TOTAL TEMPERATURE SENSORS OVERVIEW

NOVEMBER 2020

Collins Aerospace

TOTAL TEMPERATURE SENSORS

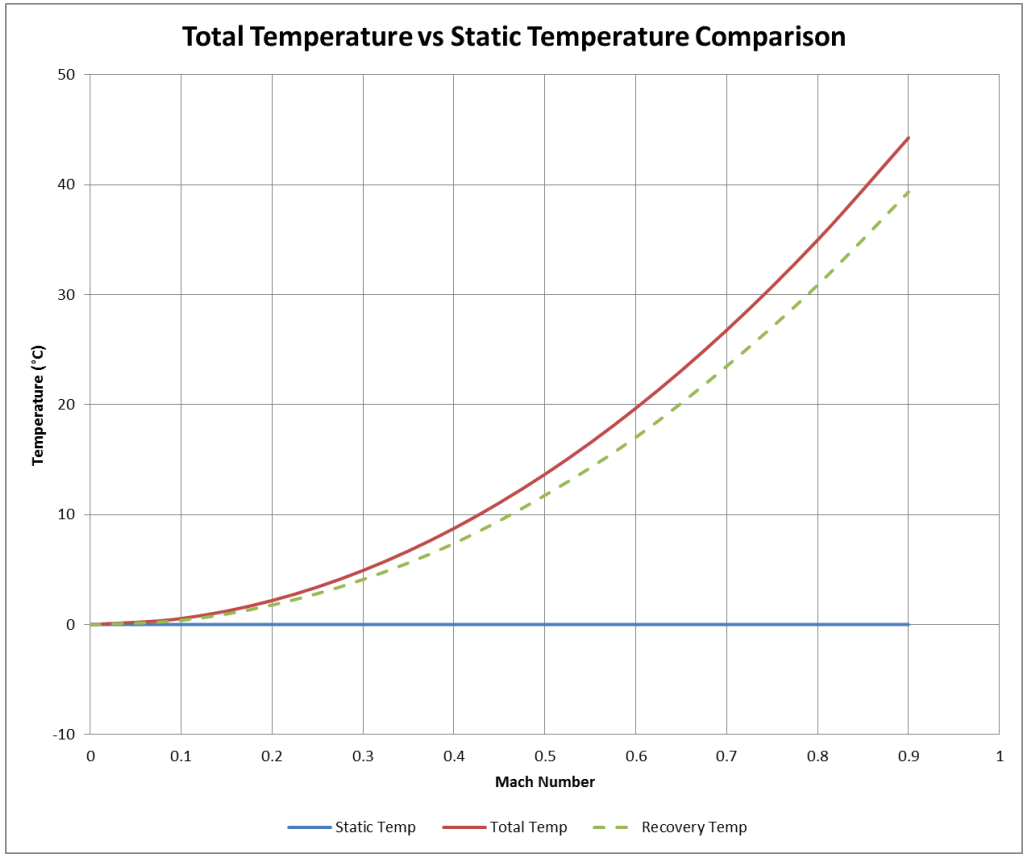
OVERVIEW

- Total Air Temperature (TAT) Sensor Basics
- History of Rosemount Aerospace Fuselage TAT Probes
- TAT Error Types
- Outside Air Temperature (OAT) Probes
- Engine TAT Probes
- Rosemount Aerospace Wind Tunnel Capabilities

TOTAL TEMPERATURE SENSORS

WHAT IS TOTAL TEMPERATURE?

- Total Air Temp (TAT) is Max Temp Which Can be Obtained by 100% Conversion of the Kinetic Energy of Flight
  - Static Temp. + Heat Due to Compression of Air
- Sensors Slow Flow to Adequately Recover Most of Total Temp (Recovery Temp)
- Can Relate Total Temp (Tt) and Static Temp (Ts) Using Formula at Right



$$T_t = T_s \times \left(1 + \frac{\gamma - 1}{2} M^2\right)$$

Collins Aerospace

TOTAL TEMPERATURE SENSORS

WHAT IS TAT USED FOR?

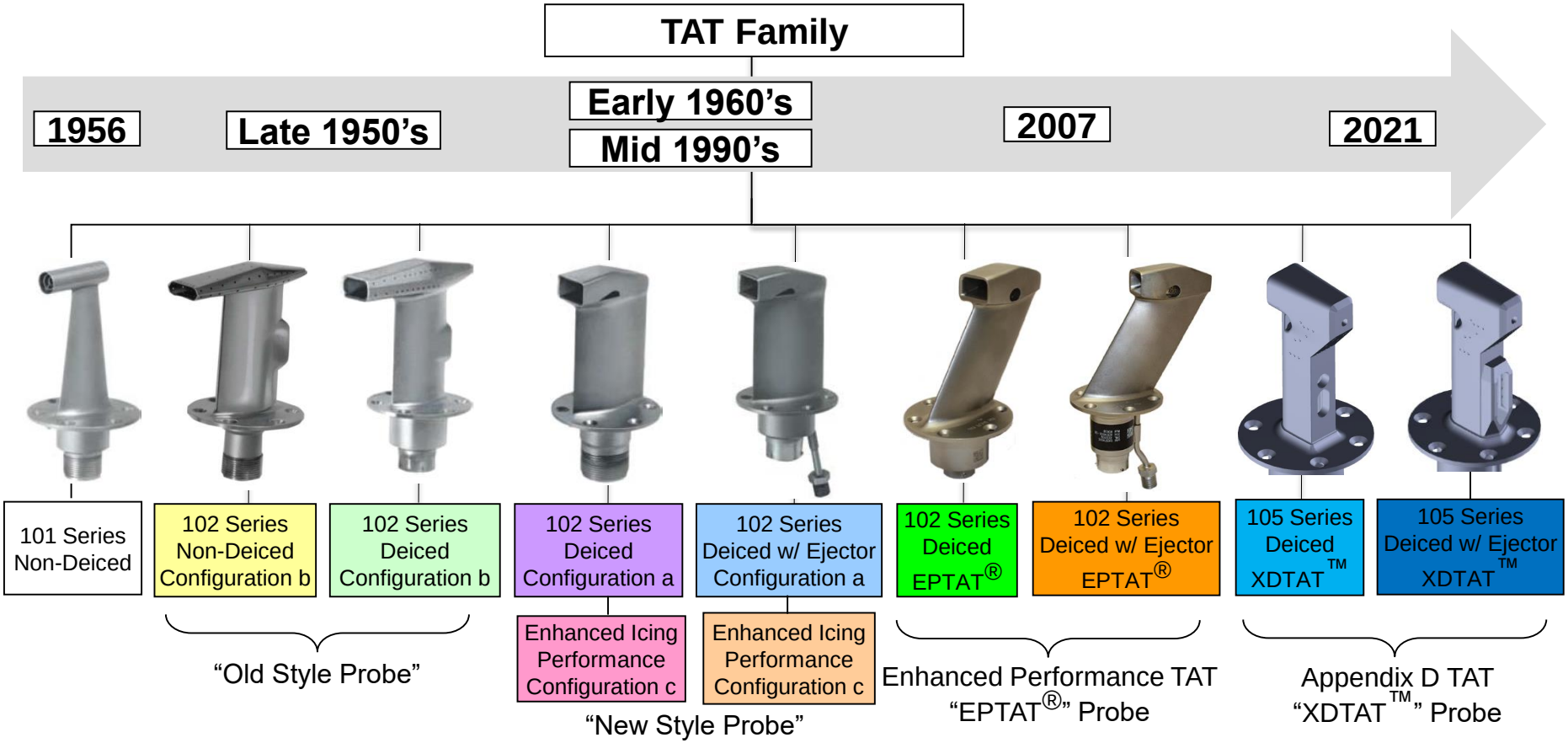
- Total Temp is Used for a Variety of Aircraft and Engine Purposes Depending on Aircraft Needs
- TAT Needed to Calculate True Airspeed (TAS)

$$(TAS) = M\ (TAT)^{1/2} \left[\frac{\gamma R}{1 + \left(\frac{\gamma - 1}{2} \right) M^2} \right]^{1/2}$$

- Engine Uses
  - Engine Control and Condition Monitoring
  - Determine Proper Fuel Flow
  - Scheduling of Inlet Guide Vanes
  - Control Fan Speeds
  - Selection of Engine Pressure Ratio (EPR)

TOTAL TEMPERATURE SENSORS

FUSELAGE TAT FAMILY

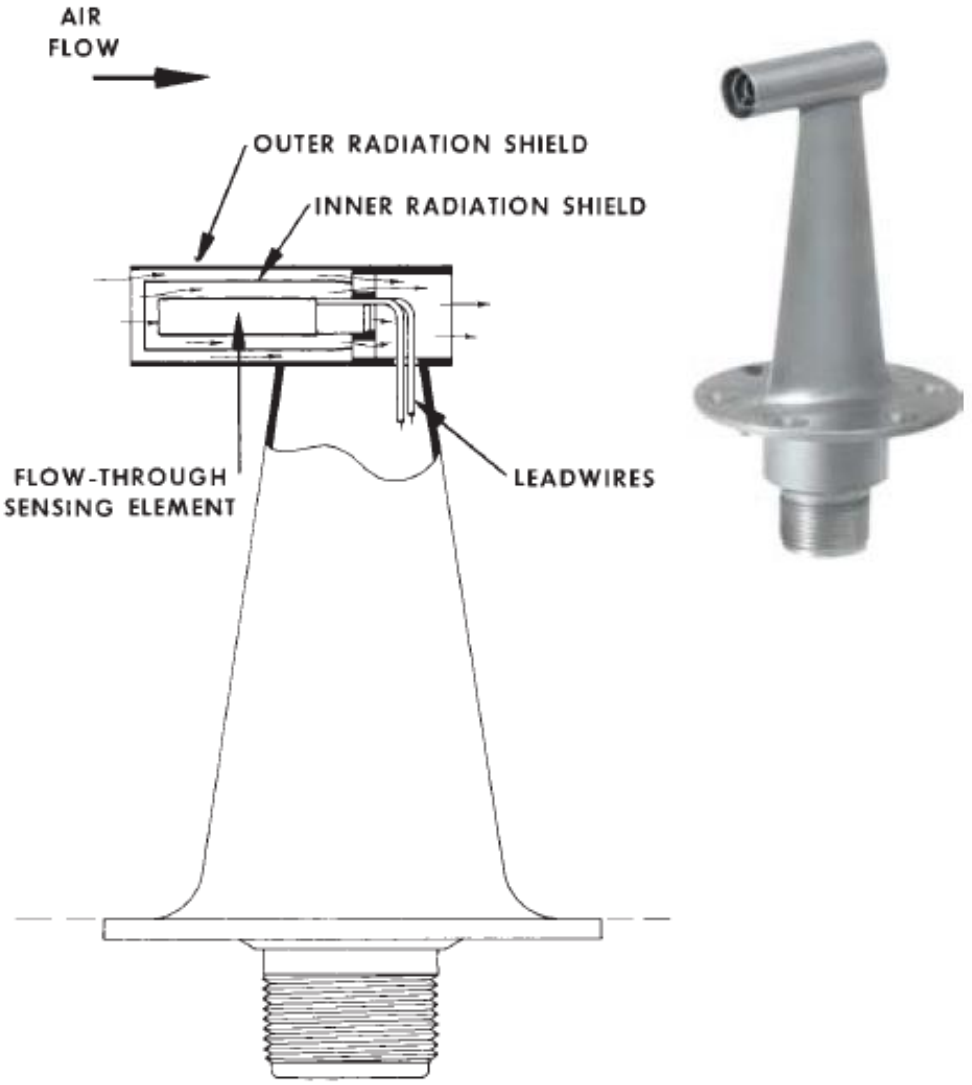


Collins Aerospace

TOTAL TEMPERATURE SENSORS

101 STYLE TAT PROBE

- Started Rosemount Engineering Co in 1956
- Developed for Supersonic Military Aircraft
- Unheated
- Stainless Steel Housing
- Hollow Tube Element
  - Allows Flow Through and Around Element Windings
- Capabilities:
  - -70°C to +350°C
  - Up to Mach 3
  - 0 to 100,000 feet

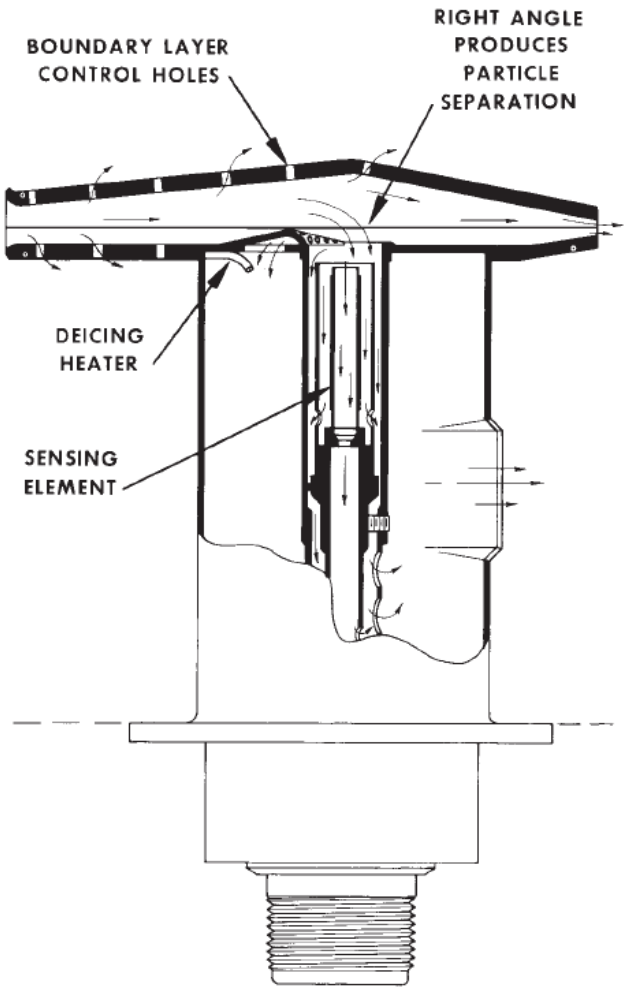


Collins Aerospace

TOTAL TEMPERATURE SENSORS

OLD STYLE TAT PROBE (CONFIGURATION B)

- Developed in Late 1950's
- Electrically Heated
  - With 28 VDC or 115 VAC
- Beryllium Copper (BeCu) Housing
- Boundary Layer Bleed Features
- Hollow Tube Element
  - Similar to Model 101
- Unheated Version Available With Fast Response Element
- Capabilities:
  - -70°C to +350°C
  - Up to Mach 3
  - 0 to 100,000 feet



Heated

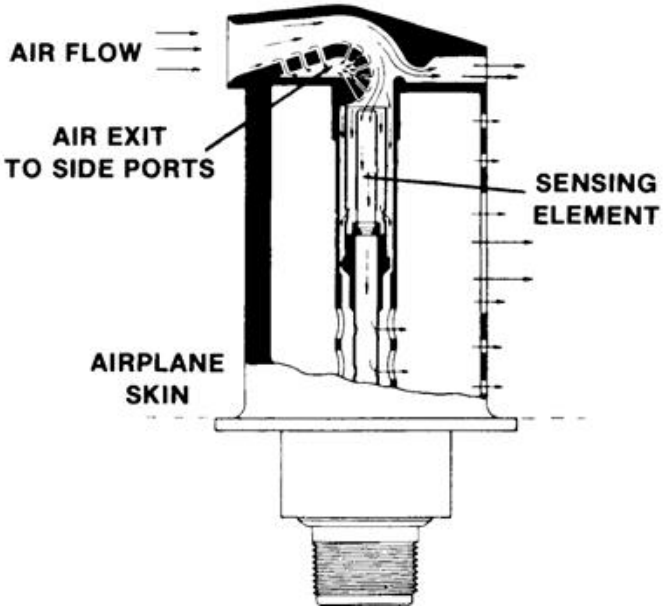
Unheated

Collins Aerospace

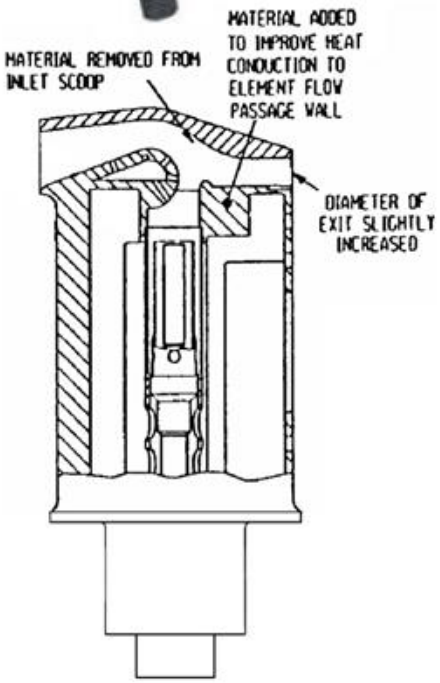
TOTAL TEMPERATURE SENSORS

NEW STYLE TAT PROBE (CONFIGURATIONS A & C)

- Developed in Early 1960's
- Improved LWC vs Config B
- Electrically Heated
  - With 28 VDC or 115 VAC
- In Mid-1990's Introduced Enhanced Icing Version
  - Allow Particles to More Freely Pass Through
  - Reduced Icing Issues
- Ejector Version Available
  - Bleed Air Helps Reduce On Ground Errors
- Capabilities:
  - -70°C to +350°C
  - Up to Mach 3+
  - 0 to 100,000 feet



Standard Configuration A



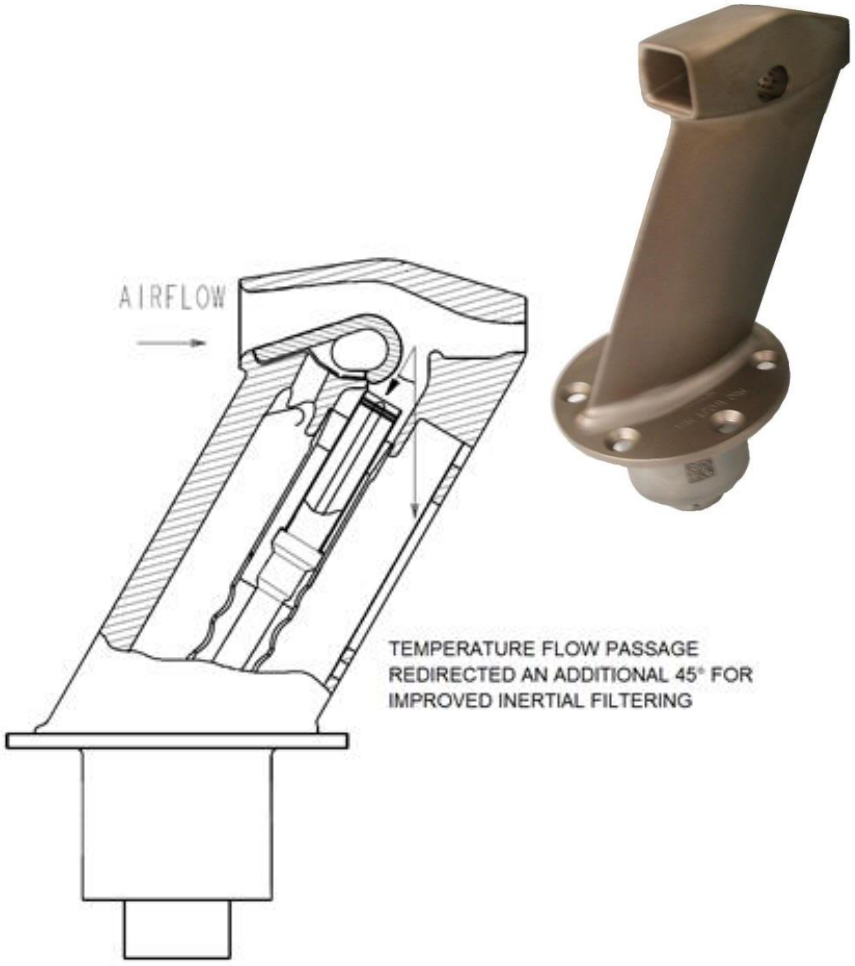
Enhanced Icing Configuration C

Collins Aerospace

TOTAL TEMPERATURE SENSORS

ENHANCED PERFORMANCE TAT (EPTAT®) PROBE

- Introduced in 2007
- Electrically Heated
  - 115 VAC only option
- Angled Housing 45° to Improve Inertial Separation
  - Improved Icing Performance
- Adjusted Internal Features to Optimize Airflow
  - Improved Accuracy
- Ejector Version Available
- Side-by-Side Solid Elements
  - Improved Reliability
  - Significantly Reduces Potential for Dual-Element Failures

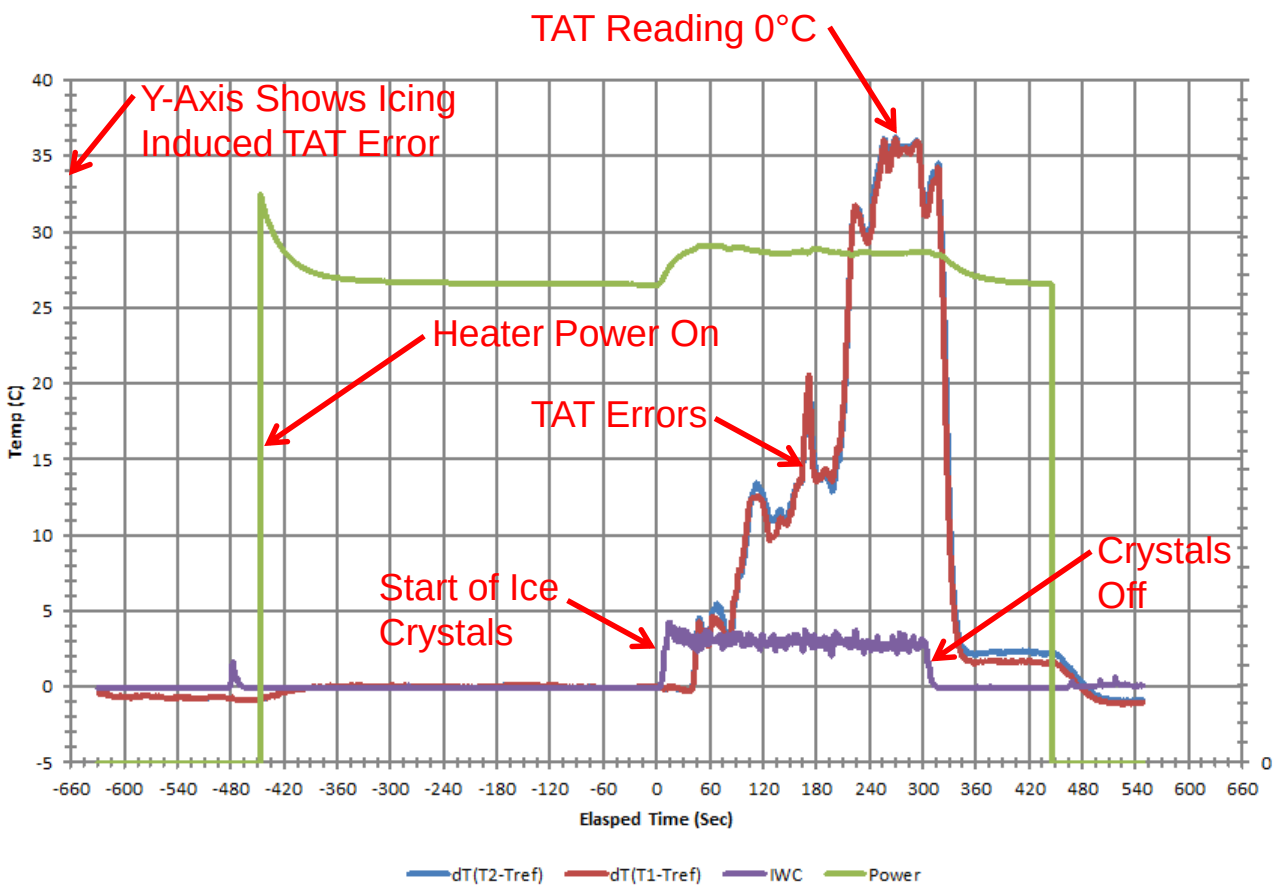


Collins Aerospace

TOTAL TEMPERATURE SENSORS

EXAMPLE OF EXTREME ICE CRYSTAL ICING ISSUES

Tunnel TAT = -36°C

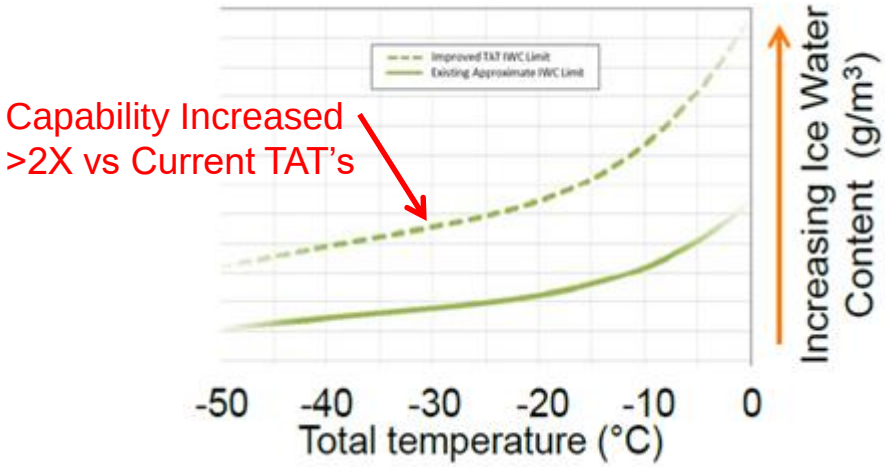


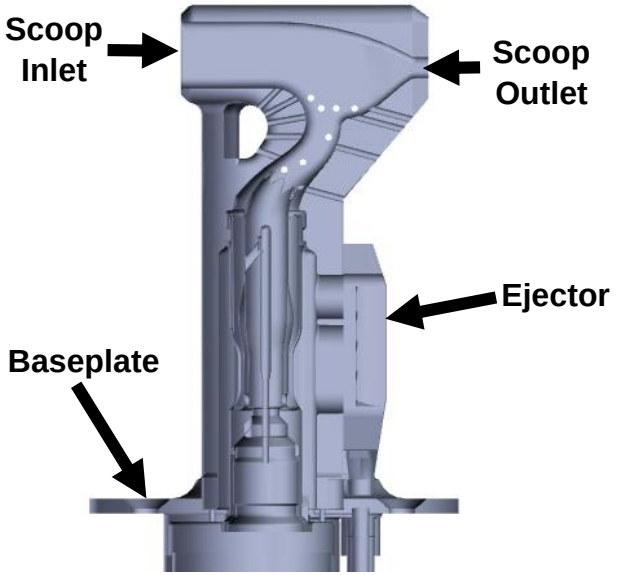
Ice Extruding Out Rear Exit Indicates Interior Ice Blockage

TOTAL TEMPERATURE SENSORS

APPENDIX D TAT (XDTAT™) PROBE

- New 0105 TAT Family
- Developed for Enhanced Icing Capabilities
  - Specifically High Ice Crystal Contents (Appendix D)
- Improved Accuracy in Both Dry and Icing Environments
- BeCu Housing
- Side-by-Side Solid Elements
- Aspirated or Non-Aspirated
  - Image Shows Aspirated Model
- Quiet Operation During Flight
- Qualification Planned for 2021





TOTAL TEMPERATURE SENSORS

TAT ERRORS

- Calibration
  - Uncertainty of Knowing Actual Temperature at a Certain Point
  - ±0.1°C With Precision Calibration Interchangeability (PCI) Resistors
- Recovery Error
  - Inability to Convert All of Kinetic Energy into Total Temperature
- Deicing Heater Error (DHE)
  - Housing Heat Reaches Sensing Element Producing Higher Reading
- Self-Heating Error (SHE)
  - Heat (I^2R) Generated From Input Current and Sensor's Resistance
- Recovery Error, DHE and SHE Nominal Errors Can Be Compensated for in SmartProbe® or Similar Air Data Computer
- Random Portion (Part to Part Variation) of Above Errors Generally Used to Calculate Overall Dry TAT Accuracy

TOTAL TEMPERATURE SENSORS

OTHER TAT ERRORS

- Insulation Resistance (IR)
  - Insulation Acts Like Resistor in Parallel With Sensing Element. Low IR Will Cause Sensing Element to Read Artificially Low.
  - Hermetically Sealed TAT Probes to Mitigate This Risk
- Time Response
  - Ability of the Sensor to Respond to Changes in Temperature or Velocities
  - Slower for EPTAT® & XDTAT™ Probes Compared to Other Styles
- Conduction Error
  - Heat Conducts From Baseplate Through Housing and Into Element
  - Generally Insignificant for Fuselage Mounted TAT's
- Icing
  - Original TAT's Designed For Use in Liquid Water Icing
  - Enhanced Icing Configuration C, EPTAT® and XDTAT™ Probes Designed to Improve Performance in Ice Crystals
  - XDTAT™ Probe Designed for Most Severe Ice Crystal Conditions

TOTAL TEMPERATURE SENSORS

OUTSIDE AIR TEMPERATURE PROBE (OAT)

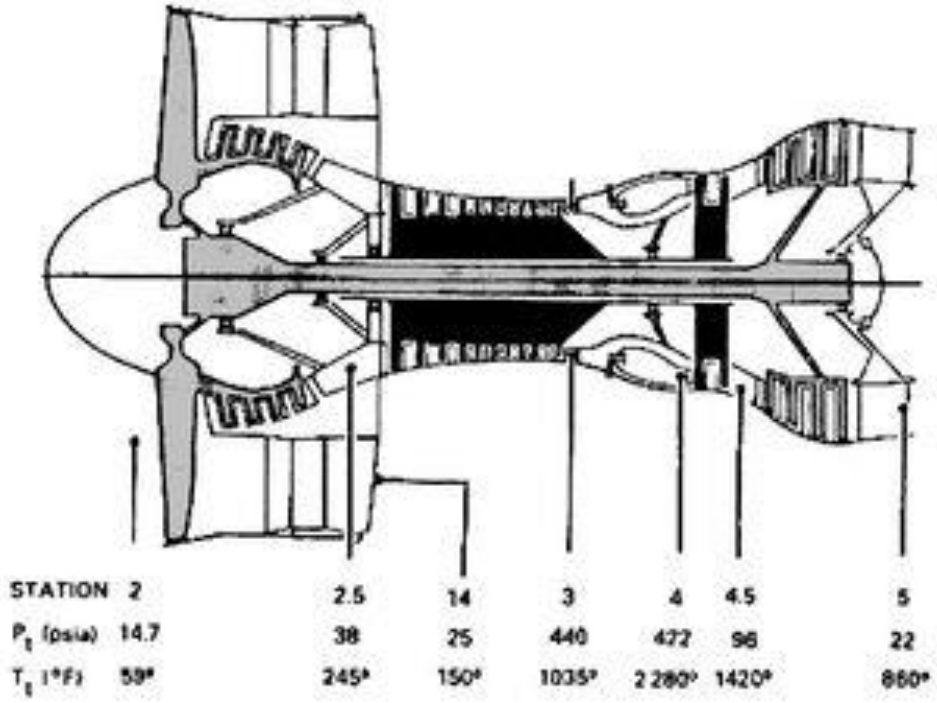
- Mainly Used for Helicopters, General Aviation, Slower Speeds
- Good Performance Up to ≈ Mach 0.4
- Unheated
- Chrome-Moly or Stainless Steel Housing
- Housing Design Allows for Very Good Accuracy Even in Severe Icing
  - Ice Builds But Element Passage Open
  - No Effect With Ice Crystals
- Solid Element
  - Slow Time Response
- Available in 100 or 500 ohms
- Capability: -70°C to +250°C

Collins Aerospace

TOTAL TEMPERATURE SENSORS

ENGINE TAT PROBES

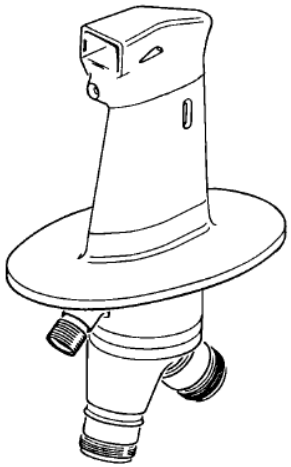
- Engines Normally Require TAT at Engine Inlet (T2) and Compressor Inlet (T25)
- Styles Vary Depending on Engine Needs
  - Immersion Depth
    - Boundary Layer Dependent
  - Heated vs Unheated
    - 28V, 115V or Hot Air Heat
  - Accuracy and Icing Needs
  - Weight and Power Considerations

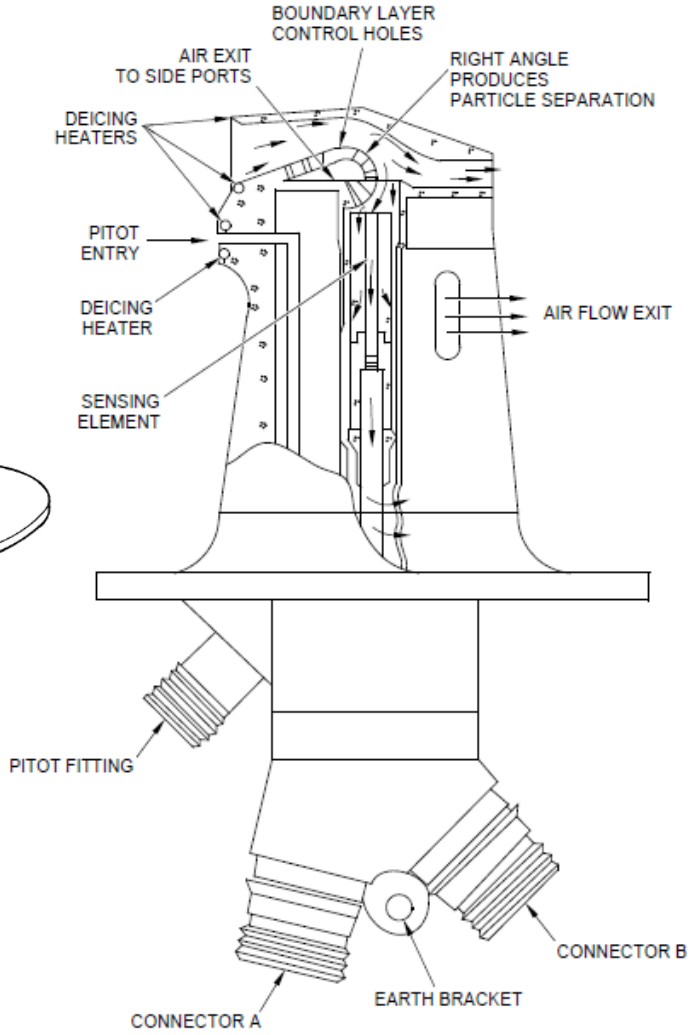


TOTAL TEMPERATURE SENSORS

LARGE SCOOP ENGINE TAT

- Similar Construction to New Style TAT
- Inertial Separation to Protect Element From Moisture and Debris
- Boundary Layer Control Holes
- Electrical Heater Embedded in Housing
  - 115 VAC
- BeCu Housing
- Side-by-Side Solid Elements
  - Rugged Construction
- Able to Meet High Vibration Levels
  - Options With Vibration Isolator
- Often Supplied With Pitot Pressure
  - P2T2 Probe

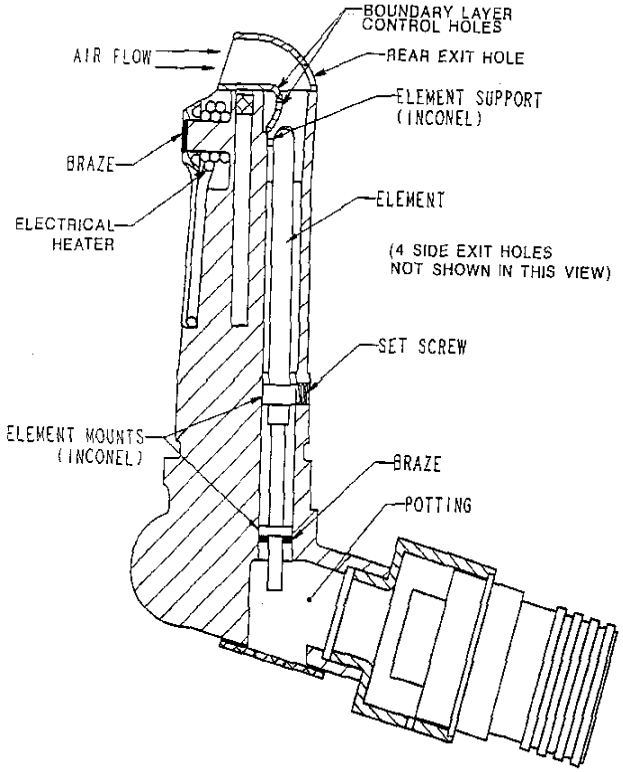




TOTAL TEMPERATURE SENSORS

SMALL SCOOP ENGINE TAT

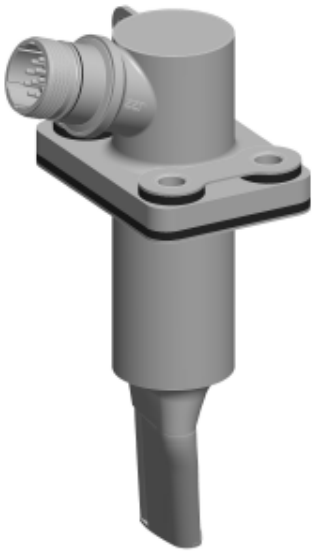
- Used for Smaller Engines
  - Regional or Business Jets
- Similar Features as Larger TAT Probes, Miniaturized
  - Can Fit in ∅ ¾” Hole
  - Worse Accuracy Than Large TAT’s
- Electrical Heater Embedded in Housing
  - 28 VDC
- BeCu Housing
- Single or Dual Solid Element on Single Mandrel
- Available With Pitot Pressure
  - P2T2 Probe

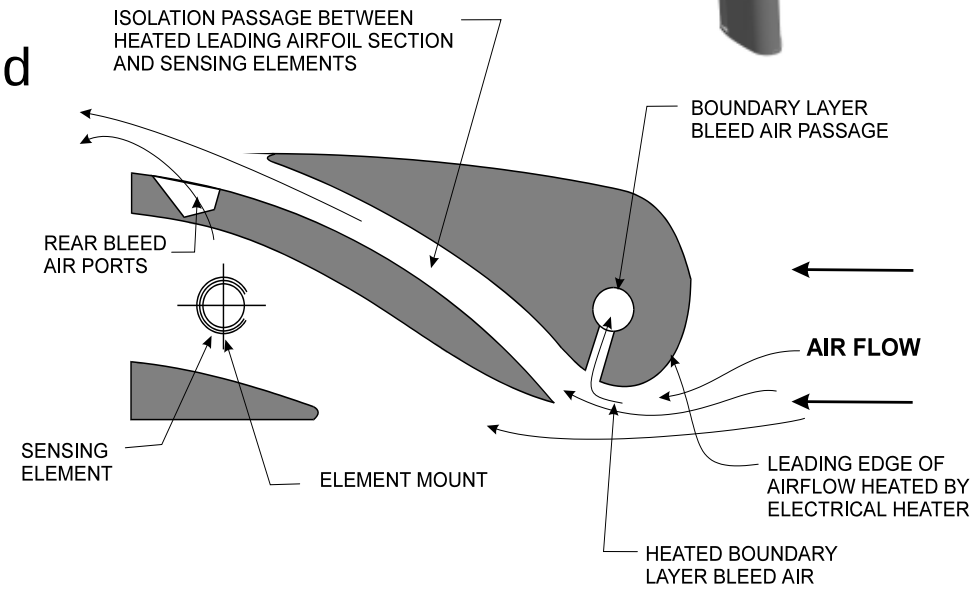


TOTAL TEMPERATURE SENSORS

AIRFOIL STYLE ENGINE TAT

- Sensor Shaped to Divert Flow Over Element
  - Pressure Delta Created
  - Protects Element From Debris, Water Droplets, Ice Crystals
- Unheated, Electrical Heated and Hot Air Heated
  - Unheated Have Comparable Accuracy to Large TAT's
  - Heated Have Worse Accuracy
- BeCu or SST Housing
- Single or Dual Solid Element on Single Mandrel

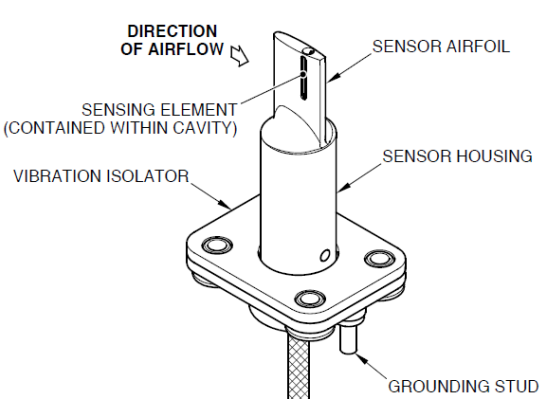


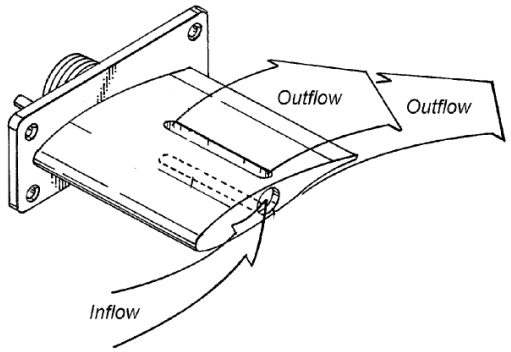


TOTAL TEMPERATURE SENSORS

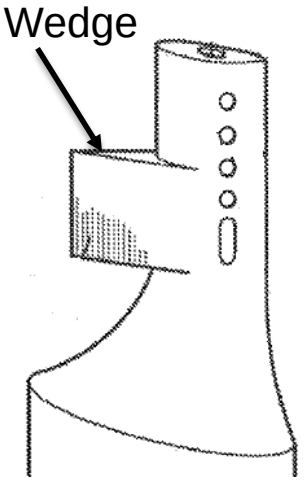
AXIAL FLOW STYLE ENGINE TAT

- Newest Engine TAT Style
  - Better Accuracy Than Airfoil
  - Reduced Ice Buildup
- Unheated
- Stainless Steel Housing
- Very Good Performance in Icing Conditions
- Dual Solid Element on Single Mandrel
- Supercritical Airfoil Used at Engine Inlet (T12) to Maximize Airspeed Range
- Ice Wedge Utilized at Compressor Inlet (T25) to Minimize Individual Ice Sizes





T12 Sensor

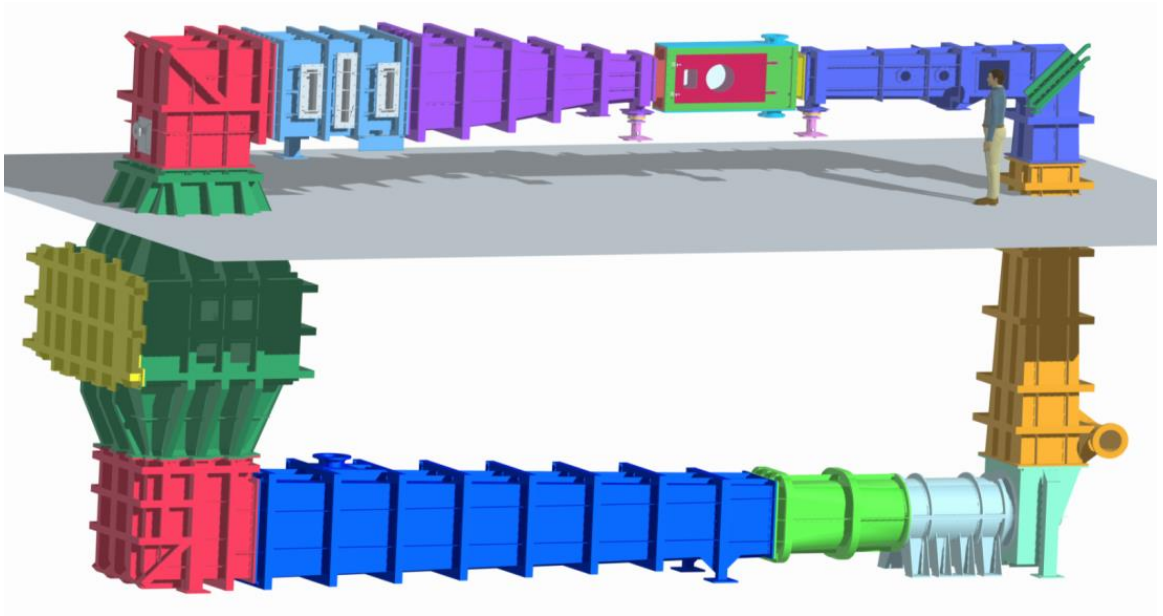


T25 Sensor

TOTAL TEMPERATURE SENSORS

ROSEMOUNT AEROSPACE WIND TUNNEL TESTING CAPABILITIES

- Advanced Icing Wind Tunnel (AIWT)
  - High speed Mach 0.9
  - Static temperature down to -60ºC
  - Altitude to 47,000 feet
  - Appendix C & D icing capabilities
- Transonic Wind Tunnel (TWT)
  - High Speed Mach 1.6
  - Liquid water icing
    - Appendix C



- Low Speed Wind Tunnel (LST)
  - Rain test capabilities to 22 g/m^3
- Vertical Wind Tunnel (VWT)
  - High Speed Mach 0.8
  - Altitude to 45,000 feet

Collins Aerospace