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Atmospheric Acoustics As A Factor In Saturn Static Testing

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Introduction

One facet of the static test firing of large space vehicles has been the generation of large amounts of acoustic energy. The rapid increase in the size of these boosters during the last few years and the resultant increase in the noise levels generated during their static testing has made the prediction and control of sound generation an important phase of rocketry. This has been expecially true since the advent of the Saturn family of space vehicles because it was found that not only was the Saturn S-I the world's largest and most powerful tool for extra-terrestial investigation but it was also the largest and most powerful man-made, steady-state noise generator. Results from field surveys of the noise have shown that the acoustic power radiated has amounted to about one-half of one percent of the total mechanical power of the engines. In the case of the Saturn S-I, this means about 40 million watts. Occasionally, during the testing of the S-I vehicle at Marshall Space Flight Center, this noise has been propagated across the Redstone Arsenal area and into the surrounding civilian communities. Because of the meteorological factors at the time of firing this acoustical energy has sometimes been concentrated into relatively small zones in business or residential areas. Such occurences have heightened the interest in determining what may be the acoustic consequences of static firing even larger rocket vehicles, whether they are to be fired at MSFC or elsewhere.

Background

Most sources of sound are vibrating bodies which cause disturbances in the air. Other sources, such as the Saturn booster, generate sound by inserting rapidly moving hot gases into the atmosphere. Such sounds have become relatively familiar to most Americans with the advent of both military and commerical turbojet aircraft. Rocket noise is not too unlike that from a turbojet, except that it is usually lower pitched than the jets' distinctive whine.

The noise environments which can be expected from the test firing of large rockets have now become important considerations in planning test sites and the surrounding supporting communities. One can consider the problem to consist of three distinct parts, each of which must be solved to achieve a complete solution.

The first of these is the noise source itself. The Saturn generates a tremendous volume of exhaust gases which moving through a relatively still atmosphere cause large amounts of low frequency sound to be generated. Part of the answer to reducing noise levels may lie in muffling the noise produced at the test stand, thus helping to lower the amount of energy originally radiated into the atmosphere. Research into methods for achieving this has been pursued at MSFC with good results. However, as larger and larger boosters are developed the cost of adding such muffling devices to the test facilities will rise accordingly.

The second aspect of the noise situation concerns the ability of the sound to reach the civilian communities which always spring up around any major missile site. Since this energy peaks below one hundred cycles per second, its attenuation due to molecular losses is quite low. Therefore, it can be seen that both the high power and the low attenuation associated with large space vehicle testing contribute to the problem. The most obvious solution to this is simply to purchase all of the land around the missile base for about twenty miles. Unfortunately, this is not often feasible since most of the bases were begun a few years ago when missiles and missile sounds were not nearly so large. As a result, small cities were built up within a few miles of most launch and static test facilities.

Another solution to this matter of the transmission of missile sounds concerns the role of weather in the transmission of acoustic energy. Under any condition in which there is a change in the value of the velocity of sound with altitude, refraction (bending) of the sound path will result. The sound can, and in fact quite often does, bend away from the earth's surface to harmlessly dissipate in the upper atmosphere. It is possible to greatly lower the sound level at a point several miles distant from the source simply by choosing the meteorological conditions under which the test is to be performed. Similarly, the sound pressure levels can be raised materially by good propagation conditions at the time of the test. It is in this particular field where the best results can be anticipated for noise control. Typical acoustic profile types and their corresponding multiplication factors are presented in Table I.

Prior to the start of the static testing of large rockets, this refractive focusing was of interest only in rare instances because of the limited signal strengths which it was possible to sustain over appreciable periods. Now, however, with vehicles such as the Saturn S-I it is possible to generate 40 megawatts for several minutes. At Marshall Space Flight Center, the problems of acoustical focusing have been of special interest because of the proximity of the city of Huntsville, Alabama. This city, which is on the north and east boundaries of Redstone Arsenal, is about 5 to 12 miles downwind from the S-I static test tower.

During the winter months, the westerly-southwesterly prevailing wind pattern intensifies and is quite often accompanied by a strong surface temperature inversion. This causes meteorological focusing along the azimuths toward the city. The focal areas do not necessarily occur within the city; they sometimes fall in sparsely-settled mountain areas beyond Huntsville. However, examination of the past meteorological data (Refs. 1 & 2) shows

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that such focusing conditions occur during about 50 percent of the day during certain winter months. (See Table II) These conditions seldom last for more than a few hours at a time but they need to be taken into consideration during the preparation sequence prior to a static test.

The third and last factor of the noise problem lies with the "receiver", or the individual who will be exposed to the noise and to its effects. A large part of the question can be resolved by an examination of the attitude that people on the receiving end of the propagation path have toward the noise. For instance, while the sound from a missile test may be no louder than that created when the man next door uses his power lawn mower, still if the test is held at 2 a.m., it may be expected that the reaction will be unfavorable. A good program of education helps to forewarn and acquaint people with sound and its affects, and a little care and consideration in the choice of test times helps to maintain a positive attitude amongst the populace.

The rocket vehicle, both guided and unguided, has since its inception been primarily a military weapon. With the impetus of wartime development, there usually was little concern with civilian discomfort. Also, since early rockets were relatively small, so were the sounds. The amount of unused "buffer" land ordinarily utilized around military installations to maintain reasonable military security proved in most instances to be quite satisfactory to attenuate the sound from missile tests. However, the development in recent years of larger rockets such as the Jupiter, Atlas and Titan has ensured that occasionally some nearby residents would be jolted out of their sleep. Nonetheless, the importance of the programs to the national defense precluded any major shifts in either tests, sites or test schedules just because of the noise.

With the creation of the National Aeronautics and Space Administration, a large civilian rocket program was undertaken for the first time, which, because of its very nature, must remain sensitive to community reaction. Assigning the responsibility for large booster development to Marshall Space Flight Center focused the noise problem from these vehicles on the community supporting this installation.

The noise from the static tests has on occasion not only been heard, but felt, in Huntsville. It was found that this has been due primarily to the weather conditions under which these tests have been performed. When strong temperature inversions have been reinforced by winds toward the city, the sound is actually focused meteorologically much in the same manner as sunlight is focused by a magnifying glass. This can result in sound pressures in both the business and residential areas of Huntsville of about one hundred times the normal (i.e., the sound pressure levels will be increased by 40 decibels). However, exactly opposite conditions have also existed and at those times not even a whisper of the Saturn was heard.

It has also been learned from experience that townspeople are not nearly so alarmed or jolted when they have been forewarned. Therefore it has become standard procedure to announce via the local newspaper, radio and television stations when a test will be held.

Generally, it may be said that the larger the space vehicle which is being tested, the larger is the amount of sound which is radiated into the atmosphere. However, there are two additional factors which greatly affect the response which may be anticipated from the surrounding communities. One of these is the frequency content of the sound from the engine test. It has been shown (Ref. 3) that as the thrust of the rocket engine goes up, the peak frequency goes down. This affects the sound level at long ranges because the lower frequencies (below one hundred cycles per second) do not attenuate as rapidly; thus a larger percentage of the original sonic energy is left to disturb outlying areas. Also, as the peak drops in frequency, additional energy is put into the sub-audible range. Since it is these lower frequencies which rattle windows and shake buildings, the "alarm level" is expected to rise with larger boosters.

Another factor affecting the amount of acoustic energy which reaches the surrounding areas is what is known as the "directivity" of the source. This is simply an index of the relative amounts of energy which are directed by the source itself in each direction. Contributing to this are not only the rocket engine and exhaust velocity parameters but also the shape and configuration of the flame deflector and test tower. After the sound has been radiated into the atmosphere, several things can happen:

1. The sound can be propagated normally as in a still room or large stadium where the effects of wind and temperature are negligible (as on a very still and quiet morning).
2. It can be directed into the upper atmosphere to be dissipated.
3. It can be directed towards one or more locations on the earth's surface.

To avoid the acoustic problems inherent in the static testing of large space vehicles a program of "selective firings" has been instituted at MSFC. Methods for forecasting and evaluating the undersirable firing conditions and for locating the areas which may be adversely affected by returning sound have been developed. These have been based upon acoustic and atmospheric soundings for the 36-hour period immediately preceding such a test. This program not only protects the surrounding communities but also allows maximum scheduling flexibility to the test engineer. This paper details both the theoretical basis and operational procedures which have been developed and follows the process for illustrative purposes through a particular Saturn static test. It is hoped that this report will present to those faced with a similar problem a complete description of the selective firing program.

Description of the Problem

The Saturn S-I with its 40 megawatts of power represents one of the largest steady-state, low-frequency noise sources in the world today. This energy is radiated into an atmospheric hemisphere with a very broad directivity (Ref. 3). In effect, a sound source with overall sound power levels of around 206 decibels (referenced to 10^{-13} watts) is created and continues over an operational period of approximately two minutes. Since much of its energy is well below one hundred cycles per second, the resonances of local structures are sometimes reached.

Under certain unfavorable atmospheric conditions, those sound rays emanating from the source at angles with the horizontal up to 20 degrees or more can be refracted such that they return to the earth's surface at considerable distances and focus a seriously high acoustic intensity within a relatively small area. Thus, on occasion, propagated sound from the Saturn test has produced annoyance and alarm at ranges of 10 miles or more within the city and suburbs of Huntsville.

Actual sound fields which exist in typical out-of-doors situations are almost prohibitively difficult to describe in detail. Since the medium for acoustic transmission is the atmosphere, it is never either homogeneous or quiescent and the boundary conditions are often quite complicated in terms of contour, vegetative covering, and manmade structures. However, it is possible to treat the problems in an approximate way by considering the following principal elements of sound propagation theory: (1) attenuation by spherical divergence, or the spreading out of the wave front; (2) attenuation due to the mechanical properties of the molecular structure of the atmosphere; (3) attenuation due to ground effects along the earth's surface; and (4) attenuation by refraction of sound fronts resulting from spatial variations in air temperature and wind. The most important of the above elements, in terms of the Saturn noise problem, is the refraction effect, which is responsible not only for bending the sound rays back to the earth but often results in focal areas of concentrated sound energy.

Calculation of Refractive Effect

Since the sound velocity in air depends upon temperature, humidity, and wind, it is the variation of these factors with altitude which determines the vertical sound velocity gradient and ultimately the refraction of sound waves. Considering first the effects of temperature and humidity, the sound speed, C, in still, dry air is given by LaPlace's equation

$$C = K\sqrt{T^*}, \tag{1}$$

where T^* is the virtual temperature in degrees Kelvin and K is a constant (20.07 for C in meters per second). The virtual temperature is defined as that temperature for the density of a parcel of dry air to equal that of moist air under the same pressure. Virtual temperature is related to the actual temperature, T, by the following expressions:

$$T^* = \frac{T}{1 - 0.377\frac{e}{p}} \tag{2}$$

where e is the water vapor pressure and p is the total pressure.

The sound velocity at a fixed point in terrestrial space is a vector quantity made up of two components: (1) a vector whose magnitude is given by C, the sound speed, and whose direction is normal to the wave front at the point; and (2) the vector wind at the point. The vertical component of the wind velocity is neglected since instrumentation with which to measure it is not readily available. Furthermore, horizontal gradients of temperature and wind are usually assumed to be negligible over the area affected by the sound source.

Conventional analysis of sound refraction depends upon the concept of sound rays, which are defined as the path of an incremental portion of an acoustic wave front. The direction of the sound velocity is tangent to the ray at each point along the ray. The main transport of sound energy takes place along these rays and the divergence or convergence of rays indicates decreasing or increasing energy concentration.

Following Cos et al. (Ref. 4), the refraction equation for sound rays states that for rays inclined but slightly to the wind

$$C + W_i \cos \theta = A_i \cos \theta, \tag{3}$$

where θ is the inclination of sound ray from the horizontal; W_i is the component of wind velocity in a given direction; and A_i, constant for any specific sound ray, is the velocity of the intersection of the wave front with the horizontal. Since the wind velocity seldom exceeds 10 percent of the sound speed within the first three to four kilometers of altitude, the refraction equation may be approximated by introducing a new term, V_i, defined by $V_i = C + W_i$, so that

$$V_i \quad A_i \cos \theta. \tag{4}$$

Toward any chosen azimuth from the sound source, the elevation angle of the sound ray, at altitude h, is related to the starting evaluation of the ray, θ_o according to the formula

$$V_h \sec \theta_h = V_o \sec \theta_o. \tag{5}$$

When the sound velocity decreases with height, the ray angle increases and the sound paths may be represented by a secant function. If the sound velocity increases with height, the ray angles decrease downward. Ray paths can be considered as segments of circles, all having the same curvature (dV/V) dh, over altitude intervals where the velocity gradient is constant with altitude. When the value of sound velocity at the earth's surface exceeds all values at higher altitudes, no surface sound return will occur. For a ray to be refracted to the surface from any upper layer, the maximum velocity attained in that layer must exceed the velocity at all points in the medium nearer the surface of the ground.

It should be realized that the usual applications of classical sound ray analysis involve various assumptions which may not be entirely justified, aside from simplifying the computational methods. The neglect of vertical wind velocity can be a serious shortcoming in those cases where natural or artifical convection, or topographic effects produce significant vertical velocity components of the order of 1 meter per second or more. The assumptions of time invariance (over 1 to 2 hours) and of space invariance (over a scale of 10 to 15 miles in a region of hilly terrain) in the sound velocity profiles are perhaps the most serious limitations.

Attenuation of Sound Along Its Path

Since it is impossible to record the sound at its source due to the extreme conditions within the jet exhaust it is necessary to evaluate the acoustic source parameters at a reference point several hundred feet away. If the attenuation by spherical divergence is considered the loss in decibels of the sound level at point P (at a distance R from the source) relative to that at a reference point P_o (at a distance R_o) from consequence of the inverse first power law

$$P = A/R \qquad (6)$$

where P is the sound pressure amplitude and A is a constant. In the absence of other effects, such as refractive focusing of sound energy, the sound level will decrease by 20 db for each ten-fold increase in R from a chosen reference point. Expressed another way, there is a loss of six decibels each time the range doubles.

The attenuation due to atmospheric absorption is comprised of: (1) "classical" absorption, produced by viscosity, conduction, diffusion, and radiation effects; (2) molecular absorption, which strongly depends upon the humidity; and (3) eddy attenuation, due to turbulent fluctuations in the wind structure. The effects of classical absorption are negligible, and at the lower audible frequencies which are of concern in this study, the molecular absorption (which depends upon the second power of the sound frequency) is quite weak. Under typical atmospheric conditions the sound loss due to molecular absorption is approximately 0.5 db per kilometer at 30 cps and four times as high as 300 cps.

The eddy attenuation, which varies with the eddy size and turbulent energy of the wind field, is especially important within the first several hundred feet altitude of the friction layer, where its effect is essentially the same in all directions. The effect of turbulent eddies is to scatter sound into shadow zones and somewhat blur the clear outlines of the classical sound ray patterns. However, few field measurements are available which are directly applicable to the problem. Measurements of wind eddy fluctuations from meteorological towers and captive balloon instruments would be essential in the quantitative determination of sound propagation into and within shadow zones. This is especially true for sound rays whose path are primarily confined to the friction layer.

The ground attenuation can be estimated from a knowledge of the acoustic properties of the surface boundary layer, in addition to the sound frequency, the heights of the source and receiver, and the horizontal components of the source-receiver distance. The general expression for sound pressure at any point is rather complicated. However, for the special case in which the source and receiver are both very near the ground (the ground is absorbent) and the distance is sufficiently great, the sound pressure is proportional to the inverse square of the distance (Ref. 5). When the ground absorption coefficient nears unity, the sound loss due to ground attenuation approaches that resulting from spherical divergence.

General Approaches to the Problem

The Test Laboratory of MSFC found it necessary to consider the effects of long range acoustic propagation as described in the previous sections, since, during certain Saturn static tests, focusing and/or intensification of sound generated during the tests did occur. Because the high frequency portion of the energy generated at the test tower was considerably attenuated by losses to the air, the sound directed into the focal area sounded somewhat like a tornado or sustained thunder. Since much of this energy was in the sub-audible frequency range, the resulting building vibration caused the audible sound outside buildings to seem less than the combined sound levels inside. Thus, residents within the focal areas became alarmed, a few even imagining that they were experiencing an earthquake.

To improve public relations with the neighboring communities, Test Laboratory has initiated a policy of "selective firings", i.e., avoiding the testing of the Saturn under atmospheric conditions conducive to high sound pressure levels in the Huntsville area. The first indication of the existence of such conditions may be taken from an appraisal of the acoustic profile (the velocity of sound versus altitude curve) along the azimuths of interest. As stated in Reference 6, it has been found convenient to divide the profiles into six categories (Table I).

The first of these is the "zero" or no-characteristics profile type. This category, while relatively rare in nature, is that which is most often assumed in the theoretical calculation of the effects of large noise sources. Thus, while neither the wind nor temperature may be individually single-layered nor homogeneous, their vector sum occasionally may be. Category one profiles cause the sound to be refracted up and away from the earth's surface. Types two, three, and four give generally similar increases in overall sound pressure level adjacent to or near the test site. Type five, with its negative gradient near the surface with a strong positive gradient above that, results in a shadow zone near the test and a focal area at some distance, usually in the 8 to 40-kilometer range.

To monitor the changing weather conditions and to provide the data for the calculation of the acoustic profiles, an atmospheric sounding station was established at MSFC. The standard government GMD-1B rawinsonde balloon tracking equipment is used. The processing of the data is speeded up somewhat through the use of digital computational techniques. It is planned to have eventually a completely automated data system.

After the rawinsonde data are transmitted to Test Laboratory, they are put on punch cards for input to a digital computer. The computer then uses these meteorological data to calculate the velocity of sound profiles along the azimuths of interest. It also calculates and plots individual acoustic ray paths. These presentations tell the acoustician the location and relative intensities of the focal areas (if any). However, it should be emphasized that thus far no direct relationship has been worked out between the ray path presentations and absolute intensities or sound pressure levels.

At the outset of this program, it was decided to obtain the services of a professional atmospheric forecaster. The Aero-Astrodynamics Laboratory of MSFC has provided this service. A standard procedure has been developed for making 24 to 30-hour forecasts, based upon U. S. Weather Bureau data from all over the North American Continent. These forecasts are of great value in scheduling tentative test days and times. Of significant interest to the forecaster is the network of meteorological stations which are within a 1000-mile radius of Huntsville. The requisite radiosonde data are available on standard teletype and facsimile circuits. The resulting forecasts are more difficult and exacting to make than those made for most non-quantitative meteorological purposes since it is necessary to forecast temperature, wind direction, and wind velocity for every 250-meter altitude increment from the surface through 4-kilometers.

Another method for predicting the sound pressure levels which will result from a Saturn static test relies upon the use of a high-powered sound source which can be used to approximate the noise from the space vehicle test (Ref. 6). A random siren coupled to an exponential horn is sounded every one-half hour. In fact, to be heard over the high background noises in the city for ten to fifteen miles, it was necessary to develop at Test Laboratory the largest and most powerful siren in the world. The change in the sound pressure levels from this siren is compared to that predicted by the forecaster when his predicted winds and temperatures are used in the ray-tracing based upon the current radiosonde data.

Thus it can be seen that the problem has been attacked in three ways: (1) radiosonde measurements of the wind, temperature, and humidity variations with altitude and the calculation of the resulting acoustic velocity profiles; (2) short-range atmospheric predictions or forecasts; and (3) direct measurement of the far-field acoustic propagation characteristics of the atmosphere. As test time approaches, the acoustician and the test engineer have several independent evaluations of what may be the acoustic ramifications of a test which may be held at a specific time and date. This system provides the test engineer the most flexibility in his test scheduling and still allows him to protect the surrounding communities.

Example of Pre-Firing Procedures

The firing of Saturn S-I static test SA-12 on March 13, 1963, gives a fine example of the processes by which acoustic and atmospheric data inputs are generated and used in the static test program. The test, however, should not be considered as representative since such holds and delays due to the atmospheric conditions are actually rare. It is included only to show the total system capability in forestalling acoustic disturbances in the surrounding areas even under the worst of conditions.

Saturn static test SA-12 was originally scheduled to fire at 1640 CST on Friday, March 8, 1963. As is the usual procedure, a weather briefing was held the day prior to the scheduled test. These meetings are attended by the Director of Test Laboratory or his representative, several acoustians and meteorologists and representatives of the Army Safety Office. The Aero-Astrodynamics Laboratory meteorological forecast personnel present their atmospheric prognoses at this time and the Test Laboratory acousticians evaluate this forecast in terms of a specific acoustic velocity profile type and the associated rise or fall of sound pressure level.

The forecast was for good weather conditions the next day, March 8, as far as firing was concerned. (No effort is made in the main body of this report to go into detail as far as either specific forecasts or atmospheric conditions are concerned.) Preparations for the test were continued and the usual second briefing six hours prior to scheduled test was planned. On the morning of March 8, the briefing was held and the general concensus of opinion was that the acoustic and atmospheric conditions were favorable. Preparations went forward until at about X-3 hours when the test was cancelled because of LOX leakages on the vehicle itself. At this time it was decided to attempt to fire on the following day, Saturday, March 9.

Saturday's weather was conducive to acoustic intensification, and the horn data that morning showed dangerously high levels in the Huntsville area. As a result, the test was cancelled around noon even though the forecast was for some improvement. The radiosonde released at 1620 CST that afternoon showed the improvement that had been forecast.

One balloon release was made at 1600 CST on Sunday, March 10, to provide continuity of data for the forecaster.

On Monday the pre-firing schedule of radiosonde balloon releases, forecasts, and sounding began again to determine the possibility of firing that afternoon. Upon the recommendation of the forecaster the test was again cancelled due to poor weather conditions. The ray tracing toward Huntsville of the meteorological conditions that afternoon verified the prediction of poor weather. The test was rescheduled for the following afternoon, but due to flooding on the Arsenal and the resulting power failures, the test was again postponed.

On Tuesday, March 12, the first briefing for Wednesday was held. A focal zone was predicted but it was anticipated that it would fall some 20 to 25 kilometers from the test site along the 45° azimuth. This area is an unpopulated zone on the side of Monte Sano mountain away from the city of Huntsville. (See Figure 1.) The prediction was for a shadow zone over Huntsville itself. This prediction looked good and the preparations continued for the firing.

The next morning (March 13) the forecast was less optimistic, but it still indicated only the mountain areas would receive any re-enforced acoustic energies. The acoustic horn was put into use to follow the progress of the sound pressure levels at various points within Huntsville. It showed that while the test would be heard in town, the sound pressure levels which would result would have no deleterious effects. The countdown proceeded and the test was completed sucessfully. At no point outside the Redstone Arsenal boundary did the sound exceed 107.5 decibels (Fig. 1). While this sound pressure level is somewhat higher than usual, it was several decibels below that which experience has shown to be the threshold of annoyance or damage in Huntsville.

Again it should be emphasized that the firing detailed above for illustration is not typical of most Saturn firings. It is used because it contains nearly all of the possible elements which might affect such static tests: weather, acoustics, component reliability - even a flood.

The recorded octave-band sound spectra are presented in Figure 2. The overall sound pressure levels are shown at the left of the chart. As might be expected, the spectra show the result of progressive attenuation in the upper octaves. Thus as the range increases the energy in the higher frequency octave band attenuates faster than that in the octaves below leaving much of the low frequency energy virtually intact. Beyond ten miles, the peak frequency of the Saturn noise is in the eight cycle per second octave band. This frequency is below the threshold of hearing and so the Saturn test may pass unnoticed except for slight rumblings and the shaking of buildings and windows.

SOUND SUPPRESSION STUDIES

As mentioned earlier, there is one additional method of lessening the effect of the noise from static tests. This is to equip the test stand with a large muffler or sound suppressor. Through the use of such a device the sound field is modified so that the acoustic source is, or appears to be, smaller in power.

Marshall Space Flight Center has been investigating the feasibility and cost of such a device for many years. In fact, the need for sound suppression has been realized and studied since the advent of large liquid propellent engines in the Jupiter and H-1 class. Development of sound suppression devices has been actively pursued at MSFC since 1960. Coincident with the design of the very large S-IC booster for the Advanced Saturn vehicle, the need for means of suppressing the sound generated during the static firing of this booster was recognized and work was begun on model testing of various designs of sound suppressors. This work has progressed concurrently with the refinement of the selective firing program.

Since the power which generates the sound is derived from the kinetic energy of the rocket exhaust jet, sound suppression is actually an effort to reduce the velocity (and thus the kinetic energy) of those jets. This problem is complicated by the very high velocity of the exhaust gases and by their high temperatures (in excess of 3000° F). However, one way to reduce the velocity quickly over a short distance is to inject water into the jet stream. Water has several advantages such as cost and ease of handling. Also in the conversion to steam the water absorbs a large amount of the heat energy as well as adding mass to the flow which in turn lowers the velocity. For instance, if the mass of water added is nine times that of the jet exhaust mass, the jet velocity is reduced to one tenth its initial speed. This would have the effect of reducing the sound energy by a factor of one thousand, a very effective method of sound reduction. The problem is the large amount of water required for any appreciable sound reduction. In fact it is not feasible to use this method if the water is to be injected by conventional pumps.

However, a successful and unique method of utilizing the water injection technique has been developed at MSFC. The mechanism and operation of the suppressor is depicted in Figure 3. The system consists of a submerged duct completely surrounded by water. The engine jet exhausts into the deflector shown on the right, passes through a diffusor and into a horizontal duct. The jet travels the length of the duct and exhausts through the tank opening at the left. In operation, 14 pounds of water is sucked into the duct for each pound of propellant and recirculated through the tank and jacket. In this recirculation, less than one-fourth pound of water is lost by vaporization.

An experimental program using a model engine and model sound suppressor has been conducted at the Marshall Center with excellent results. A 165,000 pound thrust H-1 engine was used to furnish the sound source. As the engine exhaust pumps the water into the diffusor, more water flows toward the deflector and a circulation of water is set up. This circulation cools both the suppressor and the exhaust gases. At the tank end of the suppressor, baffles and a water spray system further condense the steam, and add water previously lost due to evaporation. The overall sound power level is appreciably reduced, by 20 decibels on the average. Of particular interest is the low frequency octaves in which the sound power is reduced by about 15 decibels.

CONCLUSIONS

Up until recently, very few persons in the fields of rocketry and space exploration were concerned with anything so mundane as noise. However because of the rapid increase in the size of the vehicles to be tested and flown, many groups are now discovering the impact which such neglect can have. While some projects have been harrassed with large numbers of claims for damage and annoyance, the Marshall Center fortunately recognized the potential problems prior to the first Saturn S-I test. Although a few slip-ups have occurred, they have only served to underscore the importance of the science of acoustics. The accelerated programs which have been carried on at MSFC in the development of the large siren systems, full-scale sound suppressors and atmospheric acoustic propagation studies point the way by which the industry can avoid costly modification to the vehicles themselves or the purchase of a great deal of expensive real estate.

While much work remains to be accomplished, this effort is expected to proceed concurrently with booster development. In the field of atmospheric propagation, MSFC has under construction a line of acoustic monitoring stations beginning at the S-IC static test tower and running through the city of Huntsville, Alabama. It is anticipated that this array will allow more a complete investigation of the role of weather in the focusing of sound.

The favorable results in the tests of sound suppression have led to a continuing program investigate the effects of scaling upward in thrust and dimension. Since the H-I model suppressor is already 21 feet high, 20 feet wide and 130 feet long, the larger boosters now under consideration will call for veritable behemoths. However through the use of both techniques it should be possible to static test nearly any presently conceived space vehicle with a minimum of harmful acoustic side-effects.

REFERENCES

1. Polly, R. C. and Tedrick, R. N., Report Series "Far-Field Propagation Characteristics at The Marshall Space Flight Center", December 1962 - January 1964, R-TEST-ICA.
2. Tedrick, R. N., "Determination of Zones Subject To Meteorological Focusing", Fourth International Congress on Acoustics, Copenhagen, August 1962.
3. Dorland, W. D., "Far-Field Noise Characteristics of Saturn Static Tests", NASA TN-D-611, August 1961.
4. Cox, E. F. et al, "Meteorology Directs Where Blast Will Strike", AMS Bulletin 35: 95-103, 1954.
5. Nyborg, W. L. and Mintzer, D., "Review of Sound Propagation in the Lower Atmosphere", WADC Tech. Report 57-354, 1957.
6. Tedrick, R. N. "Performance Characteristics of a Large Free-Field Exponential Horn," MTP-TEST-63-4, 1963.

TABLE 1. ACOUSTIC VELOCITY PROFILE CATEGORIES

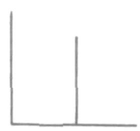
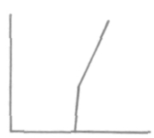
CATEGORY	DESCRIPTION	TYPICAL GRAPHS
0	NO VELOCITY GRADIENT	
1	SINGLE NEGATIVE GRADIENT	
2	SINGLE POSITIVE GRADIENT	
3	ZERO GRADIENT NEAR SURFACE WITH POSITIVE GRADIENT ABOVE	
4	WEAK POSITIVE GRADIENT NEAR SURFACE WITH STRONG POSITIVE GRADIENT ABOVE	
5	NEGATIVE GRADIENT NEAR SURFACE WITH STRONG POSITIVE GRADIENT ABOVE	

TABLE II

Percent of Days During Calendar Month During Which No Focusing or Concentration of Acoustic Energy Was Noted at MSFC.

December 1962	58.1%
January 1963	48.4%
February 1963	63.0%
March 1963	70.0%
April 1963	76.7%
May 1963	80.0%
June 1963	77.8%
July 1963	80.0%
August 1963	93.3%
September 1963	93.3%
October 1963	93.3%
November 1963	66.7%

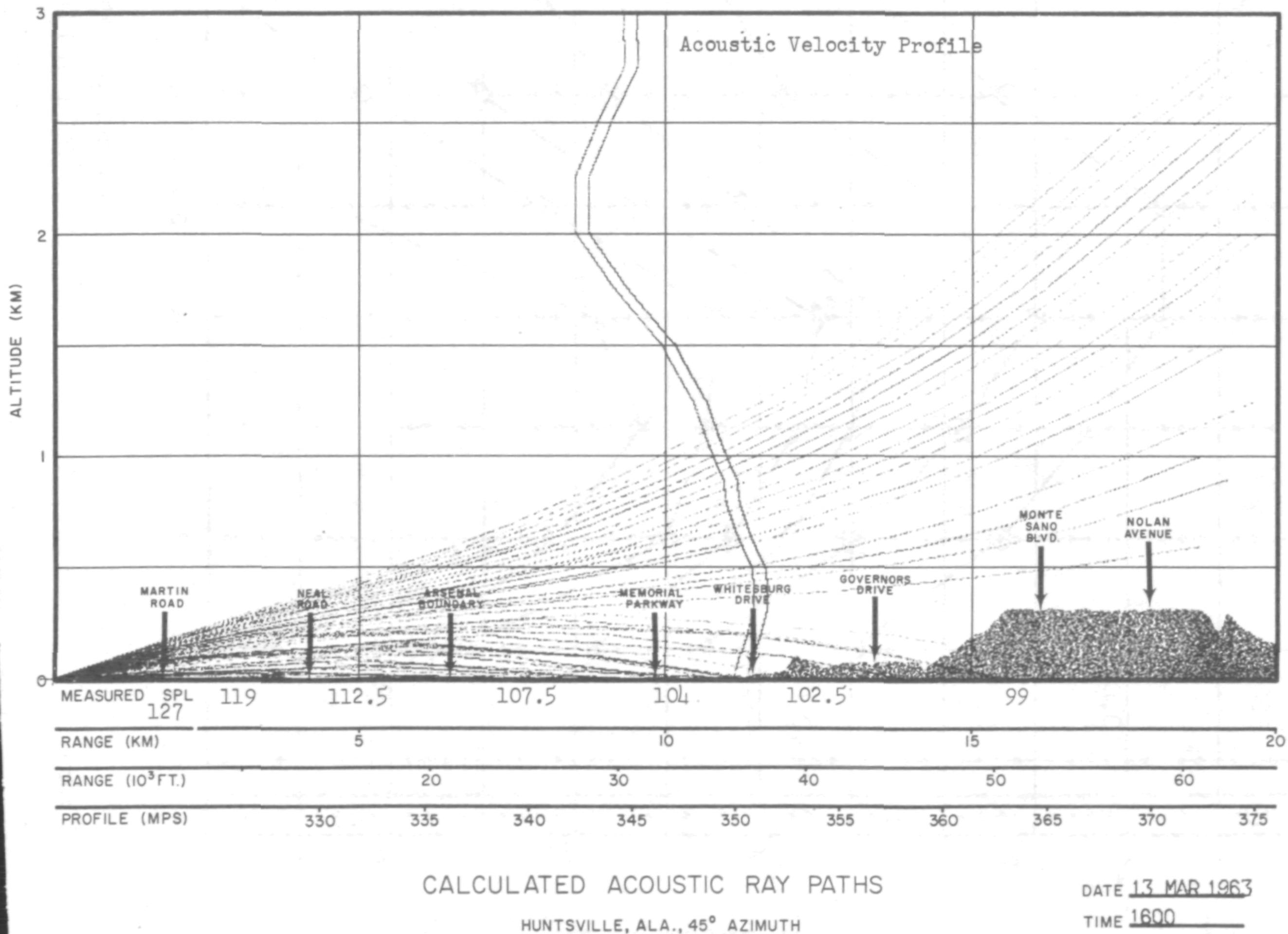


Figure 1. Computer Calculated Acoustic Ray Paths During Saturn Static Test, March 13, 1963

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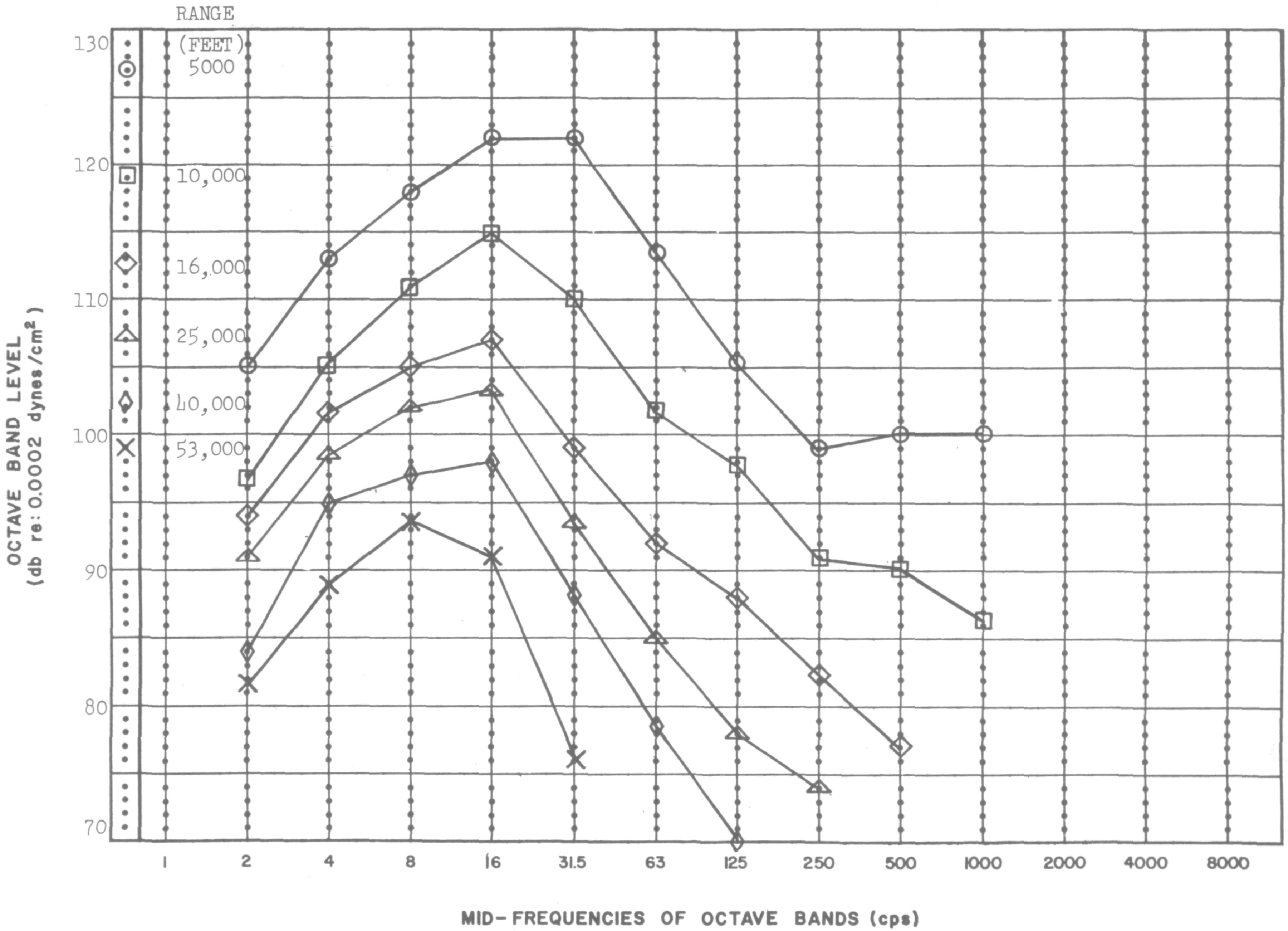

Figure 2 FREQUENCY SPECTRA AT VARIOUS RANGES FROM TEST

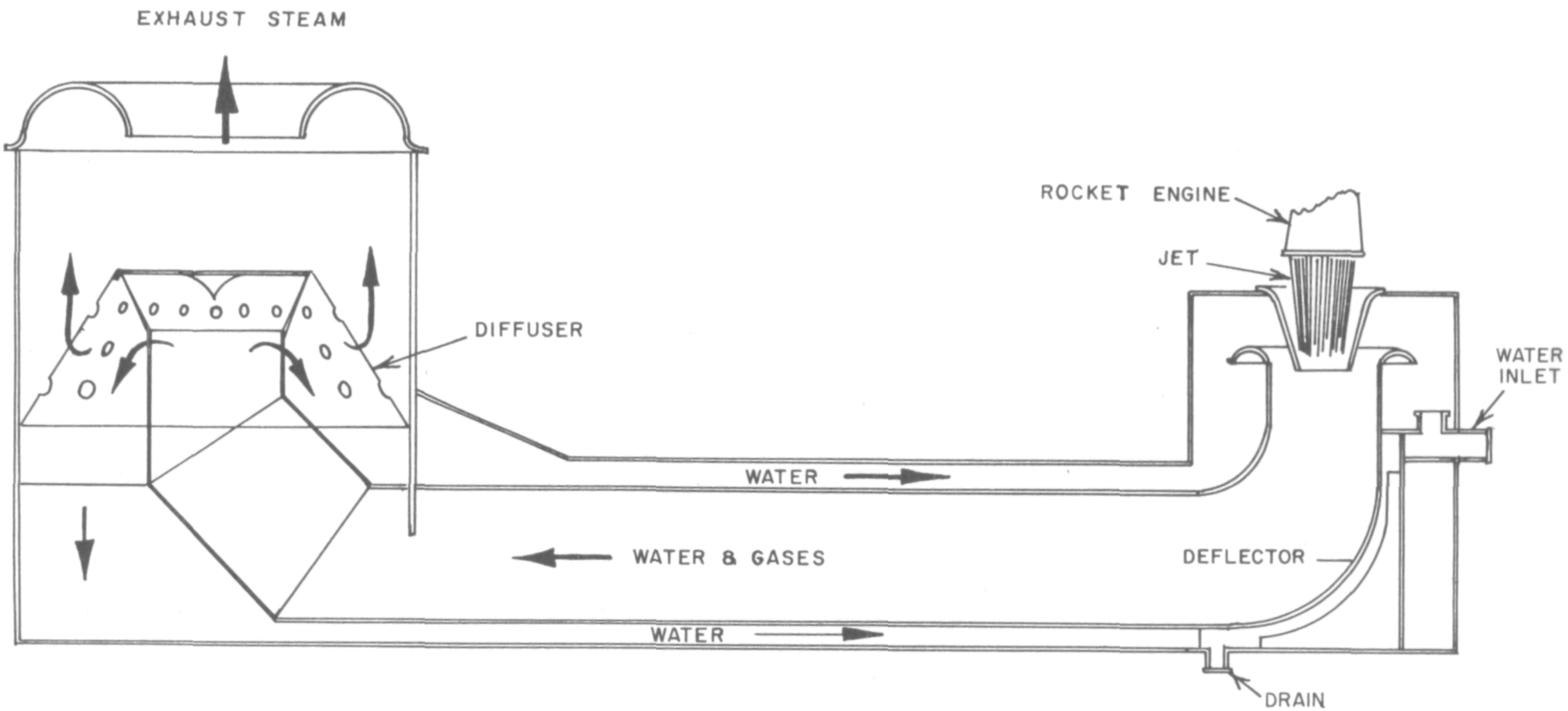

DIAGRAM SHOWING SIMPLIFIED OPERATION OF MFSC SOUND SUPPRESSOR

Figure 3.