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QUARTER SCALE SATCOM ANTENNA BLAST LOADS. (U)

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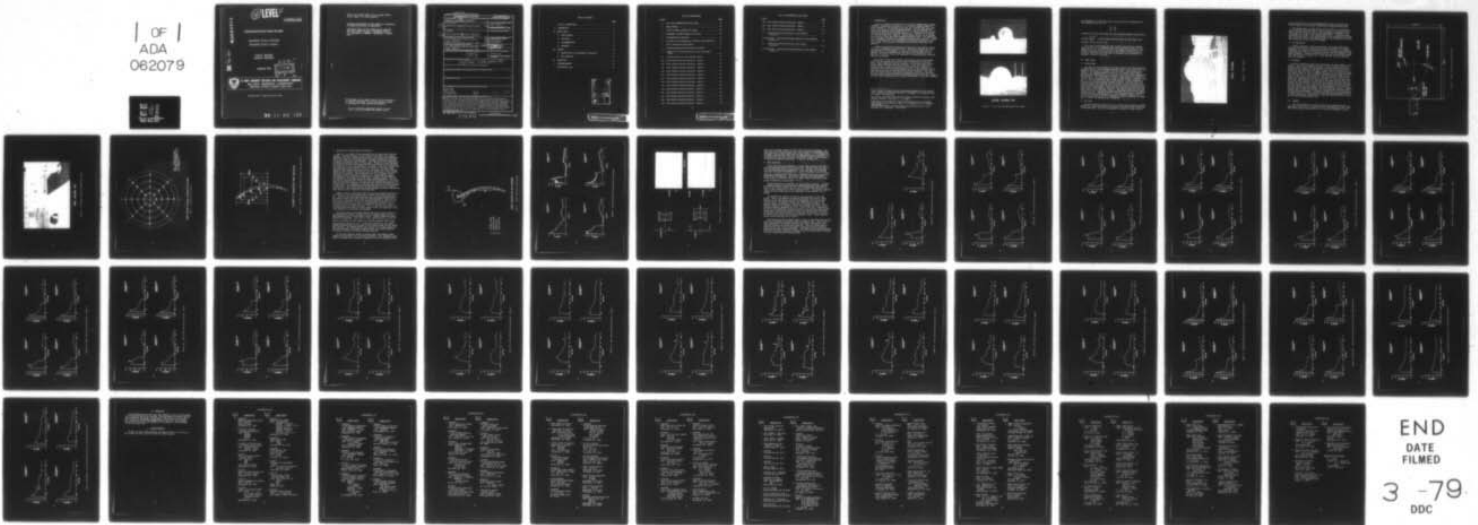
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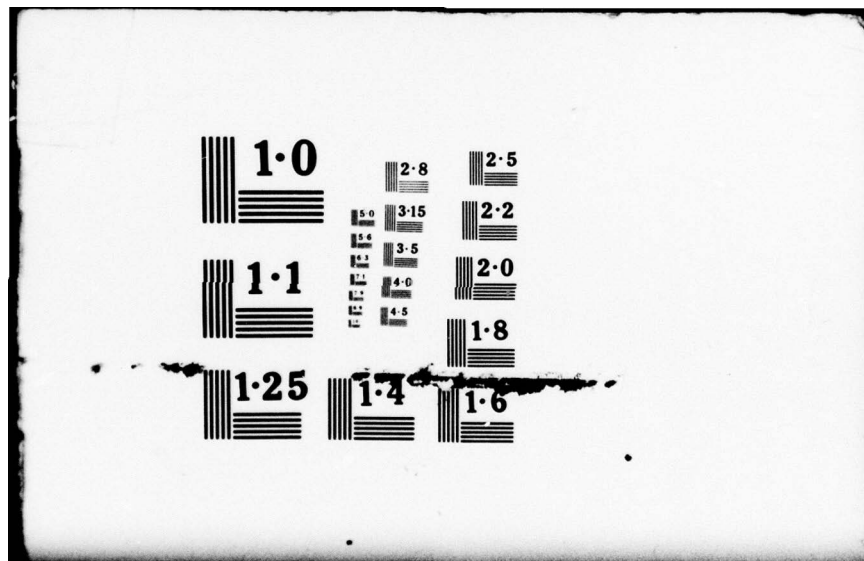
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MEMORANDUM REPORT ARBRL-MR-02861

QUARTER SCALE SATCOM
ANTENNA BLAST LOADS

Brian P. Bertrand
Rodney R. Abrahams

September 1978

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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I. INTRODUCTION

A test was recently performed for the Satellite Communications Agency (SATCOM) to determine the response of a 2.44 metre diameter antenna to blast loading^{1,2}. The purpose of the test was to obtain data that could be used for design of blast hardened antennae. The test program used blast waves emerging from the open end of a 2.44 metre shock tube to load the antenna which faced the shock tube exit at a distance of 12 metres, 24° from the centerline, Figure 1. Blast-induced strains on the antenna and free field blast data were obtained during the tests. The antenna was to be returned to SATCOM in its original condition after the tests. Therefore, modifications to it for mounting blast pressure transducers could not be made. The problem of determining actual blast loads then still remained.

SATCOM is interested in obtaining loading data to go with the strain data that was obtained during the tests. Using this loading data with a representation of the antenna in a structural response code, such as NASTRAN, the strains developed with the code can be compared to those measured in the blast tests, and confidence in hardening design using the code can be assessed.

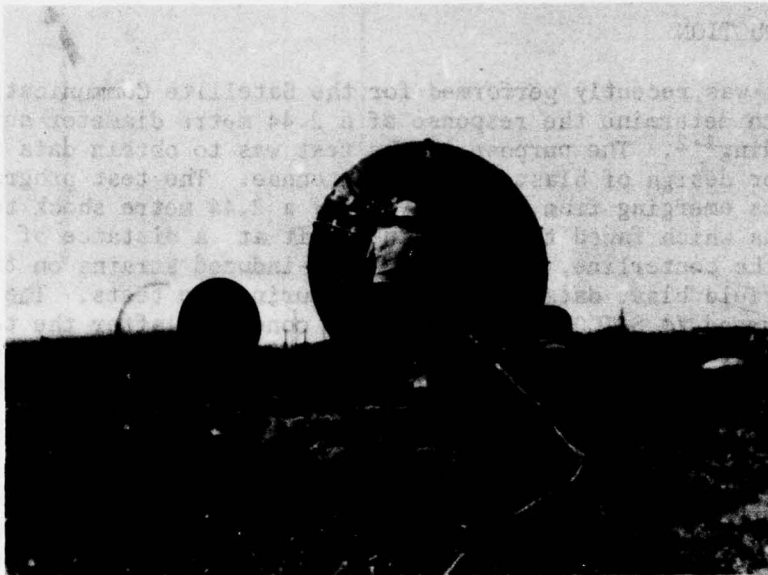
Past tests^{3,4} show that the blast wave emerging from an open-ended shock tube has pressure and duration that are functions of the shock tubes' shock overpressure and exit diameter, the distance from the exit and the radial direction from the centerline. They also showed that testing along, or near the extension of the shock tube centerline, is unrealistic for blast simulation because of the jet that emerges from the tube and the ring vortex associated with the jet formation. The tests have shown that close to the exit the distances at which the same blast pressure could be obtained from two different diameter shock tubes firing the same shock overpressures are directly proportional to the exit diameters.

¹*Blast Loading of a Mobile Satellite Tracking Antenna and of Two Simple Model Antennae*, BRL MR 2661, Aug 1976, R. Abrahams, B. P. Bertrand, and R. Pearson. (AD #A029437)

²*Blast Tests of SATCOM AN/TSC-86 Small Terminal Eight-Foot Diameter Dish Antenna*, ECOM MR, 1 Apr 1976, R. A. Lechner.

³*Overpressures and Durations of Shock Waves Emerging from Open-Ended Shock Tubes*, BRL MR 1724, Nov 1965, B. P. Bertrand and W. T. Matthews. (AD #633161)

⁴*Proposed Improvement of BRL Dual Shock Tube Facility*, BRL TN 1733, Apr 1970, B. P. Bertrand. (AD #871736)



SATCOM ANTENNA TEST

Figure 1. Full Scale SATCOM Antenna Test Setup

The durations (t) of the blast waves are also directly proportional to exit diameters (d), that is,

$$\frac{t_2}{t_1} = \frac{d_2}{d_1},$$

although past tests³ have shown that this duration function becomes more

like $\frac{t_2}{t_1} = \left(\frac{d_2}{d_1}\right)^{0.6}$ at much larger distances where the free field blast pressure is less than 0.1 kPa.

This linear relationship was used to model the full scale antenna tests, using a 57.5 cm diameter shock tube, and modelling the physical conditions of the full scale test by the diameter ratio, which is 0.24. Pressure transducers were installed in this model to obtain pressure histories from which the blast load on the model will be obtained and related to the full scale case.

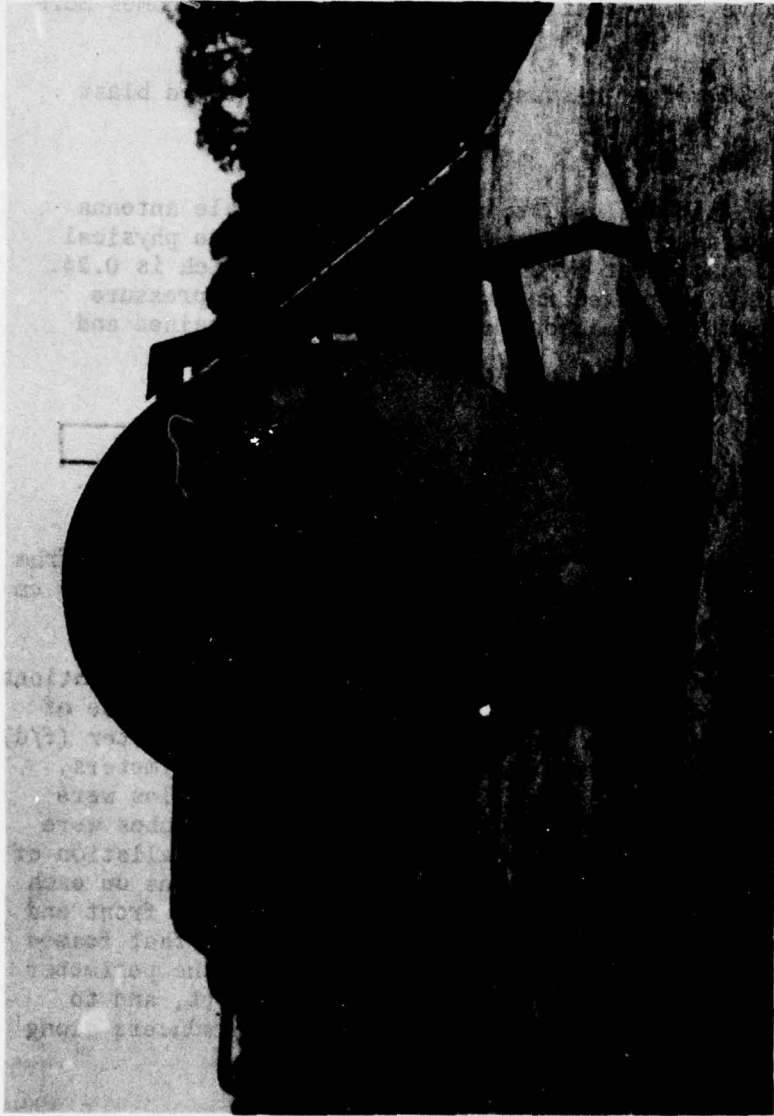
II. MODEL TESTS

A. Antenna Model

The front and rear surfaces of the model antenna were fabricated from two approximately parabolic-shaped aluminum dishes, each having a 58.4 cm diameter, one being 2.5 cm deeper than the other. These dishes were formed in the diaphragm section of the 57.5 cm diameter shock tube by pressurizing aluminum sheets, 1.6 mm thick, until the desired deformations were obtained. The front dish was formed to approximate the surface of the full scale antenna which has a ratio of focal length to diameter (f/d) of 0.3. The two dishes were then welded together at their perimeters, their concave surfaces facing the same direction. Thirteen holes were drilled through front and rear surfaces along 3 radials, and tubes were inserted joining the front and rear surface holes for the installation of blast pressure transducers. This gave four transducer positions on each radial and a center position, Figure 2. The space between the front and rear surfaces was filled with a liquid polyurethane material that foamed rigidly in place. Tabs were welded to the rear surface at the perimeter to facilitate mounting the model to a rigid framework support, and to allow rotation about its axis of symmetry to align the transducers along any of 8 radial directions in 45° increments.

B. Test Area

The area beyond the exit of the 57.5 cm shock tube on which the model antenna was tested was modified to simulate the ground surface beyond the 2.44 m shock tube. This was accomplished by backing a flatbed trailer



MODEL ANTENNA

Figure 2. Model Antenna

up to the shock tube exit and extending one side of the trailer with several sheets of heavy plywood, substantially supported from below.

The antenna model was then placed on this surface at a distance of 2.87 m from the shock tube exit on the 24° radial, its concave surface facing the exit, Figures 3 and 4. This arrangement represents a 0.24 scale model of the full scale SATCOM antenna tests. A pressure transducer mount was placed at the same distance as the antenna from the tube exit on the 24° radial on the opposite side of the centerline so that the free field blast history could be obtained.

C. Instrumentation

Pressure transducers used on the antenna were Endevco Model 8510. These are silicon disc, piezo-resistive strain transducers. A PCBM28 transducer was installed in the shock tube near the exit, and a PCB113A21 transducer was placed in the free field mount. The PCB transducers have quartz elements. Transducer outputs were recorded on tape using a Honeywell 7600 recorder at 80 kHz, FM. A time base and time zero reference were also recorded.

D. Procedure

Pressure transducers were first installed on the front surface of the antenna. There is not complete symmetry in blast loading because the ground surface beneath the antenna delays reflected pressure relief and because of the proximity of one edge of the antenna to the shock tube centerline where the blast is slightly higher. For this reason the model was rotated about its axis of symmetry and gages were relocated as necessary for each shot to assure that the pressure histories along each 45° radial of the surface were recorded. Only one shock wave level in the shock tube, approximately 100 kPa overpressure, was used for these tests. The front center position was used for all the shots on which the front surface was instrumented to assure that the pressure histories were consistent from shot to shot. The front center position was also used when the rear surface was instrumented, with the exception of one shot where the rear center position was used. For that exception, there is a corresponding shot in which the identical rear positions and the front center position were instrumented. It should be noted that a rear location and its opposite front location cannot be instrumented simultaneously because of space limitations. Figures 5 and 6 show the identification and location of the instrumented positions.

III. RESULTS

The shock pressure in the shock tube varied somewhat from shot to shot from a low of 96.5 to a high of 107 kPa, averaging 100.3 kPa. Free field blast pressure varied from 13.2 to 14.8 kPa, averaging 14.0 kPa.

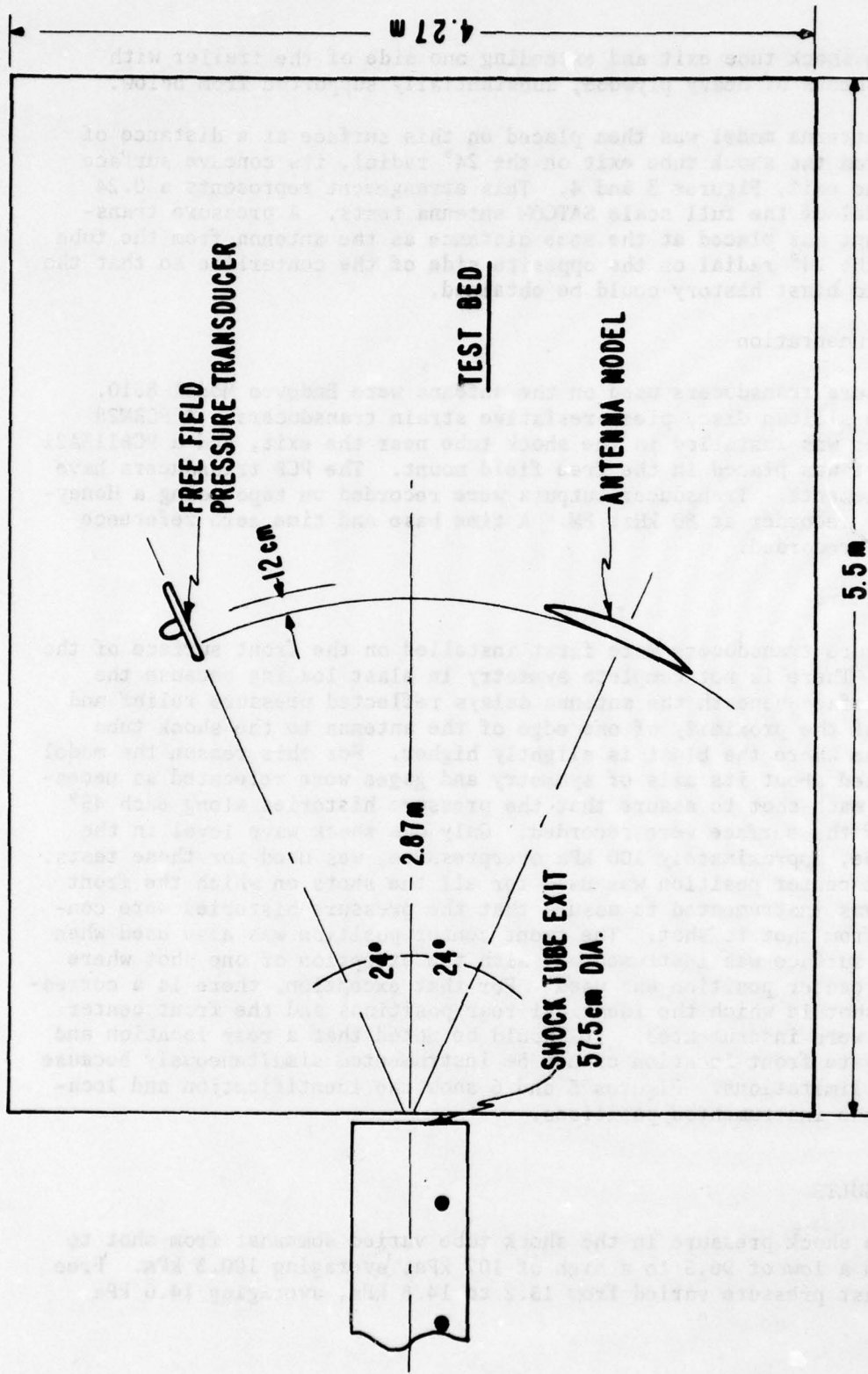
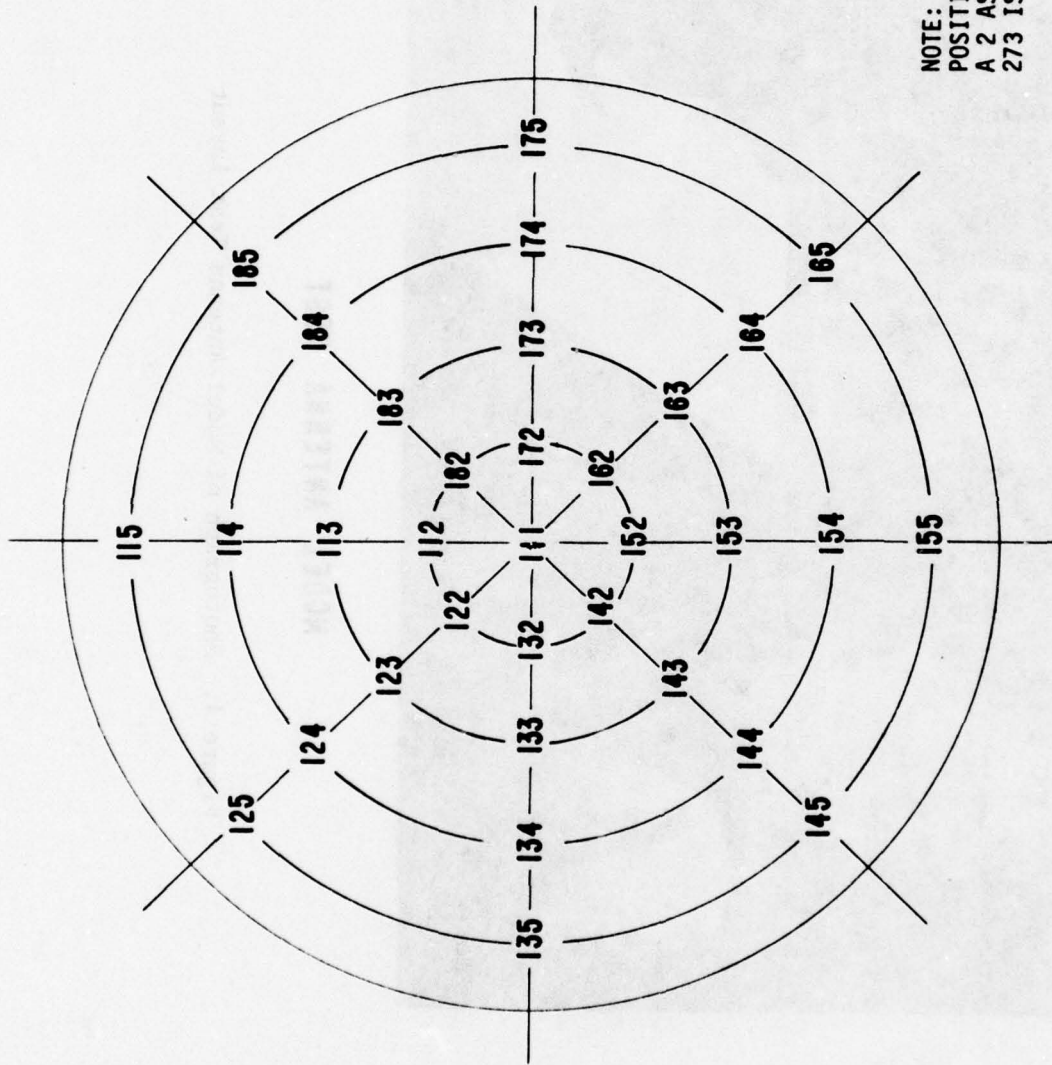


Figure 3. Sketch of Model Antenna Test Layout



MODEL ANTENNA TEST

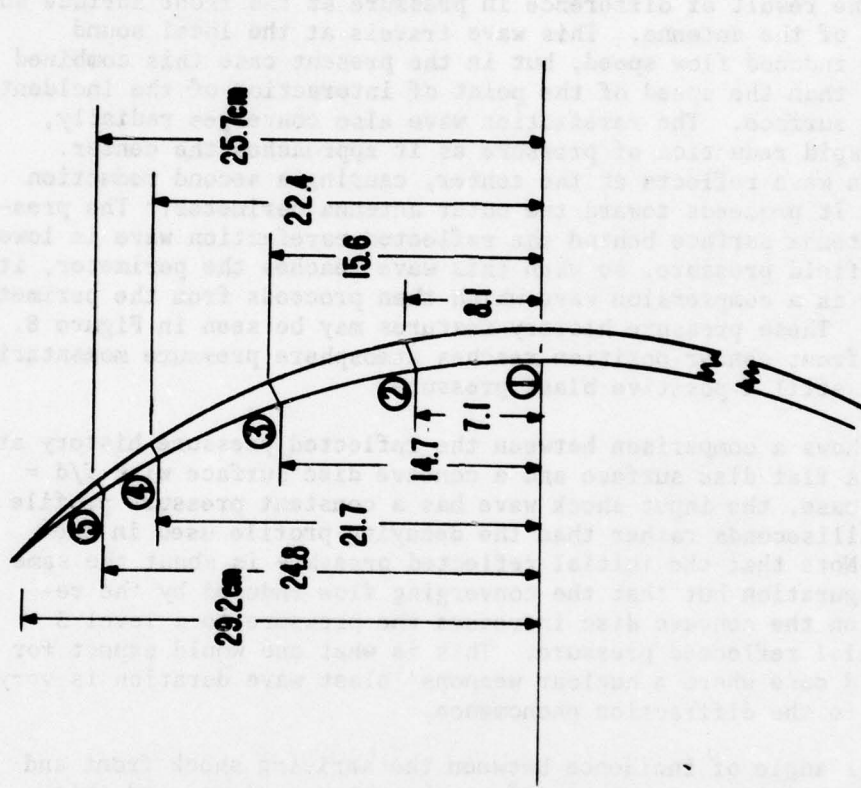
Figure 4. Photograph of Model Antenna Test Layout



NOTE: OPPOSING REAR GAGE
 POSITIONS ARE NUMBERED WITH
 A 2 AS THE FIRST DIGIT; I.E.:
 273 IS BEHIND 173.

FRONT SURFACE PRESSURE TRANSDUCER POSITIONS

Figure 5. Instrumentation Positions



DISTANCE OF TRANSDUCERS FROM CENTERLINE

Figure 6. Distances of Instrumentation Positions from Centerline

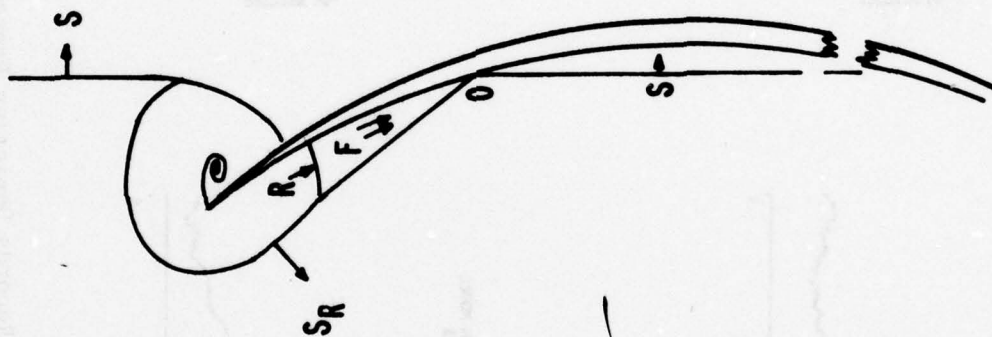
A. Description of Blast/Antenna Interaction

Figure 7 is a sketch of the interaction of the shock front with the antenna. The shock reflects on the concave front surface at an angle, inducing a flow that travels radially inward. This mass flow converging toward the center of the antenna causes a gradual compression following the initial reflection shock pressure. The magnitude of the compression increases at positions closer to the center. Closely following the point of interaction of the shock front with the front surface is a rarefaction wave that is the result of difference in pressure at the front surface and the free edges of the antenna. This wave travels at the local sound speed plus the induced flow speed, but in the present case this combined speed is lower than the speed of the point of interaction of the incident shock with the surface. The rarefaction wave also converges radially, resulting in rapid reduction of pressure as it approaches the center. The rarefaction wave reflects at the center, causing a second reduction in pressure as it proceeds toward the outer antenna perimeter. The pressure on the antenna surface behind the reflected rarefaction wave is lower than the free field pressure, so when this wave reaches the perimeter, it reflects there as a compression wave which then proceeds from the perimeter to the center. These pressure history features may be seen in Figure 8. Note that the front center position reaches atmosphere pressure momentarily while there is still a positive blast pressure.

Figure 9 shows a comparison between the reflected pressure history at the center of a flat disc surface and a concave disc surface with $f/d = 0.3$. In this case, the input shock wave has a constant pressure profile for several milliseconds rather than the decaying profile used in the model tests. Note that the initial reflected pressure is about the same for each configuration but that the converging flow induced by the reflected shock on the concave disc increases the pressure to a level 3 times the initial reflected pressure. This is what one would expect for the battlefield case where a nuclear weapons' blast wave duration is very long compared to the diffraction phenomenon.

The initial angle of incidence between the arriving shock front and the antenna front surface is about 42° at the antenna edges, and this angle decreases to 0° at the antenna center. Regular reflection theory, verified by experiment, shows that, at this shock pressure, P_S , and for angles of incidence in this range, the reflected pressure factor P_R/P_S is practically constant at 2.11. We may then expect that the initial reflected pressure will be the same at this shock pressure for the entire front surface. The induced radial flow velocity is of course greater at the greater angles of incidence occurring nearer the antenna edge but that does not affect the initial reflected pressure.

As the shock refracts around the antenna edges and expands inward towards the rear center, it is initially weakened. This weakened initial shock is followed by an increase in pressure as the flow induced by this



S - INCIDENT SHOCK
 S_R - REFLECTED SHOCK
 R - RAREFACTION
 F → - FLOW DIRECTION

SHOCK INTERACTION WITH ANTENNA

Figure 7. Shock Interaction with Antenna

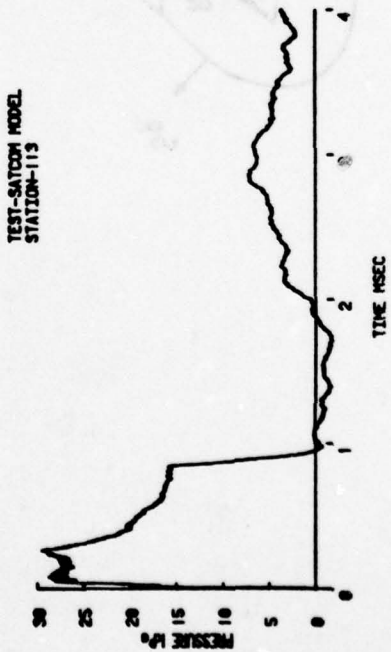
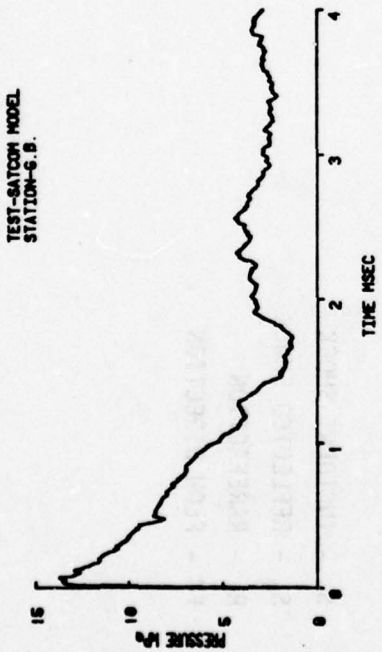
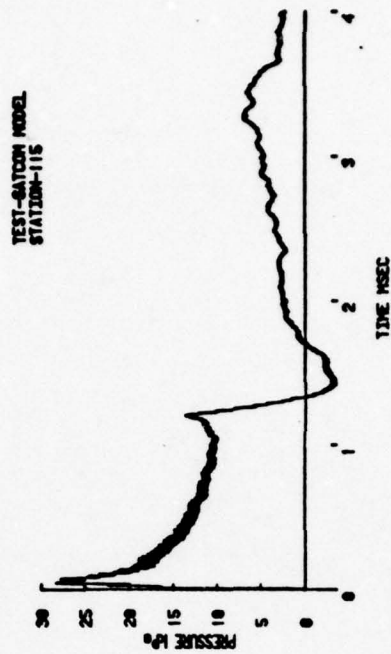
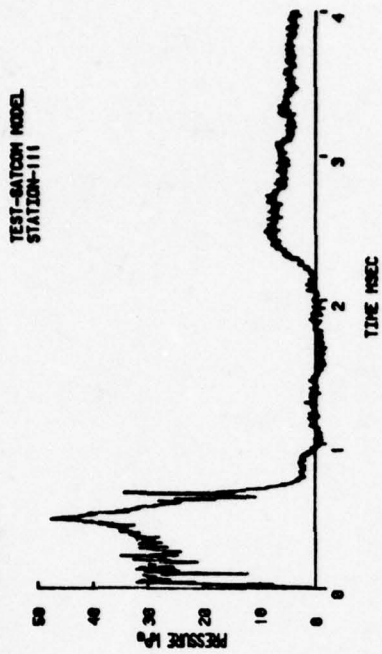


Figure 8. Records Depicting Pressure History Features

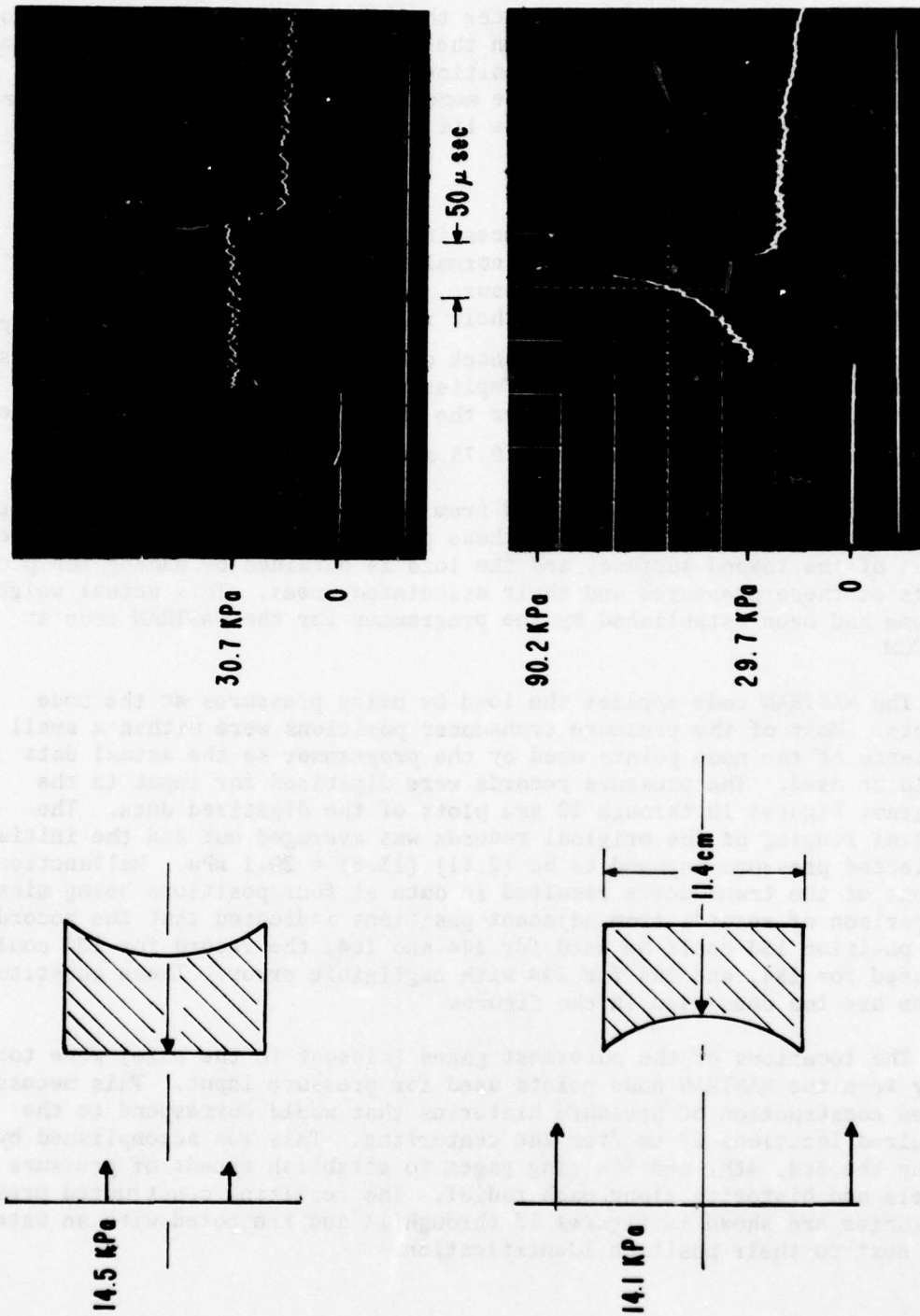


Figure 9. Comparison of Pressure History on Flat and Concave Discs

shock also converges toward the center from the antenna perimeter. The shock arrives at rear positions later than it does at corresponding front positions since it must travel down the back surface. It is interesting to observe that the rear center position pressure reaches a maximum at the same time the front center pressure momentarily reaches ambient pressure, as shown in the record of positions 111 and 211 in Figure 10.

B. Data Reduction

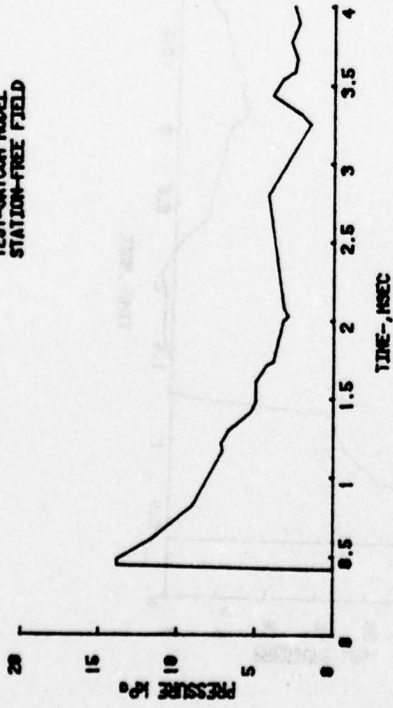
Since there were some differences in free field pressure from shot to shot, the recorded data had to be normalized. The full scale test was at 13.8 kPa free field shock overpressure, so all the data in the present tests were scaled by multiplying their values of pressure P_R by $13.8/P_{FF}$, where P_{FF} is measured free field shock overpressure and P_R is the pressure measured at each position. This implies that the reflected pressure factor P_R/P_{FF} is constant, and over the small range of pressures in the present tests this is true within 0.75 sec.

Loading histories are obtained from the pressure histories. A scheme is normally devised to associate these pressure histories with specific areas of the loaded surface, and the load is obtained by adding the products of these pressures and their associated areas. This actual weighting scheme had been established by the programmer for the NASTRAN code at SATCOM.

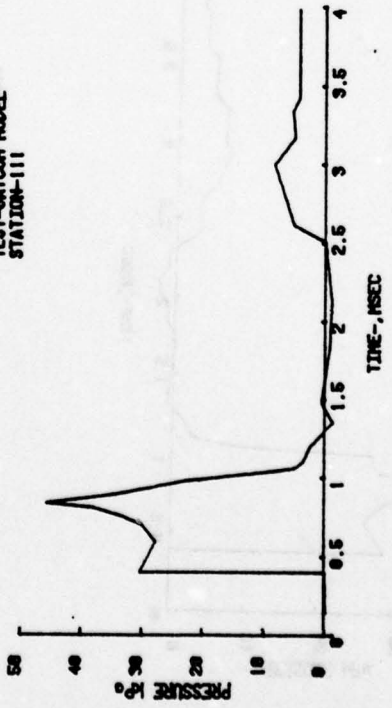
The NASTRAN code applies the load by using pressures at the node points. Most of the pressure transducer positions were within a small distance of the node points used by the programmer so the actual data could be used. The pressure records were digitized for input to the program; Figures 10 through 12 are plots of the digitized data. The initial ringing of the original records was averaged out and the initial reflected pressure assumed to be $(2.11)(13.8) = 29.1$ kPa. Malfunction of one of the transducers resulted in data at four positions being missed. Comparison of records from adjacent positions indicated that the record for position 154 could be used for 144 and 164, the record for 124 could be used for 184, and 264 for 244 with negligible error. These substitutions are the ones used in the figures.

The locations of the outermost gages (closest to the edge) were too far away from the NASTRAN node points used for pressure input. This necessitated construction of pressure histories that would correspond to the required locations 28 cm from the centerline. This was accomplished by using the 3rd, 4th, and 5th ring gages to establish trends of pressure levels and histories along each radial. The resulting constructed pressure histories are shown in Figures 13 through 14 and are noted with an asterisk (*) next to their position identification.

TEST-STATION MODEL
STATION-FREE FIELD



TEST-STATION MODEL
STATION-111



TEST-STATION MODEL
STATION-211

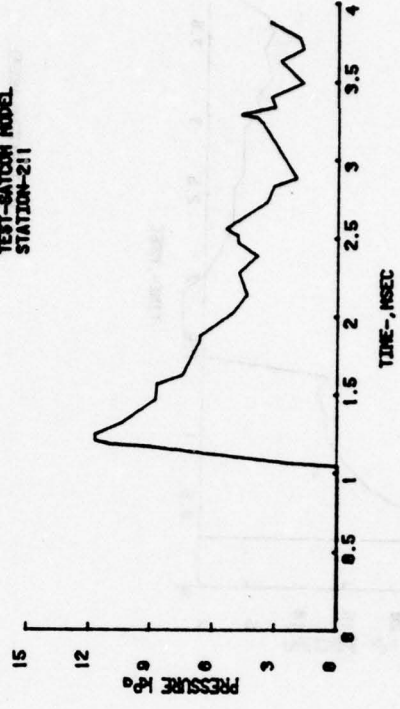


Figure 10. Pressure History at Front and Rear Center

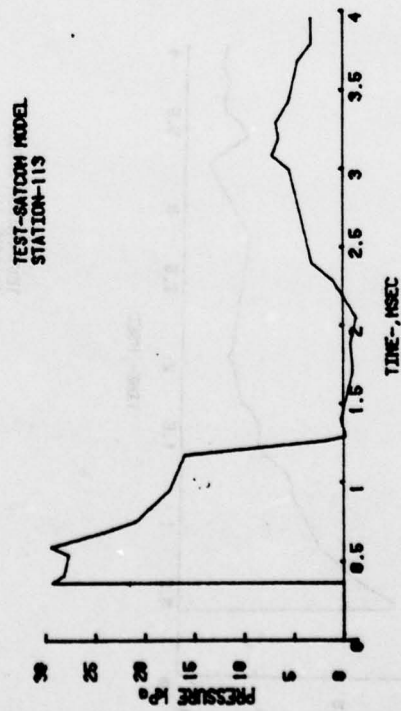
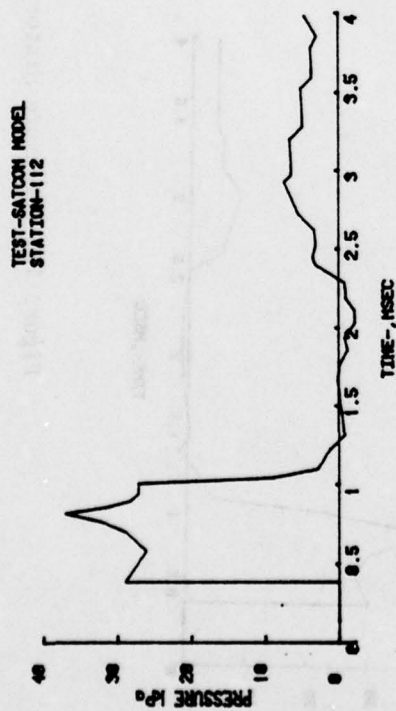
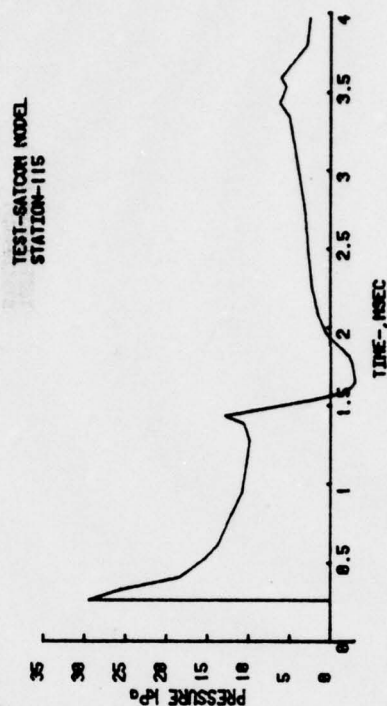
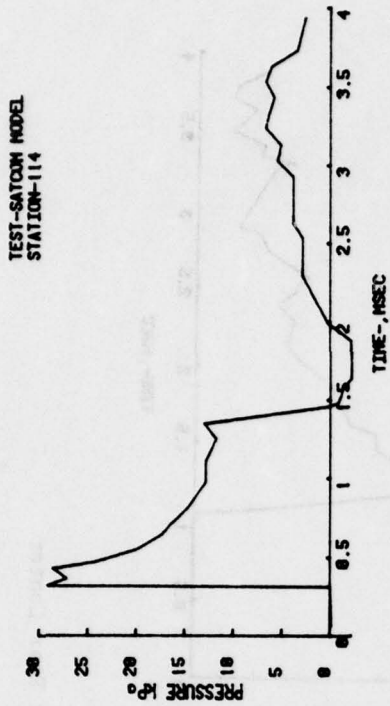


Figure 11a. Front Surface Pressure Histories: Radial 1

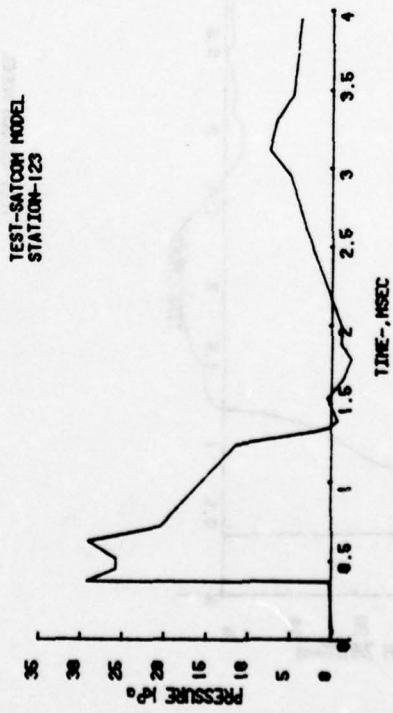
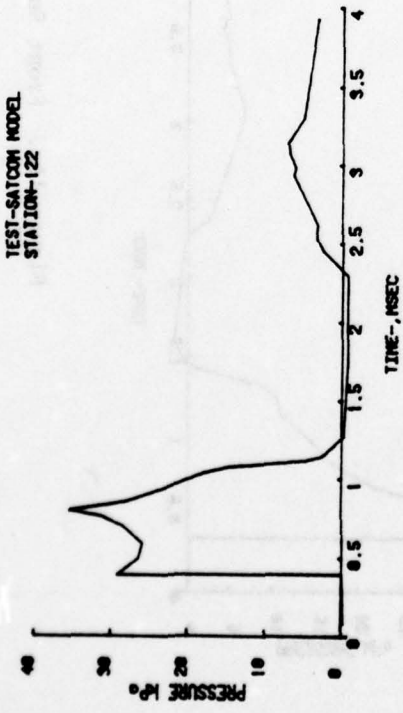
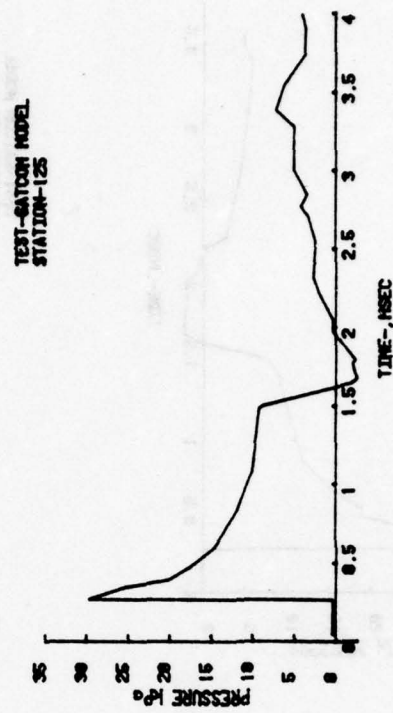
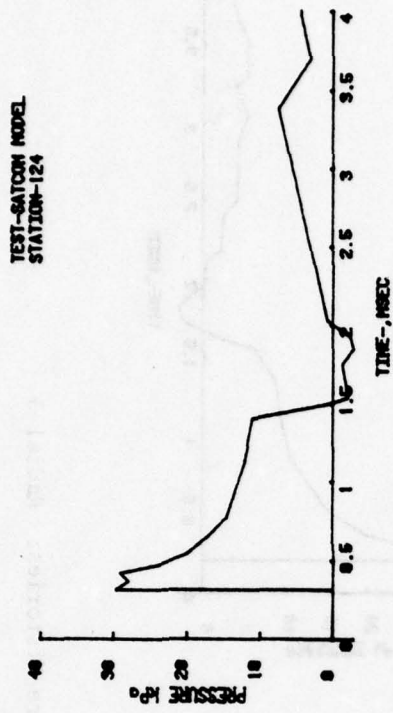


Figure 11b. Front Surface Pressure Histories: Radial 2

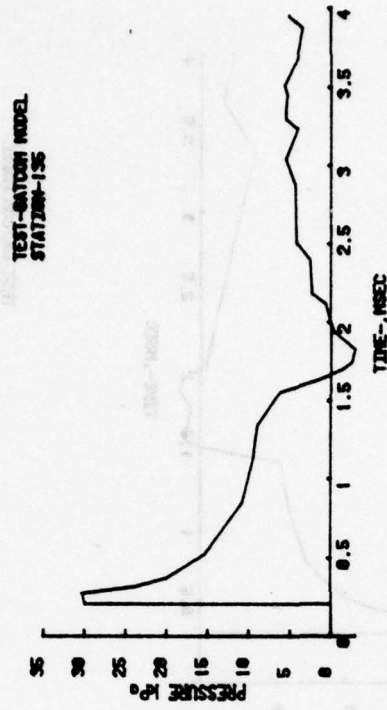
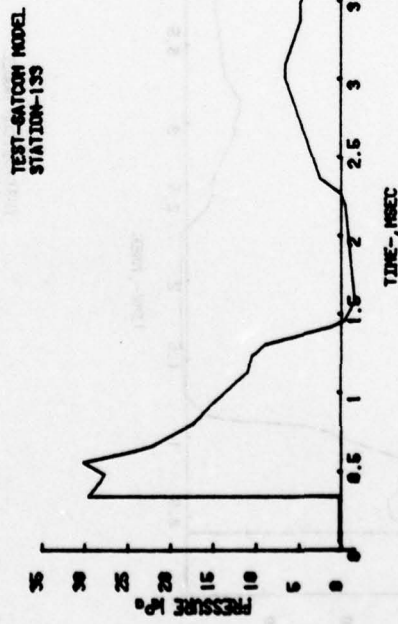
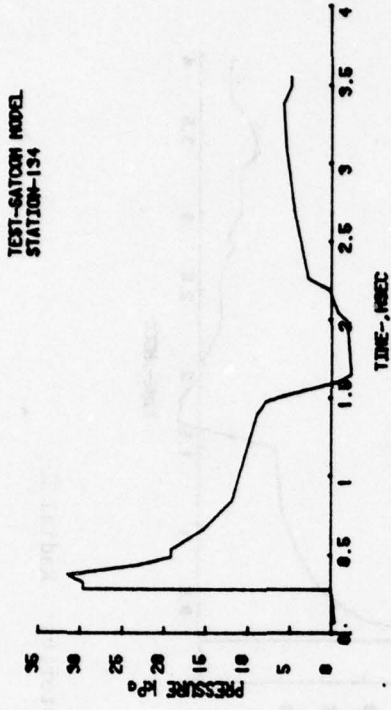
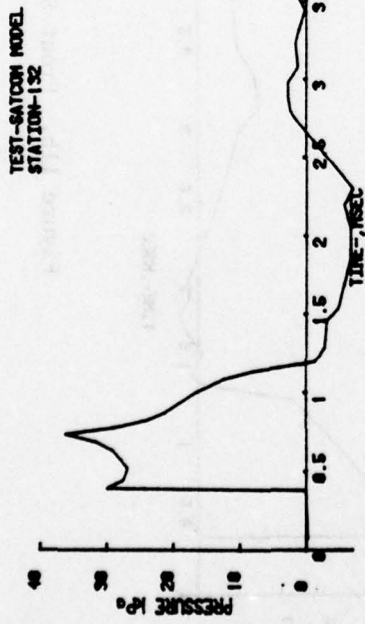


Figure 11c. Front Surface Pressure Histories: Radial 3

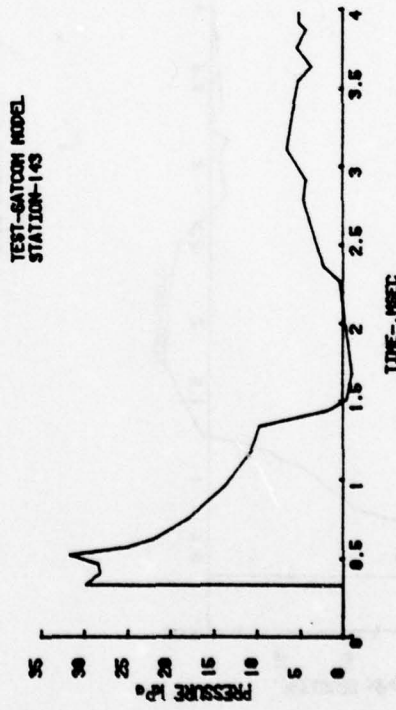
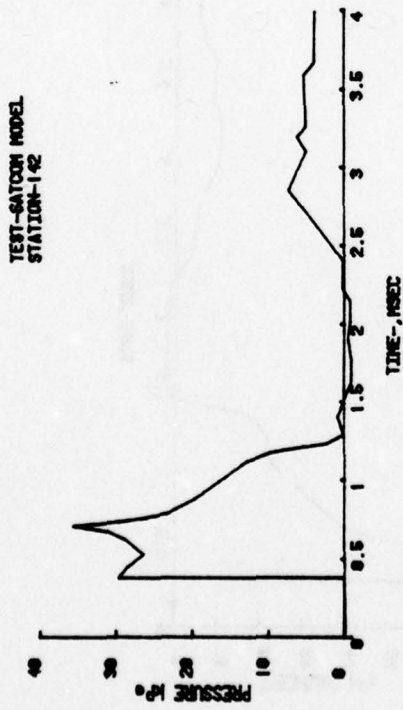
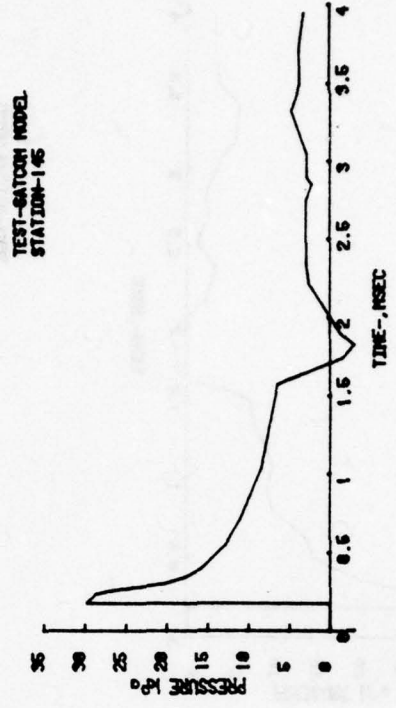
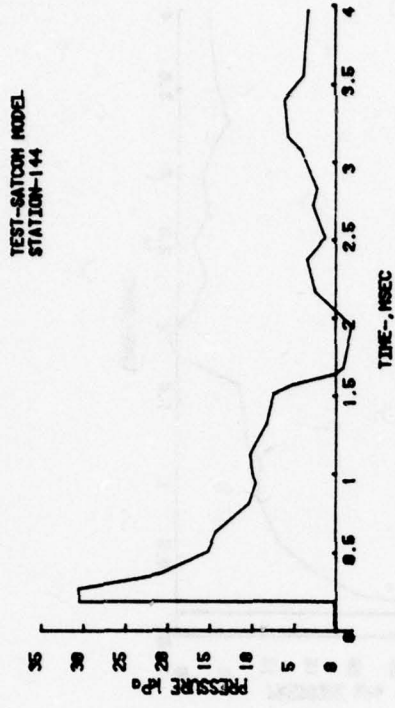


Figure 11d. Front Surface Pressure Histories: Radial 4

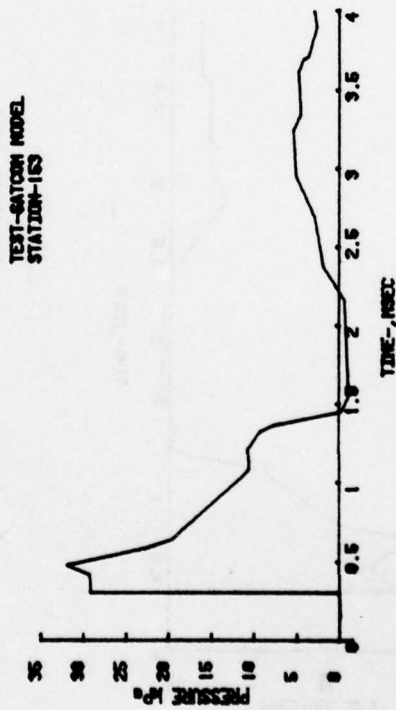
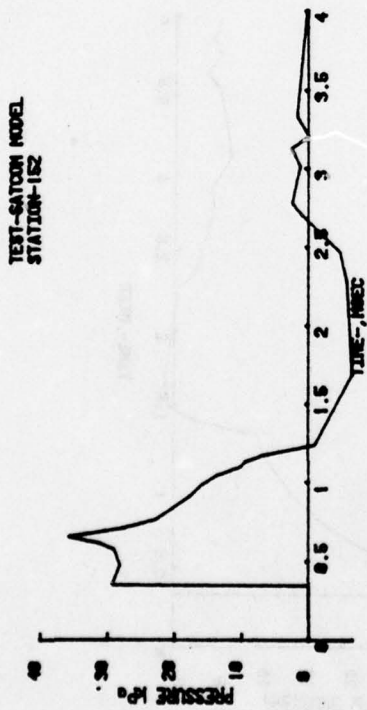
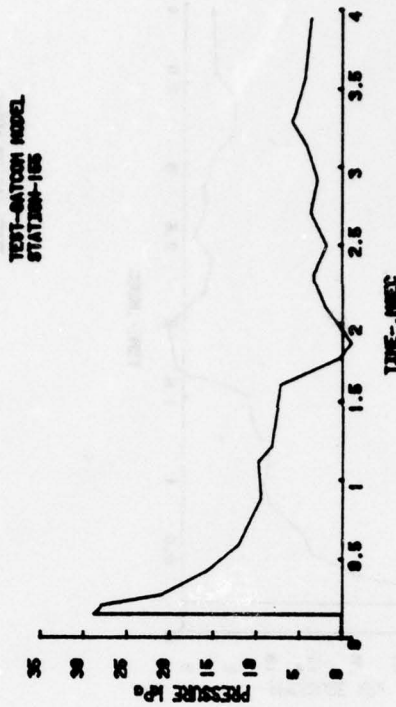
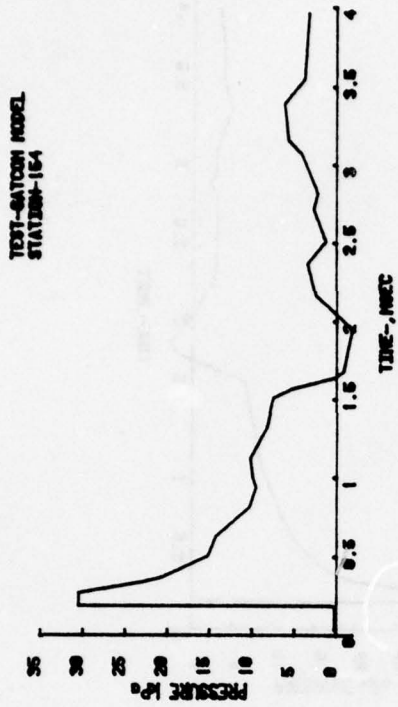


Figure 11e. Front Surface Pressure Histories: Radial 5

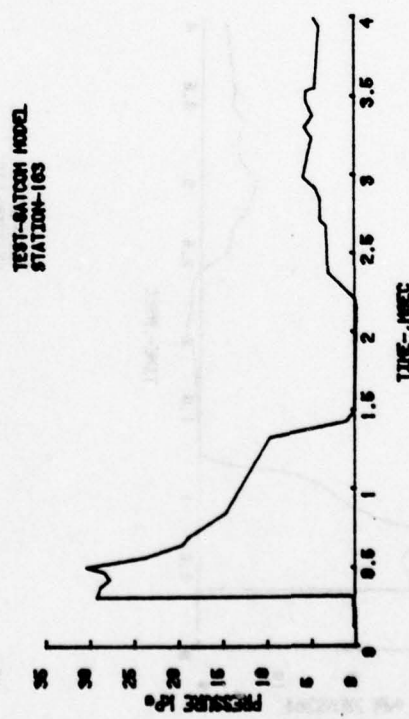
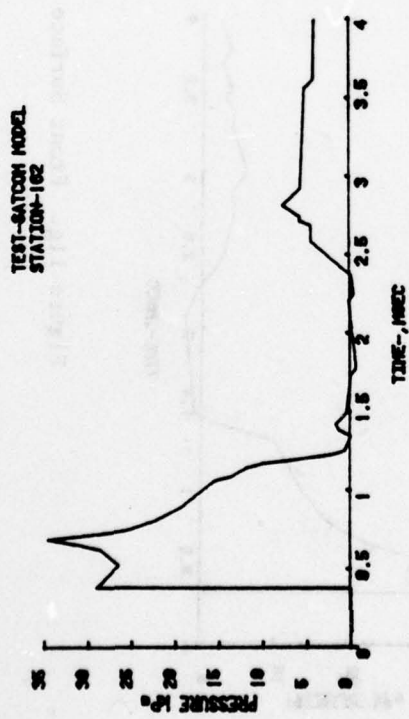
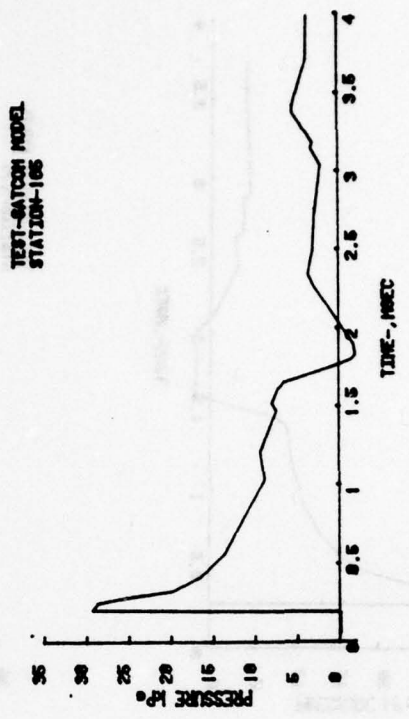
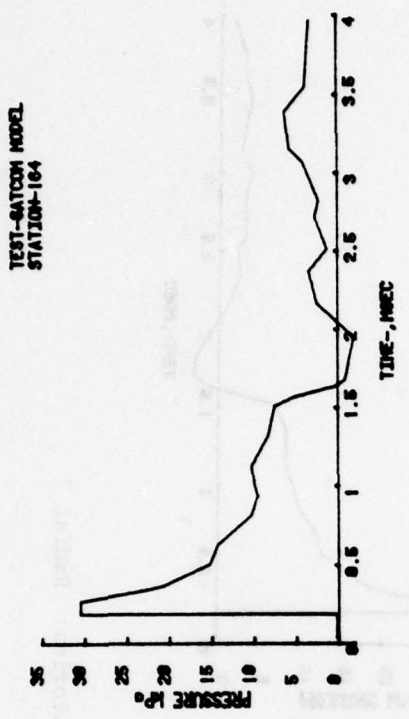


Figure 11f. Front Surface Pressure Histories: Radial 6



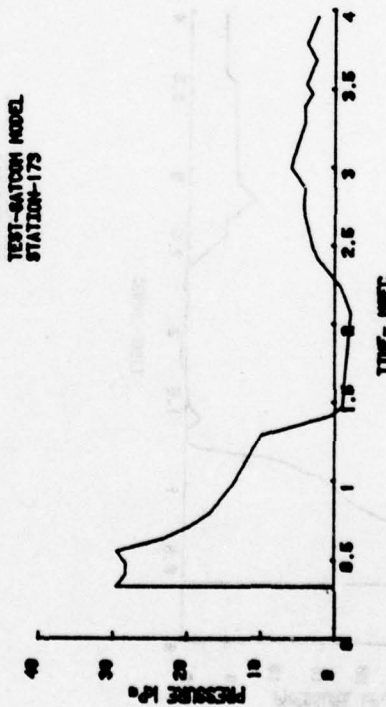
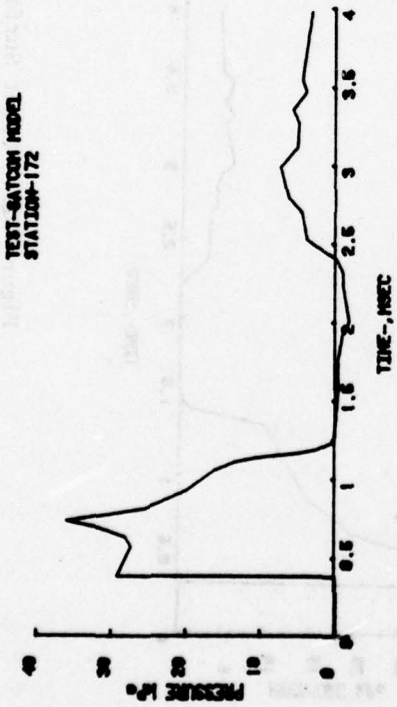
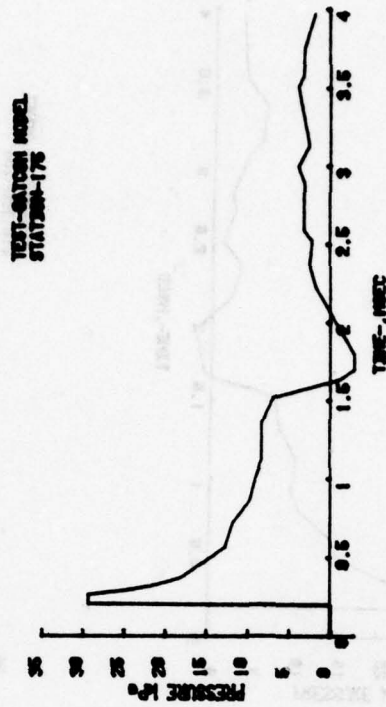
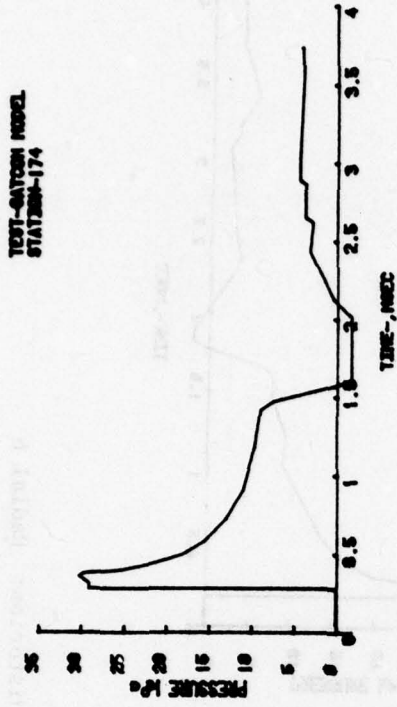


Figure 11g. Front Surface Pressure Histories: Radial 7

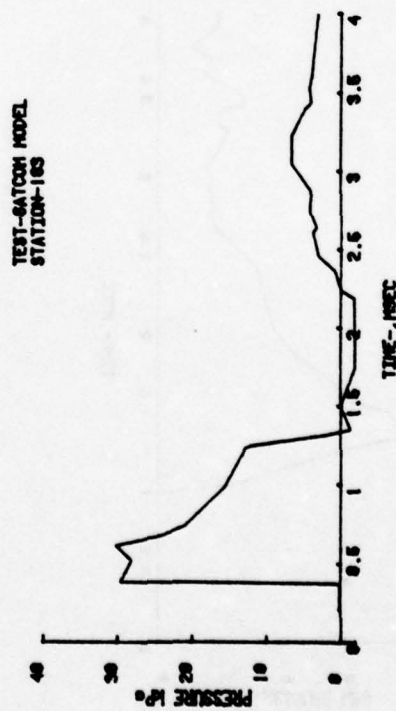
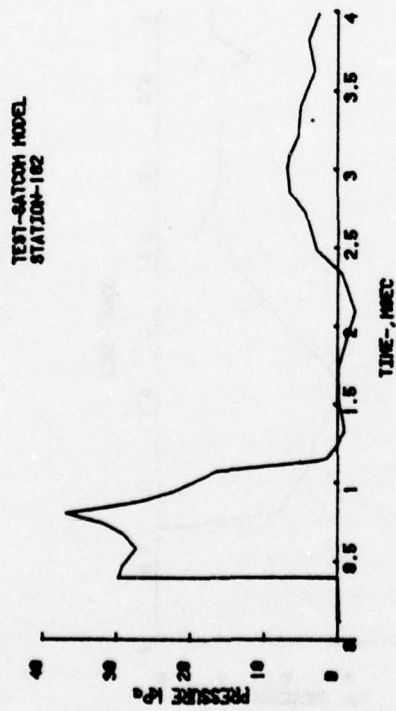
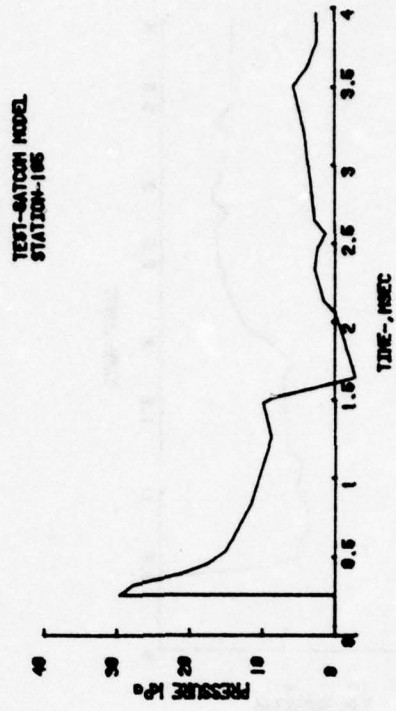
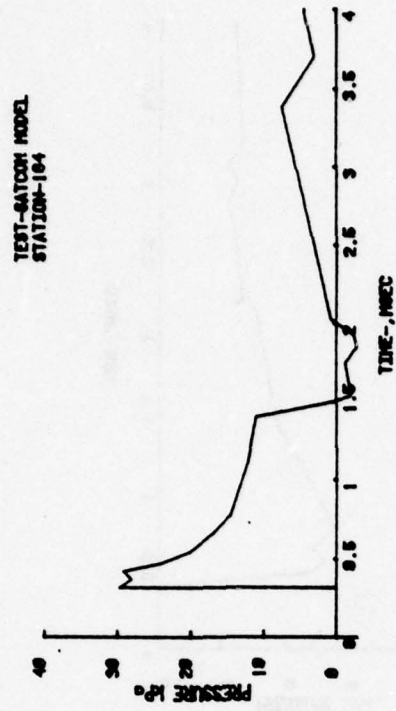


Figure 11h. Front Surface Pressure Histories: Radial 8

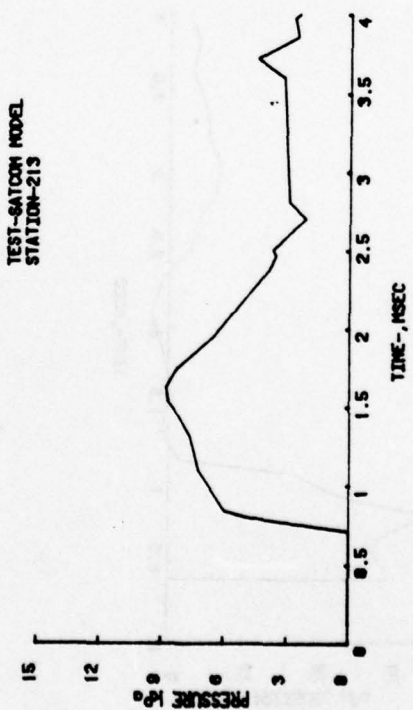
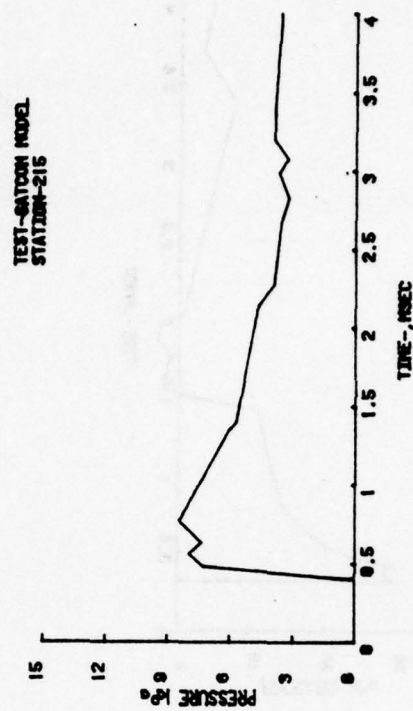
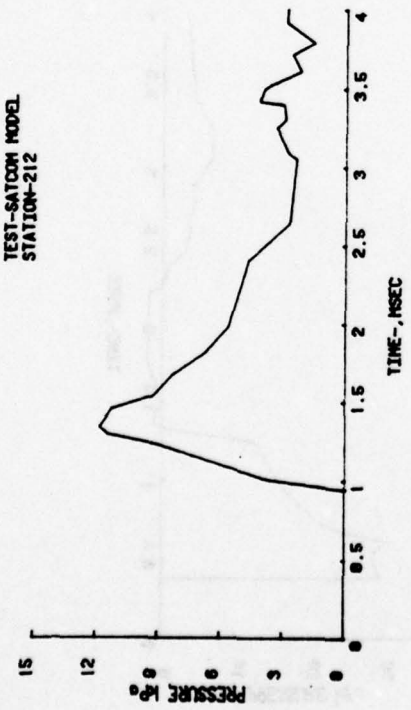
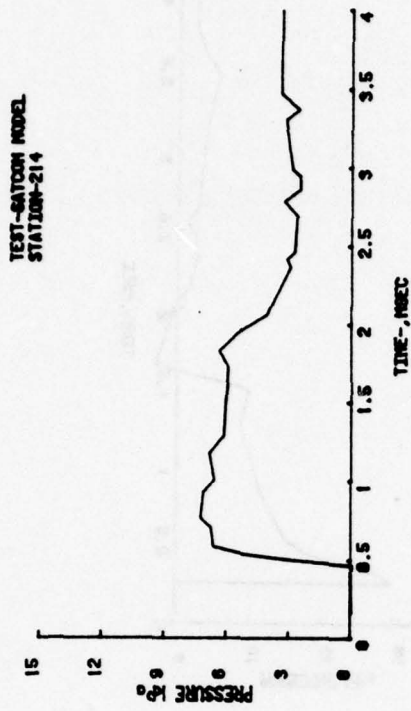
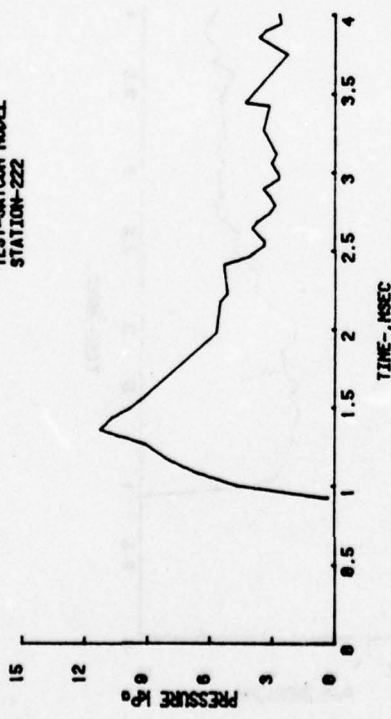
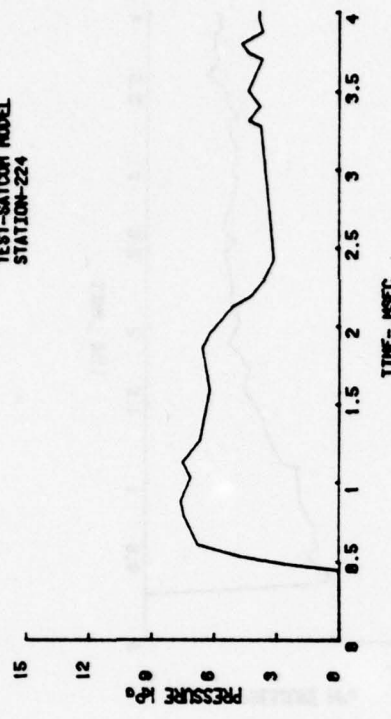


Figure 12a. Rear Surface Pressure Histories: Radial 1

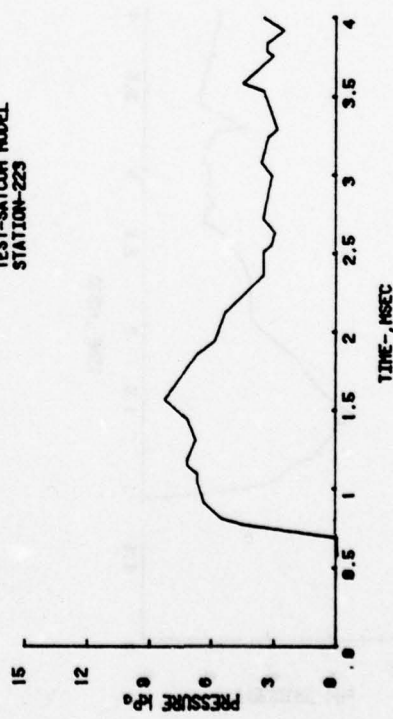
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TEST-SATCOM MODEL
STATION-224



TEST-SATCOM MODEL
STATION-223



TEST-SATCOM MODEL
STATION-225

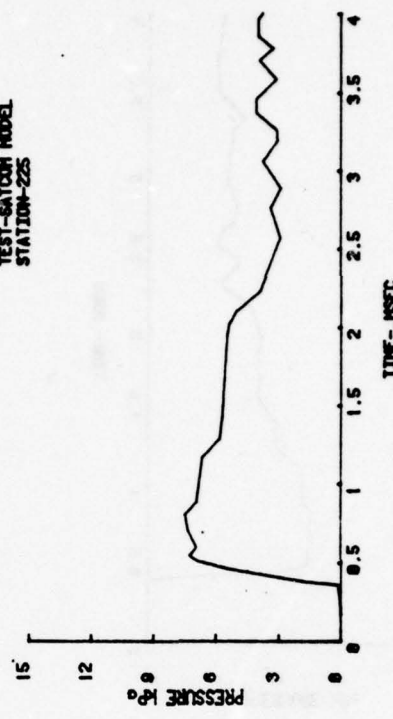


Figure 12b. Rear Surface Pressure Histories: Radial 2

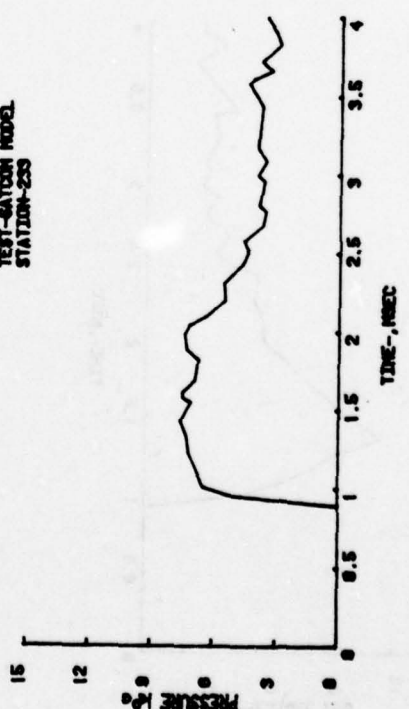
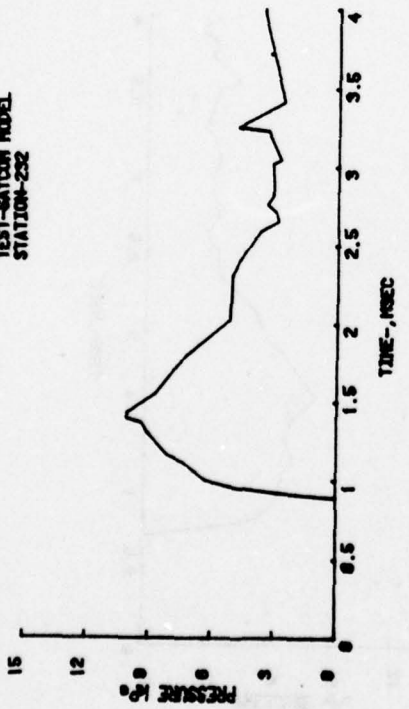
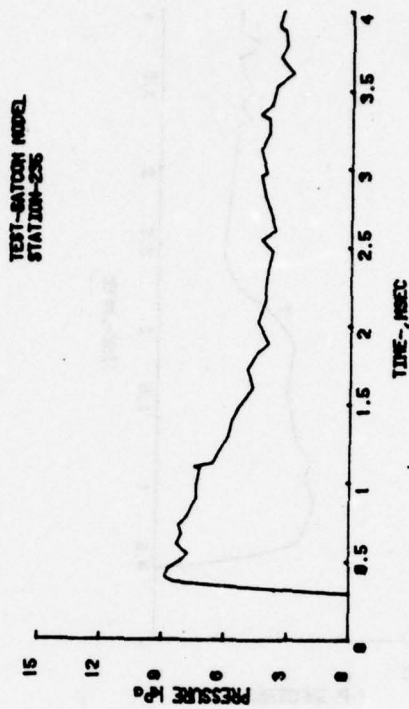
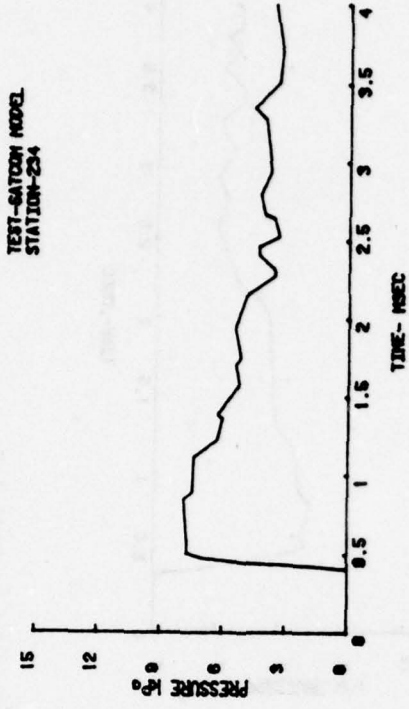


Figure 12c. Rear Surface Pressure Histories: Radial 3

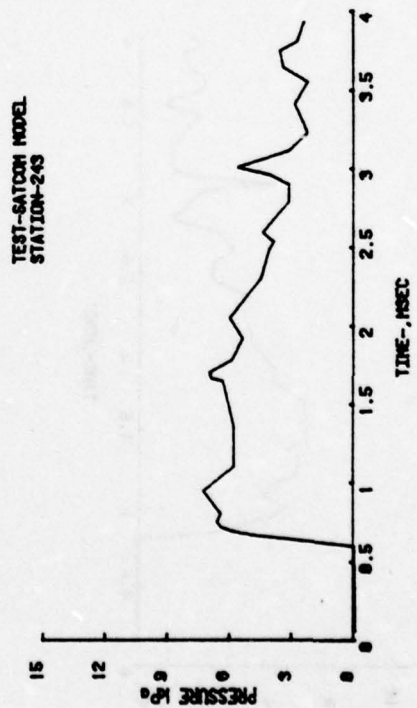
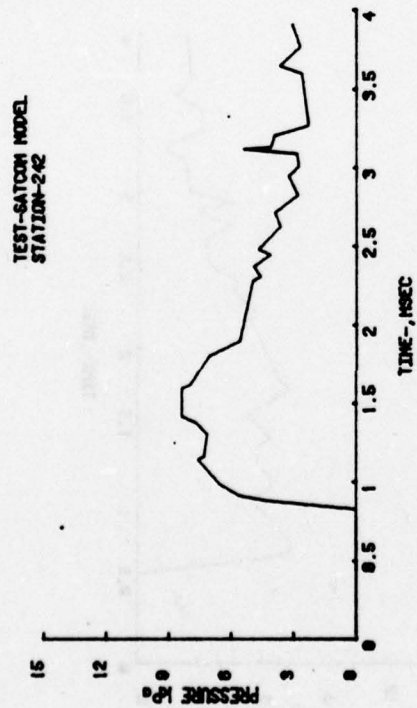
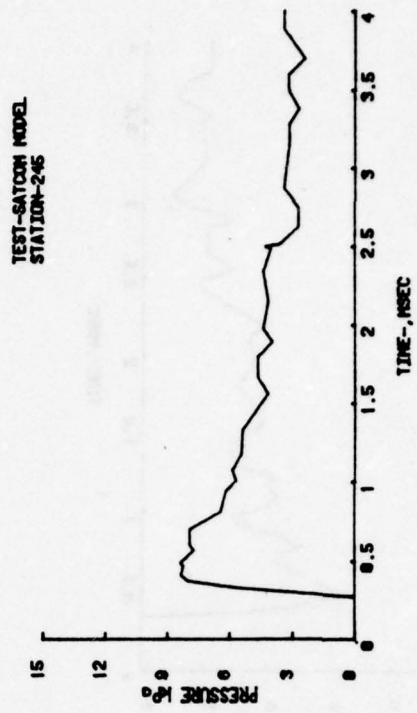
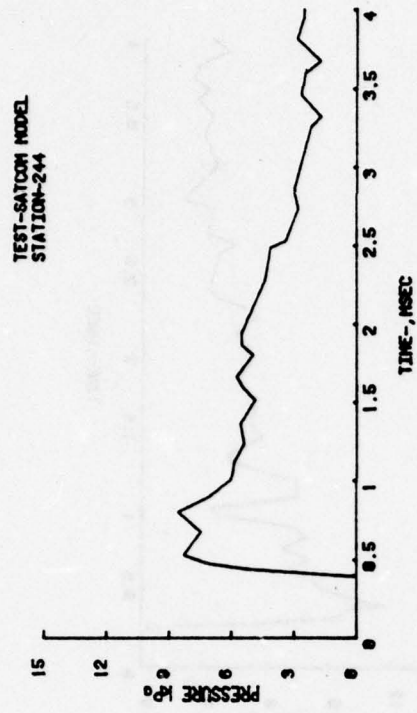


Figure 12d. Rear Surface Pressure Histories: Radial 4

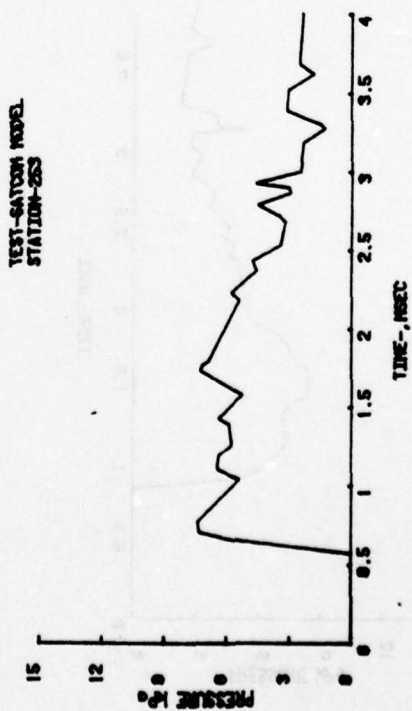
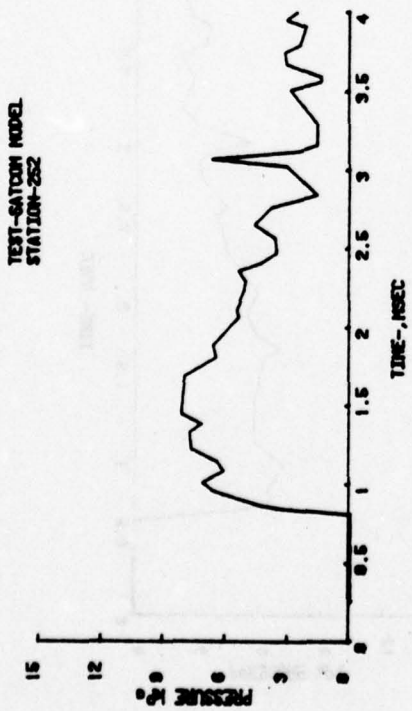
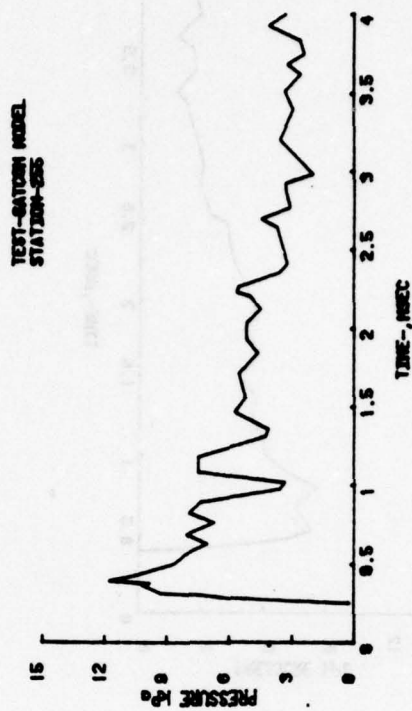
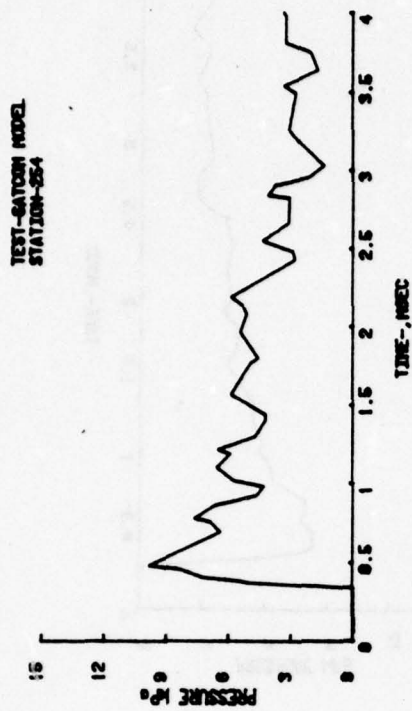


Figure 12e. Rear Surface Pressure Histories: Radial 5

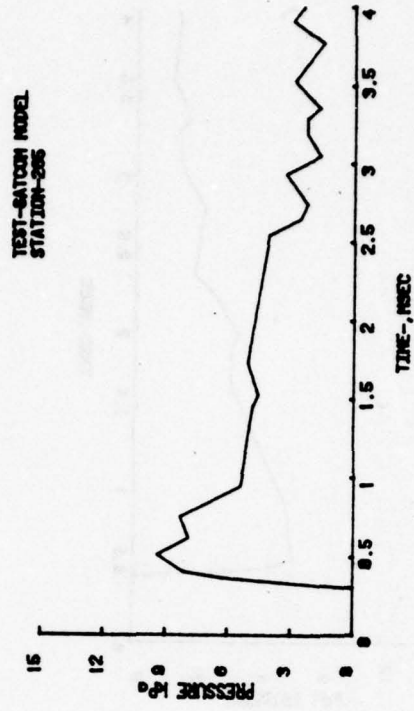
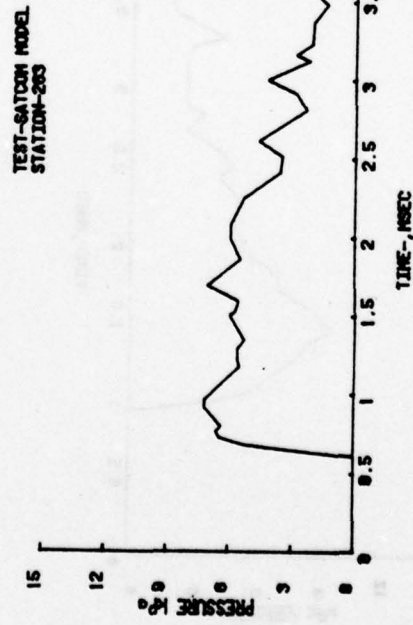
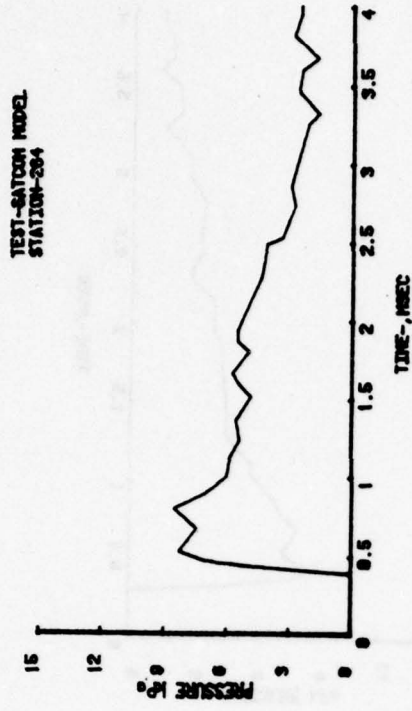
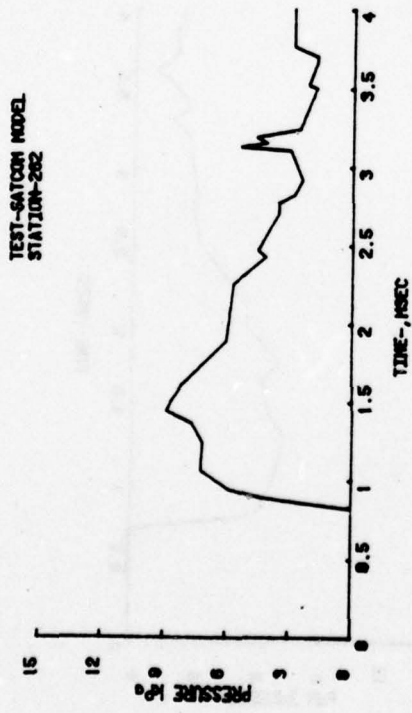


Figure 12f. Rear Surface Pressure Histories: Radial 6

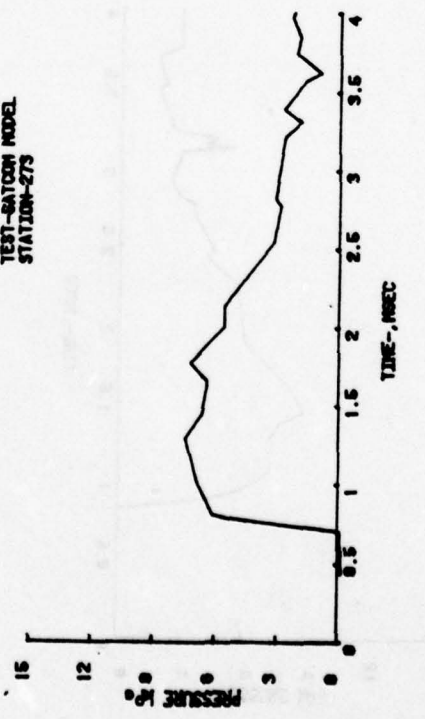
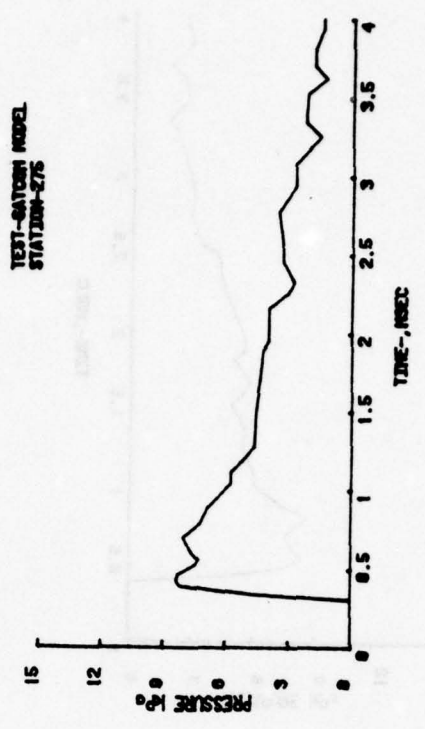
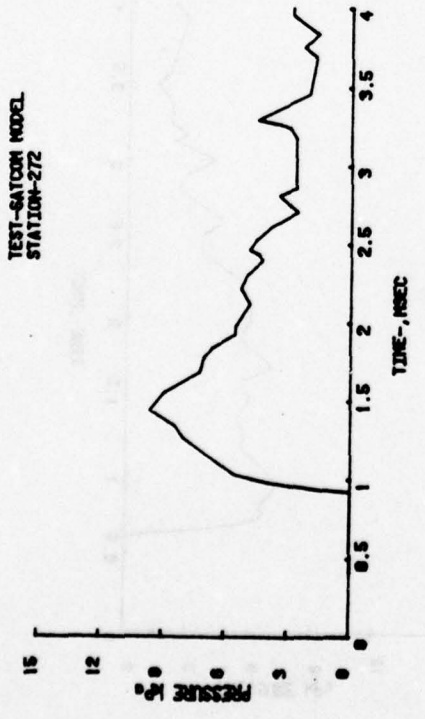
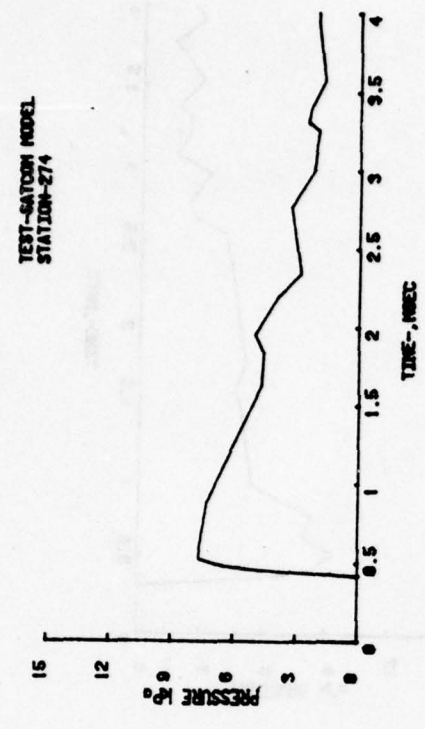
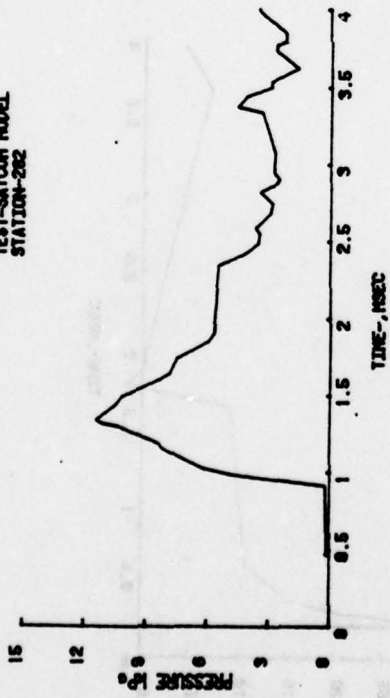
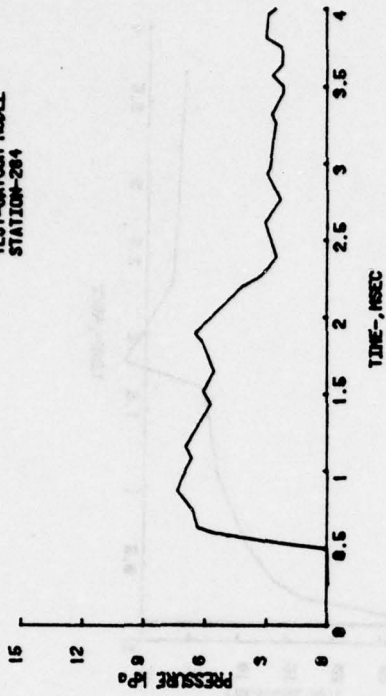


Figure 12g. Rear Surface Pressure Histories: Radial 7

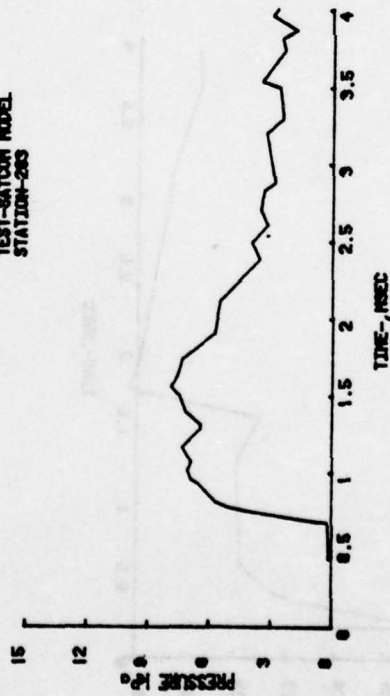
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TEST-STATION MODEL
STATION-284



TEST-STATION MODEL
STATION-283



TEST-STATION MODEL
STATION-285

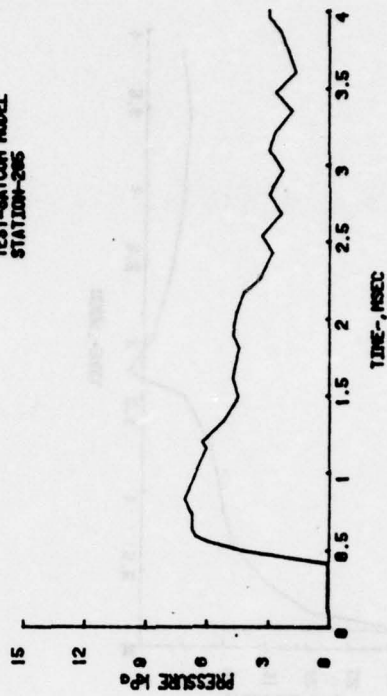
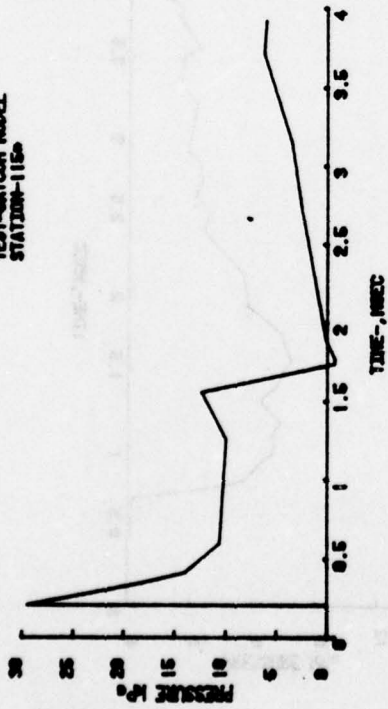
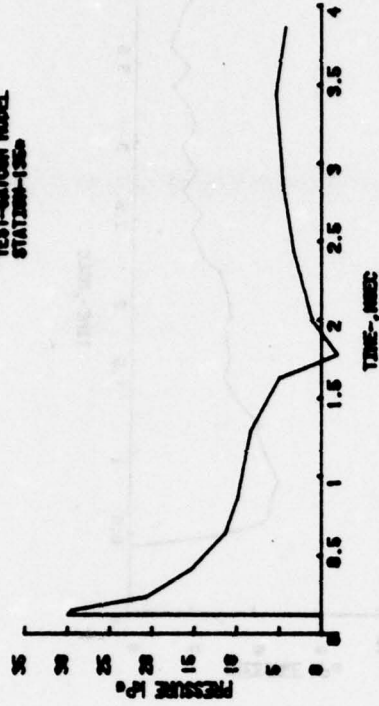


Figure 12h. Rear Surface Pressure Histories: Radial 8

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TEST-GATSON MODEL
STATION-145*



TEST-GATSON MODEL
STATION-125*

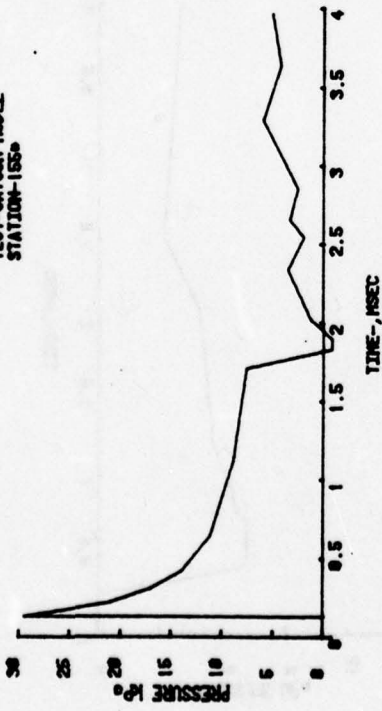


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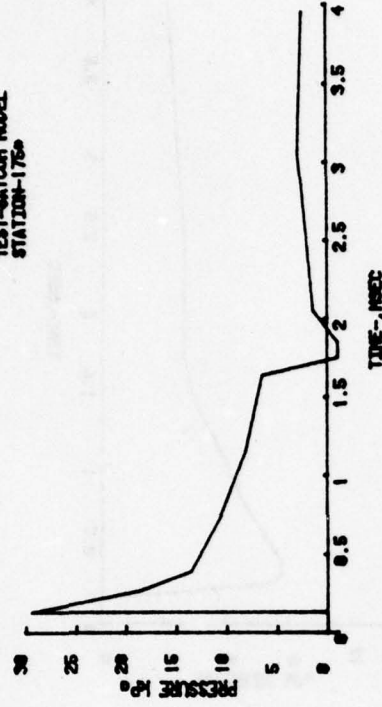


Figure 13. Constructed Pressure Histories, Front Surface Position 5*

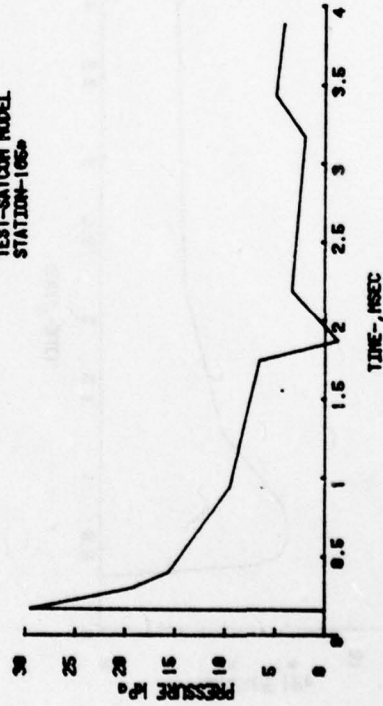
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TEST-GATOON MODEL
STATION-175*



TEST-GATOON MODEL
STATION-165*



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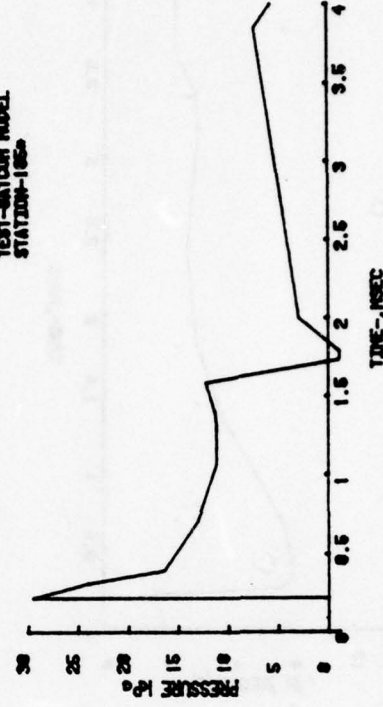


Figure 13 (Continued). Constructed Pressure Histories, Front Surface Position 5*

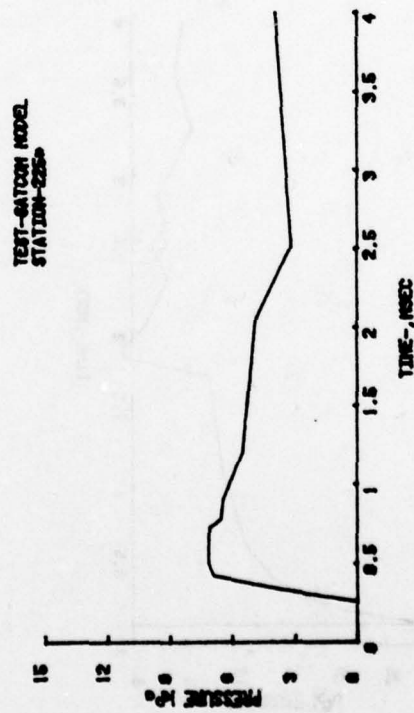
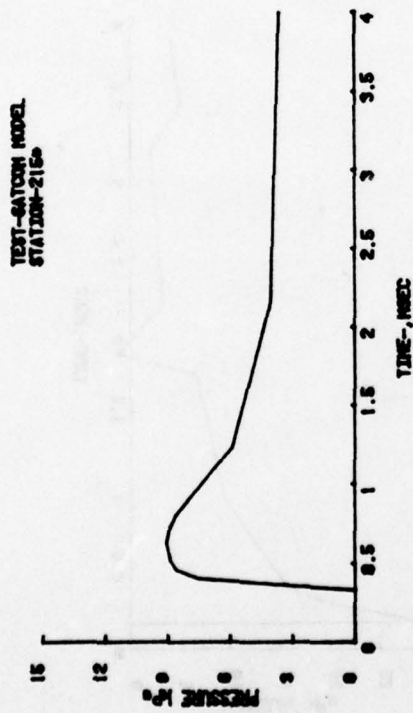
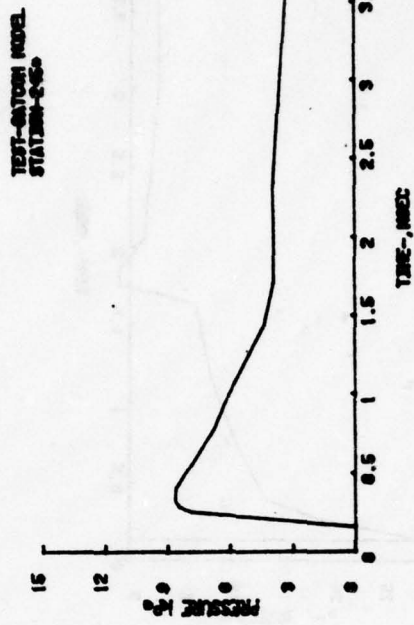
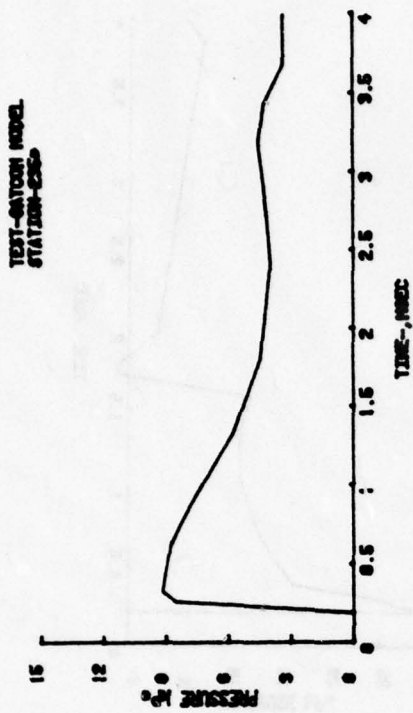


Figure 14. Constructed Pressure Histories, Rear Surface Position 5*

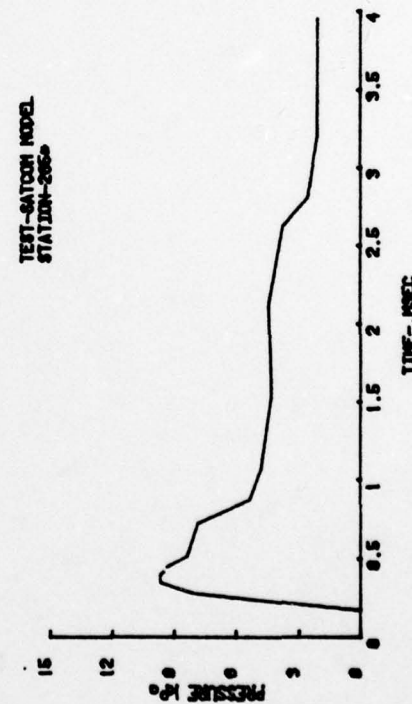
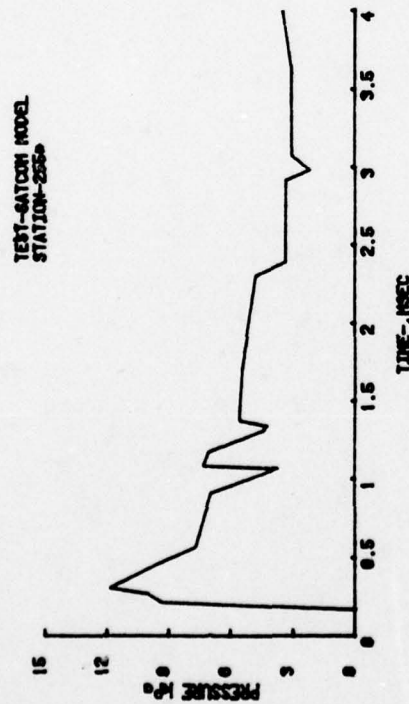
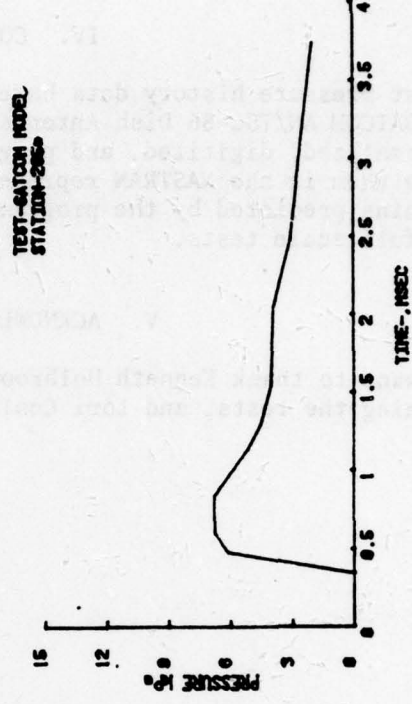
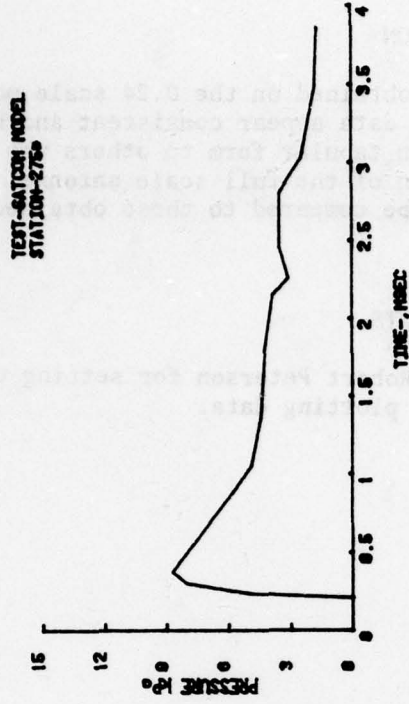


Figure 14 (Continued). Constructed Pressure Histories, Rear Surface Position 5*

IV. CONCLUSION

Blast pressure history data have been obtained on the 0.24 scale model of the SATCOM AN/TSC-86 Dish Antenna. The data appear consistent and have been normalized, digitized, and provided in tabular form to others who will use them in the NASTRAN representation of the full scale antenna. The strains predicted by the program will be compared to those obtained in the full scale tests.

V. ACKNOWLEDGEMENTS

We want to thank Kenneth Holbrook and Robert Peterson for setting up and running the tests, and Lori Conley for plotting data.

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