NASA/TM—1999-209655

Evaluation of the Tone Fan Noise Design/ Prediction System (TFaNS) at the NASA Glenn Research Center

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December 1999

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Acknowledgments

I would like to recognize Dr. Edmane Envia for his kind guidance in preparing this report and for use of pertinent graphics, data, and analysis results.

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Abstract

Version 1.4 of TFaNS, the Tone Fan Noise Design/Prediction System, has recently been evaluated at the NASA Glenn Research Center. Data from tests of the Allison Ultra High Bypass Fan (UHBF) were used to compare to predicted farfield directivities for the radial stator configuration. There was good agreement between measured and predicted directivities at low fan speeds when rotor effects were neglected in the TFaNS calculations. At higher fan speeds, TFaNS is shown to be useful in predicting overall trends rather than absolute sound pressure levels.

Introduction

The interaction of fan wakes with downstream stator vanes is a significant source of tone noise in modern turbofan engines. Accurate fan noise prediction codes are invaluable tools for engineers working to minimize tone noise through changes in blading and duct geometry. Until noise predictions can be generated quickly using computational aeroacoustic methods, system predictions that couple results from source and radiation codes are currently the design engineer’s only alternative to more simple approaches. TFaNS, the Tone Fan Noise Design/Prediction System, is one such code that has recently been evaluated at the NASA Glenn Research Center and results of that evaluation will be presented here.

TFaNS was developed by Pratt and Whitney under contract to the NASA Glenn Research Center. It is a suite of coupled codes for computing upstream and downstream propagating sound pressure levels, as well as far-field directivities. TFaNS consists of five main computer codes: AWAKEN: CFD/Measured Wake Postprocessor Version 1.0, SOURCE3D: Rotor Wake/Stator Interaction Code Version 2.5, Eversman Inlet Radiation Code Version 3.0, Eversman Aft Radiation Code Version 3.1, and CUP3D: Fan Noise Coupling Code Version 2.1.

SOURCE3D is a modified version of the BBN/V072 Rotor Wake/Stator Interaction Code. Both codes are well documented in References 1-5. Both SOURCE3D and V072 model the blades as twisted flat plates and the duct as a constant area annulus. V072 assumes axial flow through the duct while SOURCE3D can include solid body swirl in the region between the rotor and the stator. Unlike V072, SOURCE3D creates rotor and stator acoustic properties files, which are needed as input into the CUP3D program. The acoustic properties files contain rotor and stator scattering coefficients and source vector mode amplitudes for noise emanating from the stator (References 6-7).

Both of the Eversman Radiation Codes have also been modified to work within TFaNS. The TFaNS version of the inlet and aft radiation codes are able to run multiple modes and harmonics assuming unit mode amplitude input. Acoustic properties files are also output for use in the CUP3D program. The Eversman Radiation Codes are well documented, and the reader is advised to look to Reference 2 for more detailed information.

The two remaining codes are unique to TFaNS. CUP3D is a program that will couple the results from isolated blade row and radiation codes. AWAKEN is a tool that will create the SOURCE3D input file if the user chooses to input wake data from either CFD predictions or from measurements rather than using the wake models available in the SOURCE3D program.

The evaluation conducted at the NASA Glenn Research Center compares results from the latest version of TFaNS (Version 1.4) to experimental data collected from the Allison Ultra High Bypass Fan (Reference 8). Three conditions were studied: approach, cutback, and takeoff. Comparisons were also made to predictions made earlier by Envia and Nallasamy (Ref. 9) and to results from the previous version of TFaNS (Version 1.3).

Modeling

The Ultra High Bypass Fan, a low tip speed fan stage designed by Allison for NASA Glenn Research Center, was used in this study. This fan had four stator configurations and experiments were conducted to study the effect of swept and leaned stator vanes. For the study presented here, only the baseline configuration with radial vanes in the forward position was modeled with TFaNS. A schematic of this baseline configuration can be seen in

Figure 1, which also shows the bounds of the computational domains. Coordinates defining the flowpath were taken from Table I and from Figures 39 and 40 of Reference 10.

Care was taken in creating the input files for SOURCE3D and the inlet and aft radiation programs. To simplify the duct geometry as required by the SOURCE3D code, the real duct geometry was modeled as a constant area annulus. The inner and outer radii of that annulus were set equal to the values of the stator leading edge hub and tip positions, respectively. This was the most reasonable choice considering the significant area change along the flowpath and the fact that the source region was located at the stator leading edge.

Interface planes upstream and downstream of the rotor and stator must be specified within the SOURCE3D input file in order to create the acoustic elements needed by CUP3D. An arbitrary reference plane was established at the stator leading edge and the duct radius there, used in non-dimensionalization, was 11.00 inches. Interface Plane 1 was chosen to be 1.00 inch upstream of the rotor leading edge. Interface Plane 2, located between the rotor and the stator, was 1.397 inches upstream of the stator leading edge, and Interface Plane 3 was chosen to be downstream of the stator trailing edge, 2.734 inches from the reference plane (Figure 1).

Two inlet and one exhaust mesh were created for the forward and aft radiation portions of this problem. The input plane for the first inlet mesh was coincident at Interface Plane 1 described above (Figures 2a, 2b, and 2c). This mesh was used for cases for which the presence of the rotor acoustic element was taken into account. The input plane for the second inlet mesh was coincident at Interface Plane 2 and was used for cases coupled without the rotor acoustic element (Figures 3a, 3b, and 3c). Only one exhaust mesh was used in all coupling cases, and the input plane for this mesh was coincident at Interface Plane 3 (Figures 4a, 4b, and 4c).

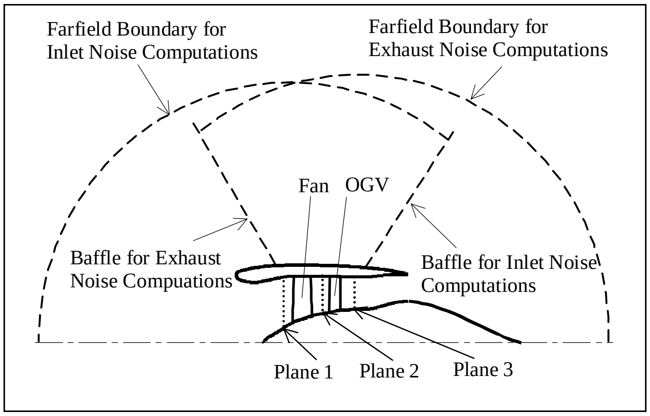

Figure 1. Ultra High Bypass Fan Baseline Configuration and Computational Domain Boundaries

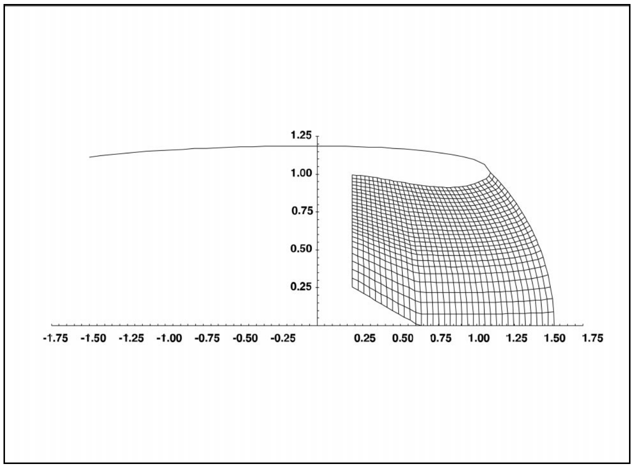

Figure 2a. Inlet Mesh with Input Plane Upstream of the Rotor Leading Edge; Detail of Mesh Within the Duct

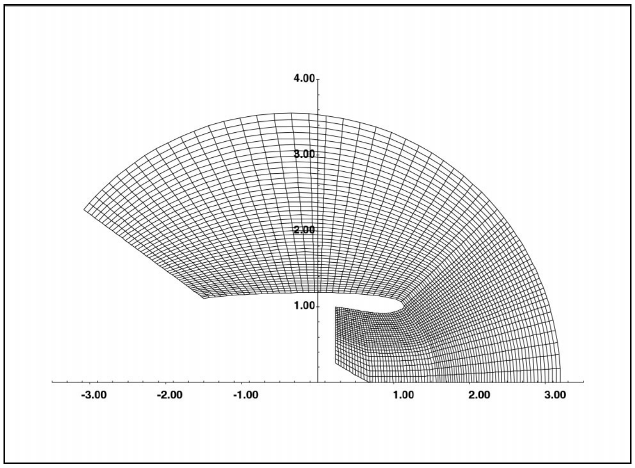

Figure 2b. Inlet Mesh with Input Plane Upstream of the Rotor Leading Edge; Detail of Mesh Near the Duct

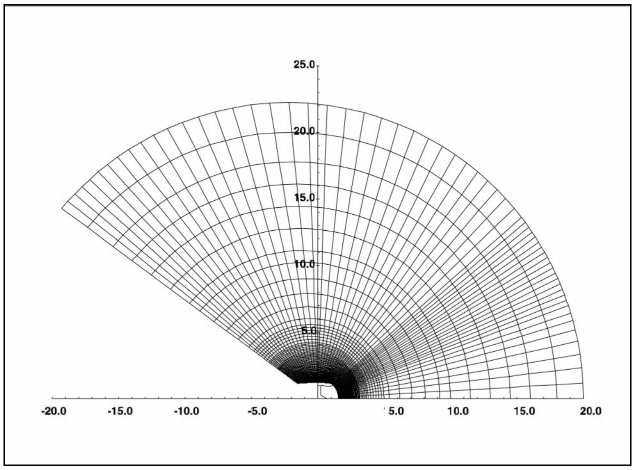

Figure 2c. Inlet Mesh with Input Plane Upstream of the Rotor Leading Edge; Detail of the Farfield Mesh

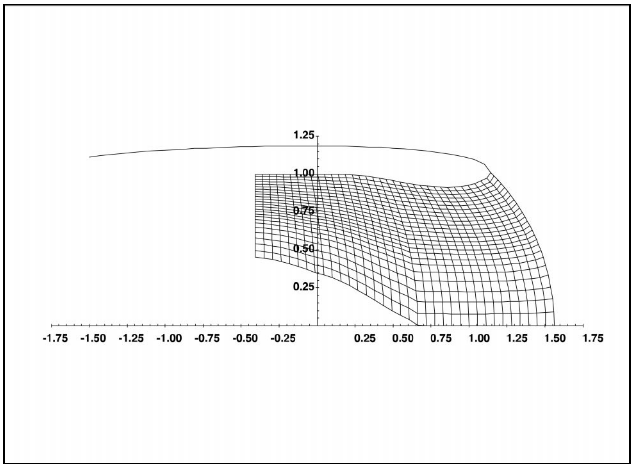

Figure 3a. Inlet Mesh with Input Plane Between the Rotor and the Stator; Detail of Mesh Within the Duct

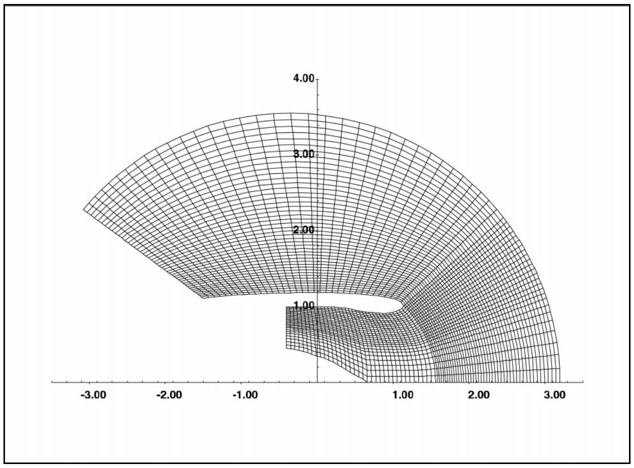

Figure 3b. Inlet Mesh with Input Plane Between the Rotor and the Stator; Detail of Mesh Near the Duct

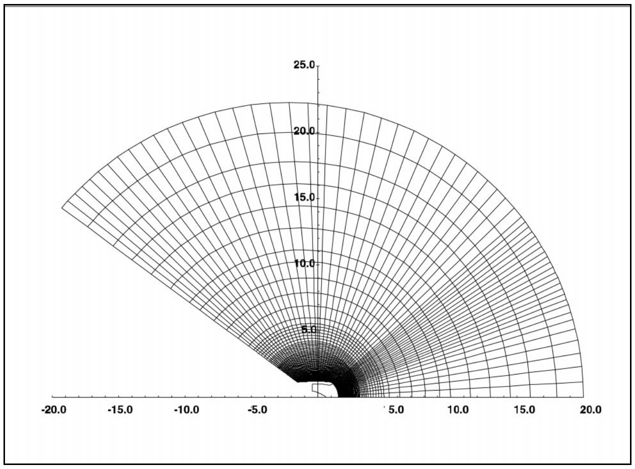

Figure 3c. Inlet Mesh with Input Plane Between the Rotor and the Stator; Detail of the Farfield Mesh

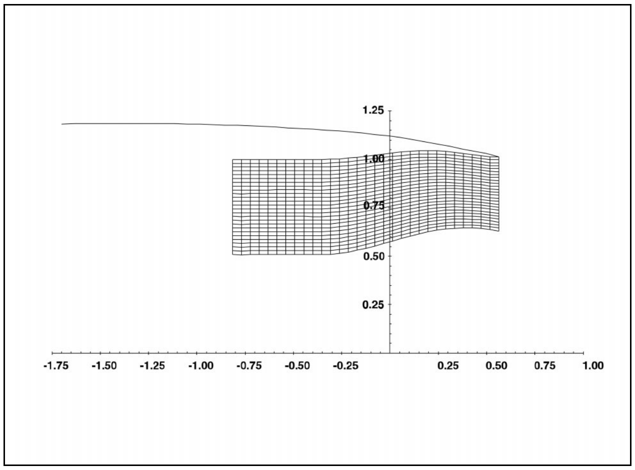

Figure 4a. Exhaust Mesh with Input Plane Downstream of the Stator Trailing Edge; Detail of Mesh Within the Duct

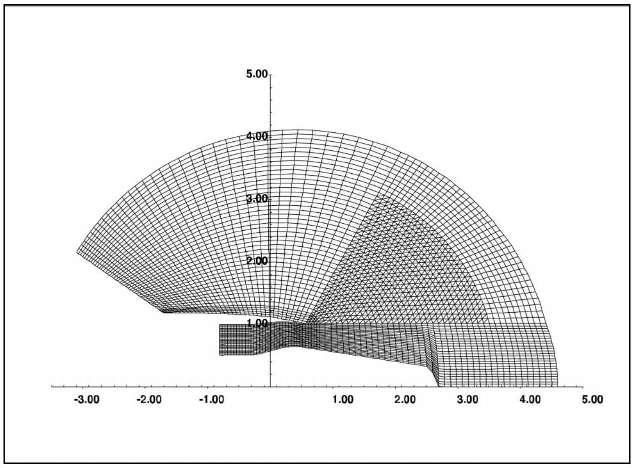

Figure 4b. Exhaust Mesh with Input Plane Downstream of the Stator Trailing Edge; Detail of Mesh Near the Duct

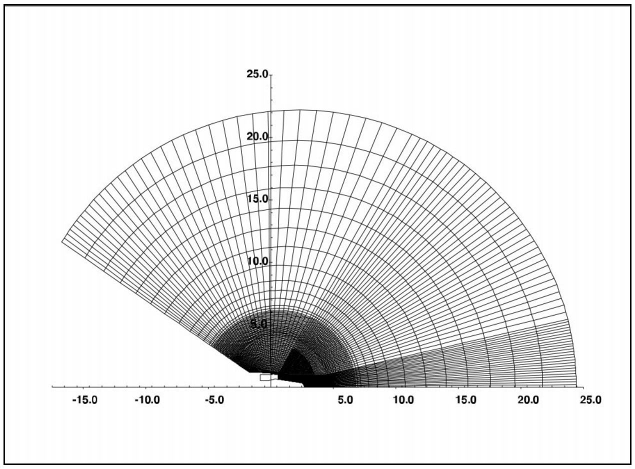

Figure 4c. Exhaust Mesh with Input Plane Downstream of the Stator Trailing Edge; Detail of the Farfield Mesh

Results

Comparisons of predicted sound pressure level sideline directivities to measurements are shown in Figures 5-7. Results from CUP3D had to be post-processed since noise at a constant radius rather than at a specified sideline are normally written to the output file. Two sets of data are shown in each of the plots—tone data and the broadband noise level at 2 BPF measured at a sideline 88 inches from the fan centerline. All predictions should be clipped at the broadband levels indicated since tone noise below these levels are unrealistic. Comparisons are presented for three operating conditions: takeoff, cutback, and approach. The rotor speed for each case is 9013 rpm, 7291 rpm, and 5206 rpm, respectively.

The graphs in Figure 5 compare the 2 BPF measurements, the predictions from Envia and Nallasamy reported in Reference 9, and the TFaNS (Version 1.4) predictions. The predictions by Envia and Nallasamy are labeled "V072 + Eversman" in the graphs since they were generated by combining the results from V072 and the stand-alone versions of the Eversman radiation codes. The effects of the rotor were neglected in these TFaNS (Version 1.4) calculations.

Comparison of the three graphs in Figure 5 show that the best agreement between the data and the predictions occurs at the approach condition. As fan speed is increased, both sets of calculations progressively overpredict the farfield noise. This degradation is due mainly to the inadequacy of the source model within the V072 and TFaNS programs. The simple model used does not represent the effects of the transonic flowfield at the higher rotor speeds. Differences between the two predictions are a result of the ways in which the radiated source is coupled. TFaNS combines the inlet and aft radiated noise internally. Noise reflected from rotor and stator elements are included when the radiated source is coupled. These reflections are neglected when the V072 results are coupled.

Figure 6 shows the comparison between the data and results obtained from TFaNS Versions 1.3 and 1.4. Corrections to the coding account for the improvements seen between the predictions from Versions 1.4 over Version 1.3, which employ identical physical models of the problem. Changes to the code improved the predictions particularly at approach conditions, with smaller differences seen at the higher tip speeds.

Finally, Figure 7 shows a comparison between the data and three different cases run with TFaNS (Version 1.4). Those cases labeled "w/o Rotor" are solutions obtained without including the rotor acoustic properties files in the coupling scheme. The input plane for the inlet radiation

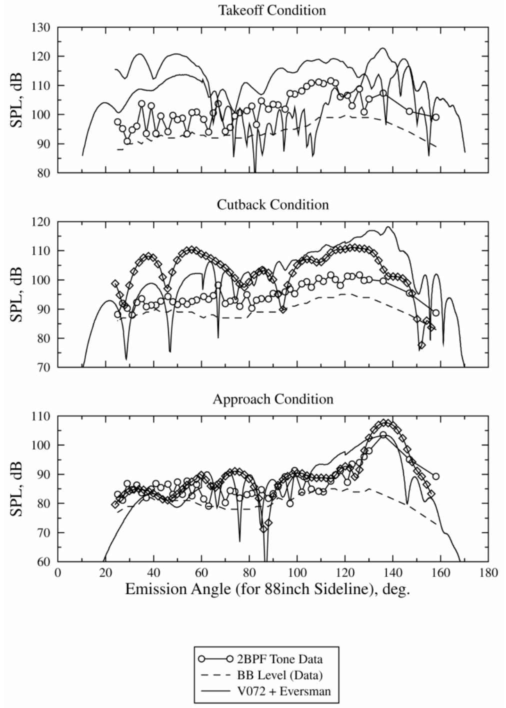

Figure 5. Comparison of Predicted and Measured Farfield Sound Pressure Levels at Takeoff, Cutback, and Approach Conditions: TFaNS vs. Reference 9 Predictions

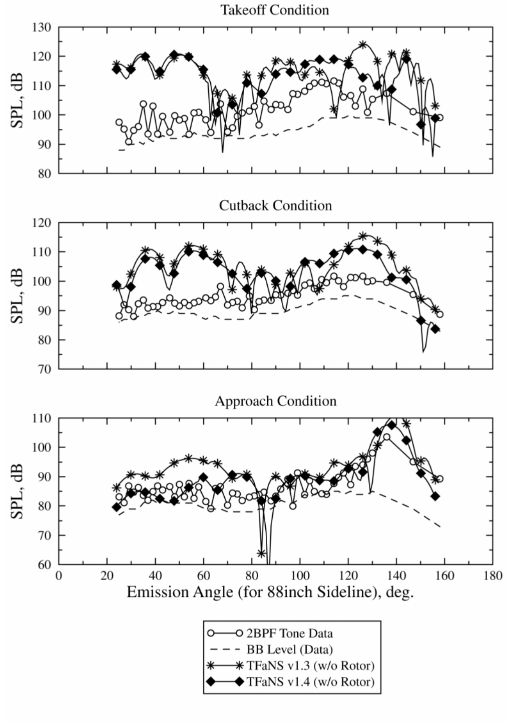

Figure 6. Comparison of Predicted and Measured Farfield Sound Pressure Levels at Takeoff, Cutback, and Approach Conditions: TFaNS Version 1.3 vs. Version 1.4

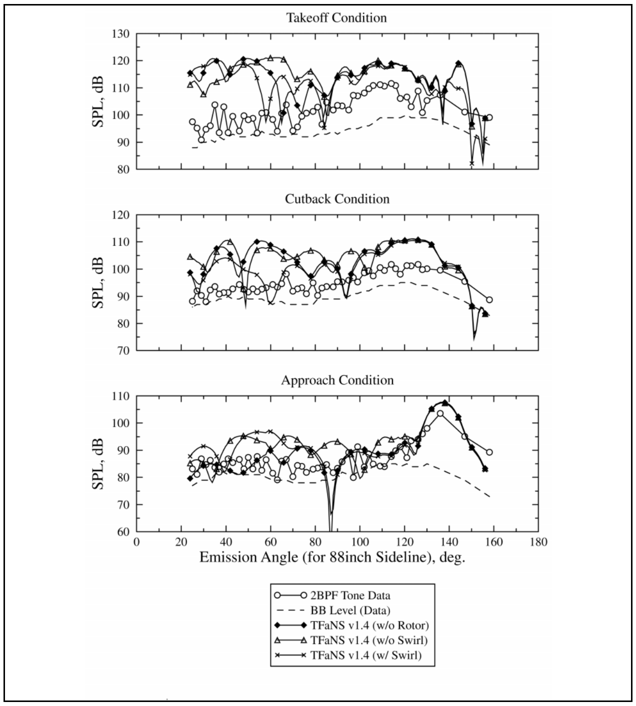

Figure 7. Comparison of Predicted and Measured Farfield Sound Pressure Levels at Takeoff, Cutback, and Approach Conditions: Swirl Effects

code for these cases lies between the rotor and the stator (Figure 3). The remaining two cases were run incorporating the rotor acoustic properties files in the program, CUP3D. The first of these cases did not include solid body swirl in the region between the stator and the rotor and is labeled "w/o Swirl." As the name implies, the case labeled "w/ Swirl" does include swirl as solid body rotation in this region. For both of the cases including rotor effects, the input plane for the inlet radiation code was located upstream of the rotor leading edge (Figure 2). As seen before in Figures 5 and 6, agreement between the calculations and the data is best at the approach conditions and progressively deteriorates as rotor speed is increased. Inclusion of the rotor, with or without swirl, does not improve the agreement between the data and the predictions for any of the fan speeds studied.

Similar findings were presented by Topol in Reference 7 for the 22" Advanced Ducted Propeller (ADP) tested in the NASA Glenn 9 x 15 Wind Tunnel. Topol gives several explanations for the weak agreement between the data and the predictions from TFaNS Version 1.4 that include rotor effects. While 2D aerodynamics can be successfully combined with 3D acoustics in the SOURCE3D program for low rotor speeds, this technique breaks down as frequencies increase. The mismatch causes inaccuracies in the rotor transmission and scattering coefficients, resulting in inflated noise predictions. Noise is overpredicted in part, too, by limitations in the panel method used to calculate the unsteady pressure distribution on the rotor blade. As described in detail in Appendix I of Reference 7, the number of panels needed to accurately calculate the blade unsteady surface pressure distribution becomes prohibitive as the relative freestream Mach number approaches the sonic condition.

Conclusions

The evaluation of Version 1.4 of TFaNS at NASA Glenn Research Center has shown that TFaNS is a useful noise prediction code particularly at low rotor tip speeds. Recent changes to the code have improved prediction accuracy at low speeds, if the influence of the rotor is omitted from the coupling scheme. At higher tip speeds, TFaNS (Version 1.4) may still prove to be useful in predicting overall trends, although absolute noise levels calculated may be higher than measurements may show.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
December 1999

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Evaluation of the Tone Fan Noise Design/Prediction System (TFaNS) at the NASA Glenn Research Center

5. FUNDING NUMBERS
WU–522–81–11–00

6. AUTHOR(S)
L. Danielle Koch

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E–12011

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM—1999-209655

11. SUPPLEMENTARY NOTES

Responsible person, L. Danielle Koch, organization code 5940, (216) 433–5656.

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Subject Categories: 07, 64 and 71 Distribution: Nonstandard

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13. ABSTRACT ***(Maximum 200 words)***

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14. SUBJECT TERMS
Noise; Acoustics; Fan; Rotor; Stator

15. NUMBER OF PAGES
12

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	