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INVESTIGATION OF THE EFFECT OF INLET TURBULENCE LENGTH SCALE ON FAN DISCRETE TONE NOISE

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SYMBOLS

B	rotor blade number
BPF	blade passing frequency, Hz
c	rotor blade chord, m (ft)
D	fan rotor diameter, m (ft)
ℓ	turbulence length scale, m (ft)
N	number of rotor blades intercepting an eddy
rpm_c	fan corrected rotation speed, rev/min
SPL	sound pressure level
τ	time delay, msec
U_c	eddy convection velocity, m/sec (ft/sec)
U	local duct velocity, m/sec (ft/sec)
Ω	rotational frequency, rad/sec
u'	longitudinal turbulence component
v'	lateral turbulence component
V_t	rotor tip-speed, m/sec (ft/sec)

INVESTIGATION OF THE EFFECT OF INLET TURBULENCE

LENGTH SCALE ON FAN DISCRETE TONE NOISE

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SUMMARY

Results of an experimental investigation at the Ames 40- by 80-Foot Wind Tunnel of fan rotor alone discrete tone noise is presented. The investigation examines rotor interaction with fan inlet turbulence. The importance of turbulence length scale is shown by comparing the fan radiated acoustic spectrum with and without modified turbulence length scales. A small-scale low pressure ratio fan was used for the experiment.

INTRODUCTION

As part of a commitment to develop methods by which V/STOL aircraft can meet projected noise standards Ames has been studying noise sources in lift fans. The importance that vane-blade ratios, vane-blade spacing, vane lean, and subsonic tip-speeds have in controlling noise generation has been understood for sometime and is further evidenced in reference 1. However, even with appropriate use of these parameters significant noise at the blade passing frequency and its harmonics has remained. The origin of this noise is not fully understood. Current techniques to further reduce this tone noise have generally been by the use of acoustically absorbent duct liners. Unfortunately, V/STOL configurations bent on minimizing propulsion system volume and weight have generally had extremely short intake and exhaust ducts leaving little area for acoustic treatment. As a result we are left with the need to discover these remaining sources and understand their noise generation process.

Emphasis is being placed on the possibility that a new tone noise floor has been reached due to rotor alone sources. Since noise from steady-state blade loading can be ruled out for multi-bladed fans, other so-called rotor alone sources have been sought. This report describes an investigation into rotor interaction with fan inlet flow turbulence. Measurements of inlet turbulence intensity, length scale and the radiated acoustic spectrum are presented for a small-scale subsonic tip-speed fan. The program was carried out in the Large-Scale Aerodynamics Branch anechoic chamber.

MODEL AND APPARATUS

The small-scale subsonic tip-speed fan used in this investigation was not scaled from any existing lift fan design but the blade number, solidity, and tip-speed approach those used in lift fan designs. Pertinent fan dimensions and performance characteristics are presented in figure 1. The fan rotor was driven by a variable speed electric motor. Support for the fan rotor and drive motor was provided by 8 non-cambered support struts located 4.5 blade chords downstream of the rotor. No inlet or outlet guide vanes were used. The fan exhaust duct passed through the anechoic chamber wall preventing the exhaust flow from recirculating within the chamber. A portion of the investigation was run with a honeycomb matrix installed in the inlet (fig. 1). The axial length of the honeycomb was 1.9 cm (0.75 in) with a cell diameter of 0.318 cm (0.125 in).

Installation of the fan in the anechoic chamber is shown in figure 2. The fan was mounted equidistant from chamber side walls and floor and ceiling.

Free field dimensions of the anechoic chamber are also shown in figure 2. Cutoff frequency for the chamber is 150 Hz.

TESTING PROCEDURE AND INSTRUMENTATION

Measurements of fan inlet turbulence intensity and length scale were made with a hot-wire "x" probe which allows measurement of u' and v' turbulence components by summing and differencing voltages. Autocorrelation of turbulence signals was made directly by use of a correlation and probability analyzer. All turbulence measurements were made between the downstream side of the honeycomb matrix and the rotor blade tip plane (fig. 1).

Acoustic data was measured with an array of 1/2 in. condenser microphones placed in the plane of the fan horizontal centerline and from a position on the fan rotational axis (0°) to an azimuth angle of 90°. The microphones were placed on a 7 foot radius from the fan bellmouth (fig. 2). All acoustic data analysis was performed with a constant bandwidth 50 Hz narrowband analyzer. Both acoustic and hotwire data were FM recorded on magnetic tape at 30 ips with a frequency response from 0 to 10 KHz. All data analysis was performed from tape recorded data.

Fan inlet steady-state static pressures were measured on the bellmouth and near the rotor blade tip plane. Fan discharge total pressure was measured at the nozzle exit plane.

RESULTS AND DISCUSSION

The present investigation followed an approach outlined in references 2 and 3. Reference 2 suggests that in a given fan inlet there is a turbulence field composed of a number of eddies with correlated regions of length ℓ.

The time for an eddy to pass a given point is ℓ/U_c where U_c is the convection velocity of the eddy. It follows that the number of blades N which can rotate past that point in time ℓ/U_c:

$$N = \frac{\ell}{U_c}\,\frac{\Omega B}{2\pi} \quad .$$

As each blade passes through the same coherent eddy it would experience a lift fluctuation and could cause noise to be generated at the blade passing frequency and its harmonics. For a more rigorous analytical treatment of this process references 3 and 4 are recommended.

Turbulence Measurements

The prime goal of this investigation was to make measurements of the duration of turbulence eddies in a given fan. If sufficient length scale was found to cause generation of discrete tone noise, changing that length scale to cause $N < 1$ should be accompanied by a reduction in the radiated tone noise. The time for a typical eddy to pass the rotor plane was determined from an autocorrelation of hot-wire measurements of u' and the assumption of frozen convected turbulence. A typical autocorrelation shown in figure 3(a) would allow 47 blades to pass through the eddy. Therefore, tone noise could be generated. The existing turbulence length scale was then successfully shortened by inclusion of a honeycomb matrix in the inlet (fig. 1). Autocorrelations of u' two inches downstream of the honeycomb matrix are shown in figure 3(b) and indicate the time for eddy passage would cause $N < 1$ and hence no tone generation.

Noise Measurements

The final phase of the investigation was to see if the radiated acoustic field showed an accompanying noise reduction. Figure 4 shows a typical far field spectrum with and without the modified length scale. Both the blade passing frequency and its first harmonic show approximately a 10 dB reduction with the modified length scale. These reductions occurred throughout the inlet radiated sound field as is shown in figure 5 for measurements at azimuth angles from 0° to 90°. Figure 5 also shows that similar noise reductions occurred over a range of fan speeds from 98.8 percent to 79.6 percent. Notice that while the radiated noise went down as a result of shortening length scale the turbulence intensity went up by over a factor of 2.

Additionally, noise data presented in figures 4 and 5 have been compared at the same rpm which implies that the same total pressure rise across the rotor occurs with and without the honeycomb matrix installed. Of course, there is some loss associated with use of the honeycomb, but figure 6 which presents fan total pressure ratio versus corrected fan rpm indicates that the loss is very small. If one assumes a V_t^5 dependence for the resultant sound pressure level, the error from comparing configurations at the same rpm and not the same total pressure rise would be less than 1 dB.

CONCLUDING REMARKS

It has been shown that there is reason to believe that sufficient fan inlet turbulence length scale can cause generation of fan discrete tone noise at the blade passing frequency and its harmonics. Reduction in turbulence length scale was shown to be accompanied by a 10 dB reduction in the SPL at the blade passing frequency and its harmonics. Further investigation into this mechanism must be conducted using space-time correlation to remove possible errors due to the assumptions made. Additional information is also needed as to what other singificant parameters may have been altered by the use of the honeycomb matrix such as steady or unsteady inlet distortion.

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3. Mani, R.: Noise Due to Interaction of Inlet Turbulence with Isolated Stators and Rotors. J. Sound Vib., vol. 17(2), 1971, pp. 123–132.
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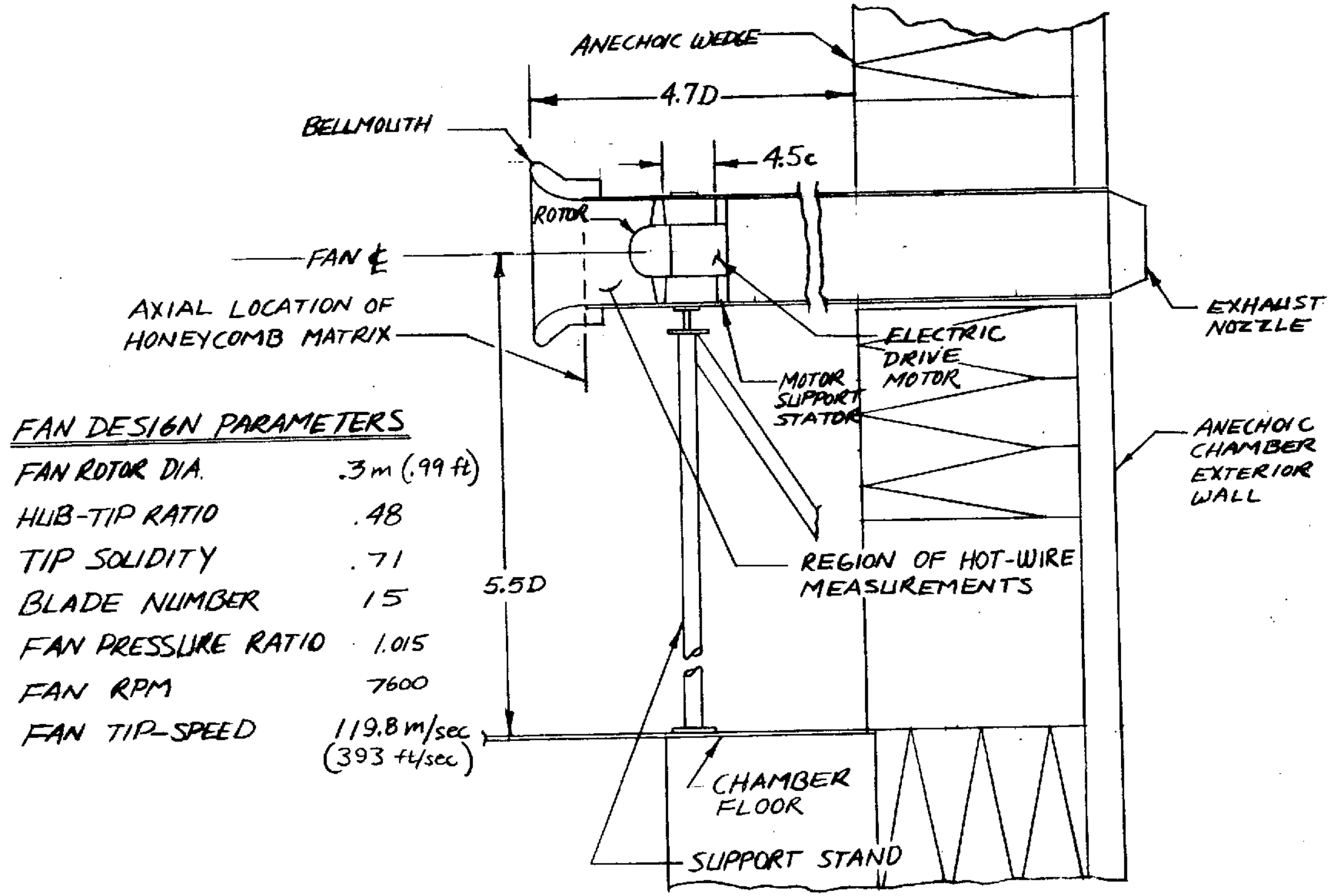

FIGURE 1 .- SMALL SCALE FAN TEST RIG IN ANECHOIC CHAMBER

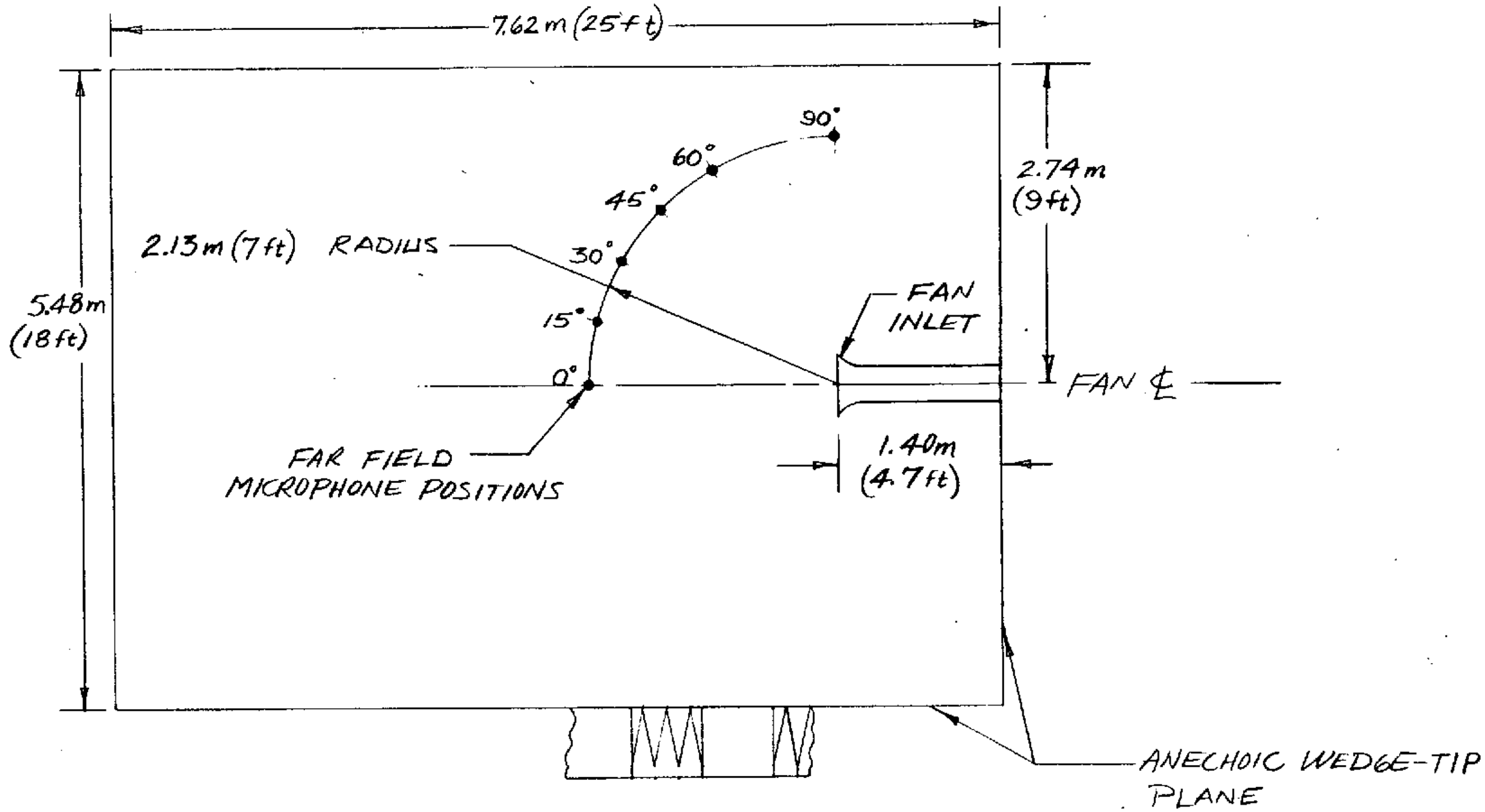

FIGURE 2 .— GENERAL ARRANGEMENT OF FAN INSTALLATION IN THE ANECHOIC CHAMBER.

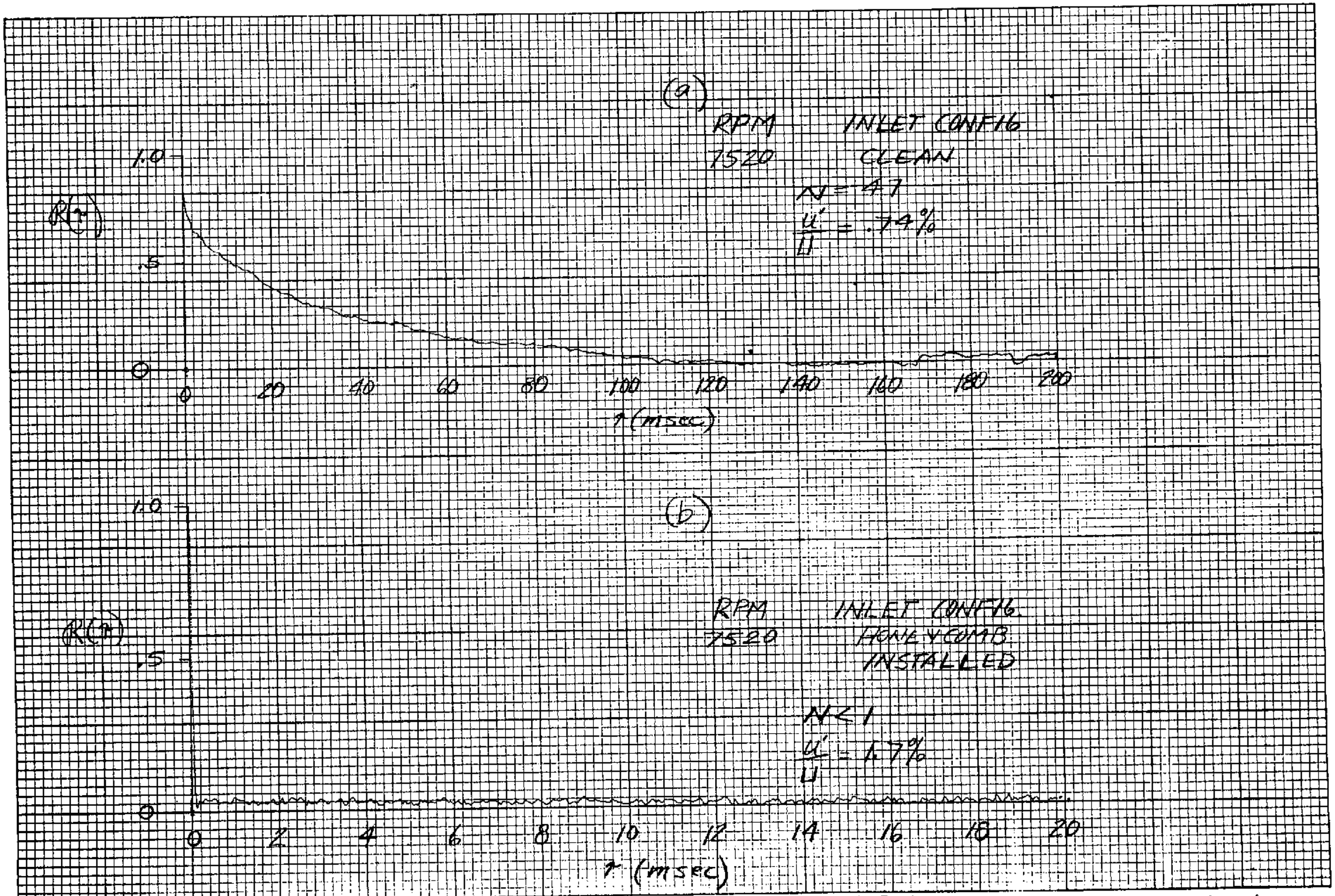

FIGURE 3. — AUTOCORRELATION OF LONGITUDINAL TURBULENCE INTENSITY u'

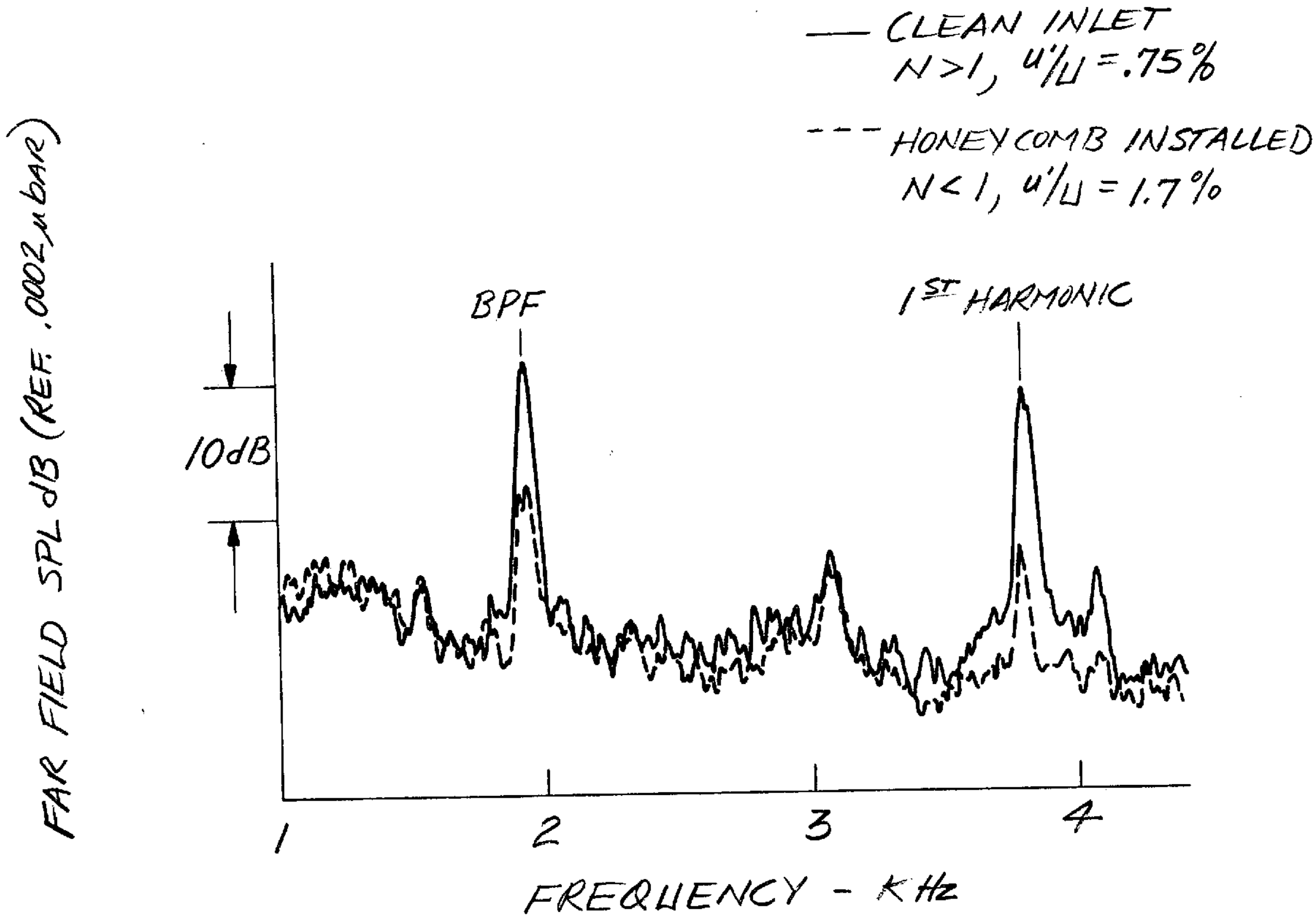

FIG. 4 - EFFECT OF TURBULENCE LENGTH SCALE ON FAR FIELD RADIATED SPECTRUM θ=30°, 7520 RPM

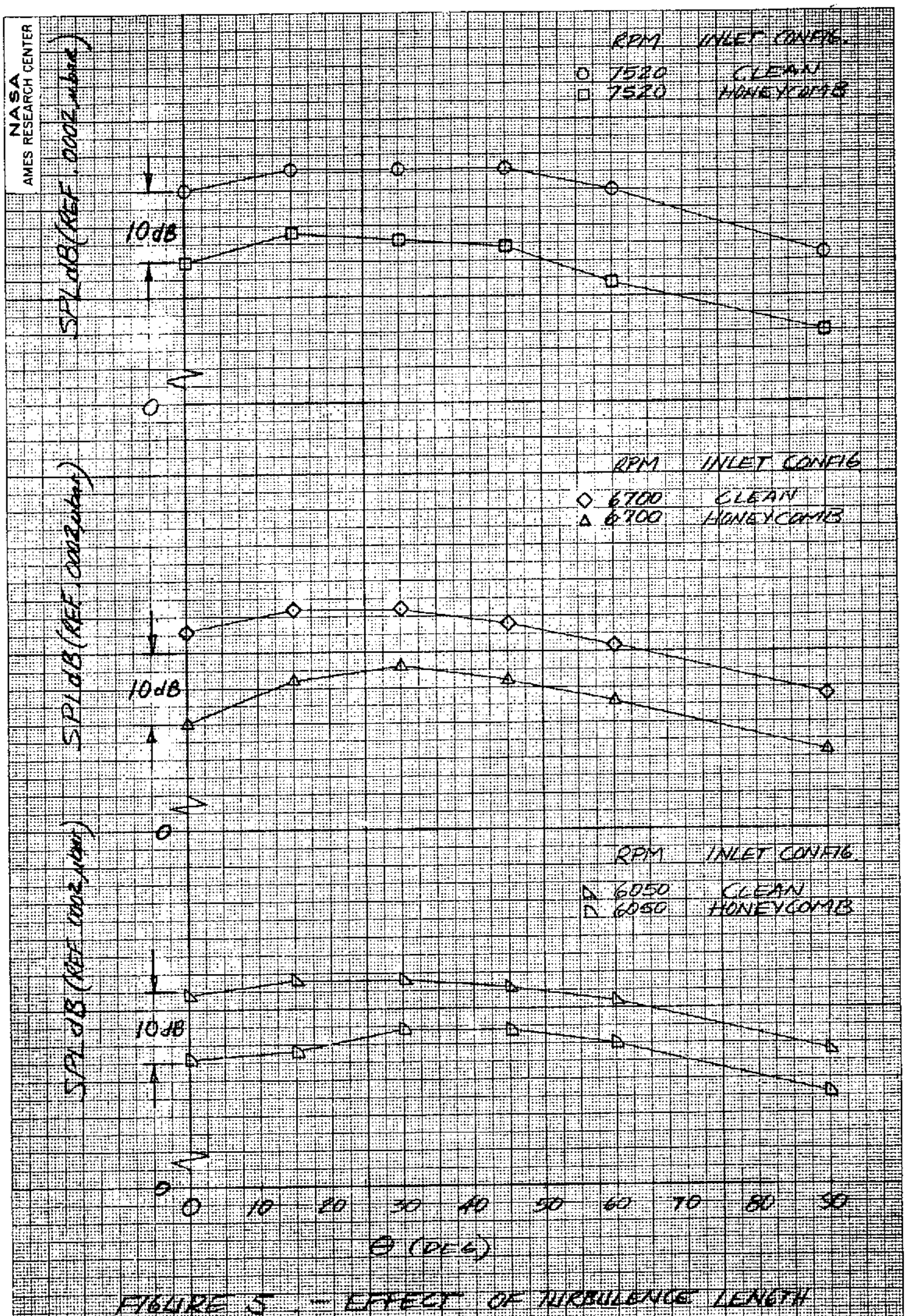

FIGURE 5. - EFFECT OF TURBULENCE LENGTH SCALE ON INLET FAR FIELD RADIATED NOISE AT THE BPF.

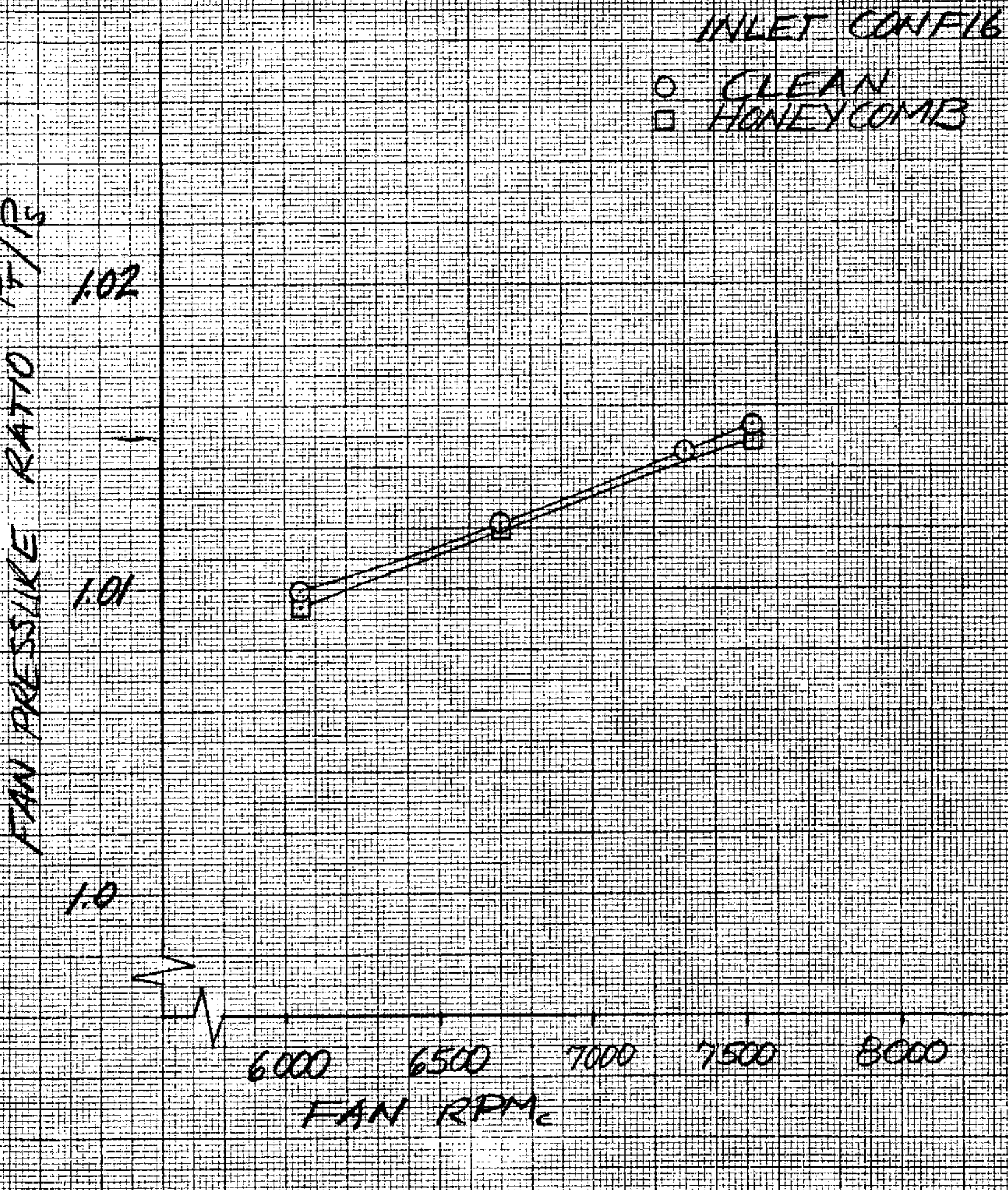

FIGURE 6.— EFFECT OF HONEYCOMB MATRIX ON FAN TOTAL PRESSURE RATIO.