Perspectives and Visions

Eugene G. Hill[1]
Aviation Safety, Federal Aviation Administration
Seattle, Washington 9805-4056

Perspectives on the roles of science and engineering in resolving global issues are discussed, with emphasis on research that would improve aviation safety in atmospheric icing. Visions of improvements that emanate from these perspectives include coupled autopilots, improved diagnosis of icing intensity, validated icing simulators, a comprehensive icing conditions standard (including development of validated engineering tools for simulation of the icing standard conditions), and flight crew training for ensuring safe operations in icing conditions. Recommendations made by Frank Lynch in an earlier AIRA presentation are endorsed. The resources required to fulfill these visions are very significant, resulting in the need for collaborative research and the leveraging of available resources to achieve. The Aircraft Icing Research Alliance is seen as a key venue for promoting this collaborative research.

I. Introduction

John McMaster's of the Boeing Company presented an AIAA invited paper a couple of years ago about the "making" of engineers. John commented that engineers get "hooked" on engineering by having that urge become alive by excellent mathematics or science teachers, or, for aeronautical engineers, by being hooked on airplanes. For me, the urge came alive well before science or math courses. Airplanes romanced me through World War II movies that graphically showed dogfights between RAF Spitfires and the German Luftwaffe. I then built "stick" airplane model airplanes bought at the five and ten cents store and often pressed my nose against the hobby shop window, drooling over the expensive 75 cents Cleveland model airplanes that were far beyond my empty pockets. All I knew was that I wanted to fly. When examined for my first eyeglasses, I hoped that the glasses would improve my eyes so that I could fly when I grew up.

During my first year in college I was surprised to learn that there was an aeronautical engineering curriculum at the University of Illinois. I enrolled in the Chicago branch of the University of Illinois, and in 1957 finished my last two years in the Aeronautical Engineering Department at the University's campus at Urbana-Champaign. After two years in the 19th Combat Engineer Battalion, I was fortunate to join the Aeronautical Engineering Staff of the Boeing Company in 1959 and remained on the Staff, until retiring in 1996, as an engineer and as a manager. During that period I attended the University of Washington, taking graduate courses in Aeronautical Engineering, and completed a Masters of Business Administration (MBA) degree at Seattle University, concentrating in international finance. My career at Boeing allowed me to be a part of aviation history with the development of the fleet of Boeing commercial air transports, dating from the 707 to the 767. My career path included flight testing, certification, airplane performance, high lift research, airplane configuration, and several years managing testing development at the Boeing Aerodynamics Laboratory.

My retirement from Boeing was triggered by an opportunity to complete my career technically as the National Resource Specialist for Flight Environment Icing. Thirty-seven years at Boeing provided me the airplane "know-how" to address the technical issues involved with the FAA assignment, and my years as a manager and my MBA training provided the skills and attributes to easy interface with FAA engineers and management.

Other than juxtaposing my ancient Post slide rule along side my Dell lap-top computer, perhaps comparing a photograph of the Boeing 727-100 rollout to an image of Hurricane Katrina derived from information produced by

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[1] Chief Scientific and Technical Advisor for Atmospheric Icing, 1601 Lind Ave., S.W., ANM-111N, Renton, WA 98055-4056, AIAA Member.

the United States/Japan Tropical Rainfall Measurement Mission provides a statement of how technology has changed during my career in the aerospace industry. These images are shown in Figures 1 and 2.

As with many others, life and my career path have impressed me with strong convictions and, hopefully, some insight worthy of sharing. Following are a few of these perspectives and visions. My first few comments will be global in nature, followed by comments on what I see that needs to be done to improve aviation safety during operations in atmospheric icing.

II. Global Thinking

While in business school during the early 1970s, brand "X" and brand "Y" management styles were highly debated. The issues resolved around the merits and fallacies of humanistic and authoritarian management. Coupled with this debate on management style were warm discussions on the role of the corporation in society, ownership of the corporation (stockholders versus management), and the importance of profits. Being a Jesuit school and being exposed to excellent coursework in social psychology and communications, the humanitarian worldview tended to be favored by most of the Seattle University School of Business MBA graduates.

The global issues of war, poverty, famine, and genocide are ages-old. Recently we have become aware of the need to address global warming and an impending depletion of economical fossil fuels. These are people problems, and we have the responsibility to solve these problems since we are stewards of our planet and should provide an inhabitable environment for our descendents. Solutions to these issues require vision and careful management of our material and human resources. Visionary leaders will be required to see the resolution of these long-term problems beyond desirable short-term gains and personal wealth. Engineering and science, coupled with the acumen to focus the necessary political, will no double be part of the solution. We as technocrats have a role to play in resolving these issues. In many ways we are more able than others to define and make clear some of these global issues for the public and, in our ability to influence the expenditures of limited research resources, we are more able to ensure that our short terms goals are aligned with the solutions to our long term problems. We are also able to design our organizations for better communications and cohesiveness and to more effectively accomplish our portion of the solution through good management of the available resources.

Of particular interest to us is our depletion of fossil fuels, especially oil. We have already seen the economic impact of oil costs being at about $50 a barrel, as compared to the $15 - $25 benchmark prices of the recent past. Airlines now know how the price of oil impacts their ability to do business, and our automobile industry has recently suffered the consequences on focusing their product lines on highly profitable but high fuel-consumption, automobiles. Also, we are now facing increased competition for oil as the economies and energy needs of developing countries like China and India accelerate. How well are we addressing the replacement of oil as an energy source? Who are our visionary leaders? What will be the future propulsion systems for our airplanes, cars, trucks, trains, and cargo ships? Is the solution close at hand and are the commercial infrastructure changes designed?

III. Icing Research for Aviation Safety

I want to narrow our focus to the issues of highest interest to us in this room, research to improve the safety of air transport in atmospheric icing. Avoidable aircraft icing accidents continue to occur. I would like to challenge you to make real several doable visions that can prevent many of these needless accidents and save lives and property.

First, I want to endorse recommendations made by Frank Lynch from this podium last year. We continue to do study the aerodynamic effects of ice accretions in low Reynolds number wind tunnels. We need to make sure that Reynolds number effects are considered in our studies. Progress is being made in this area with recent flight-testing of pneumatic deicing boot inter-cycle ice shapes. With the prohibitive cost of high Reynolds number testing at the NASA-Langley Low Turbulence Pressure Tunnel (and, perhaps its demise) and at CIRA, we should be encourage NASA to consider other visions, such as a including a two-dimensional airfoil insert as a part of upgrading the NASA-GRC Propulsion Systems Laboratory (PSL) to address engine operability in high-ice water content environments.

My first vision is that the rate of aviation accidents in atmospheric icing is no worst that than for flight in clear air. The concept that we can give up some of the safety margins for flight in icing since icing is experienced so seldom is questionable. Icing conditions present more hazards to flight than clear air and why safety margins can be reduced for more hazardous conditions seem illogical. To achieve the same level of safety as that for clear air, the margins of safety may have to be larger for flight in icing. Achieving this vision will include my other visions and more.

Development of low-cost autopilots for small airplanes that couple an automatic propulsion system throttle with the automatic flight controls system is a vision worthy of our consideration. Icing accidents and near-accident events continue to occur without full use being made of the available airplane power as the autopilot trims the airplane into the threshold of a stall. All of the resources designed into an airplane should be used to ensure safe flight. The availability of coupled autopilots, I feel, is a design feature of large aircraft that has significantly contributed to their record of safer in-flight icing operations, when compared to smaller regional and commuter type air transports. The cost of coupled-autopilots is sometimes raised as an issue for small airplanes. However, simple coupled-autopilot designs have been offered. A coupled-autopilot would also provide the opportunity to implement more effective flight-envelope protection for this class of airplanes. There may be a tendency in the aerospace community to extend the life of current products through continued tweaking and modifications to perform additional functions. There may also be a level of corporate confidence and safety found in staying with the familiar technology. In some cases, such tweaking and modifications may in the end be more expensive than moving forward with a new vision. Implementing coupled-autopilots in the smaller airplanes would be movement toward an eventual "smart ice protection system" which would further protect the airplane from the hazards of in-flight icing.

After years of debate on how best to identify icing intensities for use by the National Weather Service and by pilots for Pilot Reports (PIREPS) of icing, a vision of icing conditions reporting and forecasting that identifies icing intensity by liquid water content, average drop size, and temperature is becoming realistic. Using this information, airframe manufacturers can provide flight crews with the icing conditions that should be avoided for specific airplane designs. PIREPS could then be interpreted in terms of probable liquid water content and flight crew could use the information when entering reported icing conditions. Continued support for research underway at the National Center for Atmospheric Research subsequent cooperation by airframe manufacturers are needed to make this vision real.

We are continually reminded of our vision of improved ice protection concepts by the increasing number of small airplane in-flight icing accidents. Applicants seeking approval of ice protection systems for these airplanes are becoming increasingly sensitive to the ineffectiveness of some ice protection systems as the means of compliance with regulatory requirements lead airframe manufacturers to look more closely at the aerodynamic effects of their product's ice protection system's effectiveness. For example, the ice protection system inter-cycle ice shown in Figure 3 causes significant adverse aerodynamic effects. Ice protection system certification procedures now require consideration of ice accretion roughness that result from system's normal operation. Old technologies, such as fluid ice protection systems, may have to be re-visited. Increased use of electrically charged carbon-filament heating pads and other advanced ice protection systems should be investigated. Fulfillment of this vision has been slow, and increased attention is needed.

Most of us have a vision of minimizing the costs of obtaining approval of ice protection provisions by use of icing simulation methods. These icing simulation methods include icing wind tunnels, drop impingement and ice accretion codes, icing tankers, and analytical methods based on experience. To ensure safe flight, airframe manufacturers as well as civil aviation authorities emphasize that these simulation methods be validated before their use to eliminate the need for testing in natural icing conditions. There are no commonly accepted criteria for validating these tools, beyond visual comparisons of salient ice shape characteristics, such as the chordwise extent of ice shape or the general features of glaze ice. Some airframe manufacturers would suggest that current methods provide an adequate simulation of 14 CFR part 25 Appendix C icing conditions. A year 2000 workshop sponsored by the North Atlantic Treaty Organization Research and Technology Organization assessed how well and reliably computer codes can predict ice accretion shapes for conditions representative of in-flight icing. Figure 4 provides an example of the workshop's findings. Visually, there are differences between the computed and the icing wind tunnel ice shapes. To understand the significance of the visual differences, aerodynamic wind tunnel tests are necessary. These tests have not been performed. Low Reynolds number testing performed by the University of Illinois at Urbana-Champaign suggests that the visual differences are significant aerodynamically. The workshop findings lead the code developers to meet and understand the causes for the differences. A similar project, sponsored by the Society of Automotive AC-9C Subcommittee Facilities Comparison Panel, compared ice shapes obtained with same models in North American and European icing wind tunnels. An example of the SAE AC-9C Facilities Comparison Panel findings is shown in Figure 5. The differences between the ice shapes from the various tunnels are more striking than those from the NATO RTO Workshop. The findings also question the viability of calibrating ice accretion codes to icing wind tunnel ice shapes. In spite of the striking differences between the wind tunnel ice shapes, analysis of the icing wind tunnel data suggests that much of the differences can be traced to the use of different methods used to calibrate the tunnel's icing cloud liquid water content and drop size and to use of different spray bar nozzle technology. We can conclude that we have not yet realized our vision to use icing simulation methods to eliminate the need for natural icing flight tests in Appendix C icing conditions. Our vision is within reach, but more work is needed.

The 31 October 1994 fatal accident of a regional air transport near Roselawn, Indiana, highlighted the hazardous of flight operations in supercooled large drop (SLD) icing conditions. Recent scrutiny of the aviation safety record by Steve Green revealed that SLD conditions have caused a larger percentage of accidents and incidents than might be suggested by the frequency of exposure to icing conditions, especially for small air transports and airplanes. Following the Roselawn accident, the National Transportation Safety Board recommended that the FAA disallow flight operations in icing conditions for which safe operation of the airplane has not been shown. The Airline Pilot Association has made a similar recommendation. In response to a request by the FAA, the Aviation Rulemaking Advisory Committee (ARAC) has forwarded proposed SLD rulemaking to the FAA. ARAC also endorsed a recommendation from its working groups that significant progress toward development of reliable and confidents means of compliance for the proposed rulemaking be made before release of the proposed rulemaking for public comment. A roadmap, developed by NASA in behalf of the Ice Protection Harmonization Working Group (IPHWG), was forwarded to the FAA by ARAC. This roadmap is shown in Figure 6. The vision of a more comprehensive icing conditions standard for ensuring that aircraft ice protection provisions support safe operations in icing environments encountered worldwide is commonly understood. The inclusion of SLD as part of the icing conditions standard has been defined. A very significant research program must be accomplished before our vision of a more comprehensible icing conditions standard can be realized. Significant collaboration, nationally and internationally, will be required to complete the tasks identified by the SLD Engineering Tools Development Roadmap.

Considerations of flight hazardous associated with mixed-phase and glaciated icing conditions were also recommended by the NTSB in response to the Roselawn accident Although the IPHWG found that mixed-phase and glaciated icing conditions do not pose a hazard for airframes, the ARAC composite Engine and Power Plant Installation Working Group (E/PPIHWG) determined that these icing conditions pose a safety threat for turbofan engine operability. Subsequent to defining a standard for mixed-phase and glaciated icing conditions as a proposed Appendix K to 14 CFR part 33 and drafting proposed rulemaking for engine operation in high ice water content mixed-phase and glaciated icing conditions, the E/PPIHWG recommended completion of a Mixed-phase/Glaciated Icing Technology Plan, as outlined in Figure 7. Key elements in the Plan include:

- Instrumentation development and evaluation for high ice water content measurements.
- In situ characterization of high ice water content atmospheric environments.
- Experimental research to support development of engine ice accretion modeling and validation of these models.
- Development of requirements for test facilities that would be used to perform the above experimental research and used for showing compliance with the proposed rulemaking.

Adding mixed-phase and glaciated icing conditions to our vision of a comprehensive icing conditions standard for safe aircraft operations in icing conditions significantly enlarges what is already a major research program for SLD. In addition to development of a high ice water content probe, the NASA Viking test airplane must be instrumented and elevated to flight status. Flight test programs must be funded to make in situ measurements of high ice water content environments in geographical locations where high ice water content conditions are prevalent to better characterize that environment. Preliminary studies suggest upgrading the NASA Glenn Research Center Propulsion Systems Laboratory, shown in Figures 8 and 9, for ice particle simulation and testing of suitable turbofan engine to better understand the icing physics involved with the icing of turbofan engine cores and for obtaining data to validate engine icing models.

Achieving our vision of a comprehensive icing standard that would ensure safe operations in atmospheric icing is a major undertaking. A strategy must be developed for funding the effort if our goal is to have the comprehensive icing standard within the next five years. The magnitude of the required funding will challenge the funding of other critical research projects. Visionary leadership will be necessary.

Lastly, icing accidents continue to tell us that increased flight crew awareness is needed about the hazards associated with operations in atmospheric icing conditions, both on the ground and in flight. We are repeatedly reminded that development of such training material is not research. Work accomplished by NASA has shown the value of performing cognitive psychology research and making the effort to produce instructive and interesting icing training media. If attention is not given to properly train flight crews to safely operate aircraft in icing conditions, our other investments to ensure safe operations in atmospheric icing will be wasted. A way must be found to ensure that this key part of our vision is realized.

IV. Conclusions

Although the some of our global visions may be insurmountable, the visions that support safe air transport operations in atmospheric icing conditions are achievable. These visions are expensive and require research resources that are probably beyond the capability of any one agency or organization. Collaborative research will be required. This need for collaborative aircraft icing research underscores the importance of the Aircraft Icing Research Alliance's (AIRA) mission. Full participation in AIRA would benefit civil aviation authorities worldwide. Even though their research resources may be limited, their participation in AIRA would allow them to influence the prioritization of aircraft icing research that are important to aviation safety needs of their country.

AIRA, through fostering collaboration in field campaigns to evaluate ground and satellite based sensors for detecting and diagnosing icing conditions aloft has already contributed to making real the visions of flight safety addressed by this paper.

Figure 1. Rollout of the Boeing Model 727-100.

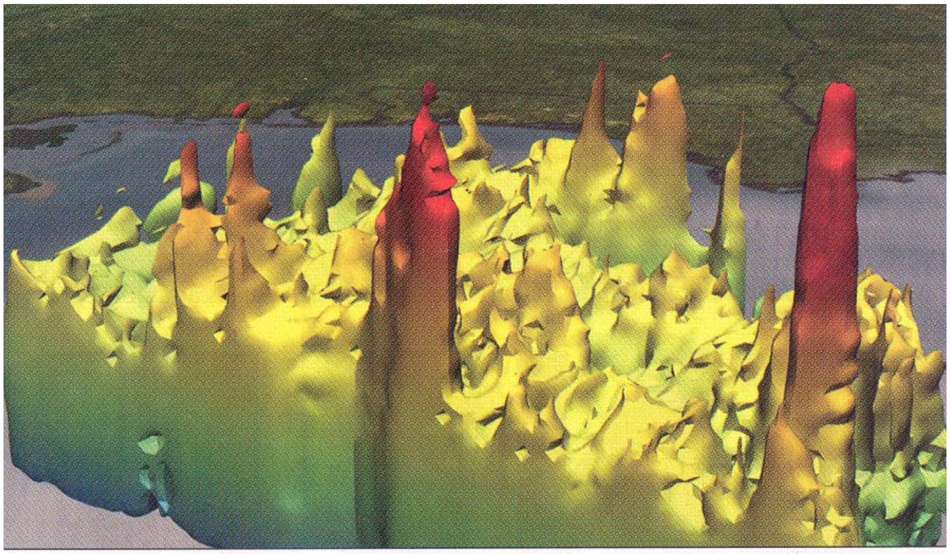


Figure 2. United States/Japan Tropical Rainfall Measurement Mission space-based precipitation radar image of Hurricane Katrina Aug. 28, one day from landfall on the Louisiana/Mississippi coast, shows the Category 5 hurricane further intensifying by pushing warmer, rain-laden towers (red) to 53,000 ft. (Courtesy of Aviation Week and Space Technology.)

Figure 3. Hybrid NACA 23012 2D (simulating a 72-inch chord airfoil) model intercycle ice before the third cycle of a pneumatic deicing boot. Three-minute boot cycle intervals were used. The test was performed in 14 CFR part 25, Appendix C Maximum Continuous Icing Conditions. (Static temperature = 14°F, LWC = 0.45 g/m^3, MVD = 20 micrometers, Spray time = 6:11 min., Tunnel airflow speed = 195 mph, Model AOA = 4°.)

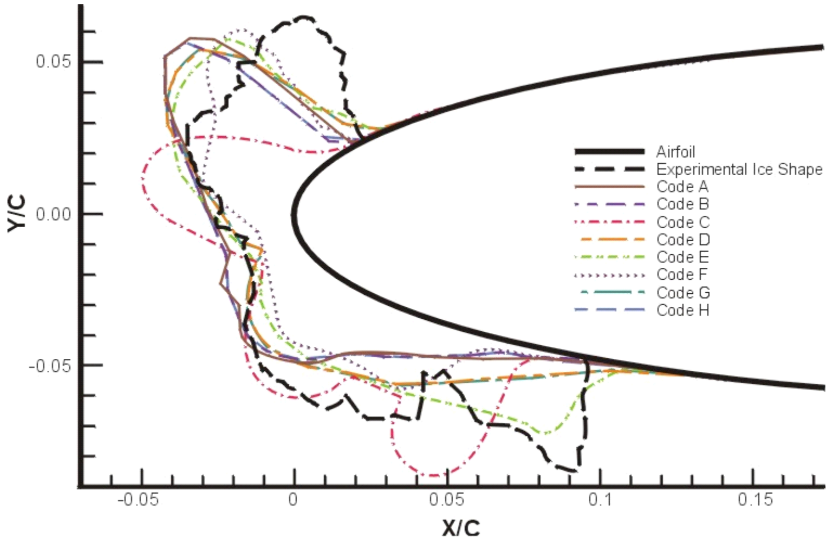


Figure 4. Comparison of Drop Impingement and Ice Accretion Code Results With Experimental Ice Accretion Produced in the Boeing Research Aerodynamic and Icing Wind Tunnel (V = 130.2 kts, TS = -7.2°C, LWC = 1.0 g/m^3, MVD = 38.8 μm, icing duration = 1200.0 s, airfoil model chord = 0.914 m).

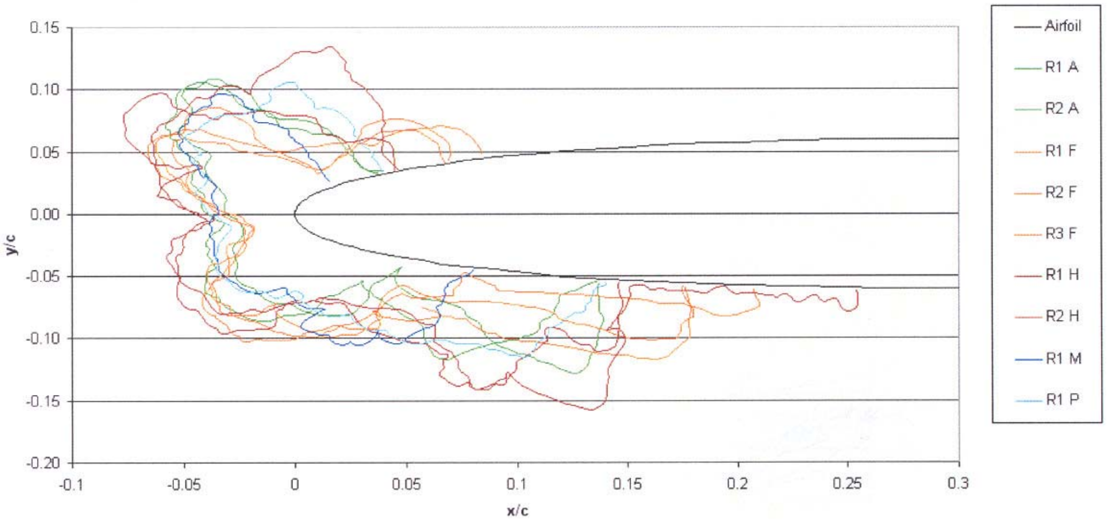
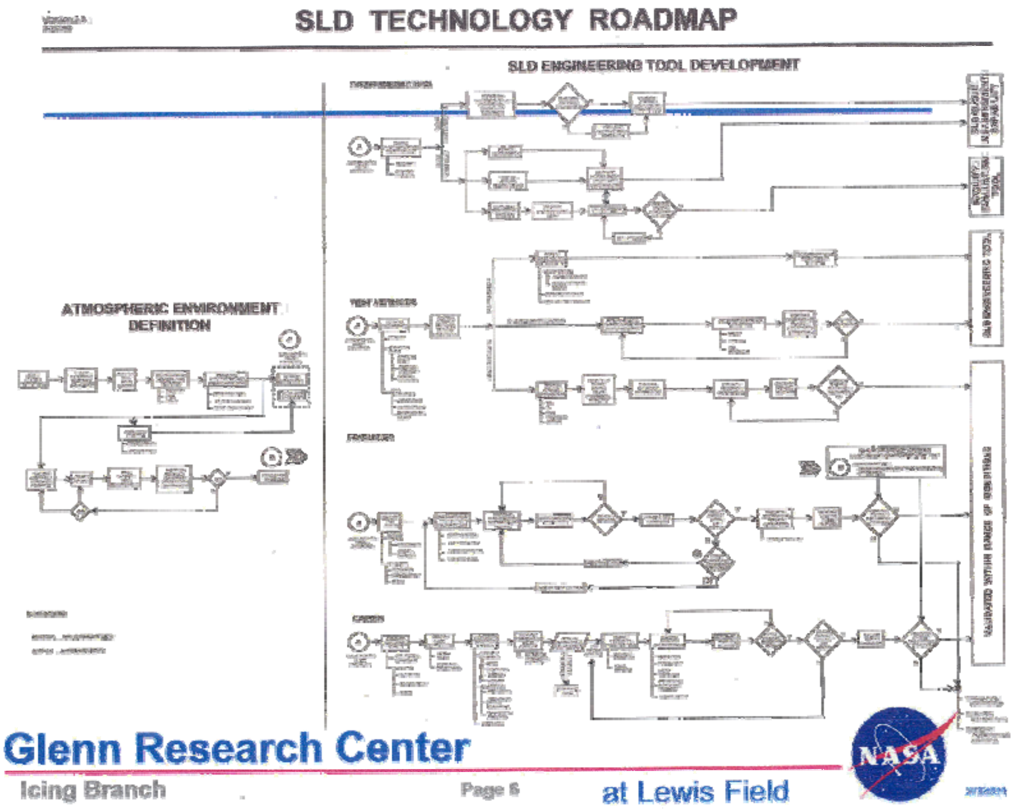


Figure 5. Example of findings from the SAE AC-9C Subcommittee Facilities Panel inter-facility ice shapes.



SLD TECHNOLOGY ROADMAP

SLD ENGINEERING TOOL DEVELOPMENT

ATMOSPHERIC ENVIRONMENT DEFINITION

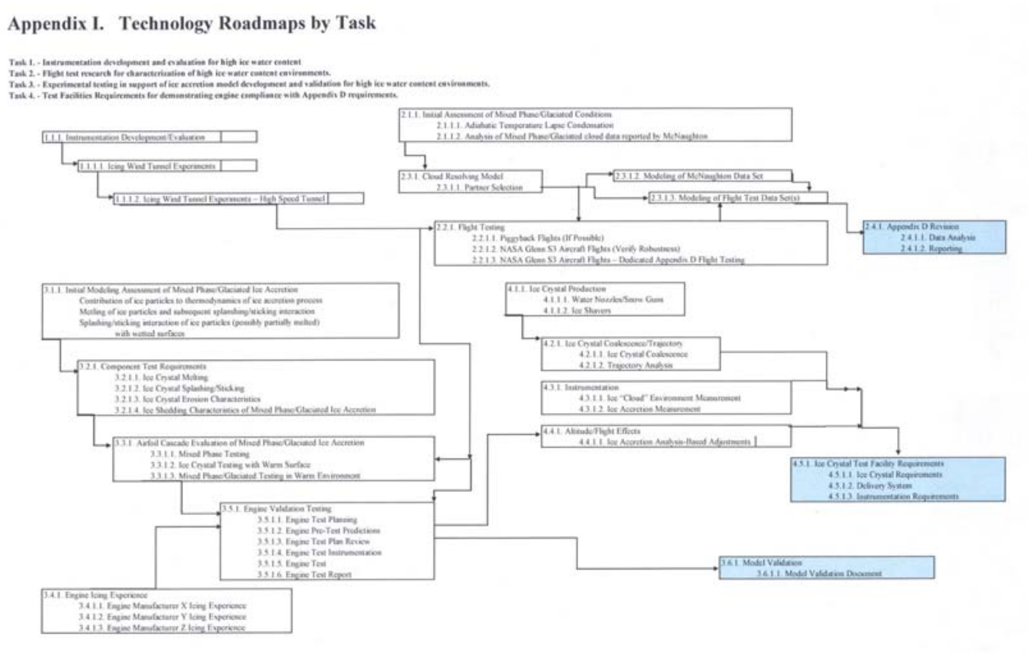
Glenn Research Center

Icing Branch

Page 6

at Lewis Field

Figure 6. Example of early CIP icing and SLD icing potential at a specific altitude.



Appendix I. Technology Roadmaps by Task

Task 1. - Instrumentation development and evaluation for high ice water content
Task 2. - Flight test research for characterization of high ice water content environments.
Task 3. - Experimental testing in support of ice accretion model development and validation for high ice water content environments.
Task 4. - Test Facilities Requirements for demonstrating engine compliance with Appendix D requirements.

Figure 7. Mixed-phase/Glaciated Icing Technology Plan

Figure 8. NASA Propulsion Systems Laboratory (PSL) at the Glenn Research Center.

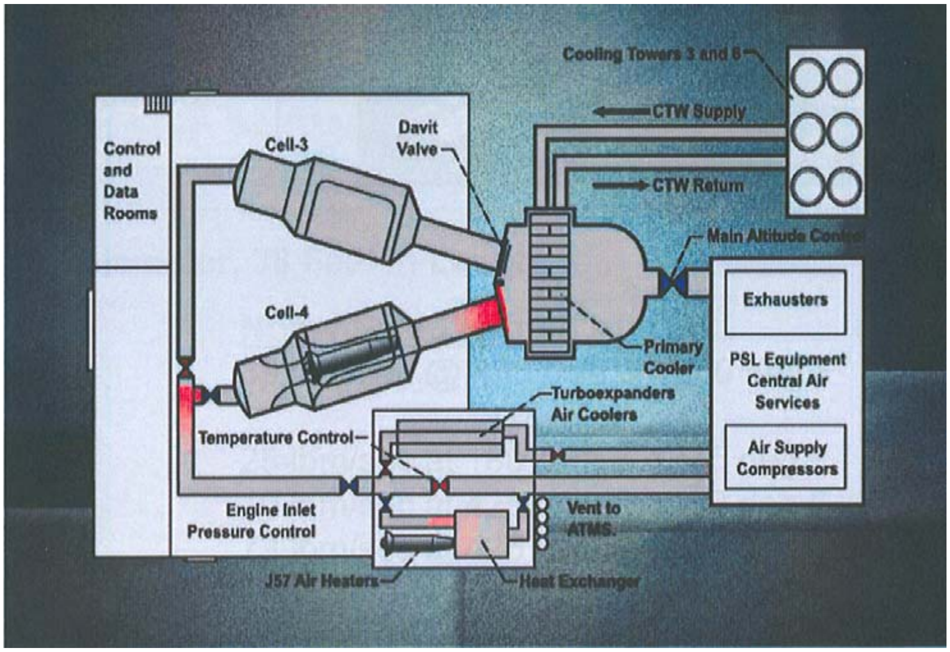


Figure 9. Schematic of the NASA Propulsion Systems Laboratory at the Glenn Research Center.