Mach Stability Improvements Using an Existing Second Throat Capability at the National Transonic Facility

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Outline

Introduction

Experimental Setup

Results

- Sonic conditions at second throat
- Mach number variability
- Correlation between Mach number and drag
- Consequences of using existing second throat

Summary and Concluding Remarks
Recent upgrades aimed at improving overall data quality at NTF

Improve Mach stability in transonic regime
- Decrease pressure fluctuations in test section for $M_\infty \geq 0.8$
- Correlation between Mach and drag in drag divergence region
- Reduction in Mach variability ➔ Drag repeatability improvements

Goals
- $M_\infty \pm 0.0005$ (Current capability : $\pm 0.001$)
- Repeatability : $C_D \pm 0.5$ counts for full-span transport models

3-prong approach
1. Second throat
2. Conditional sampling
3. Control system improvements
Use of second throats in transonic wind tunnels is common

- Effective in preventing upstream propagation of acoustic disturbances from downstream sources such as the high-speed diffuser
- Also used for fine Mach number control during model traverses
- Typically located downstream of the test section and arc sector

Examples

- NASA LaRC 8-foot Transonic Pressure Tunnel
- European Transonic Windtunnel (ETW)
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Summary and Concluding Remarks
Cryogenic, pressurized wind tunnel capable of achieving very high Reynolds numbers (flight Re for transport type aircraft)

Linear dimensions in feet

- LOW SPEED DIFFUSER
- 15:1 CONTRACTION
- LN$_2$ INJECTORS
- SLOTTED TEST SECTION
- PLENUM
- HIGH SPEED DIFFUSER
- RAPID DIFFUSER
- COOLING COIL
- ANTITURBULENCE SCREENS
NTF Test Section

Beginning of Test Section

T.S. 0 ft.

Arc Sector Center of Rotation

T.S. 13 ft.

End of Slots

T.S. 19.6 ft.

End of Test Section

T.S. 25 ft.

FLOW

Re-entry Flaps

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Existing Second Throat Capability

Combination of re-entry flaps and model support walls to set minimum area at end of test section (T.S. 25 ft.)
2.7%-scale Common Research Model (CRM) tested in NTF

Design Conditions:
\[ M_\infty = 0.85 \]
\[ C_L = 0.50 \]

Wing Parameters:
\[ AR = 9.0 \]
\[ 35^\circ \text{ LE sweep} \]
\[ S_{\text{ref}} = 3.01 \text{ ft}^2 \]
\[ \text{Span} = 62.47 \text{ in.} \]
\[ \text{MAC} = 7.45 \text{ in.} \]
\[ \lambda = 0.275 \]
Full-scale Pathfinder-I Model (PF-I) tested in NTF

Design Conditions:
- $M_\infty = 0.82$
- $C_L = 0.55$

Wing Parameters:
- $AR = 9.8$
- $35^\circ$ LE sweep
- $S_{ref} = 1.988 \text{ ft}^2$
- $\text{Span} = 52.97 \text{ in.}$
- $MAC = 5.74 \text{ in.}$
- $\lambda = 0.313$
Comparison between CRM and PF-I models

Linear dimensions in inches

<table>
<thead>
<tr>
<th>Blockage</th>
<th>CRM</th>
<th>PF-I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>2.20%</td>
<td>1.70%</td>
</tr>
<tr>
<td>Wake</td>
<td>0.06%</td>
<td>0.07%</td>
</tr>
<tr>
<td>Total</td>
<td>2.26%</td>
<td>1.77%</td>
</tr>
</tbody>
</table>

$M_\infty = 0.85$

0.027-scale
Common Research Model

Full-scale
Pathfinder-I Model
Experimental Measurements

Mach number measurement
- Total pressure in contraction
- Static pressure in plenum
- \( p_t, p_s, T_t \rightarrow M_{\text{ref}} \)
  - \( M_{\text{ref}} \) corrected to \( M_\infty \) by tunnel calibration

Force and moment measurements
- NTF-118A internal balance (cryogenic, 6-component)

Data system
- Standard
- Dynamic (high sampling)

<table>
<thead>
<tr>
<th>DAS</th>
<th>Sampling Frequency</th>
<th>Sampling Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>400 Hz</td>
<td>12 sec</td>
</tr>
<tr>
<td>Dynamic</td>
<td>12,800 Hz</td>
<td>12 sec</td>
</tr>
</tbody>
</table>
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Transonic Results

Tunnel configuration

- Baseline
- Second throat set to fully choke for $M_\infty = 0.9$

CRM data

- $M_\infty = 0.70, 0.85, 0.87$
- $Re_c = 5, 10, 19.8$ million
- $T_t = 120^\circ F, -50^\circ F, -250^\circ F$
- $\alpha = -3^\circ$ to $5^\circ$

PF-I data

- $M_\infty = 0.70, 0.75, 0.80, 0.82, 0.84, 0.85, 0.86, 0.87, 0.88$
- $Re_c = 2.5$ million
- $T_t = 120^\circ F$
- $\alpha = -2^\circ$ to $5^\circ$
Sonic Conditions at Throat

Local Mach number on sidewall row 9 from PF-I test

- Baseline vs. Choked tunnel configuration

\[ M_\infty = 0.85 \]

\[ M_\infty = 0.88 \]
Sonic Conditions at Throat

Local Mach number at T.S. 25.44 ft. on sidewall row 9 from PF-I test

- Baseline vs. Choked tunnel configuration

For choke Mach number of 0.9, sonic condition achieved at second throat for $M_\infty \geq 0.85$

Strength of shock at second throat increases as $M_\infty$ approaches choke Mach number
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**Mach Number Variability**

$M_\infty = 0.85$ in **BASELINE** tunnel configuration from CRM test

Range (R) = Max - Min

Variation within a data point is sometimes large especially for higher angles of attack

Some mean values are NOT within goal limits
Mach Number Variability

\( M_\infty = 0.85 \) in **CHOKED** tunnel configuration from CRM test

Variation within a data point is reduced for all angles of attack

Almost all mean values are within goal limits
$M_\infty = 0.87$ in **CHOKED** tunnel configuration from CRM test

Variation within a data point is significantly reduced as $M_\infty$ approaches choke Mach number

All mean values are within goals
Mach Number Variability

Variation as a function of angle of attack in BASELINE tunnel configuration from PF-I test

Range (R) = Max - Min

Upward trend of Mach variation with angle of attack at all Mach numbers
Mach Number Variability

Variation as a function of angle of attack in CHOKED tunnel configuration from PF-I test

- Overall variation levels reduced for all Mach numbers
- Trend with angle of attack also reduced for all Mach numbers

Trend with angle of attack eliminated completely at $M_\infty = 0.88$
Variation as a function of $M_\infty$ from CRM and PF-I tests

In BASELINE tunnel configuration, variation increases with $M_\infty$.

In CHOKED tunnel configuration, variation decreases rapidly as $M_\infty$ approaches choke Mach number.

40-45% reduction in variation levels at $M_\infty = 0.85$
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\( M_\infty = 0.85 \) from CRM test

Model wake drives low frequency disturbances in the tunnel

Disturbances increase with angle of attack and adversely affect Mach stability

In the CHOKED tunnel configuration, the low frequency balance axial force fluctuations were reduced, similar to Mach variability results
Correlation Between Mach and Drag

$\text{M}_\infty = 0.85$ at $\alpha=4^\circ$ in **BASELINE** tunnel configuration from CRM test

Strong correlation between $M_\infty$ and balance axial force.
$M_\infty = 0.85$ at $\alpha = 4^\circ$ in **CHOKED** tunnel configuration from CRM test

**Strong correlation between $M_\infty$ and balance axial force**

**Reduction in balance axial force variability in addition to reduction in Mach number variability**
**M∞ = 0.85 from CRM test**

- Significant correlation between $M_∞$ and balance axial force for $\alpha > 2.5°$

- CRM wing designed for $C_L = 0.5$ at $M_∞ = 0.85$

- $C_L = 0.5$ corresponds to $\alpha \approx 3°$ at $M_∞ = 0.85$

- For CRM model at $C_L = 0.5$, drag divergence begins at around $M_∞ = 0.85$
$M_{\infty} = 0.85$ from PF-I test

Significant correlation between $M_{\infty}$ and balance axial force for $\alpha > 0.5^\circ$

PF-I wing designed for $C_L = 0.55$ at $M_{\infty} = 0.82$

For PF-I model, $M_{\infty} = 0.85$ is above drag divergence Mach number for most angles of attack
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Possibility of increased model dynamics

- Shock at second throat can excite known arc sector and sting dynamic modes

- As $M_\infty$ approaches the choke Mach number and the shock strength at the second throat increases, model dynamics will also increase

- The increased model dynamics MAY negate any drag repeatability benefit gained from reduced Mach number variability
Consequences of Using Existing Throat

$\alpha = 4.5^\circ$ from CRM test

$\Sigma F', \text{lbf}$

- Sting mode
- Arcsector mode

$M_\infty = 0.85$

$\Sigma F', \text{lbf}$

- Sting mode
- Arcsector mode

$M_\infty = 0.87$
Tunnel calibration changes

- Recent tunnel calibration check-out test showed there is a small effect to the calibrated test section Mach number and the Mach number distribution
- Follow-on work will be needed to update tunnel calibration for the choked tunnel configuration
Summary

Existing second throat capability at the NTF improves Mach stability

- Sonic conditions at throat were verified using sidewall pressure data
- 40-45% reduction in Mach variation levels at $M_\infty = 0.85$
- Variation levels reduce rapidly as $M_\infty$ approaches choke Mach number

Mach variation trend with angle of attack also reduced

- Similar results with low frequency balance axial force fluctuations
- Trend is eliminated completely as $M_\infty$ approaches choke Mach number

Strong correlation between $M_\infty$ and AF in drag divergence region

- Improved Mach stability leads to drag repeatability improvements

Consequences of using existing second throat

- Possibility of increased model dynamics
- Effects on calibrated $M_\infty$ and Mach number distribution
Concluding Remarks

Strategy for reducing drag repeatability levels to within ±0.5 counts

• Use existing second throat to improve Mach stability without large increase in model dynamics
  ➢ Example: Run at $M_\infty = 0.85$ with choke setting for $M_\infty = 0.9$

• Use conditional sampling techniques to reduce remaining variation in Mach number and drag within a data point

Future work

• Update tunnel calibration for choked tunnel configuration

• Continue to investigate use of existing second throat
  ➢ Different types of models (semi-span, non-lifting, etc.)

• Plans for installing new second throat downstream of arc sector