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FAR-FIELD ACOUSTIC ENVIRONMENTAL PREDICTIONS FOR LAUNCH OF SATURN V AND A SATURN V MLV CONFIGURATION

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ACKNOWLEDGEMENT

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FAR-FIELD ACOUSTIC ENVIRONMENTAL PREDICTIONS FOR LAUNCH OF SATURN V AND A SATURN V MLV CONFIGURATION

SUMMARY

The critical use of far-field acoustic environments for launch pad siting problems, personnel protection, and control of land areas about the launch site is such that more accuracy must be used in the prediction of the far-field acoustic environments than can be provided by the more conservative methods of considering static vehicle conditions. The "Technique for Predicting Far-Field Acoustic Environments due to a Moving Rocket Sound Source" [1], which considers sound source characteristics and the effects caused by the vehicle trajectory, was used to provide the sound pressure levels given in this report.

The nominal engine operational parameters and trajectory parameters were utilized for the computations. Several typical maximum overall sound pressure level time histories (OASPL maximum versus time from launch) for various ground observation points are included which were obtained from the sequence of predicted spectra at various times of occurrence for a given ground position. The time history for a given station gives an indication of the duration of the environment and thus protective criteria can then be utilized to insure adequate safety for personnel and structure exposed to these conditions.

Acoustic environments have also been predicted similarly for a specific configuration of the Modified Launch Vehicle (MLV) for adaptation of the Saturn V. The particular MLV configuration chosen for consideration, on the basis that this vehicle's potential environmental inducement will point out the problems characteristic of those under consideration for advanced use, is a solid propellant strap-on type increasing the total booster stage thrust to 142.3×10^6 N (32×10^6 lbf). The far-field acoustic environments are dependent on the specific design and operational modes of the booster propulsion system. The predictions are not valid for any vehicle system designs of equal thrust but can be considered applicable to a conventionally designed system with the assumptions made as described herein.

The acoustic spectral environments are given in octave band sound pressure level (dB, Ref: 2×10^{-5} N/m^2) versus frequency with the respective overall or composite levels, and represent the mean of the fluctuating levels which are expected.

An isentropic homogeneous atmosphere producing no focusing conditions was adopted for predicting the environments.

DISCUSSION

The octave band sound pressure level spectra and overall sound pressure levels predicted herein may be used for personnel protection requirements, launch related equipment siting, or other pertinent needs. The predicted sound pressure level values are considered as representative of the mean of the normally expected time fluctuating sound pressures under nonfocusing atmospheric conditions. Consideration of this fluctuation can be included to account for the variation of the sound signal about the mean if necessary [1].

Many variables must be considered in predicting the acoustic environment for a far-field point in space, specifically here for the ground plane, during the launch of a large space vehicle. This prediction involves the vehicle trajectory parameters since the source is moving and apparently induces considerable effect on the source characteristics. Other variables used in describing the sound source include the engine parameters and geometrical system describing the receiving point's relative position with respect to the moving sound source.

With these variables known for any specific vehicle and trajectory, the acoustic environment for any particular point in space and time can be calculated assuming nonfocusing, i.e., noncaustic producing, climatic conditions. The predicted sound pressure levels are expected for the given ground positions at the specified times while the vehicle is at an altitude prescribed by the vehicle's trajectory. The times at which these environments will be observed on the ground at a specific location is referenced to launch time and is given with the spectra. Figures 1 and 2 are examples of the overall sound pressure level environments in time history form.

The frequencies observed at the ground stations have been obtained from consideration of the Doppler effect caused by source motion [1] as given by the vehicle's trajectory. Should the trajectory be significantly altered from the presently scheduled one, the spectrum shapes, the levels, and the occurrence times are subject to change.

The engine parameters that were used in predicting the environments are nominal operational values, given by the F-1 engine manufacturer, Rocketdyne, considering five F-1 engines of 6.67×10^6 N (1.5×10^6 lbf) thrust each at sea level. Should the engine parameters which are used now be changed, the spectral energy content and the composite overall sound pressure levels may be influenced.

In regard to acoustic energy propagation several factors should be stated. In addition to divergence, an average excess attenuation caused by molecular absorption was also considered for air-to-ground sound propagation. The absorption values are representative of those observed of the average climatic conditions [1 - 3]. The data from Parkin and Scholes [3] may be consulted concerning the vehicle on the launch pad.

The method used here for prediction has restrictions on how near the launch site the environments can be estimated. These limits are mechanical in the sense that the graphical presentations [1] representing the source characteristics under the given geometrical and dynamic conditions, are given for a limited range of observation angles depending on the source-receiver geometry; i.e., the trajectory and limited number of ground data acquisitions stations from which the original characteristics were obtained did not allow for inclusion of data from all angles about the rocket exhaust sound source. This technique, however, may be used to the extent that the source-receiver geometry permits use of the indicated distribution factor, a modified directivity function, within its given range of values. It must be noted that the technique not only provides maximum environments, but instead, when used as prescribed [1] yields the acoustic environments which are anticipated at a given ground station at a specified time from vehicle liftoff and not necessarily the maximum spectrum and maximum OASPL.

The maximum OASPL and spectra given herein were obtained by computing a progressive sequence of environments at ever-increasing times of occurrence and selecting the maximum overall and associated octave band sound pressure levels resulting from the calculations. For short distance,

i. e., less than 3 km (10,000 ft) from the launch site for this particular vehicle trajectory, the use of this technique will permit calculation of acoustic environments, but they will represent only those for some time of occurrence after the maximum OASPL would have been observed for that particular ground radius. Thus by computing a sequence of environments and observing the resulting OASPL versus time of occurrence it can be determined when the maximum value has been reached. This is permissible since the OASPL time history is a smooth continuous function in this prediction model form as is the physical case in a homogeneous medium with conventional trajectory and vehicle system. Figure 3 indicates the maximum overall sound pressure level versus distance from the launch pad as obtained from the maximum spectra for the respective observation points (Figs. 4 through 14).

For distances of less than 3 km (10,000 ft) from the launch site the maximum environments were computed from a modification of the technique [1] and from conventional methods utilizing the well known relationships between the acoustic efficiency or overall sound power level, the source-receiver geometry and the source directivity. The modification of this technique made use of extrapolation of the distribution function for lower vehicle velocities. This distribution function term, being proportional to the acoustic power radiated by a directional narrow bandwidth source, is a function of the angular orientation about the source. By extrapolation, the maximum value of the distribution function was utilized and applied as initially prescribed [1]; thus, an estimation of the maximum environment was made. Modification of this technique is applicable only if the vehicle velocity is less than the lowest velocity considered in Reference 1, and if the observation points are not in the extreme far-field; i. e., they should not exceed the 3 km (10,000 ft) radius for this particular vehicle and trajectory. The values obtained from this estimation appear reasonably compatible with those obtained from the conventional approach utilizing the acoustic efficiency approach with maximum directivity values.* Also comparison of the OASPL values predicted for the Saturn V with those measured on Saturn I/uprated Saturn I flights [4-17] appear quite compatible in regard to the relative vehicle trajectory differences (Figs. 3 and 15 through 19).

The launch of the Saturn V vehicle from a given pad of tri-Launch Complex 39 (pads A, B, & C) at Kennedy Space Center, Florida, will produce the maximum OASPL's as indicated by the contours in Figure 20 and tabulated in Table I. The constant SPL contours in Figure 20 are the maximum OASPL values anticipated for the Cape area from launch of a Saturn V from the closest launch pad. The OASPL contour lines for consideration of launch from a given

* Directivity Values for Saturn Vehicles, unpublished report by R-AERO-AU, Marshall Space Flight Center.

pad would be concentric about that pad. The maximum OASPL for a given ground station while considering a launch from a pad not the nearest adjacent to the observation point may be obtained by utilizing the spacing of the contour lines for any maximum OASPL value that, as shown in Figure 20, lies on a straight line drawn through the three pads. The adjusted OASPL contours would result in a circular pattern centered on the specific launch pad with the spacing arrangement as indicated.

TABLE I. MAXIMUM ANTICIPATED ACOUSTIC ENVIRONMENTS, FOR CONTROLLED AND UNCONTROLLED AREAS, CAUSED BY SATURN V LAUNCH FROM THE NEAREST ADJACENT LC 39 PAD

Pads & Buildings and Uncontrolled Areas	Camera Pads	WTs and Weather Sub	General Instrumentation	Radius to Nearest Adjacent LC 39 Pad Kilometers (Feet)	Max. OASPL in dB Ref: 2×10^{-5} N/m^2
	UC4			1.35 (4 500)	135.0
	UC7			1.5 (5 000)	134.0
	UC12			1.5 (5 000)	134.0
	UC9			1.8 (6 000)	132.0
Arming Tower				2.1 (7 000)	130.5
Pad 39 D N				2.4 (8 000)	129.5
Pad 39 B				2.46 (8 200)	129.0
Pad 39 C				2.46 (8 200)	129.0
Pad 39 A				2.55 (8 500)	128.0
Pad 39 D W				2.7 (9 000)	128.0
	UC5			3.0 (10,000)	128.0
		500 WT 1		3.0 (10,000)	128.0
	UC16			3.0 (10,000)	128.0
	UC17			3.3 (11,000)	127.0
		54 WT 7		3.3 (11,000)	127.0
			R/S TV & TEL/ELSSE 'C'	3.3 (11,000)	127.0
	UC15			3.3 (11,000)	127.0
Pad 41				3.45 (11,500)	127.0
Pad 42				4.5 (15,000)	125.0
		204 WT 2		4.5 (15,000)	125.0
	UC3			4.8 (16,000)	124.5
			R/S TV & TEL/ELSSE 'E'	5.25 (17,500)	124.0
			VAN MOUNTED COMMAND	5.25 (17,500)	124.0
			HRT 1	5.25 (17,500)	124.0
			R/S TV & TEL/ELSSE 'D'	5.25 (17,500)	124.0
			FCV 2	5.25 (17,500)	124.0
LCC				5.25 (17,500)	124.0
VAB				5.25 (17,500)	124.0
			ODOP TRANSMITTER	5.25 (17,500)	124.0
		54 WT 8		5.4 (18,000)	123.5
		Wea. Sub B		5.4 (18,000)	123.0
Pad 40				5.7 (19,000)	123.0
	UC8			5.7 (19,000)	123.0
			R/S TV & TEL/ELSSE 'B'	6.0 (20,000)	123.0
Static Test				6.3 (21,000)	122.5
		54 WT 1		6.3 (21,000)	122.5
			R/S TV & TEL/ELSSE 'F'	6.3 (21,000)	122.5
		54 WT 10		6.3 (21,000)	122.5
	UC14			6.6 (22,000)	122.5
	UC10			6.75 (22,500)	122.0
	UC18			6.9 (23,000)	120.5
Pad 37 A&B				9.0 (30,000)	119.0
NASA Hdqrs				10.05 (33,500)	117.0
Pad 34				11.15 (34,500)	112.0
Nearest Uncont'd Area				15.0 (50,000)	109.5
Titusville				17.1 (57,000)	108.0
Indian River City				18.45 (61,500)	106.0
Courtenay				19.65 (65,500)	106.0
Mims				20.1 (67,000)	105.5
Titusville-Cocoa Airport				21.0 (70,000)	105.0
Shelom				21.0 (70,000)	105.0

Saturn V MLV configurations are considered in predicting the acoustic environment for a typical configuration 142.3×10^6 N (32×10^6 lbf) thrust [18]. This configuration, the Saturn V with four 396-cm (156-in.) strap-on solid propellant rockets of 26.688×10^6 N (6×10^6 lbf) thrust each, was chosen in order to provide some insight to the acoustic problems that may arise with the launch of a vehicle of this particular thrust category [19]. It should be noted that the acoustic environments produced by such a configuration can vary with design changes in the engine placement geometry, engine cant angles, and other factors of this nature. At present the design of any MLV configuration cannot be taken to mean any more than a suggested system caused by many facets of the final system that must be considered from the reliability, economic feasibility, and program applicability standpoints. Therefore the far-field acoustic environments anticipated for this vehicle can serve only as an approximation because of the lack of definition of a final vehicle design. No single environment can be given that is applicable for any design concerns; thus conventional operation and design assumations are made to predict representative environments. The exhaust flows of the solid propellant strap-on systems are assumed not to coalesce with the Saturn V exhaust flow in a manner to induce significantly increased characteristic flow dimensions which lead to the development of acoustic energy in the frequency range lower than that associated with either of the separate Saturn V or a strap-on unit exhaust flows. Final design of this configuration could force the flow to any degree of coalescense and thus alter the sound source characteristics. Until this design commitment the above assumption will be made. The peak frequency, the frequency of which the acoustic spectra reach a maximum value, would not be expected to shift more than an octave lower for any practical configuration design. The amplitudes would not be expected to increase more than approximately one to two dB's in the far-field for the range of practical vehicle design changes; however, the near and mid-field environments could be much more severely increased.

Figures 21 and 22 represent the anticipated OASPL time history at the indicated radii from Saturn V MLV launch pad and are given for non-focal acoustic propagation conditions as are all environments herein.

Figure 23 represents the maximum anticipated overall sound pressure level for an MLV configuration of 142.3×10^6 N (32×10^6 lbf) thrust [19] versus distance from the launch site. This mode of prediction, as with the Saturn V cases, accounts for air to ground acoustic absorption, given previously [1], Doppler shift effects, geometry variations, and the effective sound source variation with vehicle velocity as given by the trajectory for the MLV configurations [19].

Figures 24 through 30 represent the octave band sound pressure level spectra that have been found to be the representative of the maximum environmental conditions for the given ground radii. The time of occurrence referenced to vehicle liftoff is given with the spectra and overall sound pressure levels. The spectra occurring before and after the maximum environmental conditions are not given since their OASPL values are indicated in the time histories, in Figures 21 and 22, and their characteristic shape is relatively unchanged with the amplitudes varying approximately in proportion to the respective OASPL values. The duration of these spectra environmental conditions are likewise indicated in Figures 21 and 22.

CONCLUSIONS

The maximum OASPL at any ground station, because of a Saturn V launch from the nearest pad of Tri-Complex 39, is as shown in Figures 3 and 20 and tabulated in Table I. Typical durations of the environmental conditions are evident from Figures 1 and 2. The levels given in this report are the anticipated levels without the consideration of acoustic energy focusing conditions. Meteorological studies conducted for the Kennedy Space Center area [20] do not indicate any significant probability of severe focusing caused by the prevalent conditions of the atmosphere. However, the acoustic focusing phenomenon could be observed if such inductive conditions do occur. The maximum increase in OASPL due to focusing can be estimated with some analytical basis* but as yet has not been evaluated for cases after the vehicle has left the ground plane. Further work concerning the focusing problem is being performed and should be included as a parameter in environmental predictions where prevailing meteorological conditions merit the effort.

With the present considerations given to demands for larger payload capabilities of the Saturn V, it is possible that solid propellant strap-on configurations may evolve [18,19,21 - 24]. These configurations, as planned, generate a total solid strap-on system thrust of 142.3×10^6 N (32×10^6 lbf).

Four solid propellant strap-on units — 396-cm (156-in.) diameter elements — of 26.688×10^6 N (6×10^6 lbf) thrust each, making the total booster thrust of approximately 142.3×10^6 N (32×10^6 lbf), have been specifically considered for far-field acoustic environmental prediction. This configuration

*J. H. Jones, "Sound Pressure Estimations From a Point Directional Acoustic Source Radiating in an Inhomogeneous Medium", Aero-Astrodynamics Research Review No. 3, G. C. Marshall Space Flight Center, NASA TMX-53389, October 15, 1965.

produces OASPL values from 7 to 10 dB's higher than anticipated for the conventional Saturn V configuration. Comparison of the spectra for common observation points may be made at the time of maximum environmental conditions and durations may be estimated from the time history values given for both vehicle configurations.

In regard to solid strap-on units, the acoustic power generation characteristics of the solid propellant rocket engines of the thrust category in this report have not been adequately defined as yet. Attempts to obtain the necessary data from the vertical firings of many larger solids, i.e., those with 13.344×10^6 N (3×10^6 lbf) thrust, have not been successful. Other smaller solid propellant rocket test [25 - 29] acoustic data are published with certain usable aspects. No significantly different environmental acoustic conditions, however, have been observed from the existing data that is lacking in certain respects for a complete analysis of the problem.

Mention of explicit exposure critical for personnel or structures has been purposely avoided because of the wide range of criteria given in many reports on this subject. It is difficult, if not impossible, to evaluate these wide extremes in criteria since many variables are involved. Many tests have been conducted on personnel and structures with certain hearing loss or threshold shifts for personnel criteria, and certain damage limits denoted on various structures. Some of these reports are conflicting or reach widely different conclusions concerning personnel exposure criteria, and especially contrasting results are also reached in the structural exposure test reports. Various sources indicate that dwelling structures and components are relatively indestructible; whereas, others note damage at quite meager environmental conditions. The wide spread in results is apparently caused by incomplete records on test conditions, the neglect to standardize or validate test specimens and the damage incurred, or inadequate control or description of the input environmental conditions. Therefore, use of most of the existing criteria based on tests or analytical techniques would require considerable evaluation and study concerning specific application and particular use of that criteria and is therefore beyond the specific purpose of this report.

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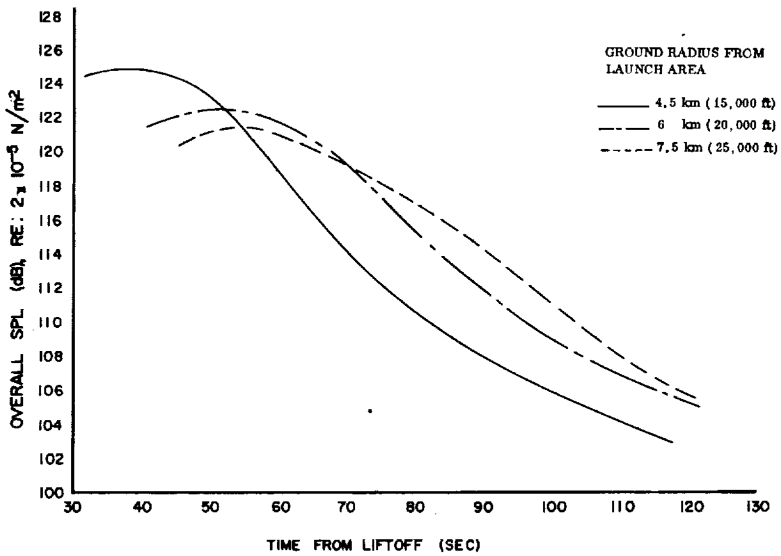

FIGURE 1. PREDICTED MAXIMUM OVERALL SOUND PRESSURE LEVEL TIME HISTORY FOR VARIOUS GROUND STATIONS FOR SATURN V LAUNCH

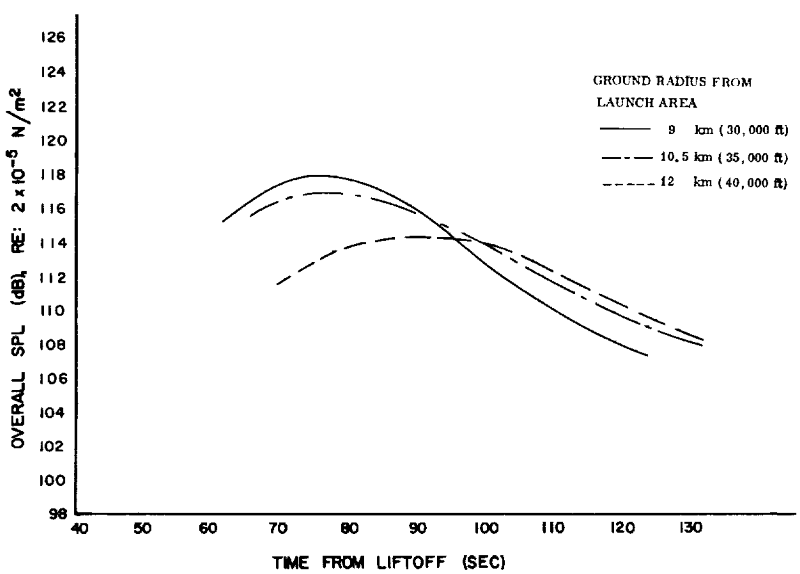

FIGURE 2. PREDICTED MAXIMUM OVERALL SOUND PRESSURE LEVEL TIME HISTORY FOR VARIOUS GROUND STATIONS FOR SATURN V LAUNCH

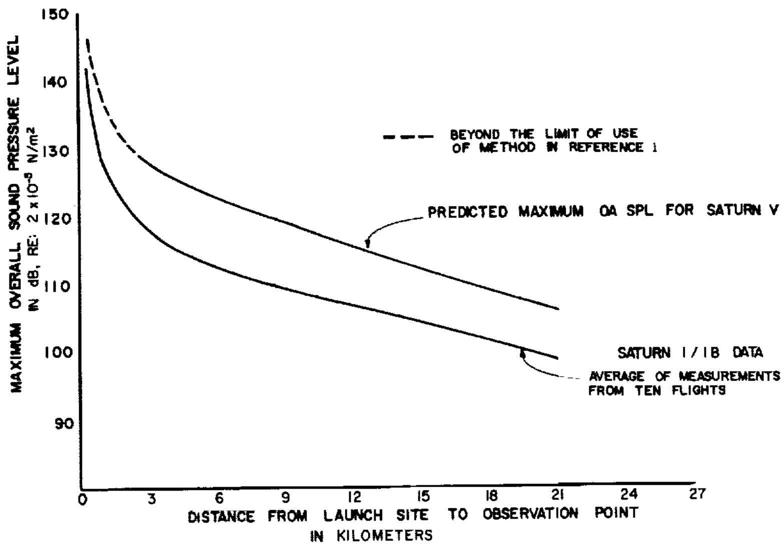

FIGURE 3. MAXIMUM OVERALL SOUND PRESSURE LEVEL, $OASPL_m$,* VERSUS DISTANCE FROM LAUNCH PAD

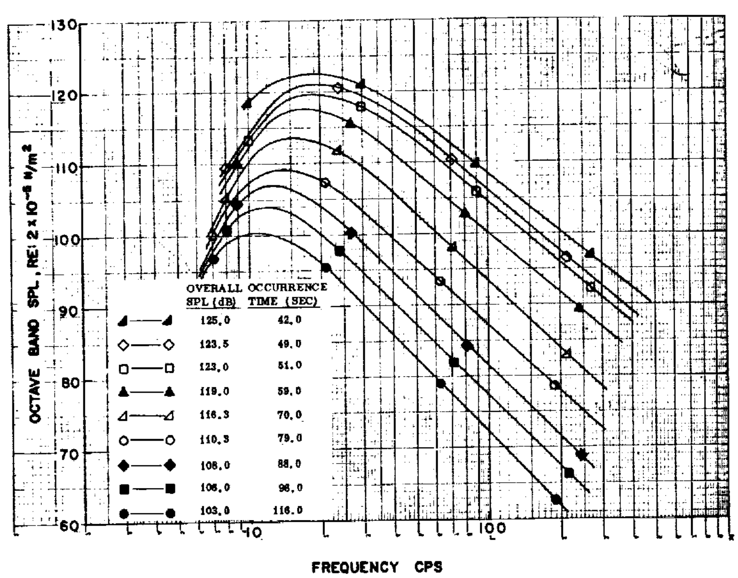

FIGURE 4. OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS 4.5 km FROM A SATURN V LAUNCH

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* For non-focal cases.

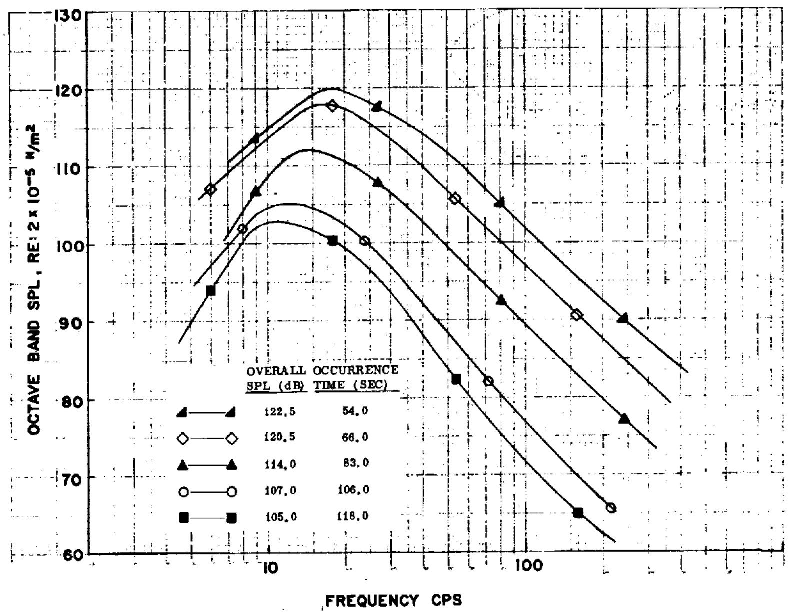

FIGURE 5. OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS OF 6 km FROM A SATURN V LAUNCH

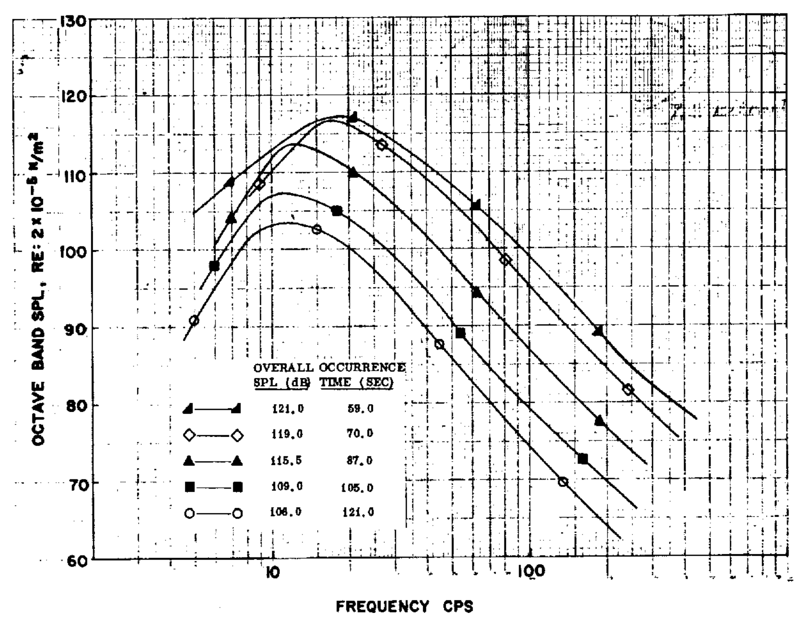

FIGURE 6. OCATVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS OF 7.5 km FROM A SATURN V LAUNCH

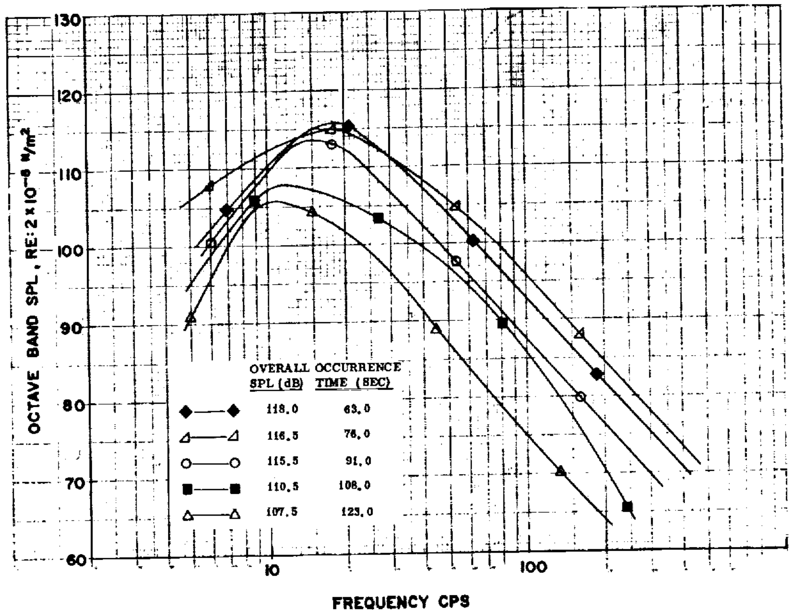

FIGURE 7. OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS OF 9 km FROM A SATURN V LAUNCH

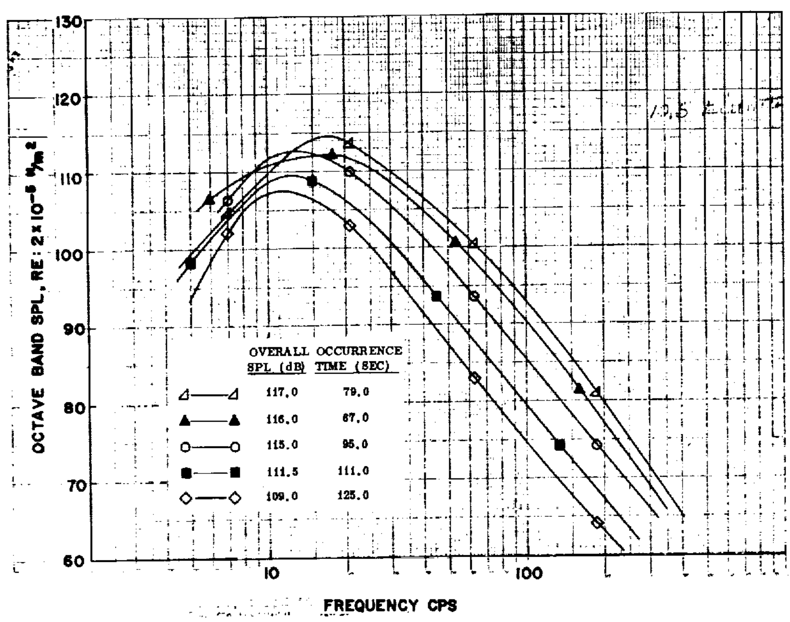

FIGURE 8. OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS OF 10.5 km FROM A SATURN V LAUNCH

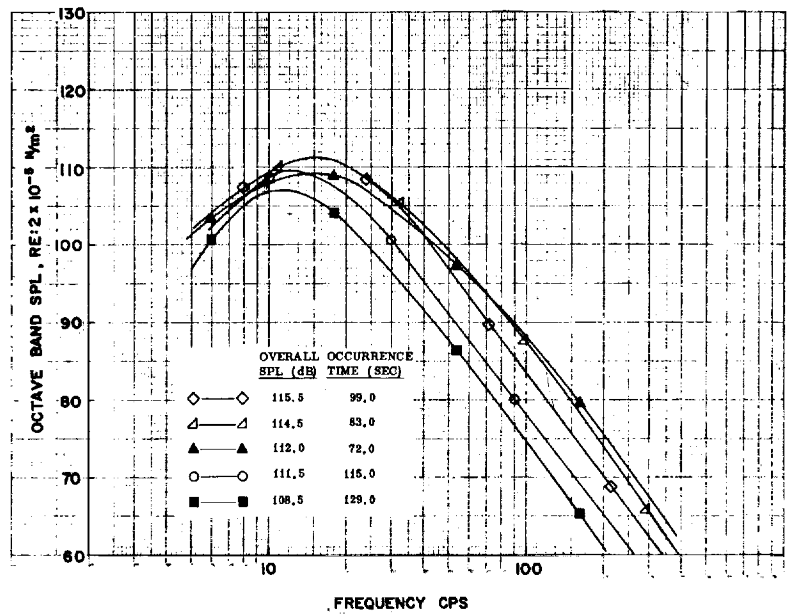

FIGURE 9. OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS OF 12 km FROM A SATURN V LAUNCH

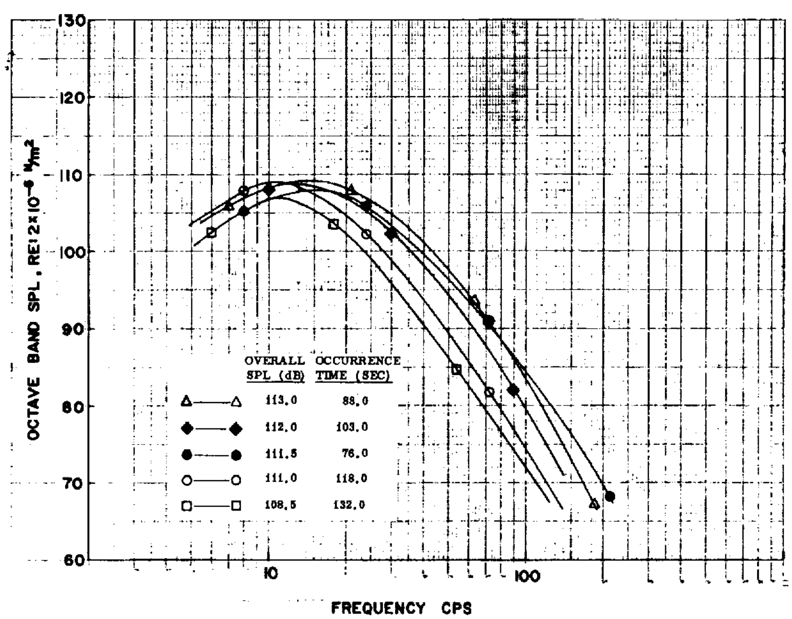

FIGURE 10. OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS OF 13.5 km FROM A SATURN V LAUNCH

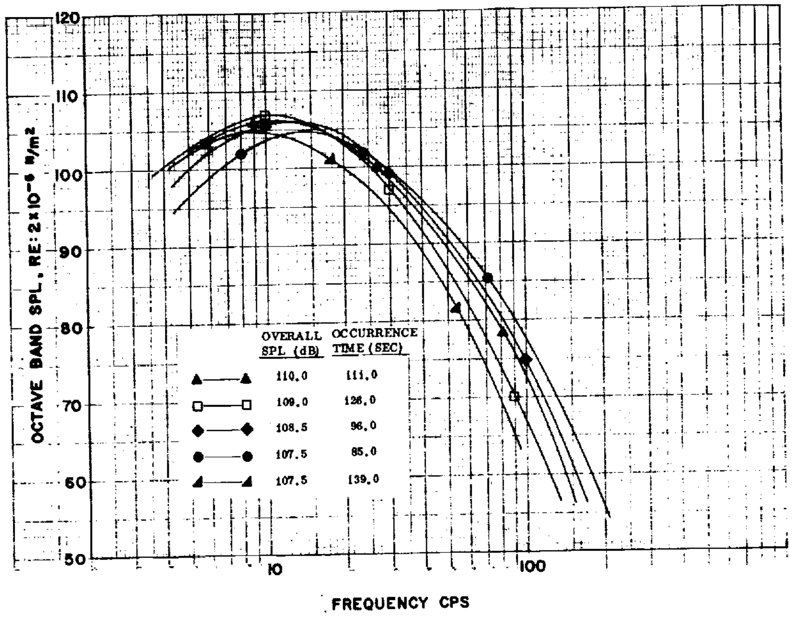

FIGURE 11. OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS OF 16.5 km FROM A SATURN V LAUNCH

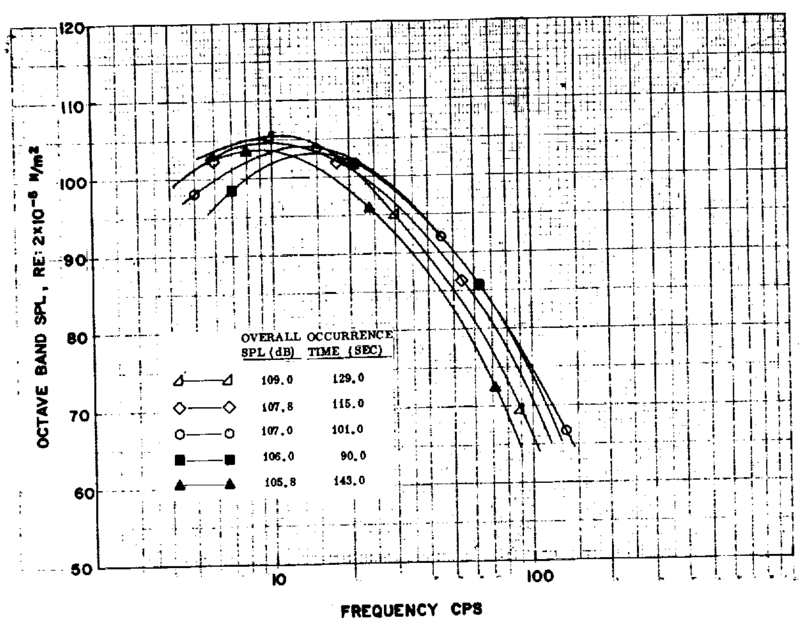

FIGURE 12. OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS OF 18 km FROM A SATURN V LAUNCH

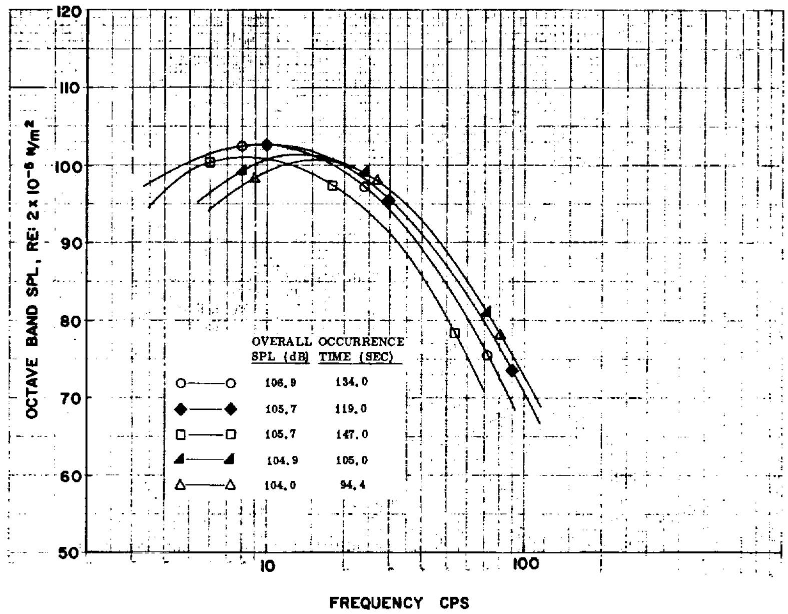

FIGURE 13. OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS OF 19.5 km FROM A SATURN V LAUNCH

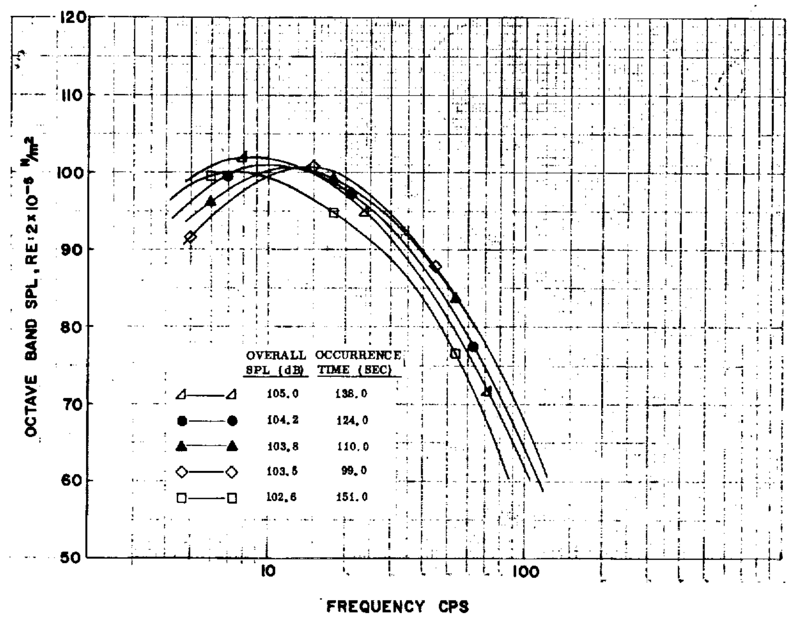

FIGURE 14. OCTAVE BAND SOUND PRESSURE LEVEL SPECTRA FOR A GROUND RADIUS OF 21 km FROM A SATURN V LAUNCH

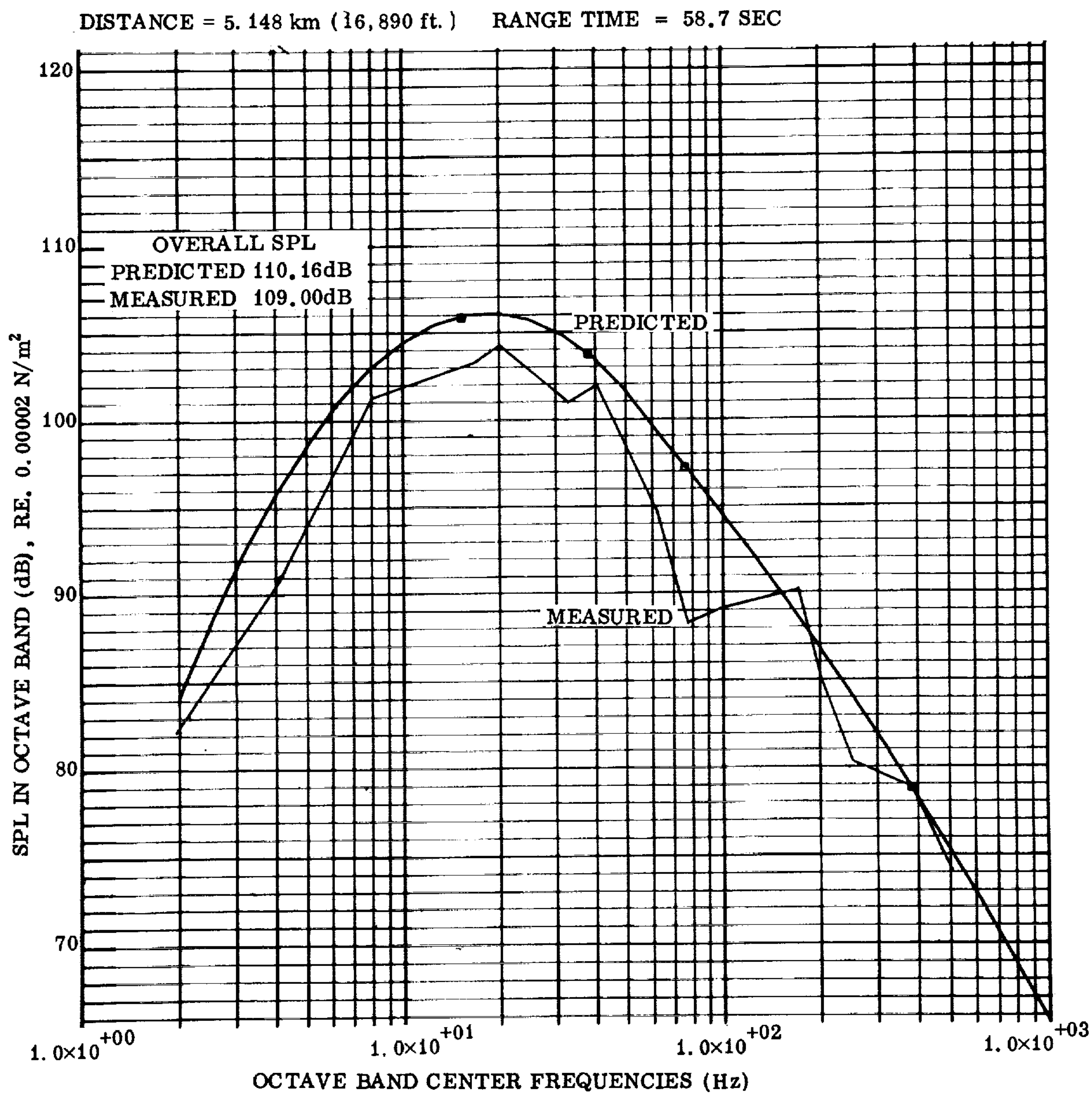

FIGURE 15. MEASURED ACOUSTIC DATA FROM SA-5 FLIGHT (SATURN I VEHICLE) WITH PREDICTED ENVIRONMENTS AT 5.148 km

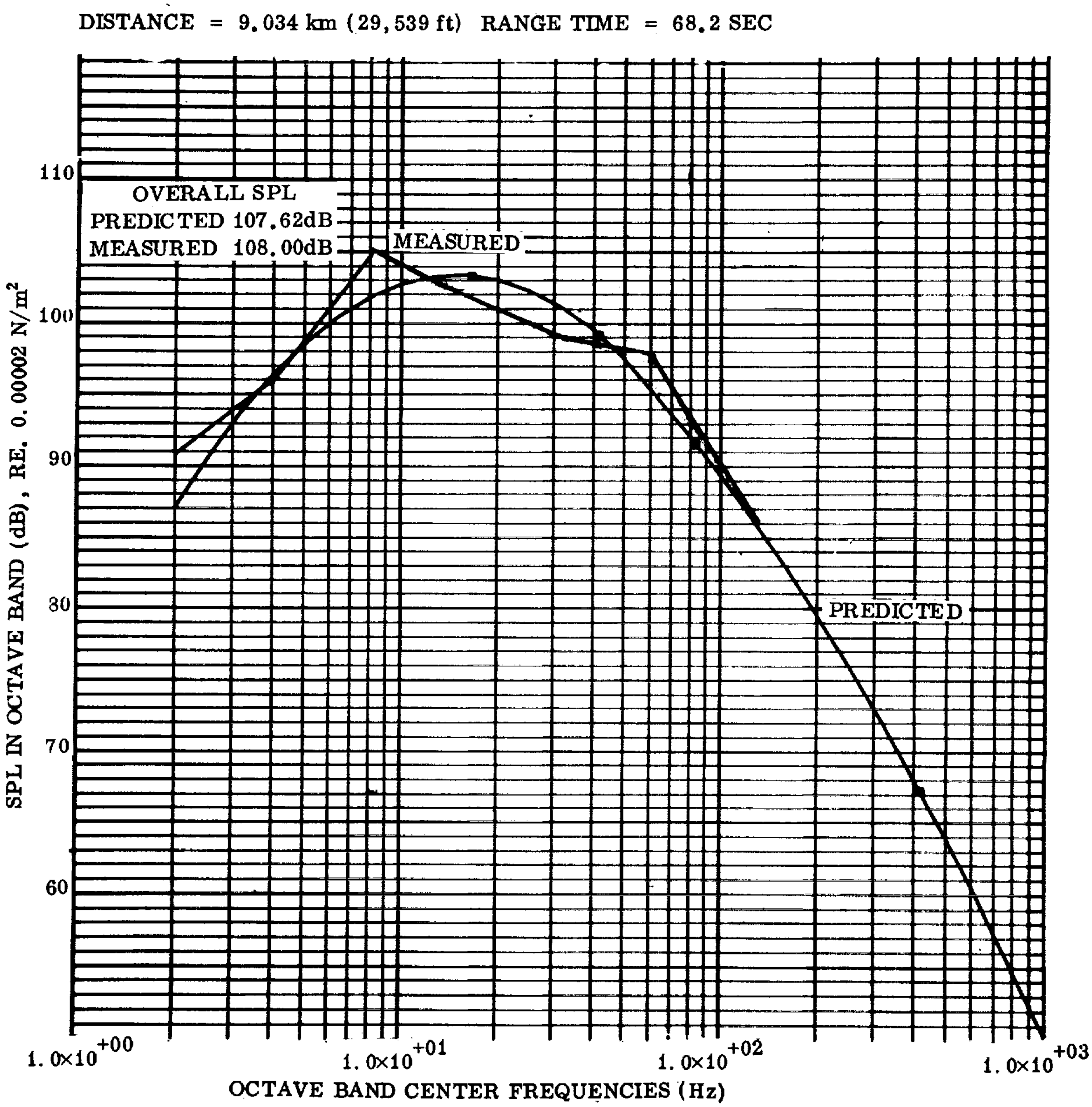

FIGURE 16. MEASURED ACOUSTIC DATA FROM SA-5 FLIGHT (SATURN I VEHICLE) WITH PREDICTED ENVIRONMENTS AT 9.034 km

DISTANCE = 13.637 km (44,741 ft) RANGE TIME = 81.4 SEC

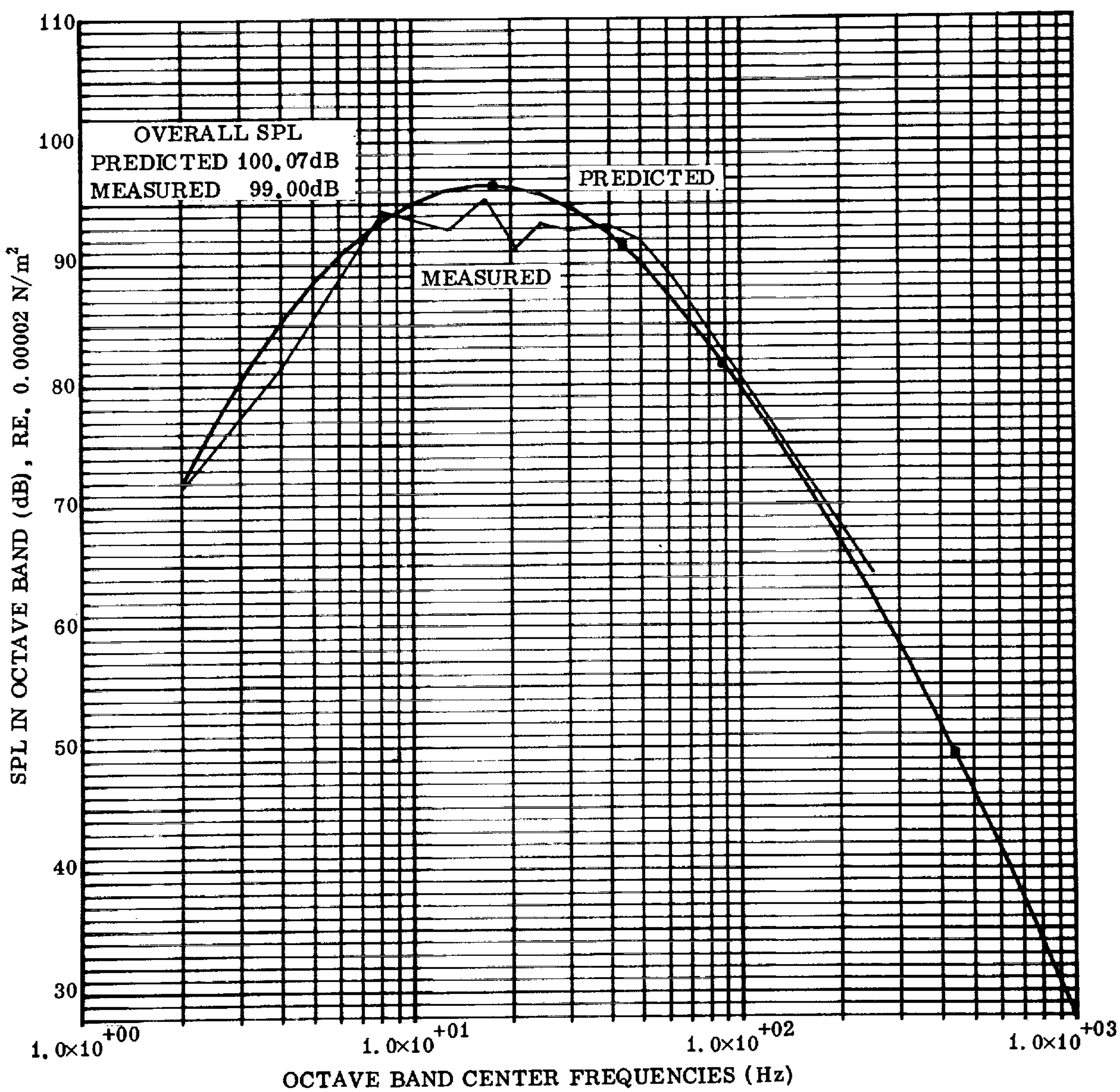

FIGURE 17. MEASURED ACOUSTIC DATA FROM SA-5 FLIGHT (SATURN I VEHICLE) WITH PREDICTED ENVIRONMENTS AT 13.637 km

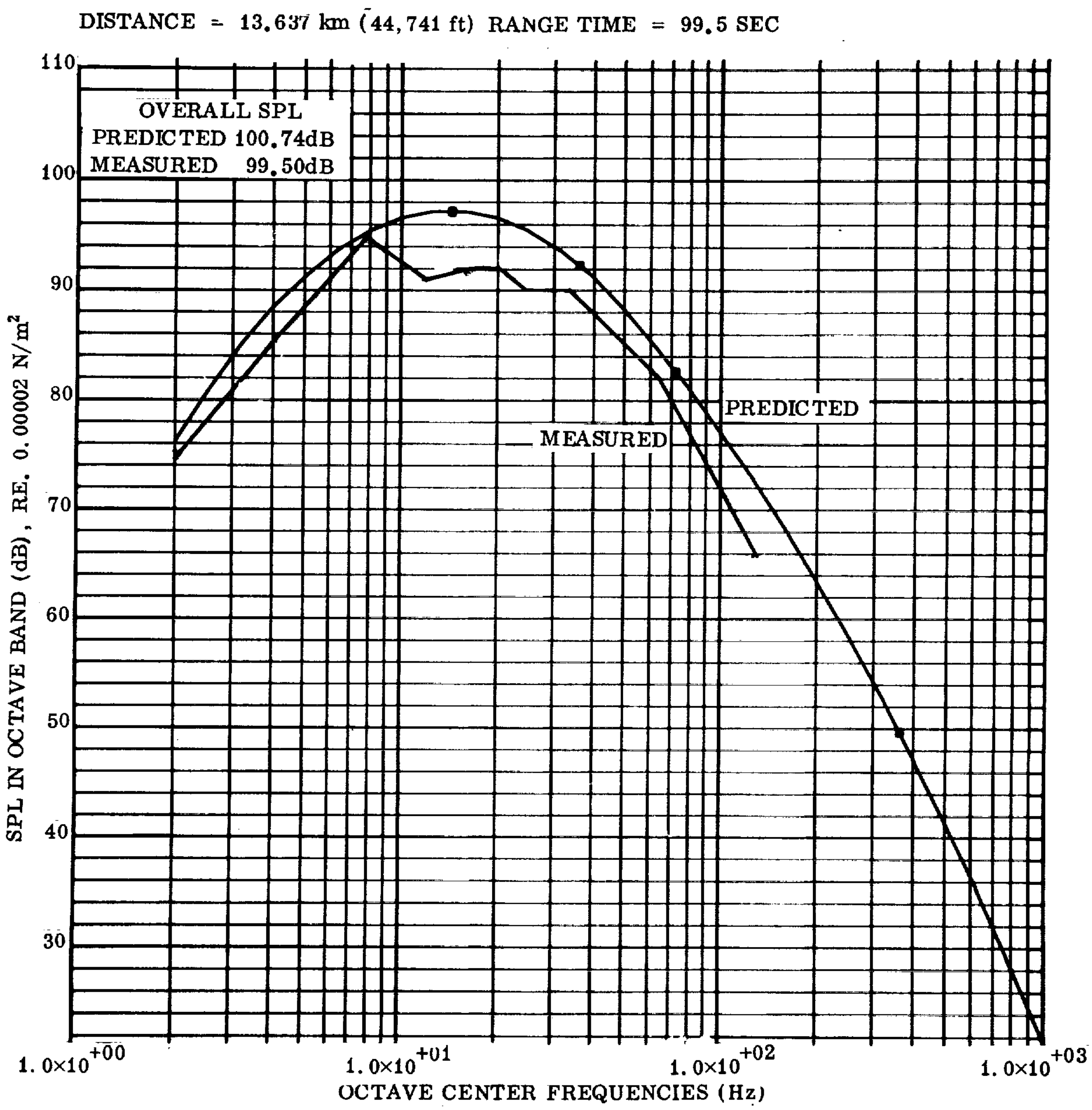

FIGURE 18. MEASURED ACOUSTIC DATA FROM SA-5 FLIGHT (SATURN I VEHICLE) WITH PREDICTED ENVIRONMENTS AT 13.637 km

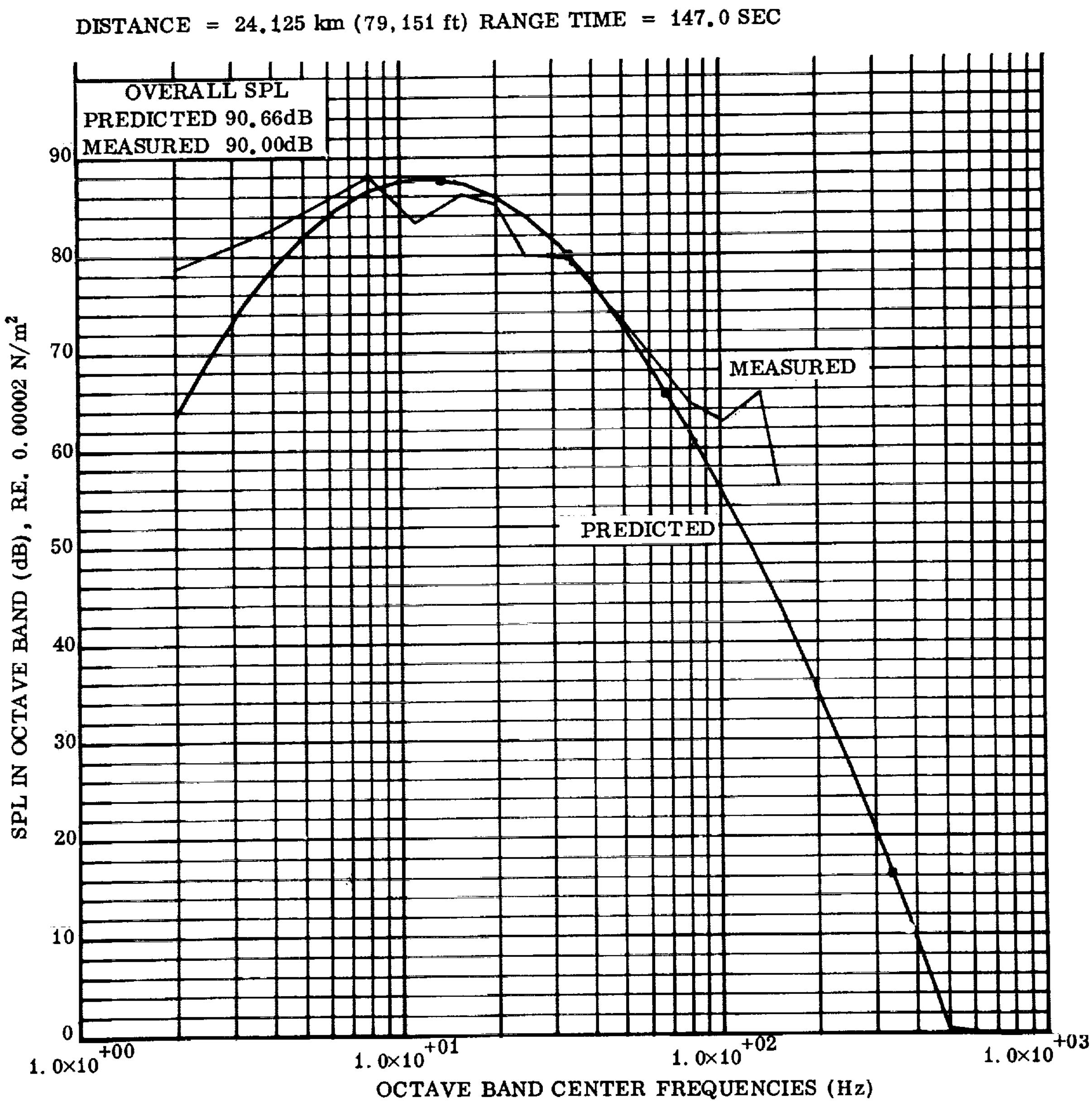

FIGURE 19. MEASURED ACOUSTIC DATA FROM SA-5 FLIGHT (SATURN I VEHICLE) WITH PREDICTED ENVIRONMENTS AT 24.125 km

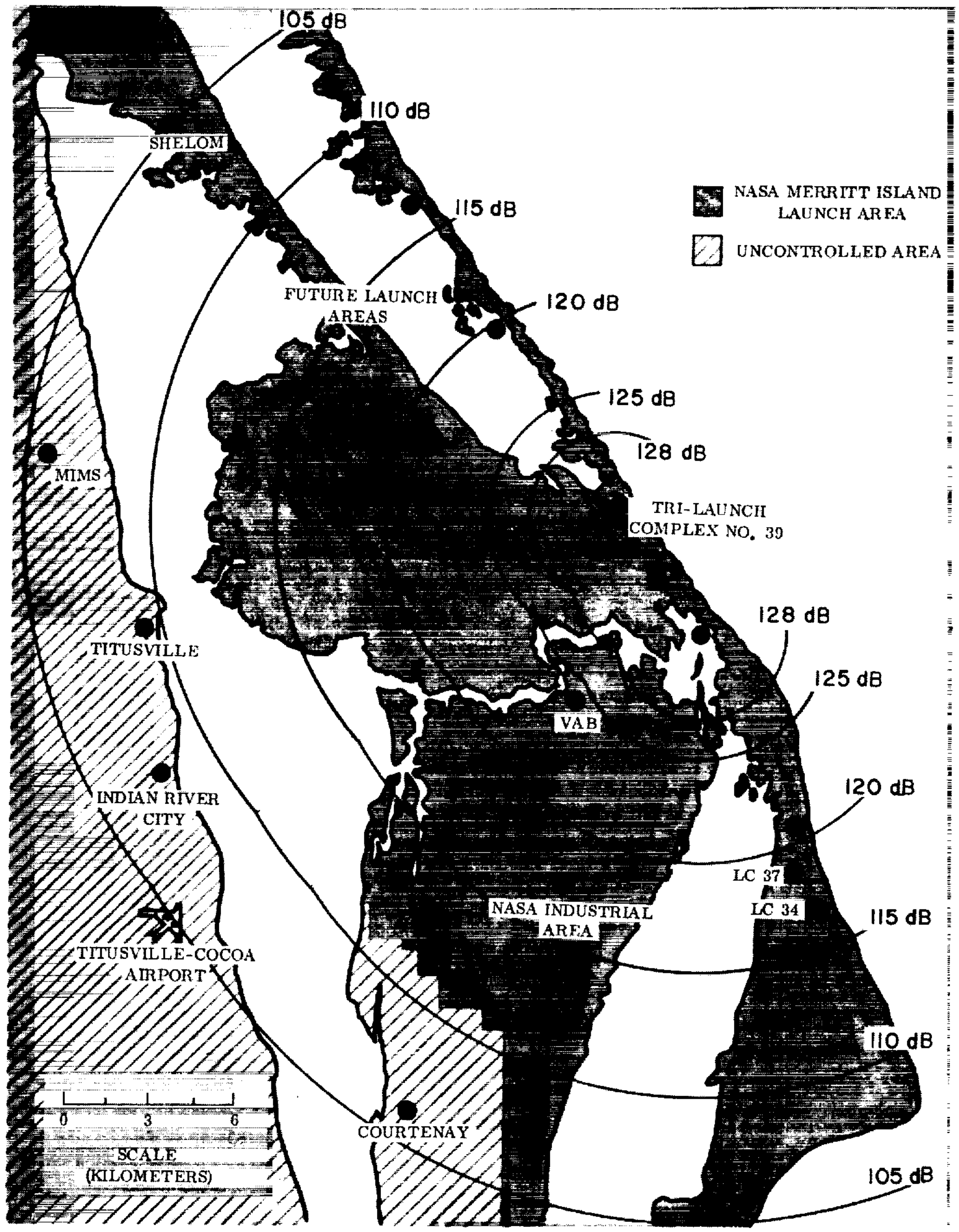

FIGURE 20. THE PREDICTED MAXIMUM SOUND PRESSURE LEVELS FOR THE MERRITT ISLAND LAUNCH AREA FOR A SATURN V LAUNCH FROM TRI-COMPLEX 39

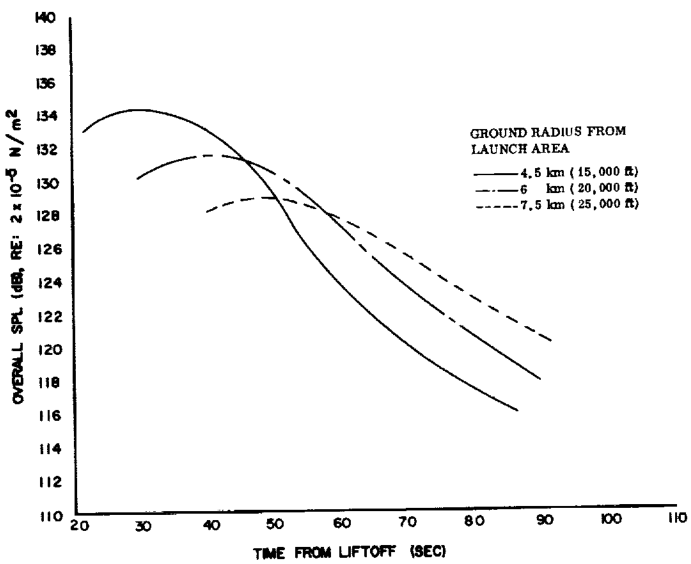

FIGURE 21. PREDICTED MAXIMUM OVERALL SOUND PRESSURE LEVEL TIME HISTORY FOR VARIOUS GROUND STATIONS FOR THE SATURN V MLV LAUNCH, 142.3×10^6 N THRUST

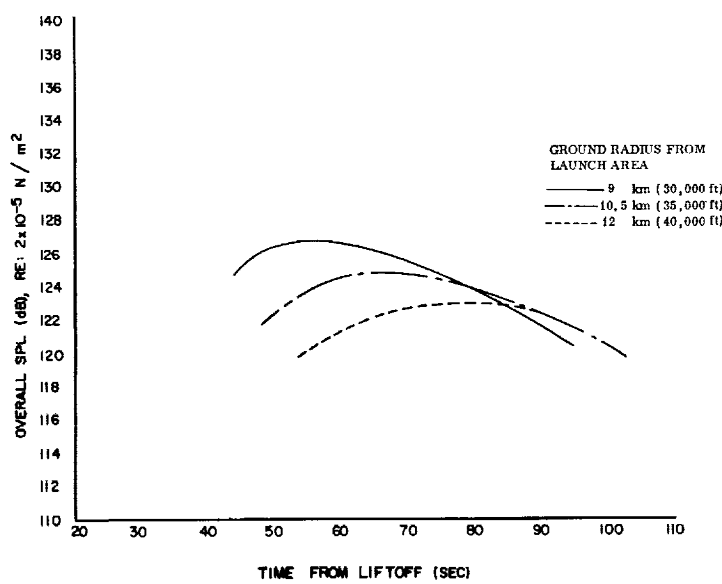

FIGURE 22. PREDICTED MAXIMUM OVERALL SOUND PRESSURE LEVEL TIME HISTORY FOR VARIOUS GROUND STATIONS FOR THE SATURN V MLV LAUNCH, 142.3×10^6 N THRUST

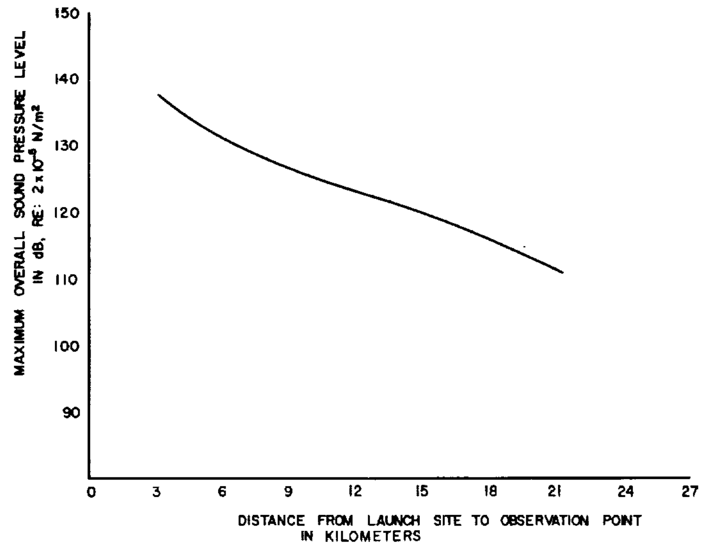

FIGURE 23. MAXIMUM ANTICIPATED OVERALL SOUND PRESSURE LEVEL, $OASPL_m$, FOR A SATURN V MLV CONFIGURATION OF 142.3×10^6 N THRUST FOR THE MLV-SAT V-25 s VERSUS DISTANCE FROM LAUNCH PAD

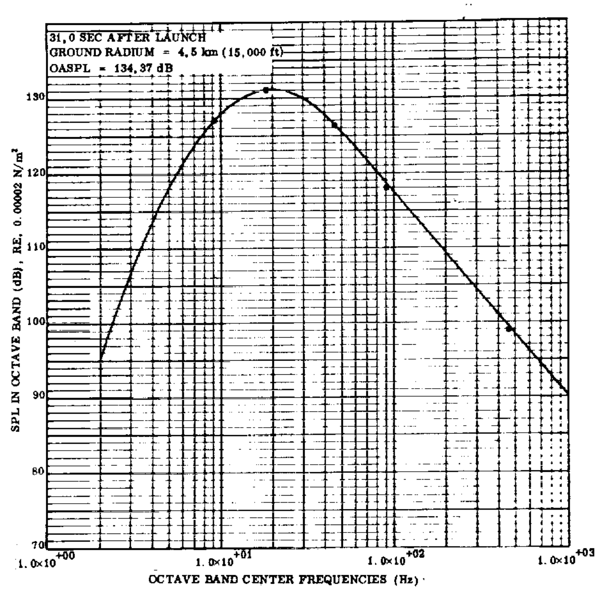

FIGURE 24. PREDICTED OCTAVE BAND SOUND PRESSURE LEVEL SPECTRUM AT 4.5 km (15,000 ft) FROM SATURN V MLV LAUNCH 142.3×10^6 N THRUST

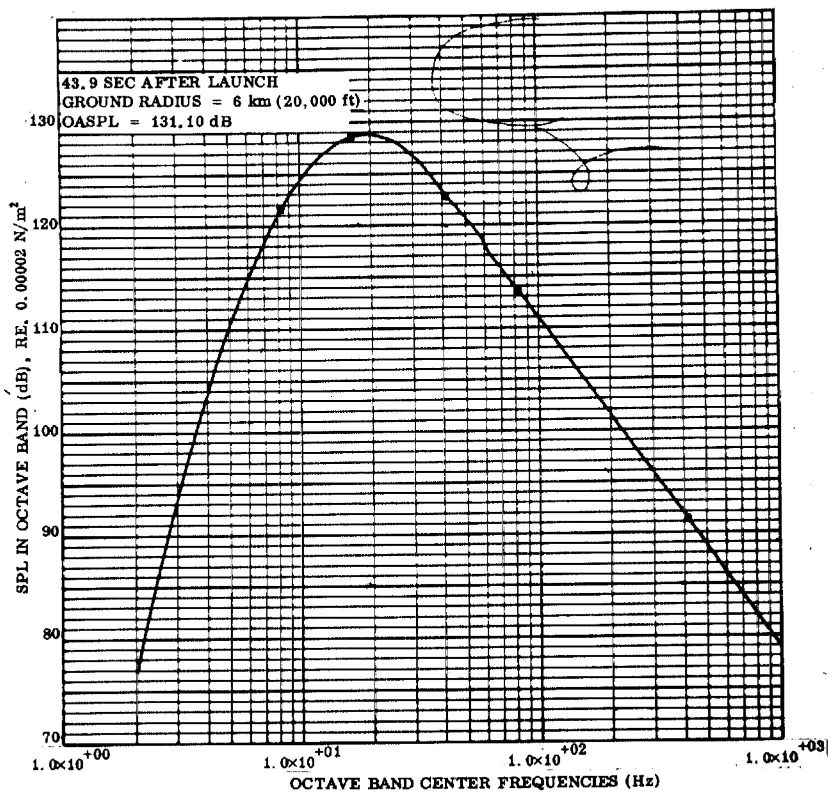

FIGURE 25. PREDICTED OCTAVE BAND SOUND PRESSURE LEVEL SPECTRUM AT 6 km (20,000 ft) FROM SATURN V MLV LAUNCH 142.3×10^6 N THRUST

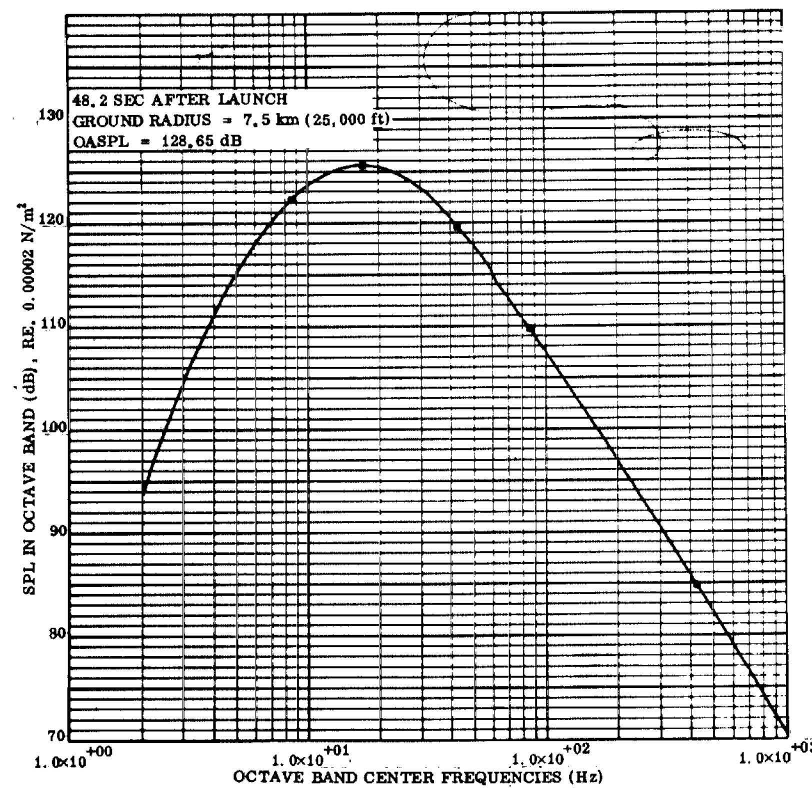

FIGURE 26. PREDICTED OCTAVE BAND SOUND PRESSURE LEVEL SPECTRUM AT 7.5 km (25,000 ft) FROM SATURN V MLV LAUNCH 142.3×10^6 N THRUST

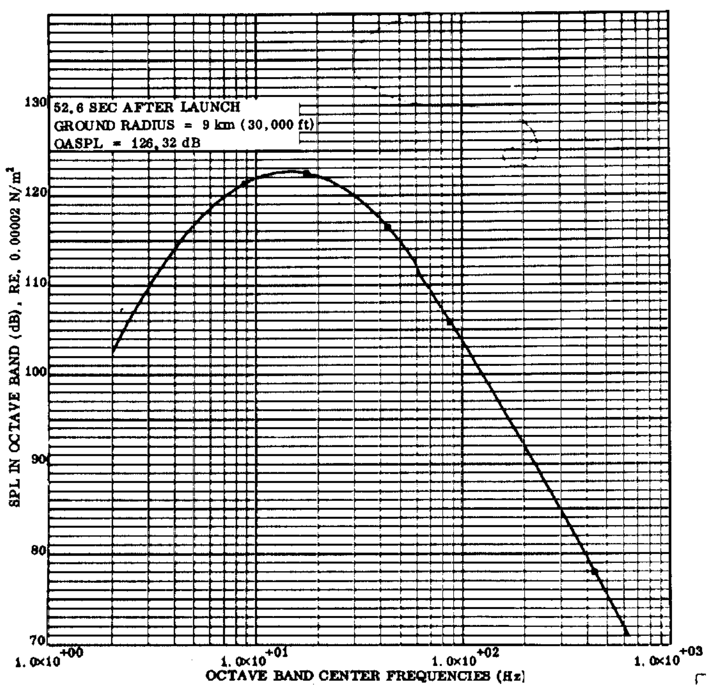

FIGURE 27. PREDICTED OCTAVE BAND SOUND PRESSURE LEVEL SPECTRUM AT 9 km (30,000 ft) FROM SATURN V MLV LAUNCH 142.3×10^6 N THRUST

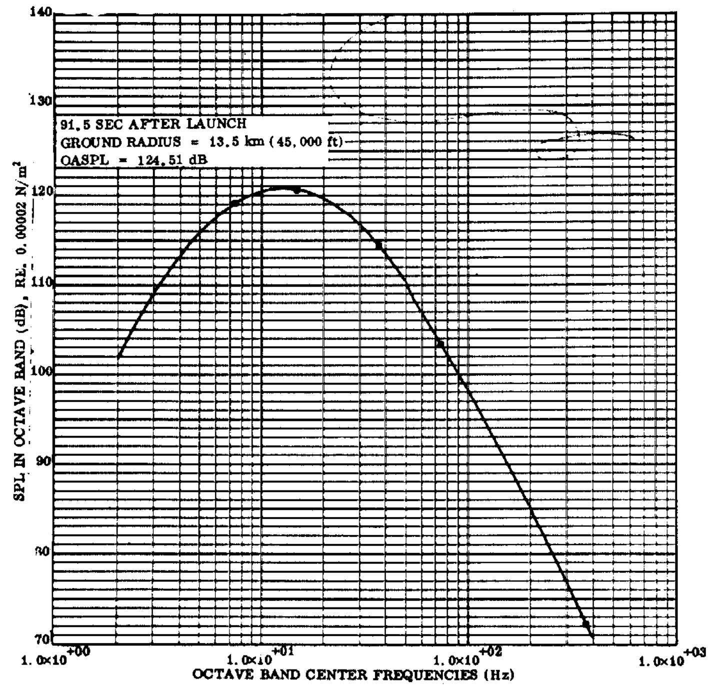

FIGURE 28. PREDICTED OCTAVE BAND SOUND PRESSURE LEVEL SPECTRUM AT 10.5 km (35,000 ft) FROM SATURN V MLV LAUNCH 142.3×10^6 N THRUST

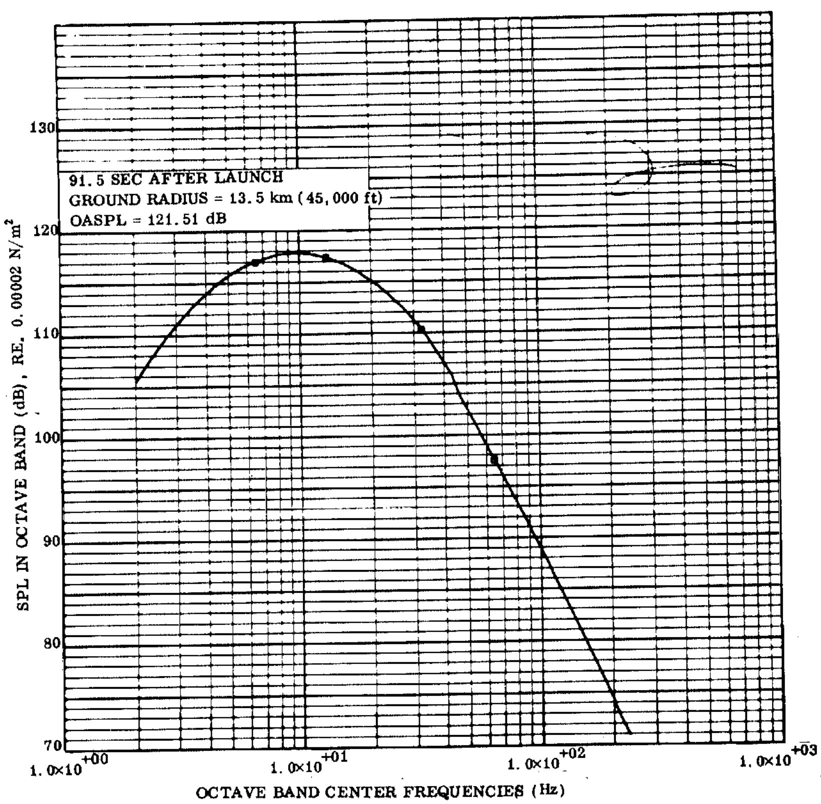

FIGURE 29. PREDICTED OCTAVE BAND SOUND PRESSURE LEVEL SPECTRUM AT 13.5 km (45,000 ft) FROM SATURN V MLV LAUNCH 142.3 $\times 10^6$ N THRUST

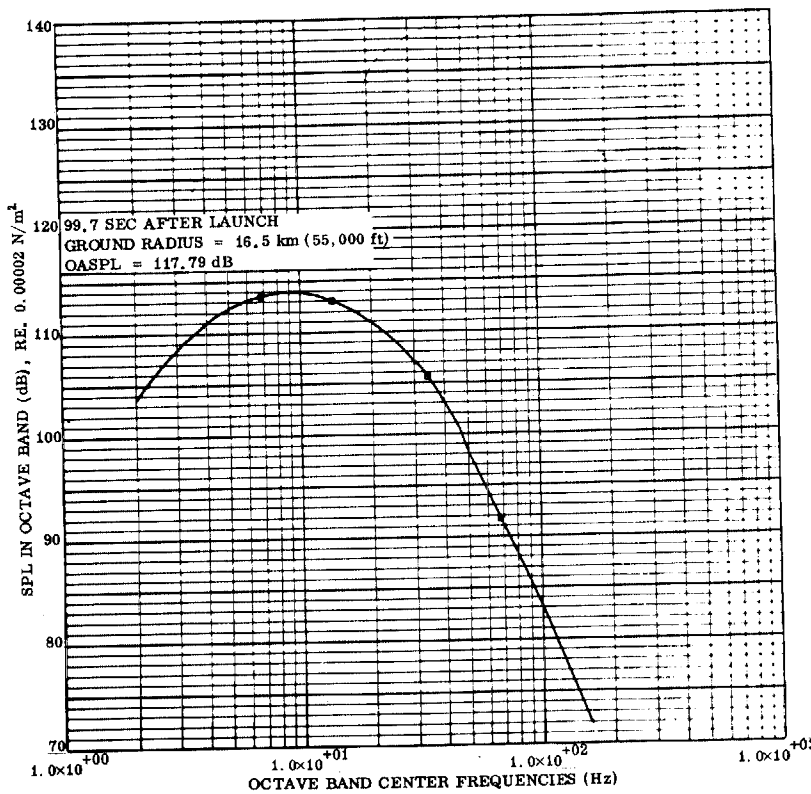

FIGURE 30. PREDICTED OCTAVE BAND SOUND PRESSURE LEVEL SPECTRUM AT 16.5 km (55,000 ft) FROM SATURN V MLV LAUNCH 142.3 $\times 10^6$ N THRUST

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