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by Bernard J. Blaha

Lewis Research Center

Cleveland, Ohio

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WIND TUNNEL INVESTIGATION OF FLUCTUATING PRESSURES ON A 1/10-SCALE CENTAUR MODEL AT TRANSONIC SPEEDS

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SUMMARY

Wind tunnel tests of a 1/10-scale Centaur model with a Surveyor nose cone were conducted over a range from Mach 0.55 to 1.95 to determine amplitudes and frequencies of fluctuating pressures that exist on the model surface at these speeds. Tests were conducted for roll angles of 0°, 90°, and 180° at 0° angle of attack. Peak-to-peak fluctuating pressure levels up to 30 percent of tunnel dynamic pressure were measured immediately downstream of the cone shoulder, the umbilical island, and on the boost pump fairing. Background noise in the tunnel made a detailed frequency analysis impractical.

INTRODUCTION

Several previous investigations showed that surface pressure fluctuations of considerable amplitude occur on missiles in the transonic speed range (e.g., refs. 1 to 5). These fluctuations are particularly severe just aft of the cone-cylinder juncture of the payload shroud and also upstream of protuberances as a result of shock and boundary layer interactions. They are also observed downstream of protuberances where the separated flow reattaches to the surface. In order to establish the fluctuating pressure distribution on a Centaur stage at transonic and low supersonic speeds, a series of tests were conducted in the Lewis 8- by 6-foot Supersonic Wind Tunnel on a 1/10-scale model with a Surveyor nose cone. Fluctuating pressures were investigated over the length of the model and in local regions of particular interest, such as the various model protuberances. Investigations were made over a range from Mach 0.55 to 1.95 at roll angles of 0°, 90°, and 180° at 0° angle of attack. The results of these investigations are presented in this report.

SYMBOLS

ΔC_p	maximum fluctuating peak-to-peak pressure coefficient, $\frac{p_{max} - p_{min}}{q_o}$
D	nominal full-scale Centaur diameter, 120 in. (304.5 cm)
f	frequency, Hz
M	Mach number
p	static pressure
q	dynamic pressure
V	velocity
l	axial distance along vehicle measured from cone shoulder
θ	angular coordinate of transducer locations
ϕ	model roll angle

Subscripts:

o	free stream
max	maximum value
min	minimum value

APPARATUS AND PROCEDURE

The model was 62.02 inches (152.5 cm) long and 12 inches (30.5 cm) in diameter and was installed in the transonic portion of the Lewis 8- by 6-foot Supersonic Wind Tunnel (fig. 1). It was comprised of three major sections: the Surveyor nose cone, the Centaur stage, and the interstage adapter. Thirty piezoelectric pressure transducers, having a rated frequency response of over 20 kilohertz, were installed on the model (fig. 2). These locations were selected to yield the general distribution of fluctuating pressures over the length of the stage downstream of the cone shoulder (fig. 2(a)) and in local regions of particular interest such as the cone shoulder (fig. 2(b)), the hydrogen vent stack (fig. 2(c)), and the umbilical island and boost pump fairing (fig. 2(d)). Table I shows the locations of the transducers in terms of l/D, which is the ratio of axial distance measured along the vehicle from the cone shoulder to the vehicle diameter. The transducers (0.25-in. (0.63-cm) diam) were mounted flush to the model surface. Dynamic pressure fluctuations were recorded on FM magnetic tape through an electrical

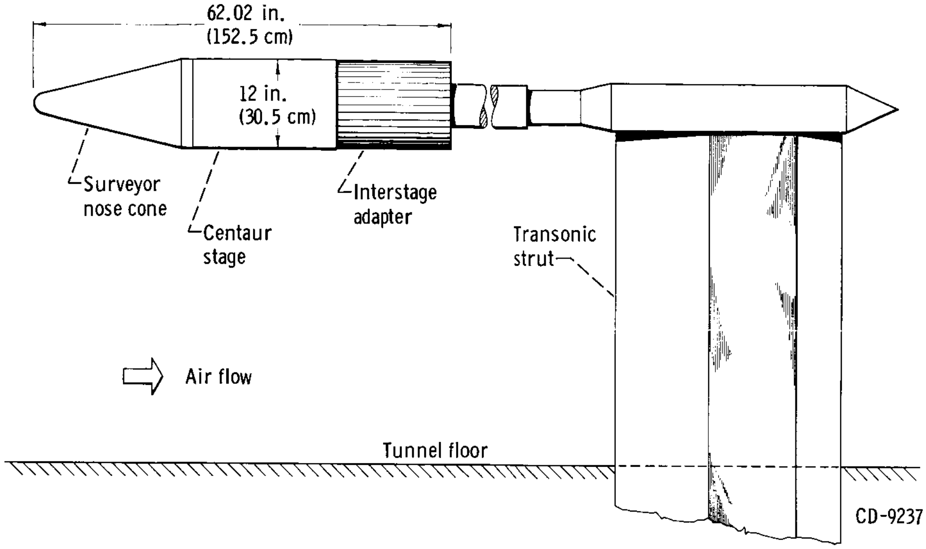
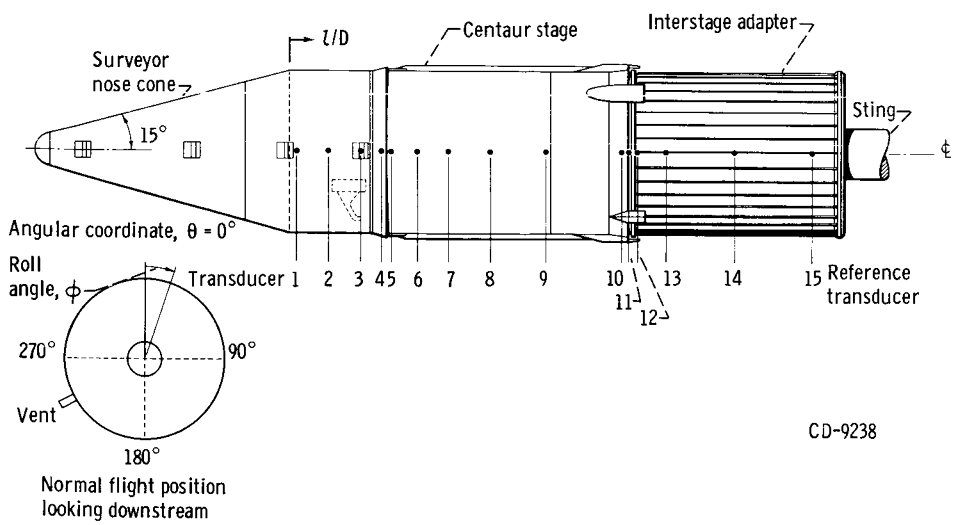
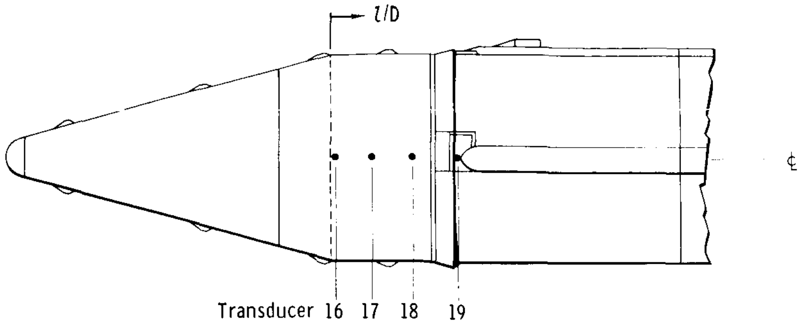


Figure 1. - Installation of the 1/10 scale Centaur dynamic pressure model in the Lewis 8- by 6-foot Supersonic Wind Tunnel (not to scale).

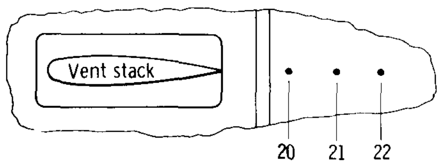


(a) Longitudinal distribution; angular coordinate, 90°.

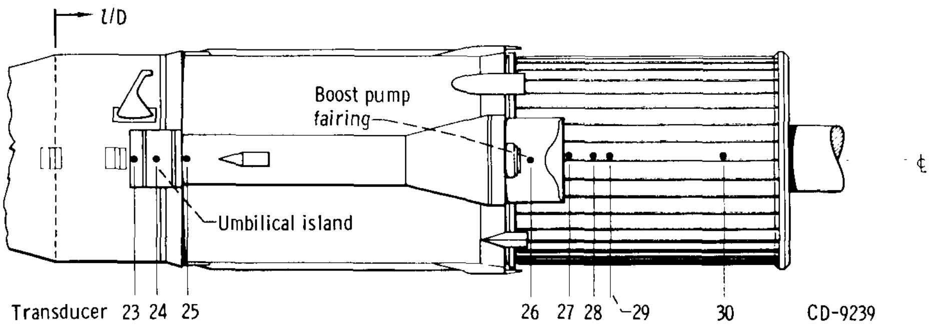
Figure 2. - Location of instrumentation on Centaur 1/10 scale model. Model roll angle, 0°.



(b) Downstream of cone shoulder; angular coordinate, 0°.



(c) Hydrogen vent stack; angular coordinate, 245°.



(d) Umbilical island and boost pump fairing; angular coordinate, 270°.

Figure 2. - Concluded.

system that had good recording characteristics up to 10 kilohertz (described in ref. 5).

The model was tested over a range from Mach 0.55 to 1.95 at roll angles of 0°, 90°, and 180° about the model centerline at 0° angle of attack to the stream flow. As seen in figure 3(a), free-stream dynamic pressure q_0 varied from 3.2 psi (2.21×10^{4} N/m^{2}) at Mach 0.55 to 9.0 psi (6.21×10^{4} N/m^{2}) at Mach 1.95. These pressures were from 21 to 25 percent higher than those expected in flight over the Mach number range for a typical high q trajectory. Figure 3(b) shows that, although the dynamic pressures significantly differed, the tunnel stream velocities were within 8 percent of those estimated for flight.

TABLE I. - TRANSDUCER LOCATIONS

Transducer number	Model location and angular coordinate, θ	Length-to-diameter ratio, l/D
1	Longitudinal distribution at 90°	0.029
2		.217
3		.455
4		.584
5		.650
6		.816
7		1.020
8		1.270
9		1.640
10		2.150
11		2.180
12		2.230
13		2.420
14		2.880
15		3.380
16	Cone shoulder at 0°	.029
17		.217
18		.455
19		.650
20	Hydrogen vent stack at 245°	.550
21		.633
22		.716
23	Umbilical island at 270°	.354
24		.500
25		.633
26	Boost pump fairing and inter-	2.320
27	stage at 270°	2.480
28		2.640
29		2.840
30		3.240

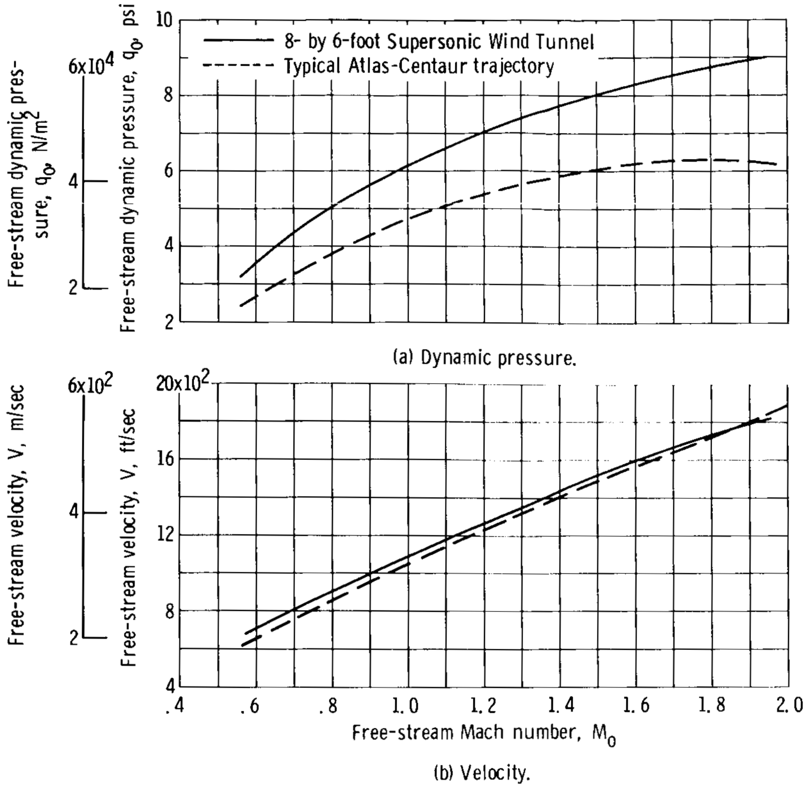
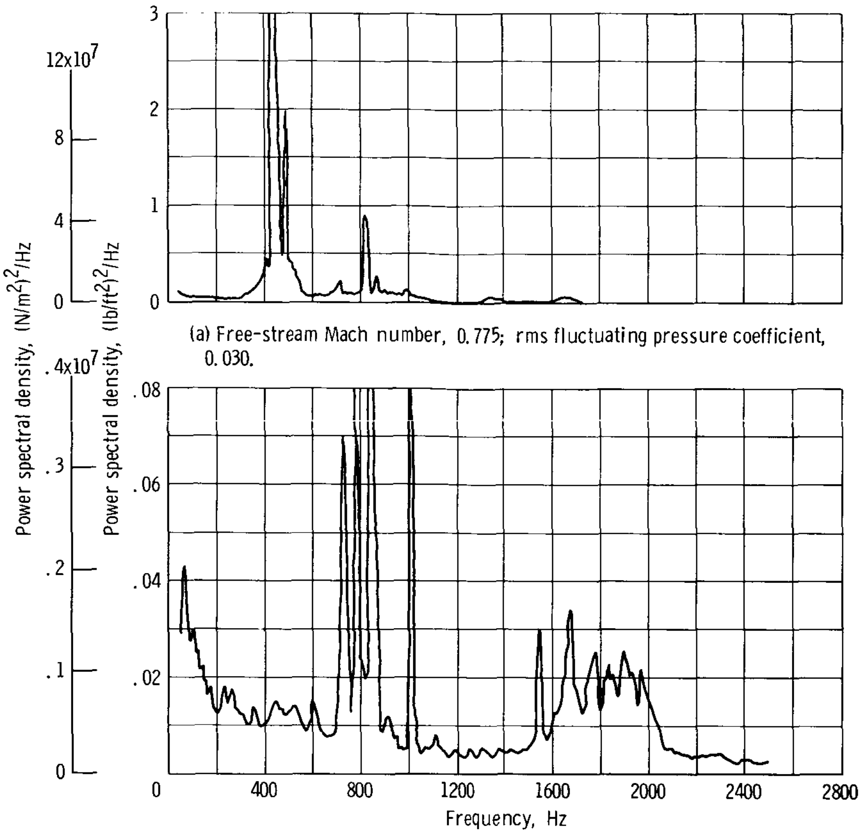


Figure 3. - Comparison of 8- by 6-foot Supersonic Wind Tunnel dynamic pressure and velocity with typical Atlas-Centaur flight trajectory.

RESULTS

Background Noise

In the early phases of the test, it was observed that discrete frequencies existed in the background noise of the wind tunnel which were not related to the flow characteristics of the test model and, hence, may not occur in flight. To further investigate the tunnel background noise, empty tunnel tests were made, and transducer measurements were obtained in the tunnel bellmouth, on the test section walls, and in the subsonic diffuser. A power spectral density analysis of a transducer located on the wall of the empty tunnel indicated the predominant frequencies and amplitudes of the tunnel-induced noise. The sound pressure levels were highest at Mach 0.775 and had a $\Delta C_{p, rms}$ value of 0.03 (fig. 4(a)). The most predominant frequencies at this Mach number were between 400 and 500 hertz and were estimated to contain about 75 percent of the rms noise signal. This noise appeared to originate from the subsonic diffuser of the wind tunnel. The lower noise signal at 820 hertz can be traced to the compressor speed. The rms noise levels were considerably reduced at Mach numbers greater than 1.0. At Mach 1.10

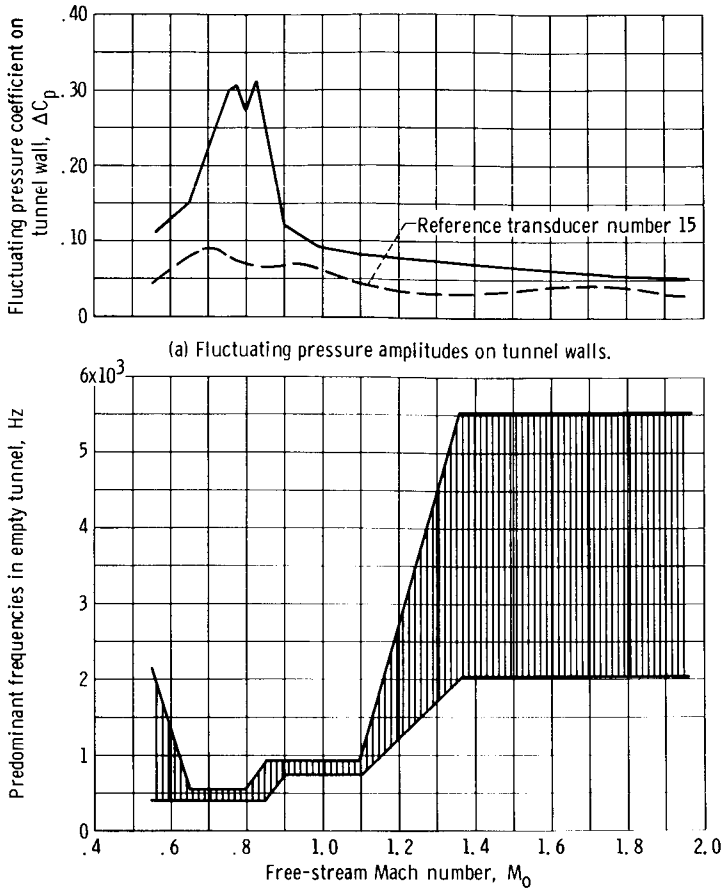


(b) Free-stream Mach number, 1.10; rms fluctuating pressure coefficient, 0.0084.

Figure 4. - Power spectral density analysis of transducer located on sidewall of empty 8- by 6-foot Supersonic Wind Tunnel.

(fig. 4(b)), the predominant frequencies varied from about 730 to 1000 hertz, with the peak amplitude at 840 hertz. Some smaller amplitude noise was present at frequencies below 200 hertz and between 1500 and 2000 hertz. The predominant frequencies and their corresponding peak-to-peak fluctuating pressure coefficient are summarized in figure 5 over the Mach number range for the empty tunnel. In general, low-frequency, high-amplitude noise signals were obtained at subsonic Mach numbers from about 0.65 to 0.90 while high-frequency, low-amplitude noise was measured at the supersonic Mach numbers.

Disturbances occurred on the test models at the same frequencies; however, the amplitudes may have differed considerably from those measured on the tunnel wall because of differences in local flow conditions. Additional disturbances also occurred on the model as a result of the local flow characteristics created by the model geometry which presumably would also occur in flight. Because of the background noise, a detailed frequency analysis of the model data was not attempted. Also, because of the



(a) Fluctuating pressure amplitudes on tunnel walls.

(b) Frequencies.

Figure 5. - Typical amplitude and frequency data obtained in empty 8- by 6-foot Supersonic Wind Tunnel.

background noise, the average fluctuating pressure level on transducer 15 was used as a reference level for all the other transducers. It was located downstream on the model interstage away from protuberances and areas where unstable and dynamic flow conditions were expected. The resulting fluctuations seen on this transducer were relatively low over the Mach number range (fig. 5(a)) and were comparable to levels expected in a turbulent boundary layer (ref. 6).

In the present report, peak-to-peak variation of the local pressure coefficient ΔC_p is presented without correction for tunnel background noise. The relative trends and distributions were presumed valid and indicated those portions of the vehicle which would be subjected to large amplitudes of fluctuating pressure in flight.

Longitudinal Distribution

Fluctuating pressures indicated by the 15 transducers mounted longitudinally on the model side at angular coordinate $\theta=90^{\circ}$ are presented in figure 6 for each Mach number tested. The ΔC_p profiles indicate that large peak-to-peak pressure fluctuations (up to 28 percent of q_o) were experienced on the Surveyor shroud at low transonic speeds, with the amplitudes decreasing to lower levels at speeds above $M_o = 0.85$. These large fluctuations could have been caused by the unstable flow conditions that exist behind a cone shoulder at transonic Mach numbers; namely, the alternate separation and attachment of the flow and eventual formation and movement of the terminal shock downstream of the shoulder. Electrical noise levels for all the transducers had an upper limit of about $\Delta C_p = 0.02$ which is below the level of pressure fluctuations, especially in the transonic regime. At the high supersonic Mach numbers, the data approach the level of electrical noise which indicates little or no fluctuating pressure activity. The peak amplitudes of fluctuating pressure in the area of the cone shoulder range up to 19 percent of q_o larger than those experienced by the reference transducer 15. A comparison with data presented in reference 1 for the longitudinal dynamic pressure distribution over a clean configuration (no protuberances) of a 0.074 scale Centaur model shows similar trends and amplitudes over the same Mach number range, especially in the area of the cone shoulder. Substantial variations in peak-to-peak pressure fluctuations existed for different model roll angles indicating an inadvertent misalinement of the model axis with the free-stream flow direction and also a significant sensitivity of the data to small angles of attack.

Figure 7 presents the data as a function of Mach number for each transducer. Again, the data show that large peak-to-peak pressure fluctuations existed on the model in the low transonic regime, with the highest being 28 percent of q_o at $M_o = 0.7$.

Data for four other transducers downstream of the cone shoulder on the Surveyor shroud at $\theta=0^{\circ}$ are presented in figure 8. A comparison with four transducers in similar positions for the complete longitudinal row (transducers 1 to 4 on fig. 7) shows similar magnitudes and trends with Mach number. The maximum ΔC_p was about 30 percent of q_o at Mach number 0.75. The Mach number of maximum activity for the two sets of transducers differs only by about 0.05. The transducers located on and near protuberances of the Surveyor shroud (transducers 3 and 19) show relatively low pressure amplitudes in comparison with those existing near the cone shoulder. The maximum value was about 20 percent of q_o at $M_o = 0.75$.

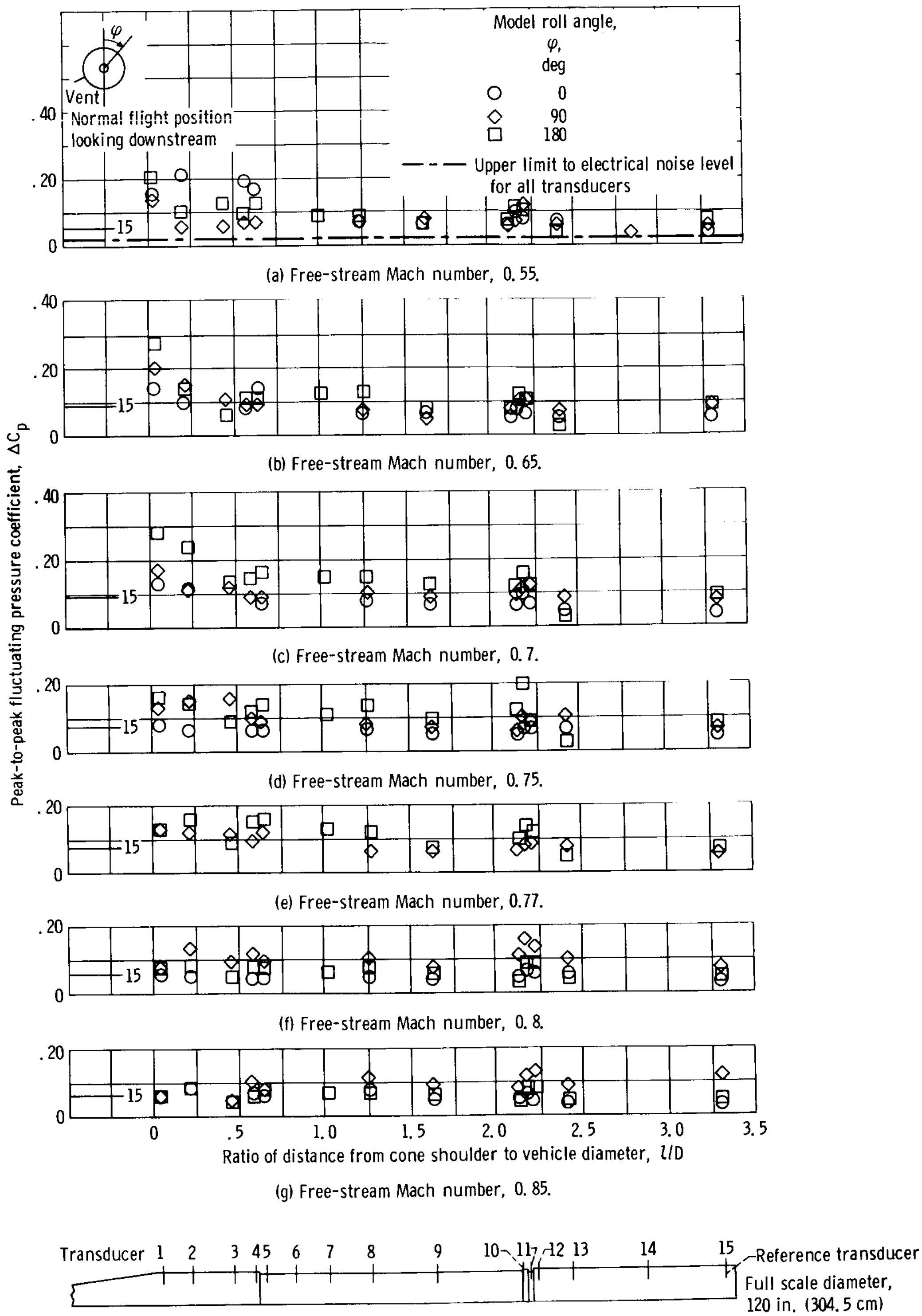


Figure 6. - Longitudinal fluctuating pressure distributions. Angular coordinate, 90°.

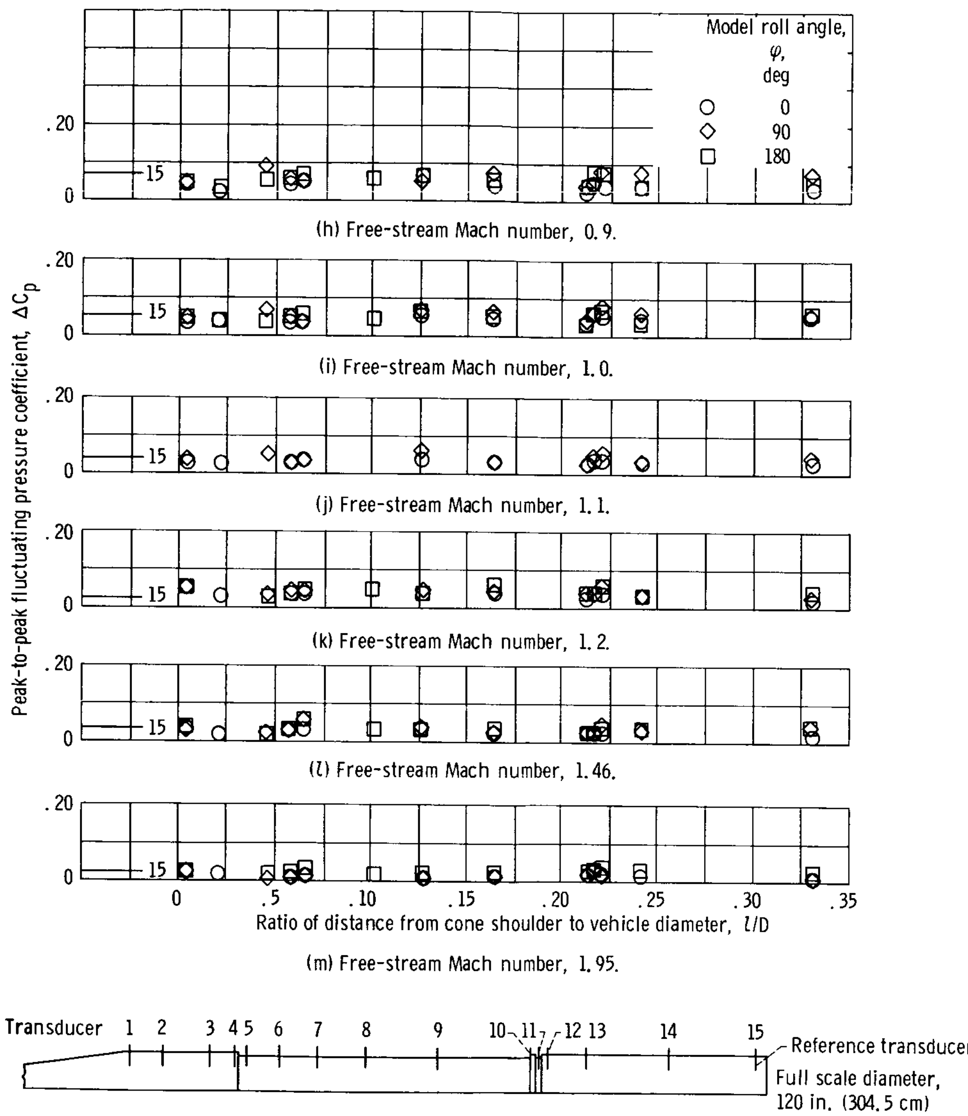


Figure 6. - Concluded.

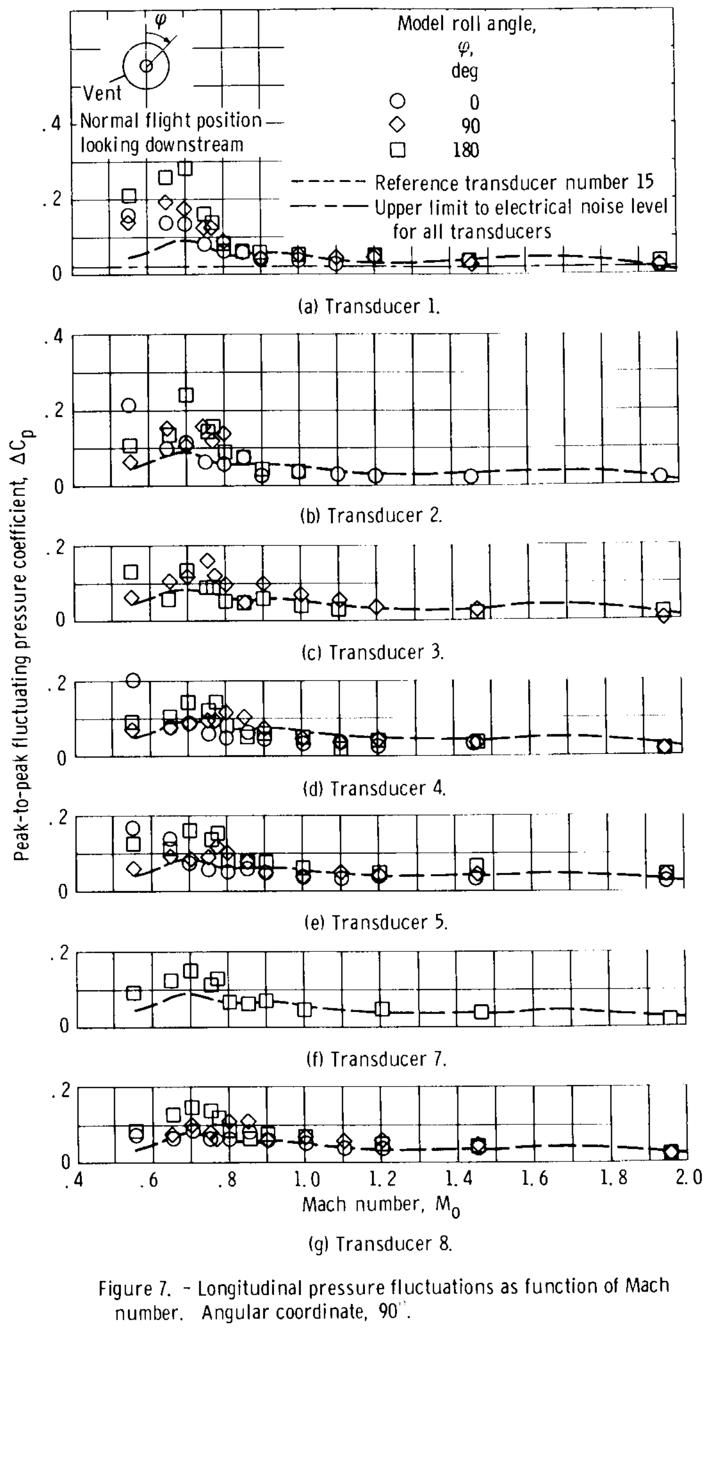
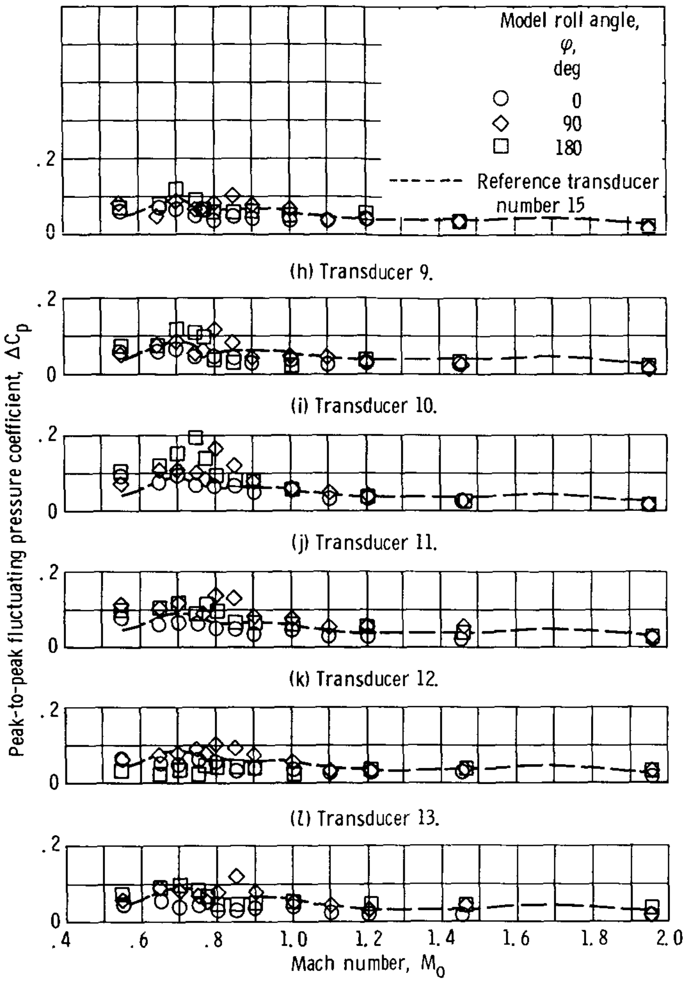


Figure 7. - Longitudinal pressure fluctuations as function of Mach number. Angular coordinate, 90°.



(h) Transducer 9.

(i) Transducer 10.

(j) Transducer 11.

(k) Transducer 12.

(l) Transducer 13.

(m) Transducer 15.

Figure 7. - Concluded.

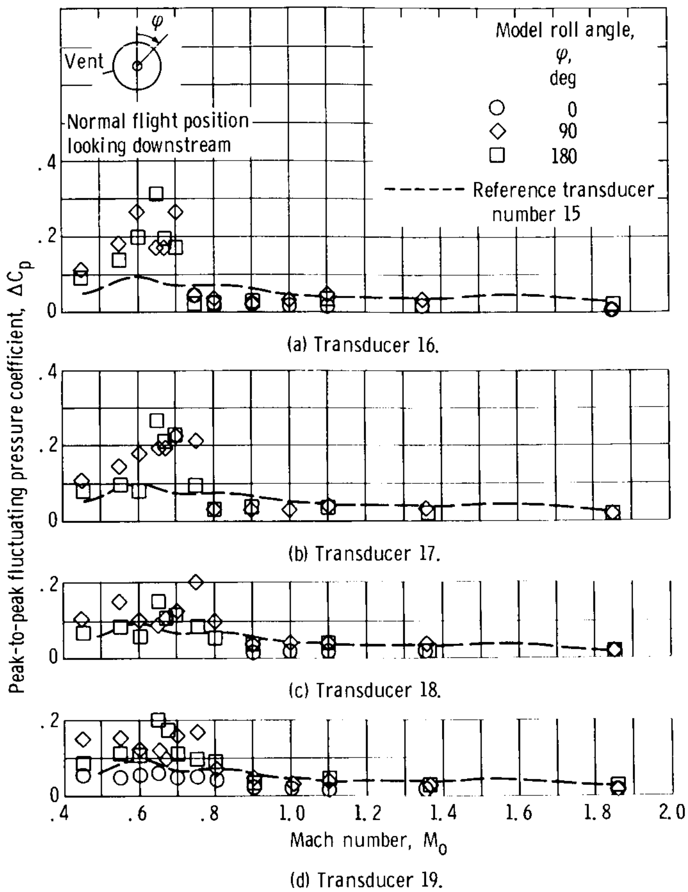
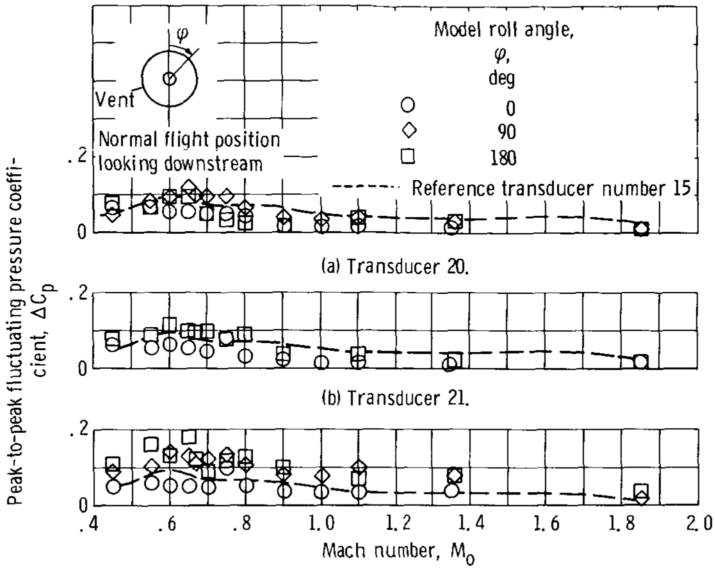


Figure 8. - Pressure fluctuations as function of Mach number for transducers downstream of cone shoulder angular coordinate, 0°.

Downstream of Hydrogen Vent Stack

The ΔC_p values for the transducers downstream of the hydrogen vent stack are presented in figure 9. Fluctuating pressure levels behind the vent appear to be low except for the transducer located farthest downstream from the stack (transducer 22). This transducer showed peak-to-peak amplitudes up to 18 percent of q_0 at $M_0 = 0.75$. This activity was probably influenced by a flow disturbance emanating from the adjacent umbilical island.

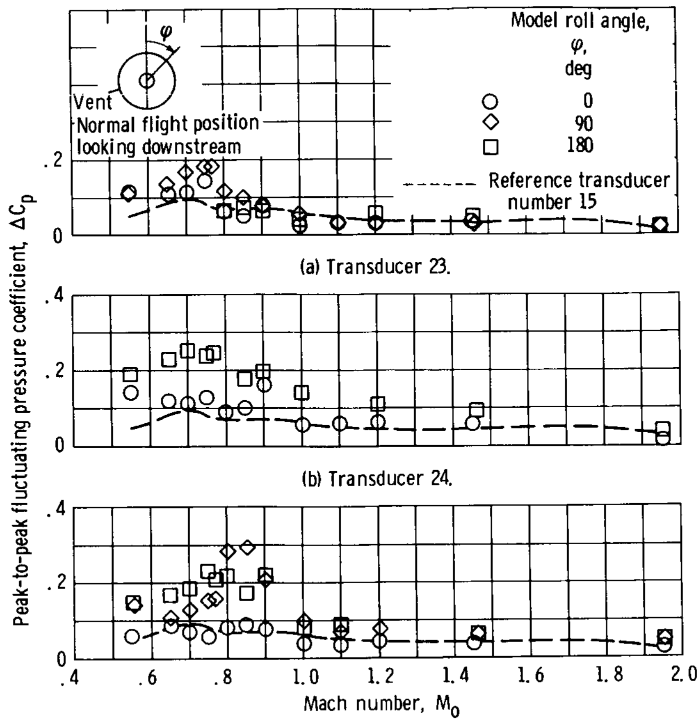


(c) Transducer 22.

Figure 9. - Pressure fluctuations as function of Mach number for transducers downstream of hydrogen vent stack. Angular coordinate, 245°.

Umbilical Island Fairing

Data from the umbilical island fairing (fig. 10) show strong pressure fluctuations ranging between 18 and 30 percent of q_0 in the transonic speed range. These fluctuations are about 5 percent of q_0 larger than those seen on other transducers in comparable positions on the model (transducers 3 to 5 on fig. 7, and 18 and 19 on fig. 8). This indicated that the umbilical island fairing geometry was contributing to the magnitude of these disturbances.



(a) Transducer 23.

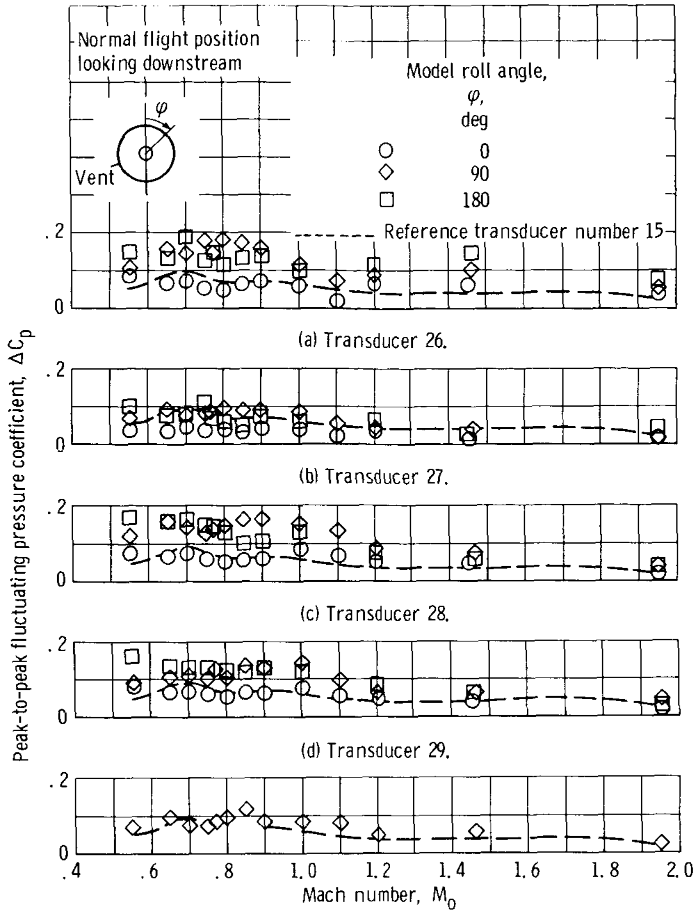
(b) Transducer 24.

(c) Transducer 25.

Figure 10. - Pressure fluctuations as a function of Mach number for transducers on umbilical island fairing. Angular coordinate, 270°.

Boost Pump Fairing and Interstage Adapter

Data from the boost pump fairing and the interstage adapter downstream of the boost pump are presented in figure 11. The transducer on the boost pump (transducer 26) showed considerable activity over most of the Mach range. At supersonic speeds, the fluctuations averaged about 10 percent of q_0. The transducers downstream of the boost pump indicated that the wake of the fairing had a definite effect on the level of pressure fluctuations. When compared with transducers 12 to 15 (fig. 7), those behind the boost pump showed an average increase in activity of about two percent of q_0. Transducer 27 showed a low level of activity because it was within the separated flow region close to the fairing, while transducer 28 showed pressure amplitudes in the transonic regime as high as 17 percent of q_0 because it was probably near the point of flow reattachment.



(e) Transducer 30.

Figure 11. - Pressure fluctuations as function of Mach number for transducers on the boost pump fairing and interstage adapter. Angular coordinate, 270°.

SUMMARY OF RESULTS

Wind tunnel tests of a 1/10-scale Centaur model with a Surveyor nose cone were conducted over a range of from Mach 0.55 to 1.95 to determine amplitudes and frequencies of fluctuating pressures that exist on the model surface at these speeds. Tests were conducted for roll angles of 0°, 90°, and 180° at 0° angle of attack. Because of noise in the tunnel, a detailed frequency analysis of the data was considered impractical. The following results were obtained:

1. Although the tunnel noise was present, those portions of the model subjected to large amplitude pressure fluctuations were determined by comparing the various transducer measurements to one transducer located on the model away from protuberances

such that it should be subjected only to the noise level of the turbulent boundary layer. The areas of maximum activity were immediately downstream of the cone shoulder, the umbilical island, and the boost pump fairing.

2. Maximum pressure fluctuations usually occurred at Mach numbers from 0.70 to 0.90. Peak-to-peak fluctuating pressure levels up to 30 percent of free-stream dynamic pressure were measured.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 22, 1967,
120-03-01-08-22.

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