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UU	UU	UU	UU		19b. TELEPHONE NUMBER 520-626-8677

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INVESTIGATOR(S):

Name: Ph.D. Jesse Little
Email: jesselittle@arizona.edu
Phone Number: 5206268677
Principal: Y

Organization: **University of Arizona**
Address: PO Box 210158, Rm 510, Tucson, AZ 857210158
Country: USA
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Submitted By: Ph.D. Jesse Little Email: jesselittle@arizona.edu
Phone: (520) 626-8677
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STEM Degrees: **STEM Participants:**

Major Goals: Acquire a transonic test section (TTS) for the 15-in x 15-in Arizona Polysonic Wind Tunnel (APWT).

Accomplishments: DoD HBCU/MI program funds ($600,000) have been used to purchase a transonic test section (TTS) for the 15-in x 15-in Arizona Polysonic Wind Tunnel (APWT). APWT currently operates only in the supersonic regime at Mach 1.75, 2.1, 2.5, 3.0, 3.5 and 4.0. The TTS and eventual acquisition of related hardware (subsonic nozzle, choke flaps and hydraulics) expands the AWPT envelope to transonic (Mach 0.8-1.2) and subsonic (Mach 0.3-0.8) conditions. A Mach 5 nozzle is also on order providing hypersonic capability. APWT is the largest university-operated polysonic tunnel in the U.S. and one of only four University-operated transonic tunnels at reasonable scale. This equipment will foster existing and new collaborations with University of Arizona (UArizona) faculty in other strong units (e.g., Optical Sciences) as well as minority-serving institutions across the American Southwest in a critical area (transonic aerodynamics) with limited university testing capacity.

Training Opportunities: Nothing to Report

Results Dissemination: Nothing to Report

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PARTICIPANTS:

Participant Type: PD/PI
Participant: Jesse Little
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Partners

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I certify that the information in the report is complete and accurate:
Signature: Jesse Clayton Little
Signature Date: 3/13/23 4:12PM

Final Report

Extending the 15in x 15in Arizona Supersonic Wind Tunnel to Transonic Conditions
W911NF1910440

Jesse Little
Department of Aerospace and Mechanical Engineering
The University of Arizona
Tucson, AZ 85721

Army Research Office
PM: Dr. Jack Edwards

March 2023

1 Abstract

DoD HBCU/MI program funds ($600,000) have been used to purchase a transonic test section (TTS) for the 15-in x 15-in Arizona Polysonic Wind Tunnel (APWT). APWT currently operates only in the supersonic regime at Mach 1.75, 2.1, 2.5, 3.0, 3.5 and 4.0. The TTS and eventual acquisition of related hardware (subsonic nozzle, choke flaps and hydraulics) expands the AWPT envelope to transonic (Mach 0.8-1.2) and subsonic (Mach 0.3-0.8) conditions. A Mach 5 nozzle is also on order providing hypersonic capability. APWT is the largest university-operated polysonic tunnel in the U.S. and one of only four University-operated transonic tunnels at reasonable scale. This equipment will foster existing and new collaborations with University of Arizona (UArizona) faculty in other strong units (e.g., Optical Sciences) as well as minority-serving institutions across the American Southwest in a critical area (transonic aerodynamics) with limited university testing capacity.

2 Introduction

Transonic aerodynamics are more challenging than subsonic and supersonic flows individually, and in some respects, even more so than hypersonic. This is because transonic aerodynamics contains a mixture of subsonic and supersonic behavior making accurate model predictions very challenging. Even the design of transonic wind tunnels (let alone the execution of actual transonic experiments) is difficult. This has resulted in a dearth of both transonic knowledge and facilities particularly at universities. This is unfortunate since many important systems operate in the transonic regime (e.g., transport aircraft, rotorcraft, turbomachinery and various projectiles). The acquisition of this equipment will allow UArizona to further its leadership in aerodynamics through research and the education of new generations of scientists and engineers with expertise in transonic flows.

This project was funded in 2019 and required two no cost extensions due to delays associated with the UArizona RFP process, COVID-19, retrofit design requirements and supply chain issues. Because of these delays, inflation has impacted the project causing it to come in approximately

30% over budget. These additional costs have been offset by internal UArizona funding. The HBCU/MSI dollars have been fully expended with the final payments (from internal UArizona funds) scheduled to be paid on delivery in late March 2023.

3 Background

The challenge of transonic wind tunnel testing can be seen from Figure 1 which plots the ratio between throat area, A*, and test section area, A. The relationship shows two Mach number solutions (subsonic and supersonic) for a given area ratio except at Mach 1 where the function has a single value of one. The gradient of the curve near Mach 1 demonstrates the challenges associated with transonic testing. Very slight changes in area ratio generate very large changes in Mach number near Mach 1. If one is only concerned about generating a transonic flow in the test section at a specific Mach number, then this is perhaps less of an issue since accurate machining of the nozzle and test section would allow operation at a given condition in the transonic regime. However, insertion of even a relatively small model in the test section changes the effective area thus affecting the test conditions. The implications are summarized by the following example paraphrased from Anderson (2012). Approximately one year before the first manned supersonic flight in the Bell X-1 by Capt. Charles Yeager in 1947, a scaled model of the aircraft was tested in NASA Langley high speed tunnel. The Bell X-1 model was 1 ft in span while the wind tunnel was 8 ft in diameter. Even with such a small model relative to the tunnel, the Mach number was limited to 0.92. As illustrated here, small changes in the test section area perceived by the flow (e.g. even from inserting a relatively small test article) completely change or limit the intended flow condition near Mach 1.

The solution to the challenge of transonic wind tunnel testing is attributed to Langley physicist Ray Wright who mathematically posed that ventilation slots around the test section would allow operation of the tunnel at compressible subsonic through sonic and into the low supersonic regime. The result was a slotted wall transonic test section that helped 20 NACA Langley Aeronautical Laboratory researchers (led by John Stack) to win the Collier Trophy in 1951. An example of a slotted wall transonic test section from the 11-ft x 11-ft transonic wind tunnel at NASA Ames is shown in *Figure*. Since that time, there have been various other advances to transonic wind tunnel design and testing. Namely, the use of a downstream choke has gained prominence located between the end of the test section and the diffuser. The choke is typically created using variable deflection flaps or rotating bars. Its purpose is to eliminate the upstream propagation of flow unsteadiness from the diffuser while also allowing more precise control of test section Mach number.

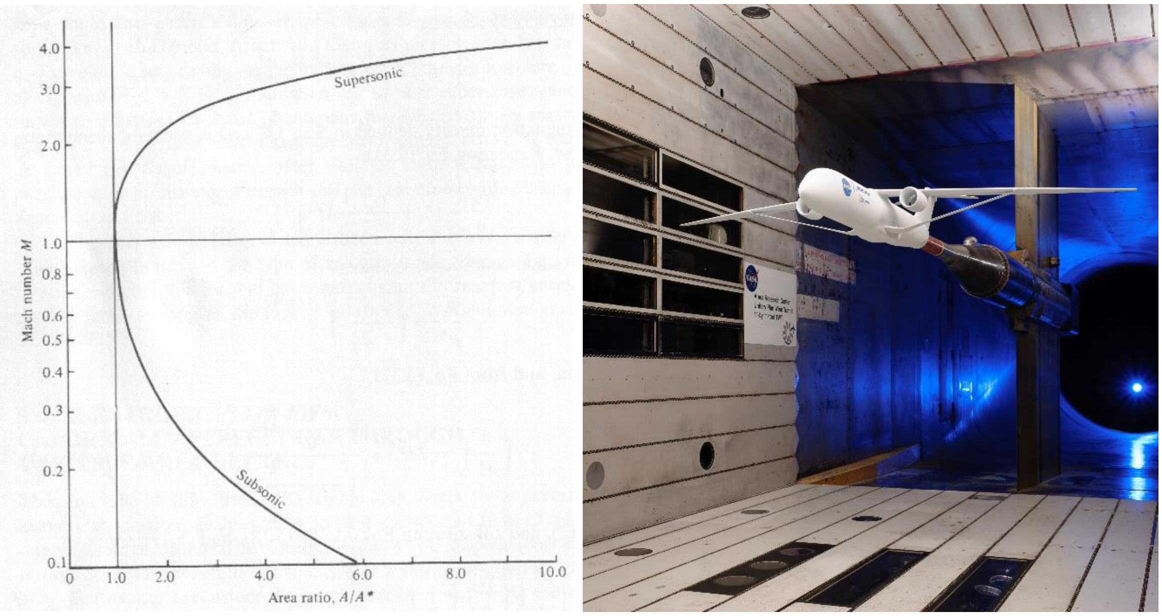

Figure 1: Area-Mach number relationship (Anderson, 2012) and a photograph of the 11-ft x 11-ft Transonic Wind Tunnel at NASA Ames showing a slotted wall test section.

4 Equipment Description

The TTS purchased here has been designed by Calspan and is based on similar successful versions housed at other locations (e.g., U. Mississippi). One of the design challenges was to retrofit with an existing tunnel for which drawings are not available. Thus, considerable time and effort (e.g., laser scanning) was required to ensure fit-up.

Figure 2 shows a transparent rendering of the TTS. Note that only components downstream of the subsonic nozzle have been purchased under this award. The complexity of the design is readily apparent showing a slotted test section surrounded by a pressure vessel which is necessary for smooth transition through the transonic regime (see Figure 1). The plenum is rated to 155 psig while the test section itself is situated for 30 psig. This is consistent with other facilities housed in industry and government labs. The test section has a slight divergence (0.65 degrees) to account for boundary layer growth in the test section. This is required since perceived blockage due to the boundary layer impacts the achievable Mach number in the test section due to sensitivity of the area ratio (see Figure 1).

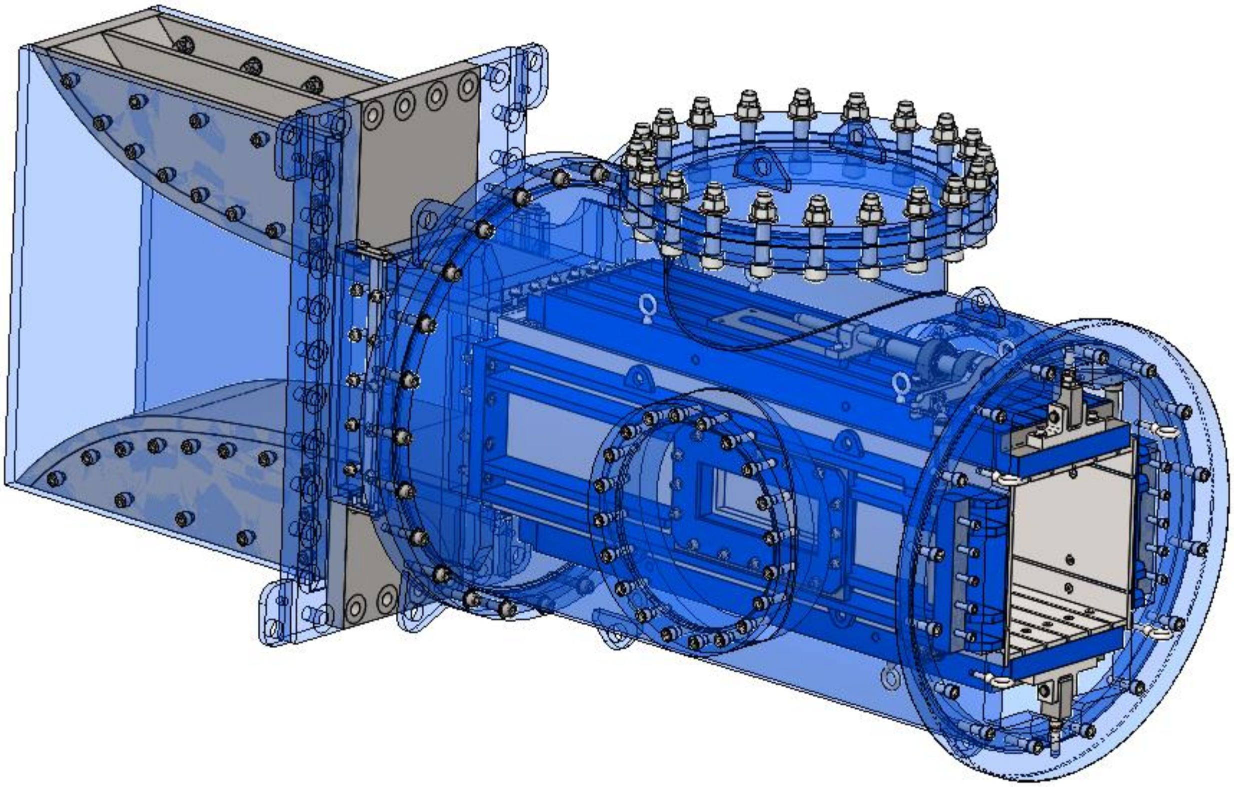

Figure 2: Transparent rendering of the TTS.

Figures 3 and 4 provide more detail on the TTS design. The section view in Figure 3 better shows the slotted walls that exist within the plenum. A rectangular window is also shown to provide optical access. Note that funding did not permit purchase of window glass nor glass to replace the blank external circular plug so this will be acquired later. The blind flange on top of the test section is used to access the reentry (or Mach) flap mechanism which is used to manage flow through the slotted walls. Additional detail on the reentry concept is provided in Figure 4 showing the direction of airflow through the flaps.

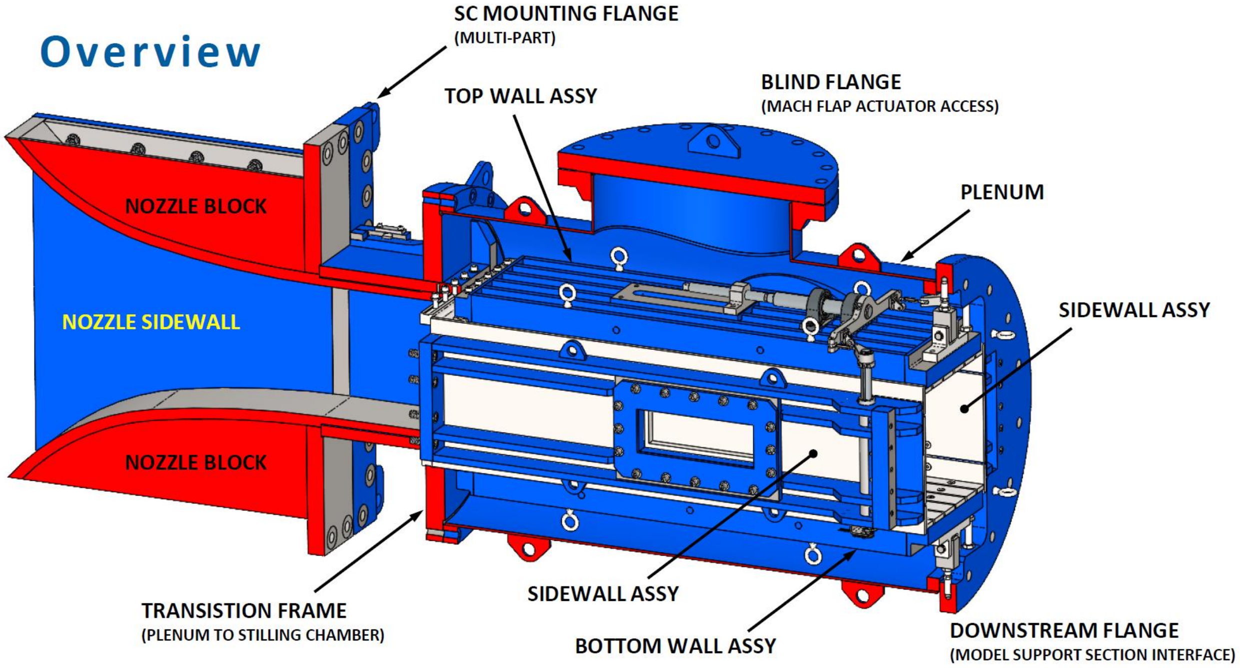

Figure 3: Section view of TTS

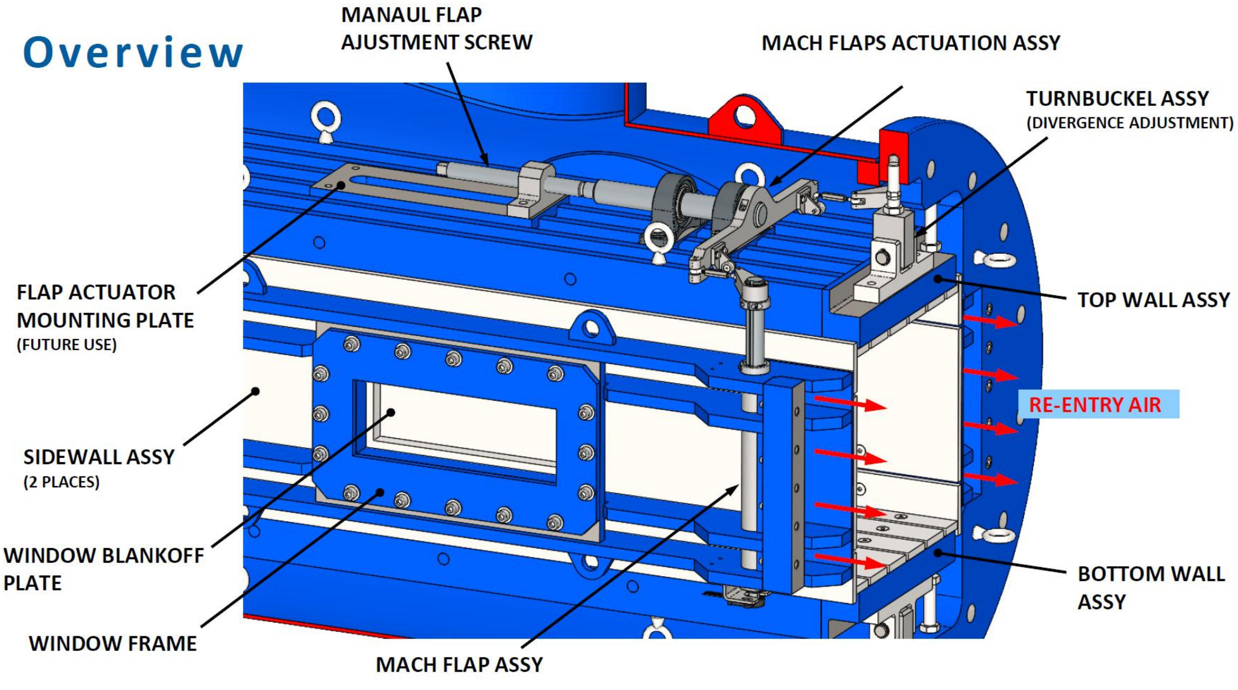

Figure 4: Detailed rendering showing Mach flap concept.

5 Current Status

The TTS fabrication is nearly finalized with delivery scheduled for March 31. The final payment, from internal UArizona funds, will be withheld until that time. Sample photographs of finalized components awaiting assembly are shown in Figure 5.

Figure 5: Sample photographs of fabricated components awaiting final assembly.

Upon delivery, the TTS will be inspected for fit and functionality. However, installation and testing will require additional funding for acquisition of the downstream choke and hydraulic system. Note that the subsonic nozzle has been funded by DURIP and will be acquired later this year. Figure 6 shows a photograph of APWT while Figure 7 summarizes the operational envelope once all upgrades are complete.

Figure 6: Photograph of APWT

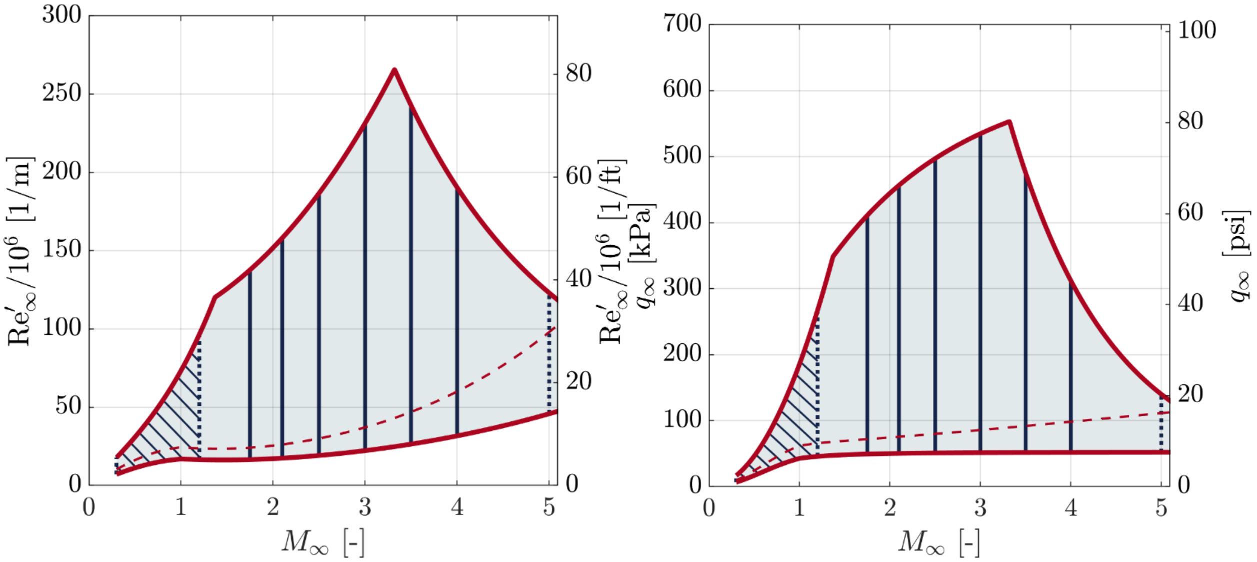

Figure 7: Estimated APWT operational envelope with existing capability (solid lines) and future capability (dotted lines and crosshatch). Dashed curve estimates minimum starting condition (empirical). Minimum operational limit is from theory and maximum operational limit is set by test section pressure (30 psig), flow rate through valves (550 lb/s) and settling chamber limit (600 psig). Actual maximum is air supply dependent and has not been determined.

6 Future Plans

Immediate research goals include extending the collective knowledge of certain aerodynamic phenomena, developed in subsonic and supersonic flows, to the transonic regime. Examples include boundary-layer transition, shock/boundary layer interaction, vortex/body interaction and separated flows (e.g., dynamic stall). More long-term efforts will focus on multidisciplinary collaborations within the College of Engineering and UArizona as a whole. Education will be advanced using traditional B.S., M.S. and Ph.D. degrees, but also through alternative programs (e.g., Master of Engineering) that target students and working professionals who require basic knowledge in specialized fields like wind tunnel testing and/or a specific flow regime (e.g., transonic, hypersonic). Outreach efforts will leverage ongoing successful programs in the College of Engineering, College of Education and the University at large that target underrepresented groups in STEM. These programs engage undergraduates as well as high school students and teachers. The size and operational characteristics of the experimental facility are attractive to the aerospace industry which will open new avenues for partnerships in both research and education. Collectively, these developments will make UArizona an even more effective producer of exceptional engineering talent.

7 References

- Anderson, J, (2012), *Modern Compressible Flow with Historical Perspective*, 3rd edition.