

Recommended Process for Determining CFD Conditions from Experimental Data Taken in the NASA Icing Research Tunnel (IRT)

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What Are Calibrated Conditions?

- Tunnel conditions are selected based on a combination of direct facility measurements that are used to establish calibration correlations
- In IRT, aero-calibration utilizes the upstream pitot tube pressure ratios and aligning them with empty-tunnel X = 0 [in] 5-hole probe measurements
- Once you have a pitot measurement and an empty tunnel measurement, a correlation can be established that says
  "When my pitot's read this, then the tunnel empty speed must be this"

Background and Rationale

- Internal flow CFD evaluations have become more prevalent in recent years due to improved access to high-fidelity computational resources and geometry
- Typically, IRT simulations using the tunnel walls rely on the calibrated tunnel conditions
  - That is: My test section UTSK is 130 knots, I should set my velocity and Mach to align with that

Freestream conditions do not exist for internal flows

- Typically, computational simulation will never produce the same correlation that the tunnel does, especially when there is a large model in the facility
- That 130 knots is not ‘real’ computationally because that value comes from an empty-tunnel calibration
- If utilized, you are essentially imposing a different velocity and non-dimensionalized condition to your simulations

Background and Rationale

- So, what should we do and when does it matter?
- The terminology that should be employed is referred to as a ‘Reference condition’ and not a ‘Freestream condition’
- What this means is that you are evaluating your computational analysis using direct measurements of the facility and removing the simulation from correlations as much as possible
- By using the pitot tube data and only the total temperature calibration, you can recover the necessary conditions for a CFD simulation
- The total temperature calibration is deemed reliable when the spray bars are not injecting water into the facility

Necessary IRT Measurement Data

Required Data:

- PTBMN (Pressure total bell mouth north)
- PTBMS (Pressure total bell mouth south)
- PSBMN (Pressure static bell mouth north)
- PSBMS (Pressure static bell mouth north)
- TTTSC (Total temperature test section calibrated)
- Pressure Tap Raw Pressures

Helpful Data:

- UTSK (U-Velocity Test Section knots)
- MTS (Mach test section)
- PAIR (Spray bar air pressure)
- TSTSC (Test section temperature static calibrated)
- RHOTS (Density test section)
- Cp (Coefficient of Pressure)

These helpful data act as a sanity check

It is recommended to compute your Cp data yourself (for consistency)

Computations

Assumptions:

$R = 287.053$

$\gamma = 1.4$

If $M_{ref} \leq 0.1$ consider using incompressible assumption

$$\frac{P_{0,ref}}{P_{ref}} = Avg\left(\frac{PTBM[n]}{PSBM[n]}\right), n = N, S$$

$$M_{ref} = \sqrt{\frac{2}{\gamma - 1}\left(\left(\frac{P_{0,ref}}{P_{ref}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right)}, M_{ref} \geq 0$$

$$T_{ref}\ [K] = TTTSC\left(1 + \frac{\gamma - 1}{2} M_{ref}^2\right)^{-1}$$

$$U_{ref}\ [m/s] = M_{ref}\sqrt{\gamma R T_{ref}}$$

$$\rho_{ref}[kg/m^3] = \frac{P_{ref}}{R T_{ref}}$$

$$\mu_{ref}[kg/m - sec] = 1.716 \cdot 10^{-5}\left(\frac{T_{ref}}{273.15}\right)^{1.5}\frac{(273.15 + 110.3333)}{T_{ref} + 110.3333}$$

$$Re_{L,ref} = \frac{\rho_{ref} U_{ref} L_{ref}}{\mu_{ref}}, L_{ref} = 1\ [m]$$

Implementation

- To achieve this in your computation, you will utilize the pitot tube reference locations to define a sampling plane that measures Mach number and you match it to your CFD M_{ref}

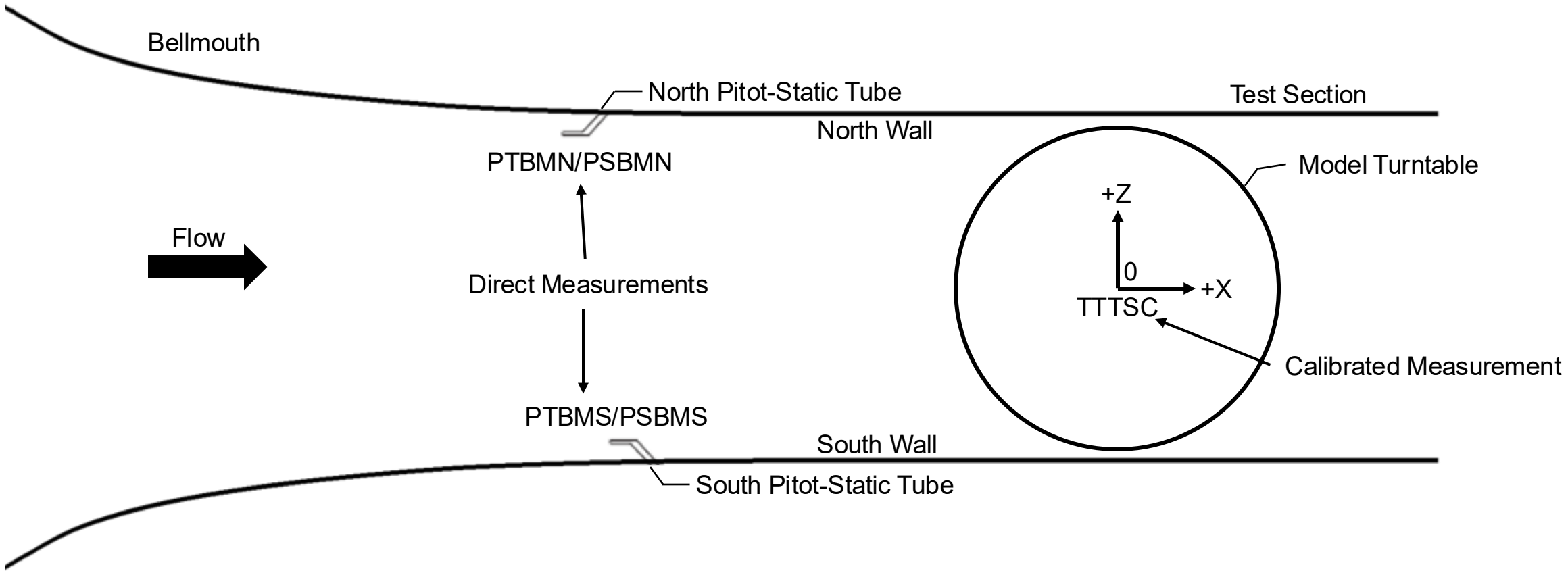
Table 1. Icing Research Tunnel Pitot Tube Locations

Position	X [in]	Y [in]	Z [in]	Diameter [in]
North	-141.85	45.58	46.08	0.22
South	-136.99	45.58	-46.08	0.22

Computation of $C_{p,ref}$ would be:

$$C_{p,ref} = \frac{P - P_{ref}}{\frac{1}{2}\rho_{ref} U_{ref}^2} \; or \; \frac{P - P_{ref}}{\frac{\gamma}{2} P_{ref} M_{ref}^2}, \gamma = 1.4$$

Mock Tunnel Diagram





EXAMPLE CASE

We are assuming that the provided required data has already been averaged from the provided tunnel data. I.e. 1-sample-per-second averaged over 30-second recording

Necessary IRT Measurement Data

Required Data:

- PTBMN (Pressure total bell mouth north)
- PTBMS (Pressure total bell mouth south)
- PSBMN (Pressure static bell mouth north)
- PSBMS (Pressure static bell mouth north)
- TTTSC (Total temperature test section calibrated)
- Pressure Tap Raw Pressures

Example Data:

- PTBMN = 98940 Pa
- PTBMS = 98940 Pa
- PSBMN = 95361 Pa
- PSBMS = 95292 Pa
- TTTSC = 272.74 K
- Pressure Tap Raw Pressure = 97326 Pa

Computations

Assumptions:

$R = 287.053$

$\gamma = 1.4$

If $M_{ref} \leq 0.1$ consider using incompressible assumption

$$\frac{P_{0,ref}}{P_{ref}} = Avg\left(\frac{98940}{95361}, \frac{98940}{95292}\right) = \frac{98940}{95326.5} = 1.03791$$

$$M_{ref} = \sqrt{\frac{2}{1.4-1}\left(\left(\frac{98940}{95326.5}\right)^{\frac{1.4-1}{1.4}} - 1\right)}, M_{ref} = 0.23115$$

$$T_{ref} = 272.74\left(1 + \frac{1.4-1}{2} \cdot 272.74^2\right)^{-1} = 269.856\ K$$

$$U_{ref} = 0.23115\sqrt{1.4 \cdot 287.053 \cdot 269.856} = 76.121\ m/s$$

$$\rho_{ref} = \frac{95326.5}{287.053\ \cdot 269.856} = 1.2306\ \frac{kg}{m^3}$$

$$\mu_{ref} = 1.716 \cdot 10^{-5}\left(\frac{269.856}{273.15}\right)^{1.5}\frac{(273.15 + 110.3333)}{269.856 + 110.3333} = 1.6997 \cdot 10^{-5}$$

$$Re_{L,ref} = \frac{1.2306 \cdot 76.121}{1.6997 \cdot 10^{-5}}, L_{ref} = 5511237/m$$

Computation of $C_{p,ref}$ would be:

$$C_{p,ref} = \frac{97326 - 95326.5}{\frac{1}{2} \cdot 1.2306 \cdot 76.121^2} = 0.5608$$



END