

ICE DETECTION SYSTEMS: A HISTORICAL PERSPECTIVE

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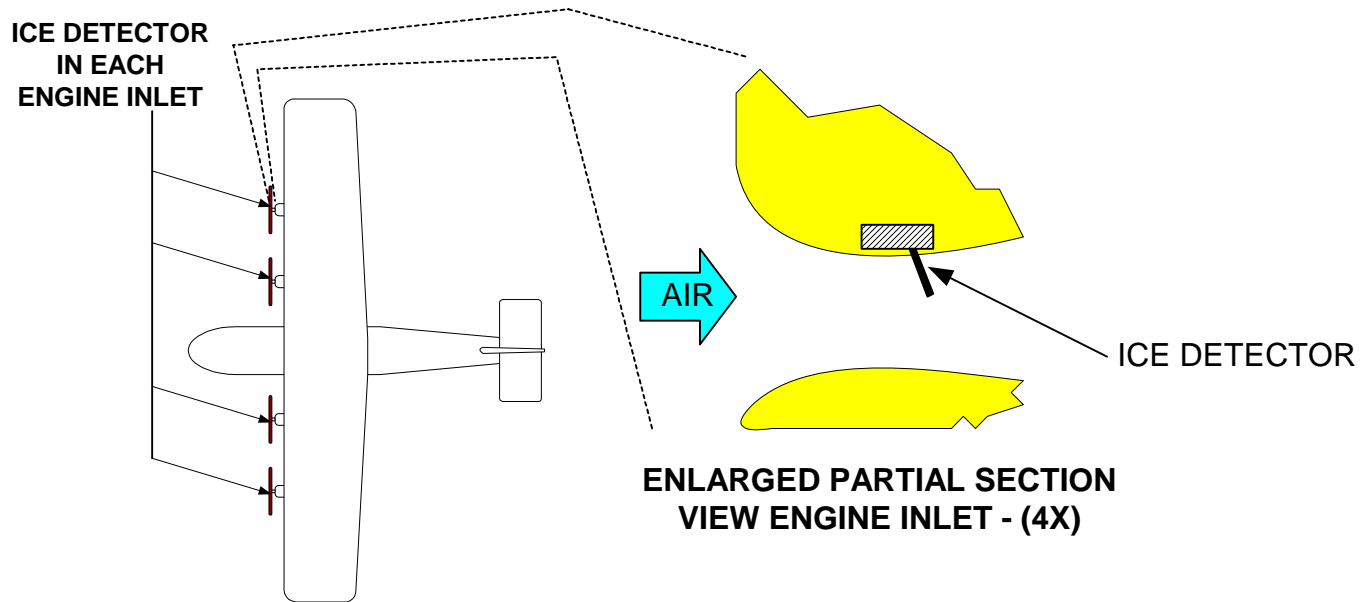
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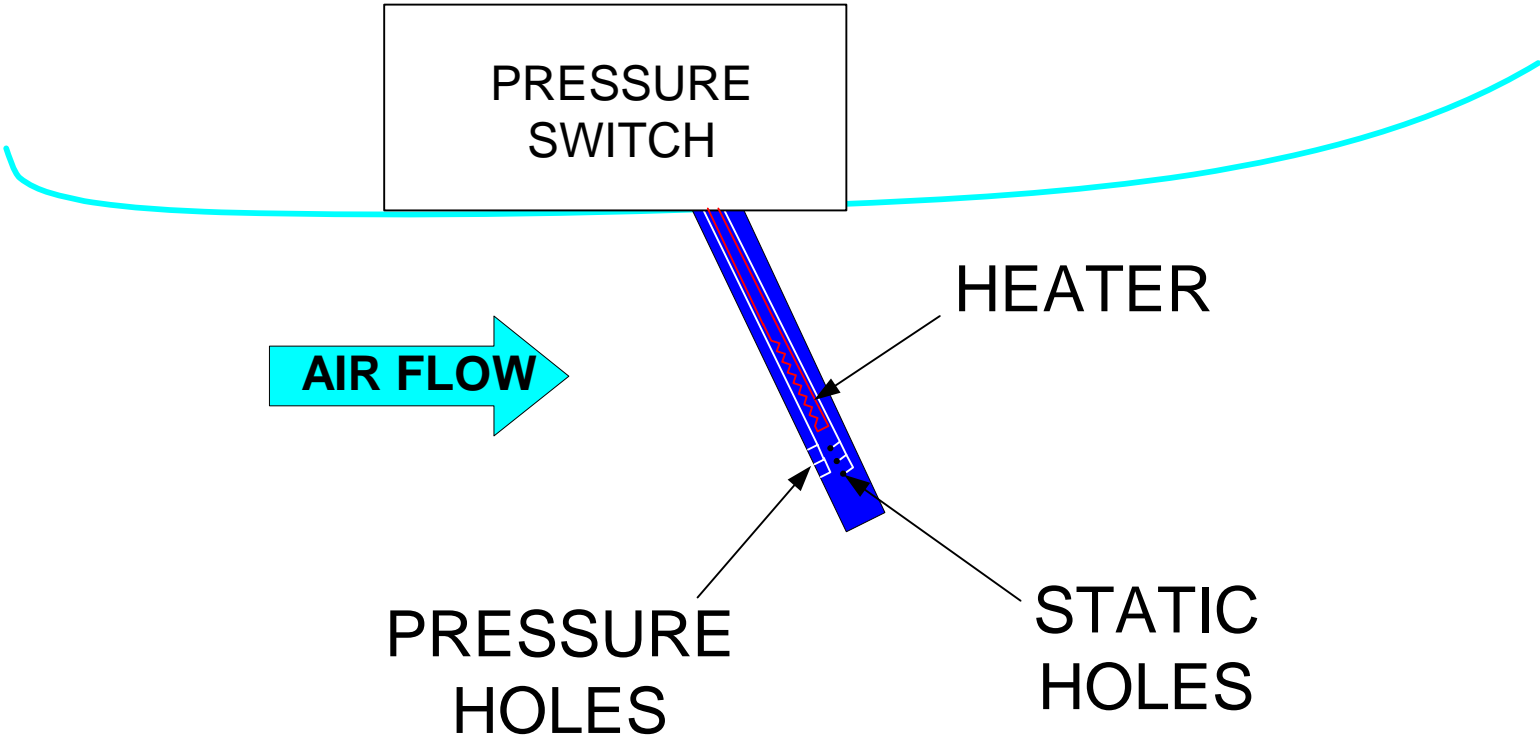
INSTALLATION OF C-130 ICE DETECTORS



ICE PROTECTION SYSTEM FEATURES:

- EACH ENGINE INLET INCLUDES AN ICE DETECTOR - ONLY THE INNER TWO ARE ELECTRICALLY ON
- WHEN THE CONTROL SWITCH IS SET TO "AUTO" EITHER DETECTOR CAN INITIAL A PROTECTION CYCLE
- THE ICE DETECTOR OUTPUT IS INHIBITED, ONCE POWER IS REMOVED, UNTIL INLET AIRSPEED EXCEEDS 40 KNOTS.

FIRST ICE DETECTOR: C-130



C-130 HEAT OF FUSION ICE DETECTOR

SENSING
ELECTRONICS

AIR FLOW

HEATER

PROTECTION GROOVE

ENLARGED PARTIAL
SECTION VIEW OF
PROBE

AIR

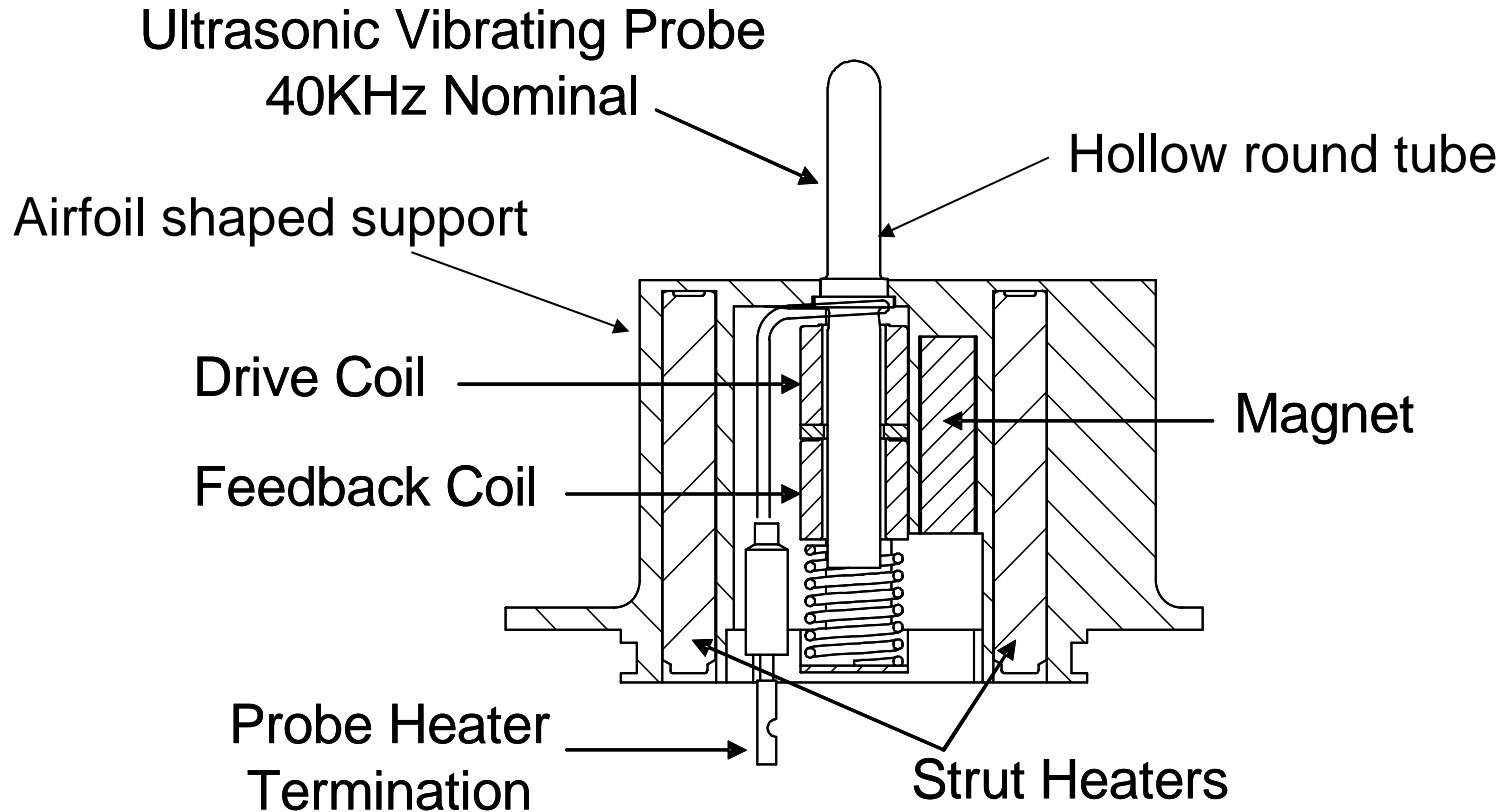
AIR

THIN WIRE

ACCRETED ICE

HEAT OF FUSION ICE DETECTOR - AS IMPLEMENTED ON THE C-130

MAGNETOSTRICTIVE ICE DETECTOR



- As ice accretes on the probe, the resonant frequency reduces due to the added ice *mass*.
- Reduction of the probe frequency below a predetermined threshold causes the ICE signal to be activated and the strut and probe to be deiced.

ICE DETECTOR VARIANTS

- 1-piece vs 2-piece systems
 - Based on space constraints
- Strut length variations
 - Used to extend probe into airstream to see droplets
- Aspirated vs Non-Aspirated
 - Bleed air from engines pulls air past probe in hover mode for helicopter applications
- Trigger vs Icing Rate
 - Threshold based on thickness
 - Threshold/Severity based on rate of ice accretion
 - Can use inverse of response time or rate of change of raw signal

ICE DETECTOR CLASSIFICATION

- Ice Accretion Detectors
 - Measures actual ice accretion on a reference or sensing surface
- Icing Conditions Detectors
 - Monitors presence of moisture and temperature conducive to ice formation
- Ice Detection Monitoring Schemes
 - Probe-Style detectors extending into the airstream are used when the exact location of ice accretion is variable or not easily monitored
 - Point Sensors can be used if the exact location of the ice accretion is known for every icing encounter
 - Broad Area Surface Detectors can be used when only certain areas are of concern
 - Remote detection is used when monitoring an entire surface

ICE DETECTION SYSTEM COMPARISON

- **Advisory Ice Detection System**
 - Flight crew still monitors temperature and visible moisture
 - Ice detector used as a back-up only
- **Primary Ice Detection System**
 - Flight crew relies on ice detector for Primary ice indication
 - IPS manually or automatically activated based on ice detector signal
- **Advantages**
 - Increased icing awareness
 - Reduced pilot workload
 - Reduced Operating Costs/Increased Performance
- **Disadvantages**
 - Increased integration complexity for Primary systems
 - Increased certification requirements for Primary systems

SIGNIFICANT EVENTS

➤ Engine Flame-Outs on DC-9

- Cold, high-humidity conditions can cause ice to form on wing upper surface due to cold soaked fuel
- Ice shed from wings during take-off lead to engine flame-outs
- Special ice detection systems installed on wings to warn against clear ice formation

➤ Engine Flame-Outs in Ice Crystals

- Engine power loss occurs at high altitudes near thunderstorms
- Ice forms on 2nd stage stators in engine core due to ice crystals
- Need to measure ice accretion in core or presence of ice crystals

➤ Roselawn Accident

- SLD droplets formed ice ridge aft of pneumatic boot leading to an uncommanded roll of aircraft
- Highlighted need for an ice detector to differentiate SLD from Appendix C droplets

SIGNIFICANT EVENTS

➤ Fredericton Accident

- Supercooled fog present with a temperature inversion and near freezing temps
- Wing stall occurred during last-minute go-around attempt
- Early stall suspected due to ice formation on wing
- No ice detection warning due to inhibit below 400 ft
- Ludlam Limit effects on response time of ice detector investigated
- Investigation highlighted need to understand ice accretion differences between wing and ice detector

ICE ACCRETION PHYSICS

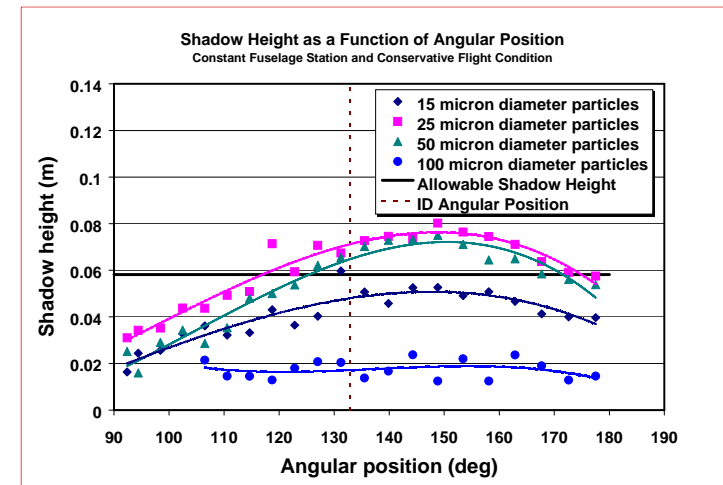
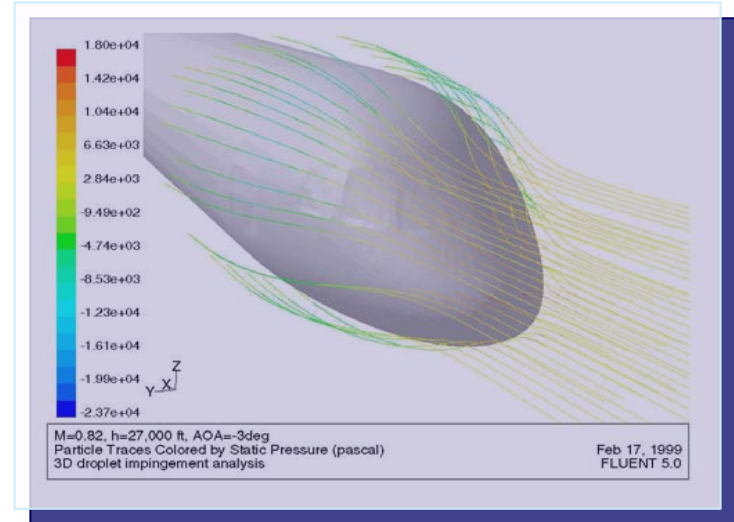
- Ice accretion is dependent upon a complex heat transfer which is a function of:
 - Geometry, airspeed, LWC, MVD, temp, etc.
- Ludlam Limit or freezing fraction effects limit the ability of all the water in Appendix C to freeze on a given surface
- Differences in geometry and local flowfields can cause differences in the freezing fraction and Critical Temperature for a given surface
- Critical Temperature is the temperature above which ice cannot form
- Differences in Critical Temperature between wing and ice detector need to be evaluated, including installation effects
- Analysis of ice accretion behavior can be performed through a combination of theoretical analysis, wind tunnel testing, and/or flight testing

SIGNIFICANT EVENTS

- Lear 45 Missed Icing Event
 - Icing Flight Test Campaign in late 1990's
 - Missed ice detection with ice accretion on aircraft
 - CFD droplet impingement analysis performed
 - Analysis showed 15 and 50 micron droplets impinge, while 25 microns do not.
 - ID location changed and exposed strut length increased to ensure proper detection
 - Investigation highlighted need to perform location analysis for ice detectors

LOCATION, LOCATION, LOCATION

- Droplet Impingement is key to proper performance of ice detection system
- CFD analysis must be performed to ensure proper impingement
- Minimize interference with other sensors
- Identify possible locations of higher LWC or airspeed than freestream conditions
- Minimize potential for damage by maintenance personnel



INDUSTRY REGULATIONS

- Currently no FAR/JARs dedicated to ice detection systems
 - FAA NPRM for update to 25.1419 to include discussion on ice detectors
- Recent Updates to AC 20-73 provides some guidance on ice detectors
- CRI/Issue Paper regarding Primary In-Flight Ice Detection
- EASA has developed an ETSO for Ice Detectors
 - Based on EUROCAE/SAE Minimum Operation Performance Specifications for ice detectors.

SUMMARY AND CONCLUSIONS

- Ice detectors have been used since 1950's
- Various ice detection technologies have been developed for various applications
- Determining a good location is key to ensuring proper ice detector performance
- Evaluation of ice detector and wing ice accretion characteristics must be performed
- Ice detectors provide increased safety, reduced pilot workload, and cost savings for operators
- Most new revenue-generating aircraft offer an ice detection system
- Regulations are being developed to help provide proper guidance for certification of ice detectors