Strategies for Running Juncture Flow CFD in the Tunnel

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Introduction

- The Juncture Flow (JF) model was tested in the NASA Langley 14- by 24-foot tunnel (14x22)
  - See NASA/TM-2019-220286, June 2019
- Running CFD in "free air" neglects the influence of the tunnel walls
- This set of slides provides some suggestions for possible ways to run CFD "in the tunnel"
- CAD files are available
  - for the 14x22 high-speed leg
    - simplified as-built shape, from laser scan
  - for the JF model, sting, and mast (at 5 deg and -2.5 deg. model incidence)
    - positioning obtained from laser scans
    - JF model is the as-designed shape
      - Discussion regarding differences between as-designed and as-built shapes is given on: https://turbmodels.larc.nasa.gov/Other_exp_Data/JunctureFlow/junctureflow_geometry.html
    - mast/sting shapes are approximated

Modeling Fidelity

- Various levels of modeling fidelity can be chosen:
  - Tunnel fidelity:
    - Include entire high-speed leg with contraction and diffuser, or (less accurately) only include a portion thereof
    - Model the tunnel walls as viscous, or (less accurately) as inviscid
      - Note: the incoming tunnel wall boundary layers were roughly 4 - 5 inches (100 - 125 mm) thick at 5 - 6 feet (1.5 - 1.8 m) behind the start of the test section for the JF test
  - Model fidelity:
    - Include JF model only
    - Include JF model and sting only
    - Include JF model, sting, and mast

Typical CFD Strategy for Boundary Conditions (BCs)

- Desired nominal flow conditions (from median dynamic pressure (Q) running conditions during Test 640):
  - M = 0.189
  - T= 288.84 K
  - Re = 2.4 million based on L = 557.17 mm
- Typical BCs for CFD:
  - At inflow plane, set total temperature and total pressure consistent with desired flow conditions. E.g., for ideal gas:

$$\frac{T_t}{T_{ref}} = 1 + 0.2(0.189^2) \qquad \frac{p_t}{p_{ref}} = \left(\frac{T_t}{T_{ref}}\right)^{3.5}$$

  - Adjust back pressure at outflow plane to achieve desired flow conditions (iteratively, by “hand” or automatically)
    - See NASA/TM–2018–219812 for example of automated method
    - Pressure was measured in the diffuser in the JF experiment, and may be used to help guide back pressure settings in the CFD; however, it is more important to match the conditions inside the test section (in whatever computational way that can be achieved)

Considerations

- Achieving “the desired flow conditions” can be difficult
  - With a model in the tunnel, where should the M=0.189?
    - Sometimes CFD practitioners choose a location in the test section that is upstream of the model, away from walls and “far enough” away from the model
      - **But this is NOT how the tunnel is run**
  - In the tunnel, upstream probes are used to measure specific quantities
    - Calibration equations then determine the conditions that would occur in the empty tunnel at a specific reference point (center of the test section at x=5.41 m); these are the reference conditions
- The tunnel inflow conditions are not strictly constant
  - For example, there is a known small pressure deficit over the center region of the tunnel of up to approx. 1 psf when the tunnel Q is around 60 psf (details provided elsewhere in “Slides Describing Measured Inflow Characteristics”)
- CFD can have difficulties if separation occurs in the diffuser near the outflow boundary
  - Possible strategies:
    - Add constant-area extension on the back of the diffuser (see AIAA-2017-4126 and AIAA-2019-0080)
    - Employ inviscid walls in the diffuser (see AIAA-2019-0080)
    - Shorten or eliminate the diffuser so that outflow occurs prior to separation

Locations of Probes in 14x22

- Probes in the 14x22 used to determine running conditions are:
  - Total Pressure (Station 711):
    - (x,y,z) = (-18.105, -7.010, -4.084) m (1.646 m away from the north wall)
  - Static Pressure (Station 758):
    - (x,y,z) = (-3.658, -3.048, 0) m (355.60 mm away from the north wall)
  - Stagnation Temperature (Station 770):
    - (x,y,z) = (-0.140, -3.234, -0.269) m (82.55 mm away from the north wall)
  - Dewpoint sensor orifice (Station 770):
    - (x,y,z) = (-0.140, -3.317, -0.187) m (on the north wall)

14x22 Equations

- Equations used in 14x22 to determine conditions*:

$$\Delta p|_{indicated} = \left(p_t|_{Sta.711} - p|_{Sta.758}\right) \ \left[lbf/ft^2\right]$$
$$C' = \mathcal{F}(\Delta p|_{indicated})$$
$$\Delta p_\infty = C' K_{pr} \Delta p|_{indicated} \ \left[lbf/ft^2\right]$$

$K_{pr} = 0.998$

$$p_{adjusted} = \left(p_t|_{Sta.711} - \Delta p_\infty\right) \ \left[lbf/ft^2\right]$$
$$M_{adjusted} = \sqrt{5\left(\frac{p_t|_{Sta.711}}{p_{adjusted}}\right)^{2/7} - 1)}$$
$$q_{adjusted} = \tfrac{1}{2}\gamma \ p_{adjusted} \ M^2_{adjusted} \ \left[lbf/ft^2\right]$$

$$C' = 1.1381 + 0.00017194\Delta p|_{indicated} + 0.0000050536\Delta p|^2_{indicated} \qquad 0 \leq \Delta p|_{indicated} < 46$$
$$C' = 1.06032 + 0.00354687\Delta p|_{indicated} - 0.000031557\Delta p|^2_{indicated} \qquad 46 \leq \Delta p|_{indicated} < 52.5$$
$$C' = 1.1473 + 0.00023339\Delta p|_{indicated} \qquad \Delta p|_{indicated} \geq 52.5$$

Additional calibration equations are used to determine the tunnel velocity and Reynolds number (see NASA/TM-2014-218513)

*Closed test section, boundary layer removal system off; see NASA/TM-2014-218513 and NASA Technical Report 20190018049, 2019.

Additional CFD Strategy for JF

- The "In_tunnel" CAD files are given in terms of the tunnel coordinate system
  - i.e., the tunnel is "horizontal" and the model is positioned at an angle of incidence
- When running the CFD simulation in the tunnel, it may be useful to shift and rotate the coordinate system to match what was used by the JF experimentalists:
  - (x,y,z)=(0,0,0) at the fuselage nose
  - x axis aligned with fuselage, z up, y out the starboard wing
  - units in mm
  - tunnel appears to be at an angle of incidence with respect to this coordinate system
- In this way, extraction of the JF data will be easier, and the velocities and Reynolds stresses will already be in the correct coordinate system

The approximate rotations/translations (in order) to get the model (with nose at (0,0,0), x axis along the body axis, z up, and y out the starboard side) into position in the wind tunnel (all units in mm) are:

- Incidence angle = 5 deg:
  - X-rotation = 0.02622944 deg
  - Z-rotation = -0.021198898 deg
  - Y-rotation = 5.00004783 deg
  - X-translation = 2873.098936
  - Y-translation = -6.155033
  - Z-translation = 217.321846
- Incidence angle = -2.5 deg:
  - X-rotation = 0.02323800 deg
  - Z-rotation = -0.02444117 deg
  - Y-rotation = -2.49995206 deg
  - X-translation = 2908.038625
  - Y-translation = -6.031538
  - Z-translation = -107.753423

Reverse the order to go from wind tunnel position to body-axis position