled for one approach to a generic airport within the terrain model. This model is used to drive the glide slope and localizer needles on the HSI and to trigger marker beacon events–early demonstrations, a stall warning light and horn and a G-meter were added to provide additional cues to the pilot.

A Fokker Control Systems (FCS) electro-mechanical stick loader supplies longitudinal stick feel for the control column and provides column position and column force to the simulation. The yoke height and column deflection limits were matched to those of the Twin Otter so that pilot forces and range of motion would be representative of the simulated aircraft.

Instructor's Station

An instructor's laptop was developed to interface with the D-Six model host and graphics computers to enable an easy-to-use set of controls. In this way, the instructor would not need detailed knowledge of the D-Six software. The instructor laptop uses a graphical user interface (GUI) to enable loading the D-Six project on the ICEFTD computers, setting up initial conditions for the simulator session, and starting/stopping the sessions (fig. 5). The GUI provides radio buttons to set up predefined initial conditions per a training syllabus. It also has switches to turn on/off clouds, winds, turbulence and to set the icing configuration (No-Ice, Tail Ice, All Iced), cloud height and depth, wind speed and direction, center of gravity, and the time of day. During the training sessions, flight parameters are displayed to the instructor in text, and the airplane position and heading are represented on a map display. This allows the instructor to provide direction similar to an air traffic controller, particularly in the scenario-based training sessions. Lastly, during the training sessions, certain flight parameters are recorded in an ASCII file on the instructor laptop for later analysis and discussion with the training pilot. Sample plots are shown in the demonstration section.

Figure 5.—Instructor's laptop GUI.

Another key feature of the GUI is the capability to introduce multi-media training material to reinforce the practical lessons provided by the ICEFTD. At the instructor's discretion, video clips from NASA's "Tailplane Icing" (1998) and "Icing for General Aviation" (2001) can be shown to the training pilot on the center screen of the ICEFTD. The video clips describe various aspects of tailplane stall and wing stall, including cues of impending stalls and recovery techniques. These clips emphasize relevant learning points by showing graphics of fundamental concepts, in-flight videos, and pilot testimonials describing events similar to what the training pilot just experienced in the ICEFTD.

ICEFTD Training Sessions

Four formal demonstrations of the ICEFTD took place between October 2004 and November 2005. In total, eighty-four pilots and flight test engineers from the industry, regulatory and military communities received practical lessons on an iced airplane's reduced performance and handling qualities.

The first two demonstrations were held in October 2004 and May 2005 at the University of Tennessee Space Institute in Tullahoma, Tennessee. Twenty-four pilots and flight test engineers from Bombardier, Cessna, Raytheon, U.S. Army, U.S. Forestry Service, the FAA, and Canada's Transportation Safety Board participated in the *In-Flight Icing and Its Effects on Aircraft Handling Qualities* short course. This short course consisted of lectures, a flight in the UTSI Navion variable stability airplane, and a simulator session in NASA's ICEFTD.

This forum provided an excellent opportunity to demonstrate the ICEFTD capabilities. The lecture materials were relevant, and the Navion flights provided an in-flight simulation of degraded flying qualities due to icing. The Navion flights and ICEFTD sessions were complimentary and offered unique practical experiences on the effects of ice on aircraft flying qualities.

The third demonstration took place at the National Test Pilot School in Mojave, California in October 2005. The ICEFTD was demonstrated as part of the one-year professional test pilot program and several short course offerings. Nineteen pilots (mostly international military) and flight test engineers were exposed to the Twin Otter icing flight characteristics. Unlike the previous demonstrations, this was not a forum focused on icing. Because of this, the video segments available in the ICEFTD were used more extensively to support the simulator sessions and emphasize the icing effects on stall characteristics and controllability. Many pilots were simply amazed at the amount of control difficulties caused by ice and were grateful to experience these problems in the simulator.

The fourth demonstration was held in November 2005 as part of the UTSI *Aircraft Icing Short Course* in Wichita, Kansas. Eighty-nine pilots and engineers from Bombardier, Cessna, Raytheon, and the FAA attended this short course. It consisted of two days of lectures followed by a simulator session in the ICEFTD for forty-one of the participants. Each was scheduled a one-hour session during the week following the lectures.

The demonstration in Wichita was the most extensive of the four demos and had benefited from the feedback following the other demonstrations. Consequently, the remaining discussion will expand on the process used and the results from this demonstration.

A briefing was held for each trainee pilot prior to the training sessions to familiarize them with the ice shapes used in the ICEFTD simulation and to review the various training profiles to be accomplished in the training session. They were also reminded that the aircraft characteristics shown are unique to the DHC–6 and that some configurations used in the training were outside of the manufacturers limitations as provided in the Airplane Flight Manual. Finally, review the pilot controls and instrument displays on the ICEFTD were reviewed.

The training profiles consisted of the following three blocks.

Familiarization with the ICEFTD and Twin Otter flight characteristics

The first block familiarized the pilot with the basic (non-iced) flight characteristics and the ICEFTD pilot controls and instrument panel. This was accomplished by having the pilot perform a takeoff and climb in visual meteorological conditions (VMC). Pilots were directed by the instructor to climb to specific altitudes, make turns to headings, and asked to apply longitudinal and lateral inputs to assess normal aircraft handling characteristics. These maneuvers consisted of longitudinal step or doublets and lateral step inputs for various flap settings. These maneuvers were accomplished within a normal traffic pattern after which a flap 30 ($\delta F = 30°$) landing was accomplished in VMC. This block typically took about 15 min to accomplish.

Icing Effects

The second block demonstrated the effects of the failure ice shapes on wing stall and tail stall characteristics. The exercise was initiated at 8000 ft above ground level with the airplane configured with No-Ice and $\delta F = 0°$. The pilot was instructed to reduce power to idle, trim the airplane at approximately 1.3 Vs (85 kts), and then decelerate to achieve a full aerodynamic wing stall. Then with the airplane in stabilized flight, the failure ice (All-Ice) would be switched ON. The pilot retrimmed the airplane at 85 kts and performed the wing stall and recovery with the ice on. Pilot comments were taken throughout the maneuver. These maneuvers were then repeated with flaps set to 20° and 40°. When the flaps reached full deflection, the pilots were instructed to either add power or reduce power to see the effects that power has on the condition they were experiencing. Also, the pilot was instructed to increase and decrease airspeed by 10 knots to observe the effect that speed has on the condition they were experiencing. Lastly, the pilot raised the flaps to return the airplane to its original trim condition and observe the normal flying characteristics of that configuration. This training block typically took about 15 min to complete.

Operational Scenario

The third training block placed the pilot in an operational situation with the iced airplane. This consisted of performing three precision approaches and landings. These exercises were initiated with the airplane at 3000 ft, 10 miles south of the airport and offset from the localizer by 1 mile. The initial condition was a speed of 120 knots and flaps up. The pilot was instructed to turn to a heading to intercept the localizer and to have the airplane configured with 20° or 30° of flap and slowed to an 85 knot approach speed by the final approach fix. The pilot was cleared for the approach and landing. Pilots with instrument ratings performed the approach tasks in instrument meteorological conditions (IMC) with ceiling set at 200 ft, while pilots without instrument ratings performed all tasks in VMC. During the first three days of training, all approaches were conducted with the wing and tail failure case ice condition. Pilots flew the first approach with flap 20°, followed by a second approach with flap 30°, and the third approach with flap 30° from which a go-around was directed followed by a visual circling approach. While circling, the pilot was then asked to execute a landing at the greatest flap angle possible with reasonable workload and safety.

During the second three days of training, the profile was altered slightly. All pilots flew the first approach in the No-Ice baseline and flaps at 30°. The second and third approaches were then flown with the failure case All-Ice condition and at 20° and 30° of wing flap, respectively, and in either VMC for inexperienced pilots or IMC for experienced pilots. The purpose of the change was to allow pilots one practice approach to evaluate the basic approach task workload. Experienced pilots were also given 10 knot crosswinds on their third approach. To quantify the impact of icing and wing flap configuration, experienced pilots were asked to evaluate each approach and landing task within specified tolerances using the Cooper-Harper handling quality rating (HQR) system. This training block took about 30 min to complete.

In total the training sessions took approximately one hour to complete. In this way, these profiles enabled a throughput of about 7 pilots per day. Over the course of six days, forty-one pilots were trained

Results from the Training Sessions

The range of pilot experience was quite large, from highly experienced test pilots with over 10,000 hr of flight experience to private pilots with very few hours. The following results are generalized from observations and notes made by the NASA and UTSI simulator instructors.

Icing Effects

These exercises demonstrated stark differences in handling characteristics and pitch control between the non-iced Twin Otter and the Twin Otter with failure case ice shapes. For example, no abrupt pitch or roll tendencies occurred during stalls with the non-iced Twin Otter. However, during stalls with failure ice, pilots experienced and commented on the “roll-off” tendency, especially with flaps set at 20°. These roll-offs resulted in steep bank angles, sometimes reaching or exceeding 90°. Figure 6 contains plots from one of the flap 20° stalls. The first 100 sec shown is a stall maneuver for the No-Ice configuration. Note that there were no strong roll off or pitch down tendencies at 70 sec when the stall angle was achieved. After 100 sec, the All-Ice switch was enabled, and the stall maneuver with ice was performed. Observe at about

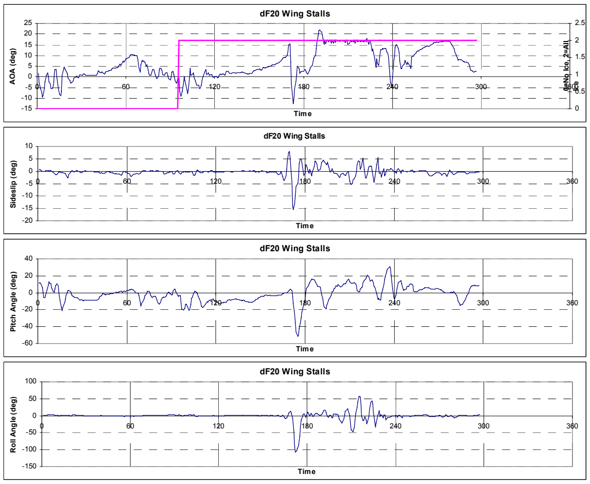

Figure 6.—Flap 20° wing stalls (No-Ice and All-Ice).

170 sec the abrupt stall with large sideslip and roll the pitch angle achieved a 50° nose down attitude during the recovery.

During flap transitions with failure ice, pilots noted flap position in relation to the first signs of controllability problems. Many pilots expressed some surprise when encountering the very high control forces associated with wing flap extension, and discovered the difficulty in maintaining good pitch attitude control. All pilots experienced large pull forces to maintain 85 knots as flaps transitioned beyond 20°, and when the column force also became oscillatory, most were unable to maintain good airspeed control. As power was added, the forces increased and when power was set to idle, the forces decreased. Likewise, as airspeed increased, the pull forces increased and were more oscillatory and when airspeed was decreased, the forces and oscillations were reduced. When flaps were raised, all noted that the forces and oscillations went away when flaps were less than 15°. This introduction provided a necessary practice and orientation for the more difficult approach tasks that followed.

Operational Scenarios

These exercises were developed to provide realistic pilot task with the iced aircraft. Since icing issues often arise during the approach and landing phases, it was appropriate to look at these phases for the exercise. Performing the approach using basic instrument displays required a higher pilot workload to perform the task. From the outset it was apparent that for some pilots, the workload was high in order to fly the basic IMC approach task using the raw data glide slope and localizer presentation. This was the reason for changing the training profile during the second week, so pilots could get a feel for the basic task workload with no compensation for ice, and comparisons on the pilot performance and HQR's could be made between the No-Ice and All-Ice configurations.

No-Ice Approach and Landing

This first IMC task allowed the pilots an opportunity to understand the workload of the basic task, while developing their instrument scan. Pilot performance and ratings indicated good flying qualities with relatively low levels of pilot compensation required to meet the desired performance of the task. This exercise was initiated in the clouds, and the pilot was given heading and altitude instructions to intercept the localizer. The flaps were transitioned from $\delta F = 0°$ to $\delta F = 30°$ by the final approach fix, and the pilot was to maintain 85 knots on final approach. The pilot made power changes and trim changes accordingly as flaps and speed were set to maintain descent rate along the glide slope. All pilots were able to trim the airplane and fly with one hand on the yoke, and one hand on the throttle.

Data from one of these approaches are shown in figures 7 and 8. This pilot felt the workload was fine; he could make radio frequency changes, read maps, etc. It took him some time to get established on airspeed and had some lateral overshoots on the localizer. Overall, he rated the task with an HQR = 3 (aircraft characteristics were fair with some mildly unpleasant deficiencies, but desired performance was achieved without improvement).

All-Iced Approach and Landing

Pilot performance and HQR's for the approach and landing in the All-Ice configurations generally indicated a much more challenging airplane to fly.

The second and third approaches were made with All-Ice and $\delta F = 20°$ and $\delta F = 30°$, respectively. When the flaps were lowered, the control anomalies experienced during the flap transition were revisited. With $\delta F = 20°$, a slight pull force was required even with full-nose up trim in order to maintain the 85 knot target approach speed. With $\delta F = 30°$, a significant pull force (15 lb) was required to maintain 85 knots. Force oscillations occurred on top of these steady pull forces, making speed and attitude control difficult. Most pilots used two hands on the yoke to control the airplane.

Many pilots found that the workload associated with flying an approach to CAT I minimums with the failure case icing condition was in many cases at the limits of their abilities. Handling problems were caused by horizontal tail ice, but the task was further complicated by the failure ice on the wing, which resulted in lateral handling problems made it difficult to control airspeed.

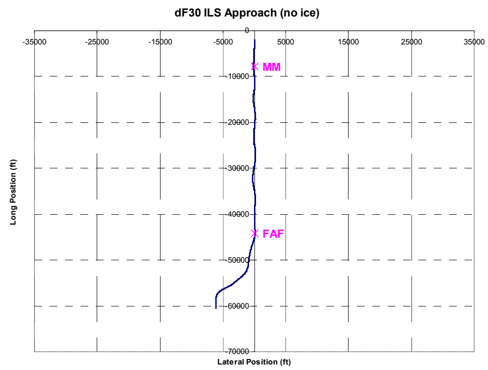

Figure 7.—Position trace—flap 30° approach (No-Ice).

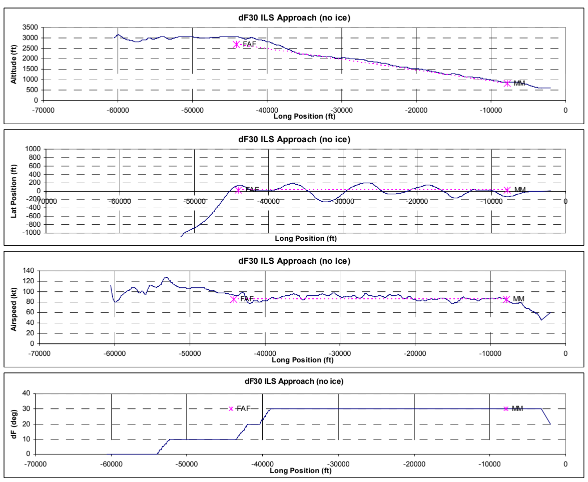

Figure 8.—Flap 30° approach (No-Ice); data referenced to position.

In some cases, wing stall recoveries were difficult due to the high induced drag at high angle of attack and low altitude. Increased power was not enough to break the stall, and there was not much altitude to exchange for airspeed. These cases would sometimes result in a crash. All experienced pilots found that most of their attention had to be devoted to controlling pitch to achieve vertical path performance. This element of the task consumed most of their attention because of icing related instability, high control forces, inability to trim, and related pitch control anomalies. Although not sensed by the pilot, during the pitch excursions, the G-meter would often cycle between 0 to 2.5 G. Because of the intense amount of attention required for pitch control using a basic attitude indicator, lateral path performance and airspeed control usually suffered.

Data from one of these approaches is shown in figures 9 to 11. This pilot had difficulty throughout the approach. Airspeed was consistently high, which made the pitch control more difficult. Power changes were

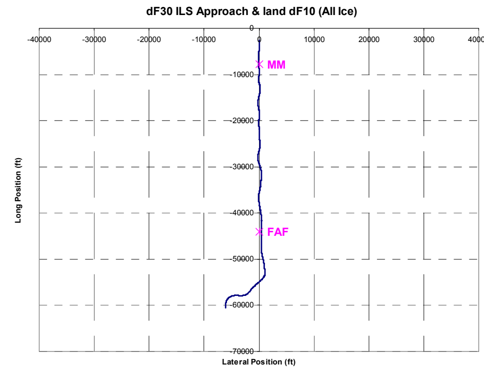

Figure 9.—Position trace—flap 30° approach (All-Ice).

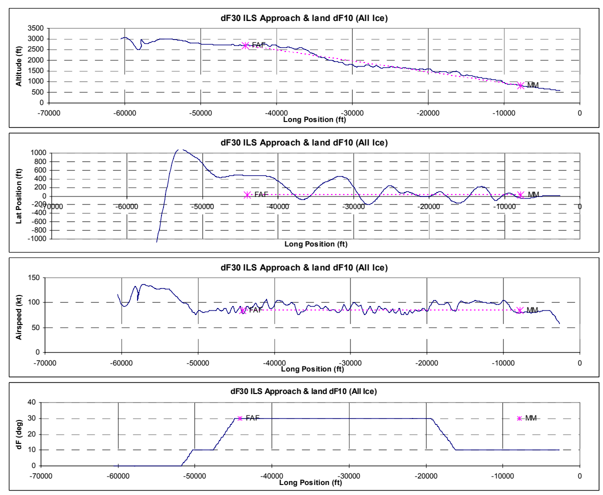

Figure 10.—Flap 30° approach (All-Ice); data referenced to position.

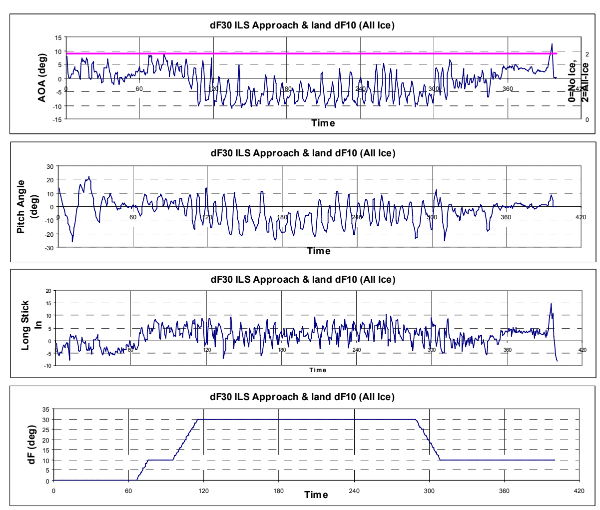

Figure 11.—Flap 30° approach (All-Ice) time history.

large and abrupt, which degraded handling further. Concentrating on the longitudinal problems, he failed to intercept the localizer initially and had multiple lateral overshoots throughout the approach. Towards the middle of the approach, the large pitch oscillations caused multiple stall warnings as G was increased and airspeed decreased. Since it was clear that the pilot was task saturated, the instructor suggested raising the flaps to 10° to finish the approach. The workload was considerably deceased with this configuration, and the pilot was able to successfully land the airplane. Note in figure 11 when flaps reached 10°, the oscillations in angle of attack, pitch angle, and longitudinal input were greatly reduced. This pilot rated the iced airplane with δF = 30° as an HQR = 10 (aircraft characteristics have major deficiencies, and that control would be lost during some point of the operation).

Handling Quality Ratings

After each approach and landing, pilots familiar with HQR's were asked to use the Cooper-Harper rating system to rate their ability to complete the approach and landing tasks within specific adequate and desired performance metrics. The HQR's from sixteen pilots who performed the approaches in the No-Ice/ δF = 30°, All-Ice/δF = 20°, and All-Ice/δF = 30° configurations were compiled into figure 12.

For the No-Ice, δF = 30° configuration, pilots rated the approach and landing between an HQR = 2 to HQR = 4. Many pilots commented on the lack of practice as contributing to the higher rating, and this point should be considered in using the actual HQR number. Even without much practice, the general rating was that desired performance was achieved and aircraft characteristics were good to fair with some deficiencies.

For the All-Ice, δF = 20° configuration, pilot ratings ranged from an HQR = 4 to HQR = 9. The increase in the ratings was certainly due to the reduced stability

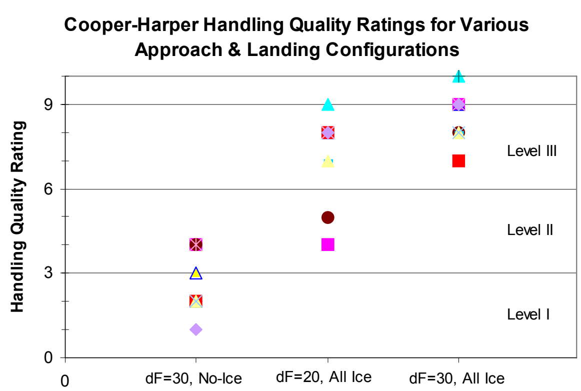

Figure 12.—Cooper-Harper ratings.

and controllability as well as the handling anomalies associated with icing. The increased spread in the numbers reflected to some degree the skill level and experience of the individual pilot receiving the training. Additionally, the spread could have been influenced by the "learning curve" or proficiency gained as the training progressed and pilots became more familiar with the displays and aircraft characteristics. This was an expected result as pilot task performance generally improved with practice and it did affect pilot ratings. In a more rigorous pilot evaluation setting, a certain amount of time would be given to pilots to develop a baseline level of proficiency and familiarization before rating a task.

For the All-Ice, δF = 30° configuration, pilot ratings ranged from an HQR = 7 to HQR = 10. This increase in the ratings reflects the increased workload associated with the greater amount of pilot compensation at the higher flap setting. In this configuration, none of the pilots were able to meet the adequate performance metrics of the approach due to the inability to trim, the large and oscillating column forces, large pitch excursions when making power changes (one-handed operation), and loss of situational awareness on the lateral position. As stated above, some pilots encountered wing stalls and were unable to recover in this configuration due to increased drag and limited altitude. Although most pilots rated the δF = 30° approach the worst case condition, a few rated this task slightly better (lower compensation) than the δF = 20° approach. These pilots felt that the proficiency acquired on the δF = 20° approach, which was flown before they flew the technically more difficult δF = 30° approach, was the reason. Overall, pilot ratings accurately reflected the inability of meeting performance requirements with flaps extended. Most pilots exited the training device perspiring freely and commenting that no additional workout was needed for the rest of the day. These comments confirmed the physical effort and intense concentration required to perform the training tasks.

Pilot Comments on ICEFTD Training Sessions

All pilots commented very favorably on their training experience and the applicability it had to their present occupations. Pilots who had participated in development programs for aircraft with reversible controls identified strongly with the characteristics shown by the ICEFTD. Others who had not had this experience were in general surprised by the amount of effort it took to perform the given tasks. None had ever encountered the levels of control forces or feedback activity as was demonstrated during this simulation. One pilot commented that he recently completed an extensive icing development and certification program on a Part 25 business jet with a major aerospace company. During the development phase with 22.5 min ice shapes on the horizontal tail leading edge, he observed large, uncommanded stick pumping and pitch transients when flaps were moved to the landing configuration. He also noted that the aircraft could not be trimmed at the approach speed. Stick pumping developed and strengthened as the aircraft accelerated with increase power setting. The simple procedure of raising the flaps to the last setting completely eliminated the problem. This pilot was pleasantly surprised to observe that the ICEFTD accurately simulated the same phenomenon that he had experienced, even though the two aircraft were radically different in design, tailplane configuration, and powerplant. The lectures and the ICEFTD demonstration gave him a clear understanding of what he had experienced during their icing program. He strongly recommend the ICEFTD to any flight test crew (test pilots and flight test engineers) who are in the process of preparing for an icing development or certification program. He considered this training a "must have"!

Instructor's Observations and Recommendations

The workload associated with the basic IMC approach task made a significant difference in the pilot's ability to meet either the desired or adequate performance criteria in the failure case ice shape configuration. We think this is a very important observation that should be considered when performing actual aircraft handling evaluations with ice shapes, especially if an aircraft displays handling differences with failure case ice. Even minor handling deficiencies coupled with a high workload task can result in unacceptable "average pilot" performance. The draft Advisory Circular 25.21–1X proposes that approaches be made with failure case ice, but does not specify that the pilot executing these approaches perform them with vision restricting devices. Another consideration is that when first encountering an icing failure case the average pilot may not have the benefit of a "learning curve" as was recognized by most pilots participating in this training.

Conclusions

The Ice Contamination Effects Flight Training Device was successfully demonstrated to eighty-four pilots and flight test engineers through four venues. Training sessions familiarized pilots with the aircraft simulation, illustrated differences in wing and tail stall character due to ice shapes, identified cues and variables that reduce or exacerbate the problems, and, lastly, placed the pilots in an operational scenario with the iced aircraft to demonstrate the potential extent of the problem icing can pose. All of the pilots who participated in the demonstrations were complimentary of the ICEFTD and found the training to be applicable to their occupations.

The ICEFTD successfully demonstrated that icing effects can be modeled accurately in flight training devices to show how they alter flying qualities significantly. Clearly, simply adding weight and increasing drag in pilot training simulators does not sufficiently model the change in stall characteristics that pilots would experience in real-world operations. Based on the potential safety benefits of this training, the authors recommend that the technology demonstrated herein be considered for incorporation in current full flight simulators or flight training devices.

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13. ABSTRACT ***(Maximum 200 words)***
The development of a piloted flight simulator called the Ice Contamination Effects Flight Training Device (ICEFTD) was recently completed. This device demonstrates the ability to accurately represent an iced airplane's flight characteristics and is utilized to train pilots in recognizing and recovering from aircraft handling anomalies that result from airframe ice formations. The ICEFTD was demonstrated at three recent short courses hosted by the University of Tennessee Space Institute. It was also demonstrated to a group of pilots at the National Test Pilot School. In total, eighty-four pilots and flight test engineers from industry and the regulatory community spent approximately one hour each in the ICEFTD to get a "hands on" lesson of an iced airplane's reduced performance and handling qualities. Additionally, pilot cues of impending upsets and recovery techniques were demonstrated. The purpose of this training was to help pilots understand how ice contamination affects aircraft handling so they may apply that knowledge to the operations of other aircraft undergoing testing and development. Participant feedback on the ICEFTD was very positive. Pilots stated that the simulation was very valuable, applicable to their occupations, and provided a safe way to explore the flight envelope. Feedback collected at each demonstration was also helpful to define additional improvements to the ICEFTD; many of which were then implemented in subsequent demonstrations.

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