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Abstract

During February 2017, aerodynamic and acoustic testing was performed on a scale-model high bypass ratio turbofan rotor, R4, in an internal flow component test facility. The objective of the testing was to determine the aerodynamic and acoustic impact of fan casing treatments designed to reduce fan rotor noise. The baseline configuration consisted of the R4 rotor with a hardwall fan case. Data provided on the supplemental DVD (available online from www.sti.nasa.gov) are supplied in MathWorks MATLAB® data format from an acoustic run with the baseline configuration on the fan's nominal operating line.

W-8 Single Stage Axial Compressor Facility

The test was conducted in the W-8 Single-Stage Axial Compressor Facility at the NASA Glenn Research Center. A schematic of the facility is shown in Figure 1. The facility is capable of delivering up to 7,000 hp at speeds up to 21,240 rpm to a 22-in. fan or compressor. Up to 100 lbm/s of air is provided from an atmospheric inlet. Flow conditioning screens in the inlet plenum reduce the turbulence intensity at the fan to less than 1 percent. The flow through the facility is controlled by a sleeve throttle valve. The air can be exhausted through an atmospheric exhaust system or an altitude exhaust system. Facility instrumentation can include up to 400 channels of steady pressure and thermocouple measurement, tip clearance sensing, and up to 96 channels of high speed rotating fan data.

Atmospheric inlet and exhaust were utilized for the baseline acoustic testing described in this paper.

Test Hardware

The Source Diagnostic Test (SDT) fan rotor (Refs. 1 and 2) was used for this test. The fan, designated R4, was designed by General Electric Aircraft Engines and is a 1/5 scale model of a high bypass turbofan. Figure 2 shows the fan model hardware installed in the W-8 facility. The fan has a 22-in. diameter with 22 titanium blades and a design speed of 12,657 rpmc. The fan had a nominal tip clearance of 0.020 in. at the design speed. A summary of the fan's design parameters is shown in Table 1. This fan was chosen for its titanium blades, since over-the-rotor treatments have been shown to damage composite blades. The data from previous testing (Refs. 1 and 2) was used to avoid stall so that blade stress measurements would not be needed during this test. For acoustic measurements, fan exit instrumentation was removed to prevent unwanted noise sources.

Test Conditions

Nine fan operating conditions were chosen to correspond with those used in prior tests (Refs. 1 and 2). These conditions are on the nominal operating line with corrected fan speeds and corrected mass flows shown in Table 2. For each condition, the Mach number over the in-duct array was calculated from static pressure measurements in the array case. The fan inlet Mach number was then calculated based on the area change between the array and the fan leading edge. The fan inlet axial Mach number combined with the circumferential Mach number based on fan rotation speed at the blade tip were used to calculate a fan tip Mach number.

In-duct Array

While the internal flow is adequate for fan performance measurements, acoustic measurement can only be made in the duct. In order to obtain insight into the acoustic performance of fan model hardware an inlet in-duct array was designed and fabricated for the W-8 facility. The array, shown in Figure 3, has 128 potential sensor locations arranged in two axial arrays with a 1/2 in. axial spacing, and a circumferential array with a 4° spacing, all at a constant diameter of 22 in. For the testing described, a subset of 85 sensors containing half of the circumferential array and both axial arrays were utilized. The sensor locations are shown in Table 3, where the axial station is in inches relative to the fan stacking axis at 170.000 in. Increasing angles are clockwise forward-looking-aft, which is opposite the direction of fan rotation. The sensors used were Kulite® XCS-133-093-25A pressure transducers with a 25 psia range. The sensors were installed into 1/8 in. stainless-steel tubes and then installed into nylon adapters as shown in Figure 4. Signal conditioning was provided by a Precision Filters, Inc. Precision 28000 Signal Conditioning System with Octal-Channel Bridge Conditioner Cards (28118). The output from the Precision Filters 28000 was connected to Mark of the Unicorn, Inc. (MOTU®) 24 I/O analog to digital converters and acquired using Boom Recorder software. The Kulite® pressure transducers were calibrated with a Brüel & Kjaer Multifunction Acoustic Calibrator (Type 4226) generating a Sound Pressure Level (SPL) of 114 dB at 1 kHz.

Data Format

On February 15, 2017, aerodynamic and acoustic measurements were obtained of a subscale high bypass turbofan model in the W-8 facility. At each of the nine conditions in Table 2, 10 sec of aerodynamic and acoustic data were recorded. The aerodynamic data were sampled at 1 Hz and averaged to provide the Mach numbers in Table 2. The in-duct array data was acquired at a 96 kHz sample rate. A once-per-revolution signal was acquired on channel 96. The once-per-revolution signal (1/rev) is an approximately 0 to 1 V square wave with rising edges when the rotor TDC is at the static hardware TDC. The sensor time-series data have been converted to Pascals and stored in MathWorks MATLAB® data files y1_[condition no.].mat. The once-per-revolution signal is stored in volts on channel 96. Within each data file, each channel is stored as a separate array named y1_[condition no.]_[ch.]. Therefore, in each data file there will be 86 total arrays including the 1/rev.

References

1. Van Zante, Dale E., Podboy, Gary G., Miller, Christopher J., Thorp, Scott A., “Testing and Performance Verification of a High Bypass Ratio Turbofan Rotor in an Internal Flow Component Test Facility,” GT2007-27246.
2. Hughes, Christopher E., Jeracki, Robert J., and Miller, Christopher J., “Fan Noise Source Diagnostic Test – Rotor Alone Aerodynamic Performance Results,” AIAA-2002-2426 or NASA/TM—2005-211681.

TABLE 1.—SOURCE DIAGNOTIC TEST (SDT) FAN DESIGN PARAMETERS

Parameter	Value
No. of fan blades	22
Fan tip diameter, in. (m)	22 (0.56)
Hub/tip ratio	0.30
Corrected tip speed, ft/s (m/s)	1215 (370)
Fan design speed, rpmc	12,657

TABLE 2.—SET POINT AND INLET CONDITIONS ON THE NOMINAL OPERATING LINE

	Set point conditions			Inlet conditions		
Condition no.	Percent fan speed	Corrected fan speed, rpmc	Corrected mass flow, lbm/sec	Inlet array Mach no.	Fan inlet axial Mach no.	Fan tip Mach no.
1	50.0	6,329	46.9	0.212	0.236	0.596
2	60.0	7,594	56.2	0.256	0.286	0.718
3	61.7	7,809	57.8	0.264	0.296	0.739
4	70.0	8,860	65.9	0.305	0.343	0.843
5	77.5	9,809	73.4	0.344	0.389	0.940
6	80.0	10,126	75.9	0.359	0.407	0.974
7	87.5	11,075	83.7	0.404	0.460	1.075
8	95.0	12,024	91.8	0.455	0.523	1.183
9	100.0	12,657	97.2	0.491	0.569	1.259

Table 3.—IN-DUCT ARRAY SENSOR LOCATIONS

Circumferential array			
Location			File
#	Station, in.	Angle, deg	Ch.
44	145.095	186	2
45	145.095	190	3
46	145.095	194	4
47	145.095	198	5
48	145.095	202	6
49	145.095	206	7
50	145.095	210	8
51	145.095	214	9
52	145.095	218	10
53	145.095	222	11
54	145.095	226	12
55	145.095	230	13
56	145.095	234	14
57	145.095	238	15
58	145.095	242	16
59	145.095	246	17
60	145.095	250	18
61	145.095	254	19
62	145.095	258	20
63	145.095	262	21
64	145.095	266	22
65	145.095	270	23
66	145.095	274	24
67	145.095	278	25
68	145.095	282	26
69	145.095	286	27
70	145.095	290	28
71	145.095	294	29
72	145.095	298	30
73	145.095	302	31
74	145.095	306	32
75	145.095	310	33
76	145.095	314	34
77	145.095	318	35
78	145.095	322	36
79	145.095	326	37
80	145.095	330	38
81	145.095	334	39
82	145.095	338	40
83	145.095	342	41
84	145.095	346	42
85	145.095	350	43
86	145.095	354	44

Long axial array			
Location			File
#	Station, in.	Angle, deg	Ch.
87	145.595	270	45
88	146.095	270	46
89	146.595	270	47
90	147.095	270	48
91	147.595	270	49
92	148.095	270	50
93	148.595	270	51
94	149.095	270	52
95	149.595	270	53
96	150.095	270	54
97	150.595	270	55
98	151.095	270	56
99	151.595	270	57
100	152.095	270	58
101	152.595	270	59
102	153.095	270	60
103	153.595	270	61
104	154.095	270	62
105	154.595	270	63
106	155.095	270	64
107	155.595	270	65
108	156.095	270	66
109	156.595	270	67
110	157.095	270	68
111	157.595	270	69
112	158.095	270	70
113	158.595	270	71
114	159.095	270	72
115	159.595	270	73
116	160.095	270	74
117	160.595	270	75

Short axial array			
Location			File
#	Station, in.	Angle, deg	Ch.
118	145.845	272	76
119	146.345	272	77
120	146.845	272	78
121	147.345	272	79
122	147.845	272	80
123	148.345	272	81
124	148.845	272	82
125	149.345	272	83
126	149.845	272	84
127	150.345	272	85
128	150.845	272	86

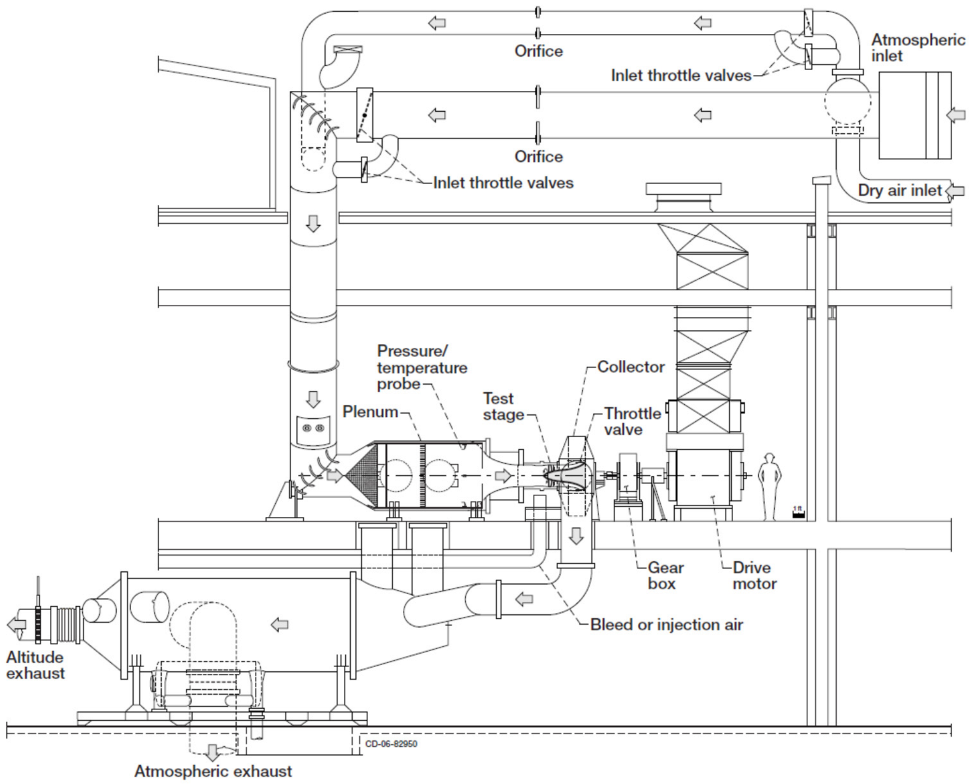

Figure 1.—Schematic of the W-8 Single Stage Axial Compressor Facility at the NASA Glenn Research Center.

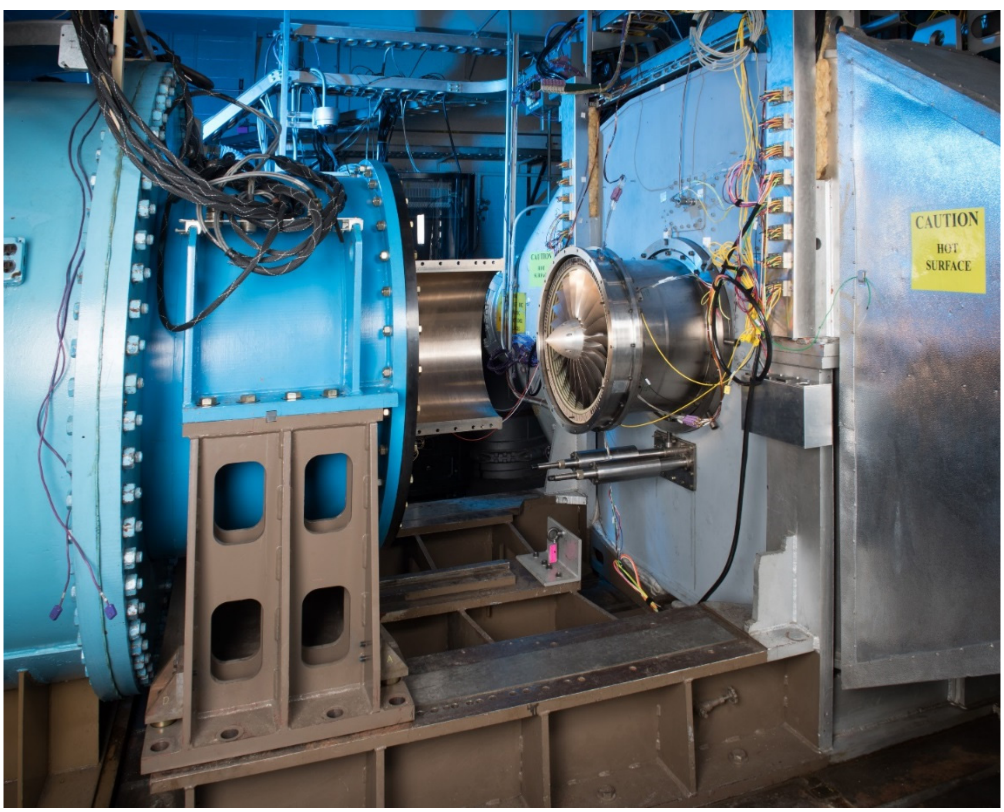

Figure 2.—Source Diagnostic Test Fan Hardware installed in the W-8 Single Stage Axial Compressor Facility.

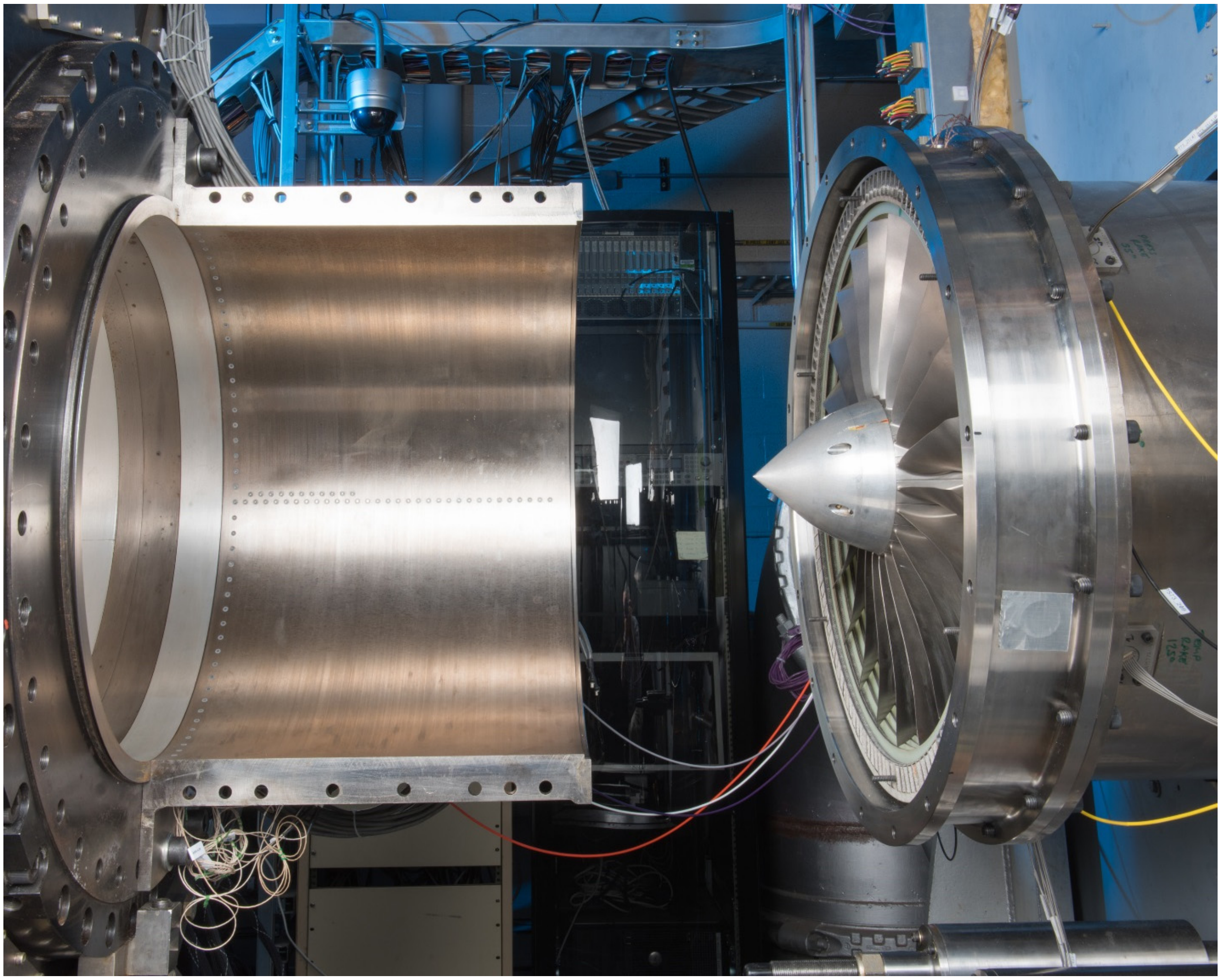

Figure 3.—Inlet In-duct Array Installed in the W-8 Facility.

Figure 4.—In-duct Array Kulite® Sensor Insert.