Active Control of Aerodynamic Noise Sources
- Final Report -
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Abstract

Aerodynamic noise sources become important when propulsion noise is relatively low, as during aircraft landing. Under these conditions, aerodynamic noise from high-lift systems can be significant. The research program and accomplishments described here are directed toward reduction of this aerodynamic noise. Progress toward this objective include correction of flow quality in the Low Turbulence Water Channel flow facility, development of a test model and traversing mechanism, and improvement of the data acquisition and flow visualization capabilities in the Aero. & Fluid Dynamics Laboratory. These developments are described in this report.

1 Introduction

Issues of aircraft noise reduction are of significant interest to the aerospace industry and to NASA. Airframe noise generation is of particular importance during landing conditions, when high-lift and landing-gear systems are deployed. One of these noise sources is the deflected leading and trailing-edge wing flaps. This project therefore considered aerodynamic noise associated with a half-span Fowler flap, with particular attention on the flap-end region.

The first phase of this project included correction of several flow quality problems in the Low Turbulence Water Channel (LTWC) facility. One of these issues was a flow nonuniformity due to an axial pressure gradient in the supply manifold. This original manifold was a 16-inch diameter, 8-foot long perforated pipe, which returned flow to the upstream end of the LTWC flow-conditioning tank. As mentioned in the project proposal, a simple modification had been designed and tested to correct the manifold pressure gradient. Scale-model tests indicated that a linear reduction of cross-sectional area along the manifold axis provided the desired uniform axial pressure distribution for an axisymmetric (360°) distribution of perforations. At the start of this project, the proposed correction to the LTWC flow problem therefore included a 1-D horizontal manifold with linear area reduction, followed by a diffuser to distribute the flow across the vertical extent of the flow-conditioning tank. In this design, the flow would pass from the manifold to the diffuser via perforations distributed over a 45° sector.

Final scale-model tests were subsequently conducted to confirm uniform manifold pressure for the non-axisymmetric exhaust flow, that is radial exhaust over a 45° sector. Unfortunately, these tests indicated that manifold pressures became non-uniform with non-axisymmetric exhaust flow. After considering several other approaches, the existing cylindrical manifold geometry was abandoned. Following this, a 2-D manifold-plus-diffuser design approach was adopted. This solution to the flow uniformity problem is described in Section 2.1.1 - Uniform-Flow Manifold. As described in the yearly project narratives, the above developments had the result of redirecting the focus of efforts on this project. However, several difficult facility issues were resolved, and significant experimental tools were developed as described below.

The other issue of LTWC flow quality to be addressed under this project was that of turbulence reduction. At the start of this project, the LTWC flow-conditioning tank included the 16-inch diameter supply manifold described above, and a 7:1 contraction section. Provision for turbulence reduction in the flow conditioning tank had been made, but the devices were not in place. Through this project, a six-stage turbulence reduction system was designed, fabricated, and installed in the LTWC facility. This is described in Section 2.1.2, Turbulence Reduction.

Important experimental capabilities were developed in the Aero. & Fluid Dynamics Laboratory through this project. General data acquisition capabilities were upgraded to a PC-based system employing VXI technology. An analog-to-digital converter card, with DSP, was added to this data-acquisition system. Other general capabilities that are new include an oscilloscope and an anti-aliasing filter with ultra-low band pass for use in the LTWC facility. Specific equipment developed for this project include a wing traversing mechanism with load balance and a wing model based on the NASA LaRC EET design. These new wing model and traversing capabilities are described in Section 2.2, EET Wing Model.

A primary objective of the NASA Faculty Awards for Research (FAR) program is to "support and involve disadvantaged graduate and undergraduate students," requiring that a minimum of 25% of NASA funding be expended for this purpose. During this project, two graduate students and eleven undergraduate students were supported, accounting for 40% of NASA funds. The fraction of NASA funds expended on salaries to students of known minority ethnicity was 20%. Of the students hired, 70% were of Hispanic ethnicity. Students working on this NASA-FAR project were intimately involved with the development processes described above, from design conception through fabrication and installation. Most of these students completed senior design projects associated with this work. Beyond the salary support noted above, this grant provided these students with the materials and equipment support necessary to complete their projects. Thus, NASA funding expended to support and involve disadvantaged students was in excess of 25%.

2 Accomplishments

2.1 LTWC Flow Conditioning

A number of key additions to the LTWC flow conditioning were made through this project. These include the uniform flow manifold and the turbulence reduction components. While development and installation of the turbulence reduction components proceeded as planned; correction of the manifold nonuniformity became problematic, as noted above. Through support of this grant, however, these problems were corrected, as will be described below. Final testing of the uniform flow manifold awaits the acquisition of two perforated sheet components, which are to be placed between the horizontal-vertical manifold and vertical manifold-diffuser interfaces.

2.1.1 Uniform-Flow Manifold

1-D Manifold Development

The uniform-flow manifold design concept is based on linear area reduction to provide a uniform axial pressure distribution. This approach assumes viscous effects are negligible for a low aspect ratio (length/diameter < 10) manifold. From Bernoulli's equation for inviscid flow, manifold pressure is maintained constant if internal flow velocity is constant. For a uniform exhaust flow distribution along the manifold axis, this simple reasoning leads to a corresponding linear reduction of the manifold cross-sectional area. Design concepts for the 1-D manifold were tested in the apparatus shown in Figure 1. Two differential static-pressure measurements, as shown, were used to determine the pressure coefficient at each measurement port.

Linear area variation for the cylindrical geometry manifold was accomplished using a parabolic centerbody insert. This geometry is shown, for the 1:10 scale model tests, in Figure 2(a). In these tests, the axial pressure gradient was measured for the parabolic insert

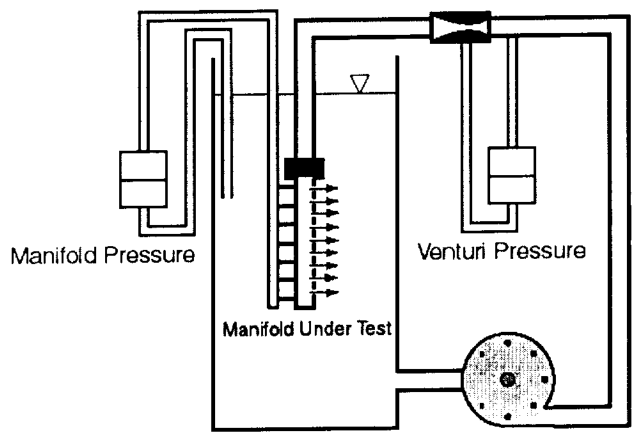
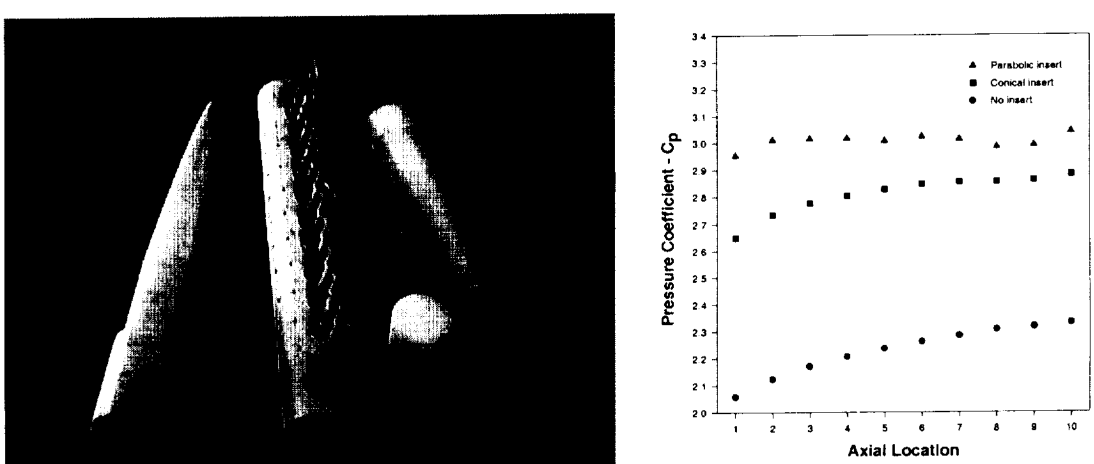


Figure 1: Manifold test apparatus.

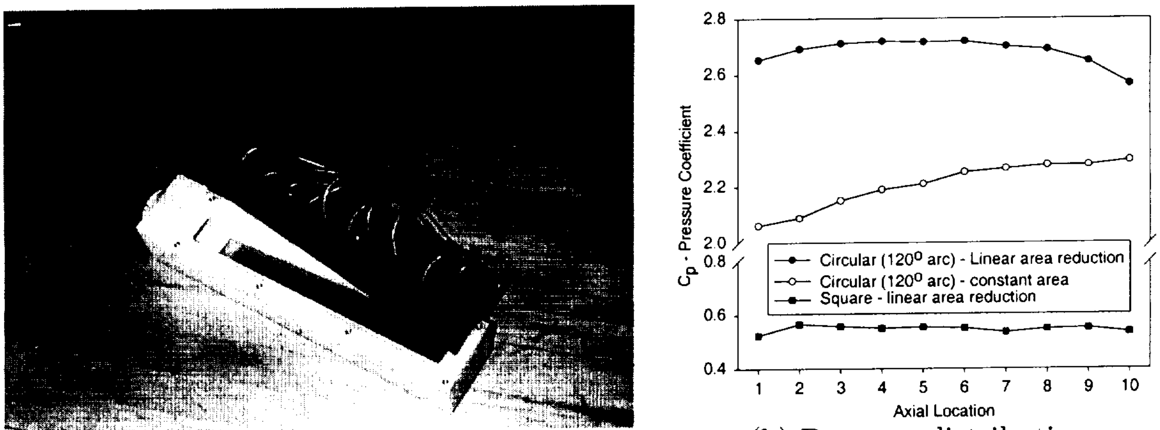
as well as for the conical insert and the plug insert. The conical insert would be relatively easy to fabricate at full scale, and the plug insert corresponded to the constant cross-sectional area case. Our objective was to verify the design concept before full-scale fabrication, in particular to evaluate viscous effects toward the end of the manifold, where the annular flow area diminishes to zero. The corresponding results for the 360 ° axisymmetric exhaust flow is shown in Figure 2(b).



(a) Cylindrical manifold with inserts. (b) Pressure distribution.

Figure 2: Test apparatus and results for axisymmetric manifold.

A nearly flat pressure distribution is observed for the parabolic insert. When the 120 ° exhaust geometry was tested, however, an undesirable axial pressure gradient was present, as shown in Figure 3(b).



(a) Square manifold with insert. (b) Pressure distribution.

Figure 3: Square crossection manifold and results for 120 degree cylindrical manifold and for square manifold.

It may be observed that, for the 120° case, the flow is no longer axisymmetric. Thus, cross-flow on the centerbody insert must be present. Viscous effects, including flow separation on the leeward side of the insert may be expected. The eventual solution to this problem was the square manifold geometry, shown in Figure 3(a). The desired uniform axial pressure distribution is observed in Figure 3(b) for this geometry.

2-D Manifold Development

Confirmation of uniform manifold pressure for the square cross-section manifold led to the final 2-D manifold design. A horizontal manifold, followed by a vertical manifold, distributes the flow over the full width of the flow-conditioning tank, and 33% of its height. The remaining vertical expansion is handled by a 1:3 area ratio diffuser. This design is shown in Figure 4.

Figure 5 shows the manifold installation, including the transition wall penetration and the 2-D manifold components. The diffuser is currently being fabricated and installed in the LTWC facility.

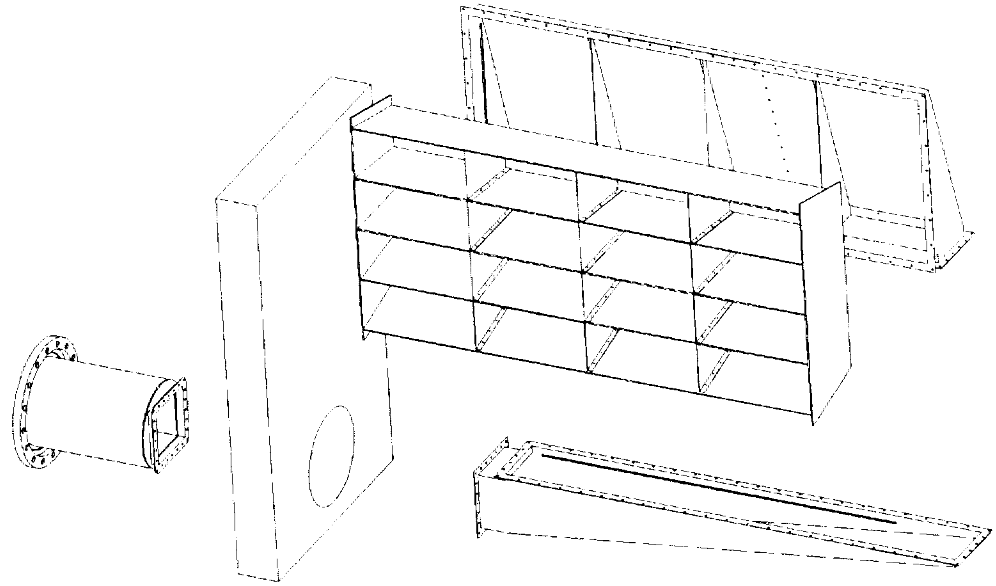
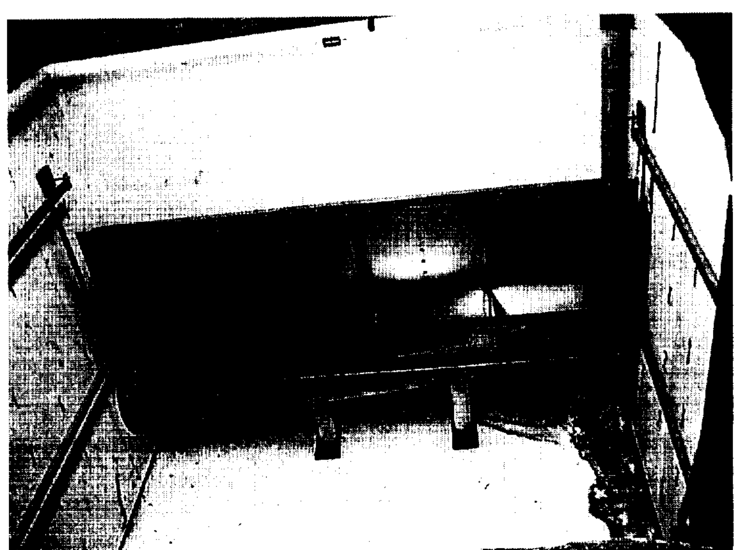


Figure 4: Uniform-flow manifold design exploded view, including circular-to-square wall penetration, horizontal and vertical manifolds, and diffuser.

(a) Transition installation.



(b) Horizontal and vertical manifold installation.

Figure 5: Uniform-flow manifold installation.

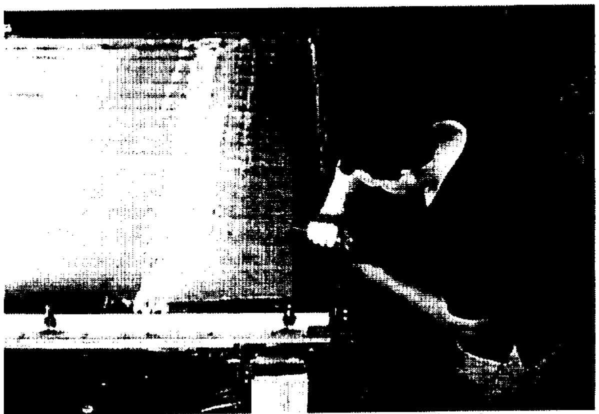
2.1.2 Turbulence Reduction

A six-stage turbulence reduction set was designed and installed in the flow-conditioning tank of the LTWC facility. Each stage has a stainless steel frame to support and tension the associated screen material. The turbulence reduction stages are as follows

1. Screen frame, tensioned stainless steel screen (30 mesh, .0625 dia. wire), fiber filter media mounted on upstream face.
2. Screen frame, tensioned stainless steel screen (30 mesh, .0625 dia. wire), honeycomb mounted on upstream face (3/8-inch cell by 4-inch thick aramid fiber).
3. Screen frame, tensioned stainless steel screen (30 mesh, .0625 dia. wire).
4. Screen frame, tensioned stainless steel screen (30 mesh, .0625 dia. wire).
5. Screen frame.
6. Screen frame.

Screen panels were tensioned by hand until taught. Initial clamping and tensioning is shown in Figure 6(a). The first two screen panels also support filter media and honeycomb, respectively. Installation of honeycomb in the second screen panel is shown in Figure 6(b). The LTWC flow conditioning tank and test-section observation deck are also visible in the background of Figure 6(b). The turbulence reduction system is complete and operational, with the final two screen frames in place, but empty. It may be desirable to fill these at a later date, depending on results of flow quality tests. The entire turbulence reduction set may be moved approximately six feet in the streamwise direction to adjust the size of the stilling chamber. A flow channel inside the conditioning tank is established by wall and floor fairings of 1/4-inch PVC sheet. These extend between the supply manifold and the exit contraction.

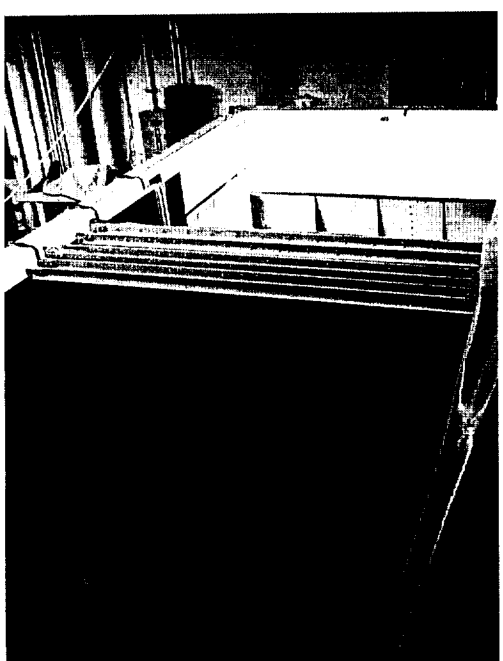
The turbulence reduction system installation is shown in Figure 7. View (a) is looking upstream in the flow-conditioning tank. The face of the last turbulence reduction screen is visible in the foreground, and the vertical manifold is seen in the background. View (b) looks in the cross-stream direction. The PVC fairing, which defines the flow channel along the walls and floor, is also visible in these views.



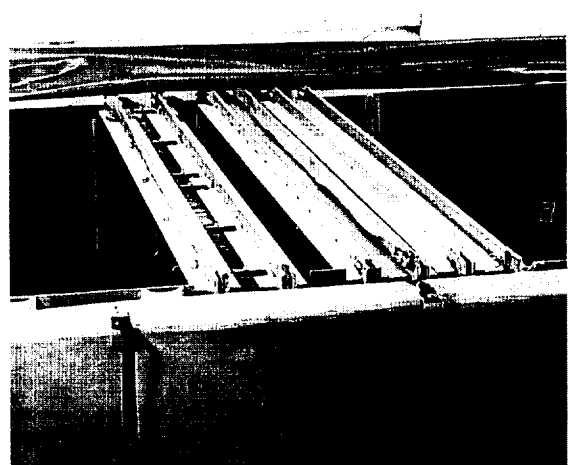
(a) Turbulence screen tensioning.

(b) Honeycomb-screen assembly.

Figure 6: Flow conditioning assembly.



(a) Screen-set upstream view.



(b) Screen-set cross-stream view.

Figure 7: Turbulence reduction installation.

2.2 EET Wing Model

The Fowler-flap wing model is based on the NASA LaRC EET airfoil geometry. For fabrication purposes, it is assembled in two parts: the main wing element, and the flap assembly. These components are shown in Figure 8. Provisions are made for two flap deployment angles using two interchangeable sets of flap brackets. The flap assembly includes the following components: outboard Delrin flaps, inboard Delrin flap, aluminum flap cove. A stainless steel flap-assembly bracket ties the flap assembly to the main wing element. The main wing

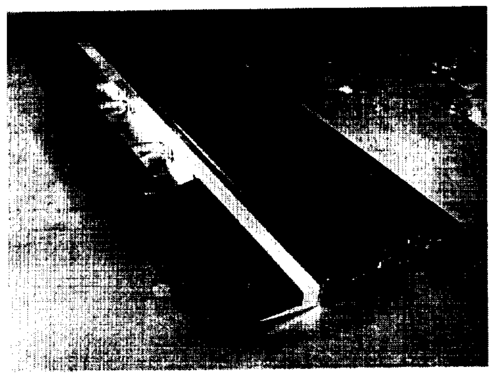
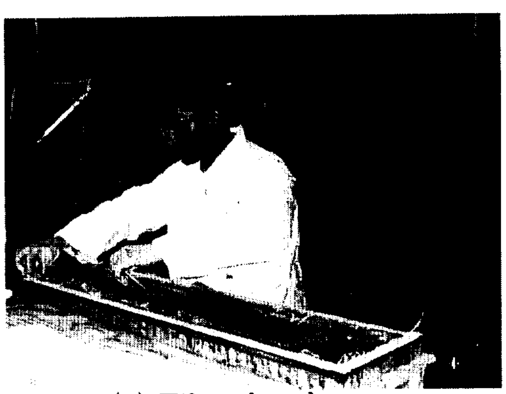


Figure 8: EET wing assembly.

element is fiberglass-epoxy composite. Its upper and lower halves were fabricated using a vacuum-bag approach, as shown below.



(a) Fiberglass lay-up.

(b) Vacuum bag.

Figure 9: EET wing development.

A servo controlled traversing mechanism was designed to support the wing model, as shown in Figure 10.

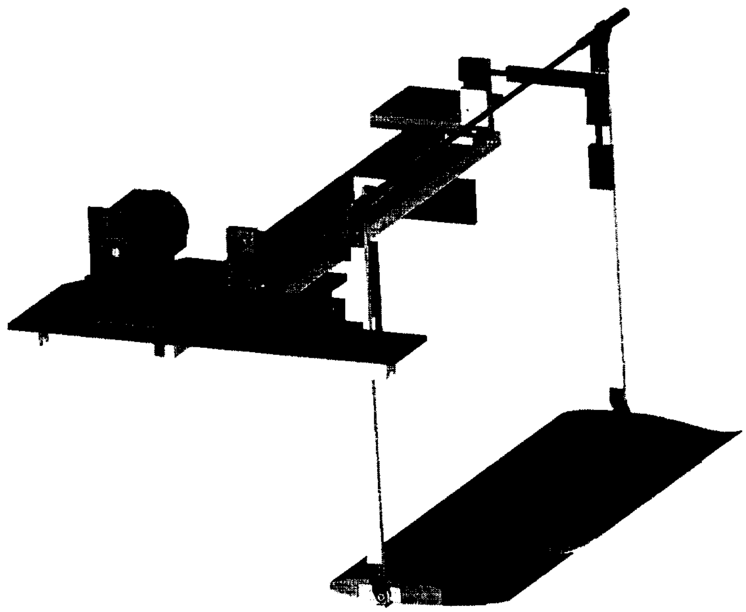


Figure 10: Wing-traversing mechanism assembly.

The 1-D servo drives the pitch angle through a chain/cable drive train on each support arm. Load balances located at the upper end of these support arms provide lift and drag measurement.