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PROFILE TYPES OF SOUND SPEED IN THE LOWER ATMOSPHERE AND THEIR RELATIONSHIPS TO ACOUSTIC FOCUSING

by
Dr. O. Essenwanger

April 1966

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ABSTRACT

The derivation of characteristic profiles for the sound speed is discussed and a classification system introduced. The system comprises 32 types of sound profiles with subsequent division into three groups, namely without and with returning rays and with focusing. The idealized 32 prototypes of the classification system are based on the percentage reduction for orthogonal polynomials and the sound speed profiles are classified by utilization of the maximum relationship with the prototypes.

The types show significant relationship with acoustic focusing and display practically no seasonal, azimuthal, or climatic variation for focusing. Therefore, seasonal, azimuthal, and climatic changes are caused by the occurrence of types. These seasonal, climatic, and azimuthal fluctuations of the types are presented.

ACKNOWLEDGMENT

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1. Introduction

The propagation of acoustic noise, created during static test firings of big space boosters, and the radiation of high acoustic energy in the vicinity of static test facilities have given rise to new studies in this relatively well established field of physics. The problem of predicting days in which the atmospheric conditions are favorable for creating high acoustic energy in the surroundings of test facilities is of special interest.

Although numerous prediction schemes can be developed, based on a variety of different principles, a classification system for the sound speed profiles can be a reasonable basis for the study of the relationship between acoustic parameters and the sound speed profiles. The classification system further permits the investigation of the interaction between atmospheric and sound speed profile and thus promotes our knowledge and understanding of the acoustical wave propagation as influenced by the weather situation.

Therefore, an attempt is made to introduce a workable scheme for classifying the sound speed profile and for studying their relationship with some acoustic parameters. In summary, a system of 32 types of sound speed profiles, with subsequent division into three groups (derived from their relation with wave propagation), can adequately describe the variety of profiles.

2. Classification of the Sound Profile

The method described later in this report could be employed for any type of sound speed profile from the ground to any selected altitude. Since the application of the classification system in our case was primarily intended to be for wave propagation in the vicinity of the Huntsville, Alabama, test facility of the Marshall Space Flight Center, National Aeronautics and Space Administration, the classification of the sound speed profile in the first 3 kilometers of the atmosphere was considered sufficient. Thus, the later established sample and the profiles include only the sound speed in the first 3 kilometers.

Grouping of sound speed profiles by other authors exists. Heybey[1] has presented profiles in relationship to focusing and returning rays. Another system was used by Perkins.[2] Perkins employs five basic types of sound profiles derived for their association with acoustic intensity. Although his system is self-consistent and serves his purpose adequately, it is not diversified enough to fit our goal. In Appendix B of Perkins' report,[2] 32 cases are illustrated. Further classification in his method is done by subjective judgment. This is hardly possible for a data sample containing about 250,000 sound speed profiles as employed in this investigation. Thus, other ways had to be invented whereby classification could be established by machine methods.

A certainly interesting scheme was delineated by Lund,[3] although it was primarily derived to classify weather situations. He selects a first weather situation and places all other situations into the same class if the linear correlation coefficient to this first prototype is larger than 0.70. Thus, he eliminates all similar situations from the material and starts with a new prototype. The procedure is repeated until all situations are classified.

This idea has certain potential, although some objection can be made against the selection system of Lund's weather situation prototypes. It will be proved below that his system is based upon a random selection and that a systematic selection of prototypes is possible. The systematic scheme has been engaged later in the selection of the sound speed profile types.

Explaining the systematic scheme, one may go back to the linear correlation coefficient, r_{XY}, which may be expressed by

$$r_{XY} = \frac{\text{Cov}}{\sigma_X \sigma_Y} \, . \tag{1}$$

σ denotes the respective standard deviation of the elements X and Y and Cov stands for the covariance, which may be expressed by

$$\text{Cov} = \frac{\sum (X_i - A_o)(Y_j - B_o)}{N} \, . \tag{2}$$

A_o and B_o represent the respective mean values of the elements X_i and Y_j, N the number of observations. If it is possible to express the elements X_i and Y_j by orthogonal polynomials, such is the case for the sound speed profile from surface through 3 kilometers altitude, then $X_i - A_o$ becomes

$$X_i - A_o = A_1 \phi_{1i} + A_2 \phi_{2i} + A_3 \phi_{3i} + \ldots A_n \phi_{ni} \, . \tag{3}$$

Analogously,

$$Y_j - B_o = B_1 \phi_{1j} + B_2 \phi_{2j} + B_3 \phi_{3j} + \ldots B_m \phi_{mj} \, . \tag{4}$$

ϕ_i denotes orthogonal polynomial functions, A_n and B_n coefficients. Since the input X_i and Y_j are sound speed profiles to be correlated, they can be brought into the same format, thus $i = j$ and $m = n$. This leads to a covariance

$$\mathrm{Cov} = \frac{1}{N}\sum \left| A_1 B_1 \phi_{1i}^2 + A_2 B_2 \phi_{2i}^2 + \ldots A_n B_n \phi_{ni}^2 \right| \tag{5}$$

with

$$\sum \phi_{ni} \phi_{ki} = 0 \text{ for } n \neq k. \tag{6}$$

Further,

$$\frac{1}{N} \sum \phi_{ni}^2 = \sigma_{\phi_n}^2 \tag{7}$$

and finally, the correlation coefficient

$$r_{XY} = \left[\frac{A_1 \sigma_{\phi_1}}{\sigma_X} \; \frac{B_1 \sigma_{\phi_1}}{\sigma_Y} \ldots \frac{A_n \sigma_{\phi_n}}{\sigma_X} \; \frac{B_n \sigma_{\phi_n}}{\sigma_Y} \right] \tag{8}$$

If one remembers that the percentage reduction, Z_{iX}^2, is defined by

$$Z_{nX}^2 = \frac{A_n^2 \sigma_{\phi_n}^2}{\sigma_X^2} \tag{9}$$

with

$$\sum Z_{nX}^2 = 100 \text{ percent}, \tag{9a}$$

one may express the correlation coefficient by

$$r_{XY} = \left| Z_{1X} \cdot Z_{1Y} + \ldots Z_{nX} Z_{nY} \right| \tag{10}$$

or,

$$r_{XY} = \sum Z_{nX} Z_{nY} \tag{10a}$$

In Equation (10a), Z_{nY} represents the prototypes or idealized types of any classification scheme and the Z_{nX} denotes the element to be classified, which in this case is the sound speed profile. The correlation coefficient, r_{XY}, must be computed for all idealized types and the maximum correlation determines the class into which the sound speed profile is grouped. Employing the maximum correlation is the first deviation from Lund's[2] method.

A second change from Lund's[2] method is the systematic spacing of the idealized types. In effect, the Z_{nY} are prototypes in an n-dimensional system and can be spaced randomly or systematically. This will influence the association of the Z_{nX} with the Z_{nY}, as may be demonstrated in the following example.

Assume the main interest is in Z_1 and Z_2 and all remaining terms are summarized under Z_3. Then, a two-dimensional system for Z_1 and Z_2 evolves as illustrated in Figure 1. It is irrelevant whether the class division employs equal intervals in a linear or quadratic scale. The latter offers the advantage that the total percentage reduction can be easily added up and a diamond shaped plane develops with classes as displayed in Figure 1. The sign is taken from the coefficients (Equation 10). Although the association with the prototypes was later performed for the individual profile, for proving our point, it can be assumed that the profiles to be classified can be represented by the midpoints of the class fields. For example, assume that there exists only one prototype, $Z_{1Y}^2 = 100$ with $Z_{2Y}^2 = 0$, which is identified with the uppermost dot in Figure 1. Under a selection scheme of a correlation coefficient of ≥ 0.7, the top five lines would be associated with this prototype and eliminated from the material.

Equally spaced prototypes, as indicated by the dots in Figure 1, are introduced and the maximum correlation for the midpoint of the class fields is selected to indicate the association. Then, a system of divisions arises as indicated by the heavy lines in Figure 1. It should be noticed that the idealized prototypes contain no Z_3 in this scheme and, therefore, the correlation coefficient and the association with the prototypes are determined by Z_{1X} and Z_{2X} only.

It is obvious that in a system where the prototypes are introduced subsequently and not simultaneously (or a priori), the elements to be classified are not grouped by this maximum correlation. (The first five lines of class fields would have been eliminated by the first prototype, before one goes to the next one.)

Further, it is evident that random spacing of the prototypes will result in inadequate coverage of the total Z_1, Z_2 plane. Thus, unnecessary prototypes must be introduced merely to classify remainders.

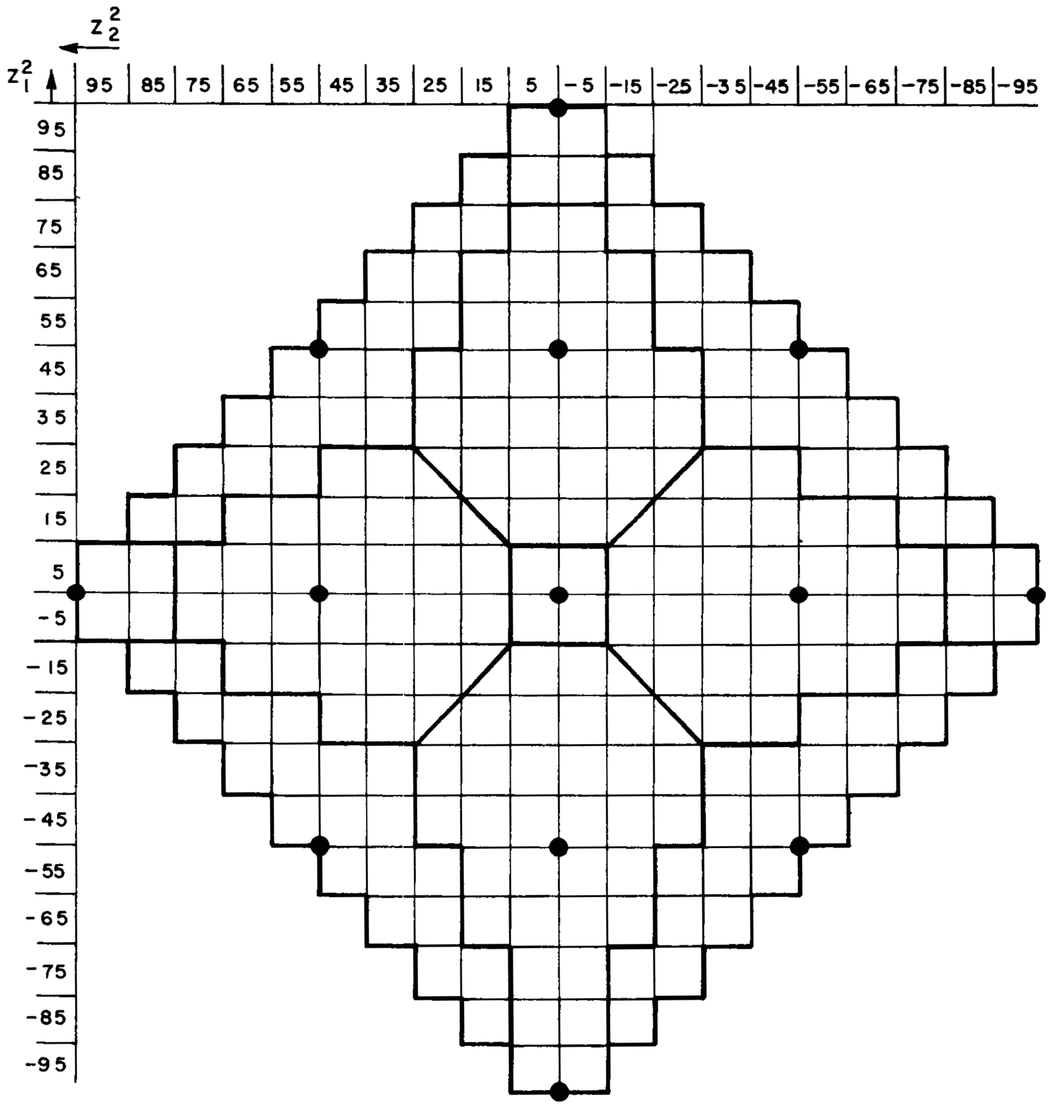


Figure 1. Association of Classes with Idealized Types

The example could be expanded to include more than the first three polynomial terms. Similar conclusions than obtained for the presented example are valid.

The fact that no realistic profiles may arise could be brought up as an objection to a systematic spacing of prototypes. This would be factually correct, if the prototypes would be considered final. Since the prototypes are used to separate the material into classes only, they serve a similar purpose as a class division for a frequency distribution. Practically nobody would base such a class division on random limits. Empirical data can then be derived for the separate groups and realistic profiles can then arise.

Although the author has utilized in the later part equally spaced prototypes as outlined in Figure 1, there virtually exists an infinite number of possibilities to systematically arrange for schemes of prototypes. This is equivalent to choosing the initial class of a system of class divisions for a frequency distribution. The present system proved quite convenient and efficient.

Figure 2 illustrates an example for an empirical frequency distribution in the Z_1, Z_2 plane. The majority of empirical profiles in the groups will then determine the actual characteristic profile.

Figure 3 displays in the layout of the Z_1, Z_2 plane the placing and appearance of the later employed prototypes. Types 1, 2, 11, 12, and 21 through 24 are connected with Z_1 and Z_2 only and are individual types in their respective boundaries. All other types are subdivided by higher order coefficients and appear only as an image in the Z_1, Z_2 plane. The prototypes are described in detail in Paragraph 3 of this report.

3. Types of Sound Speed Profiles and Relation to Focusing

The establishment of a system of prototypes has been discussed in Paragraph 2 of this report. The respective Z_{nY}^2 values for the prototypes and the numbering of types are contained in Table I. Individual terms of orthogonal polynomials are types 1 through 6 with positive coefficients and 11 through 16 with negative coefficients. Types 21 through 32 are mixtures involving Z_1Y, Z_2Y, and Z_3Y with the respective signs. In types 40 through 46, with mixtures containing higher orders than Z_3Y, the frequency of occurrence was low and thus association was not separated by sign. The subdivision into four parts such as in types 21 through 24 was omitted. For the investigation of the

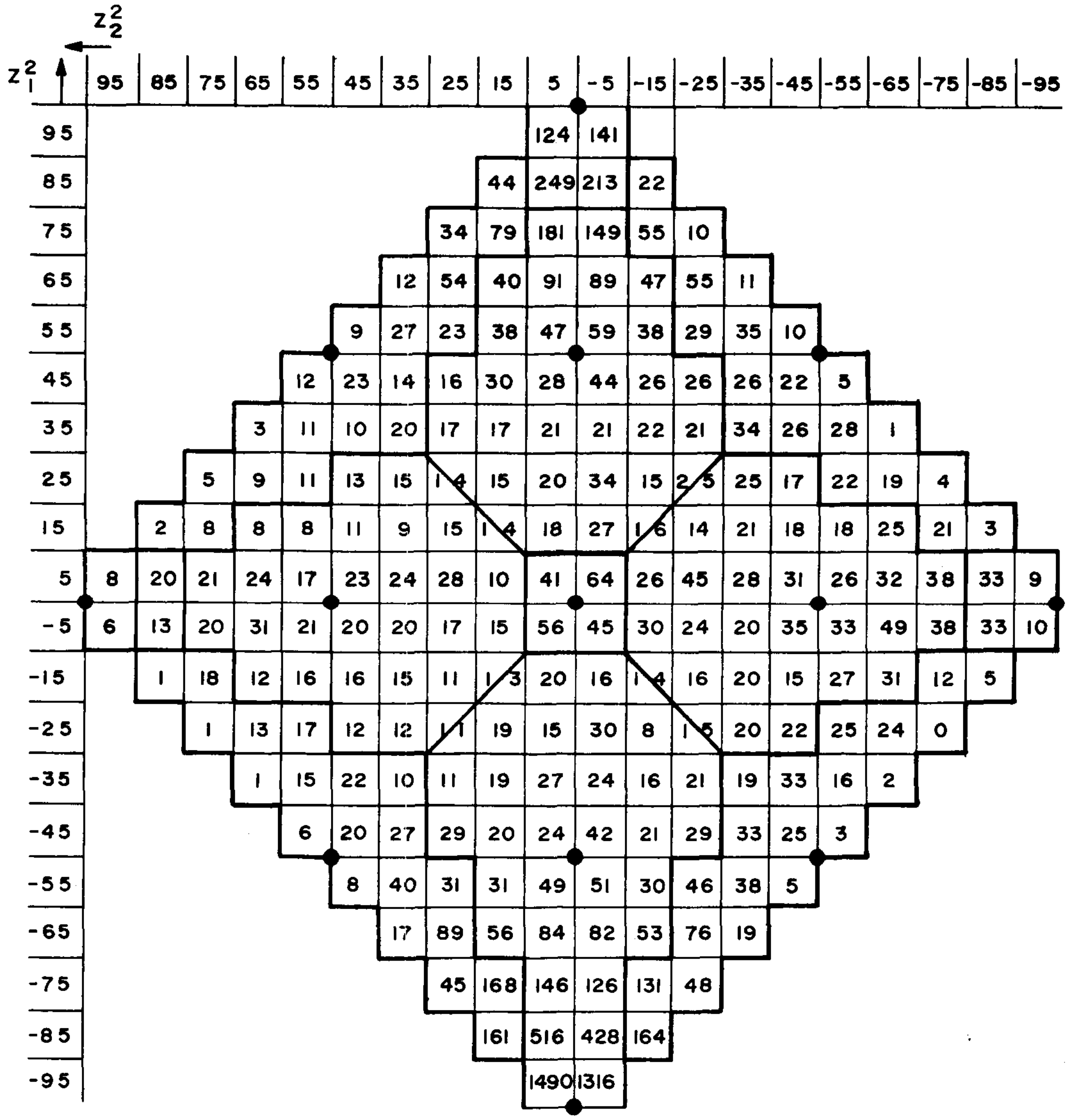


Figure 2. Association of Classes with Idealized Types

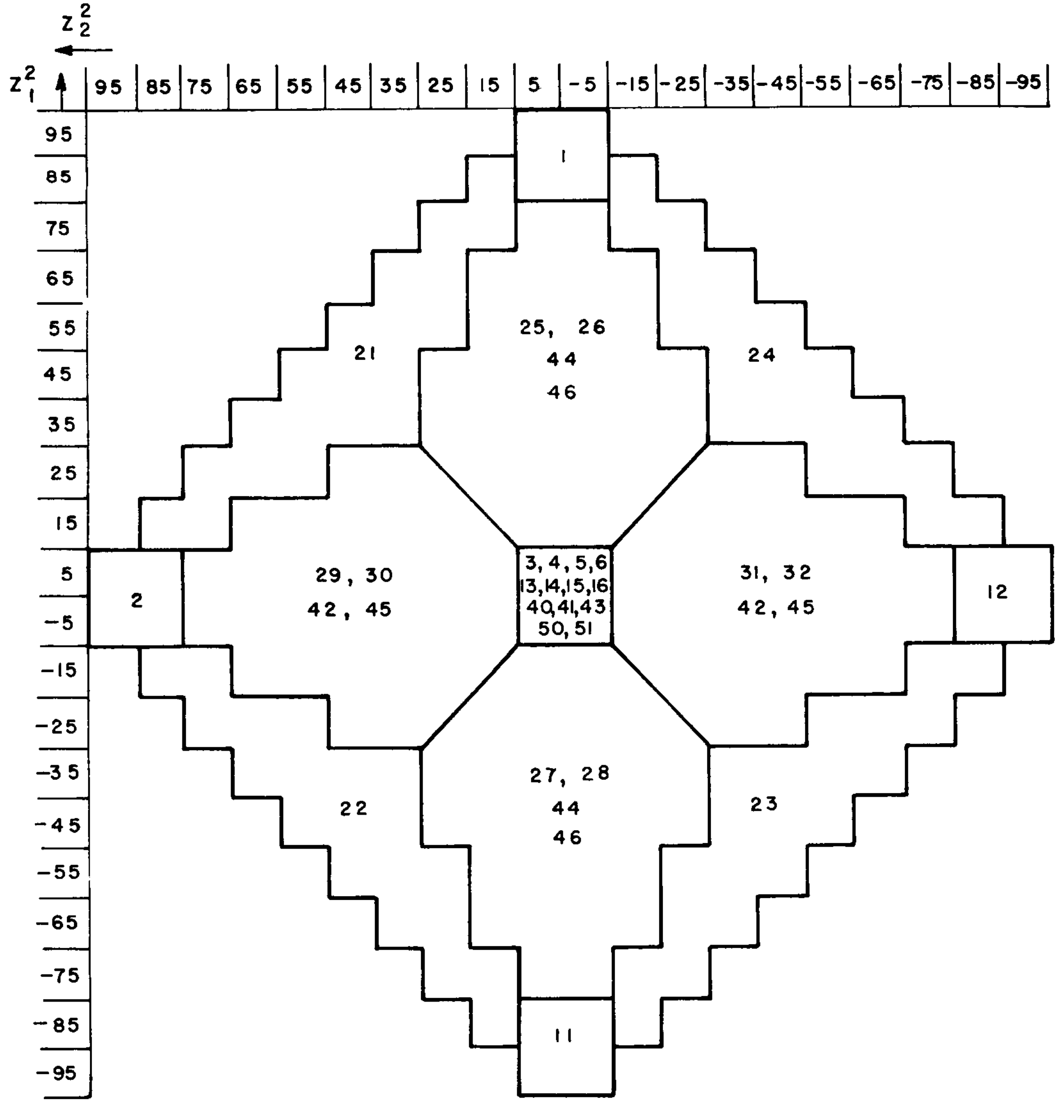


Figure 3. Type Association in Field of Z_1^2 Versus Z_2^2

Table I. Idealized Types

Type	Z_1^2	Z_2^2	Z_3^2	Z_4^2	Z_5^2	Z_6^2
1	100					
2		100				
3			100			
4				100		
5					100	
6						100
11	-100					
12		-100				
13			-100			
14				-100		
15					-100	
16						-100
21	50	50				
22	50	- 50				
23	- 50	- 50				
24	- 50	50				
25	50		50			
26	50		- 50			
27	- 50		- 50			
28	- 50		50			
29		50	50			
30		50	- 50			
31		- 50	- 50			
32		- 50	50			
40			50	50		
41				50	50	
42		50		50		
43			50		50	
44	50			50		
45		50			50	
46	50				50	
50	$\sum_{1}^{6} Z_i^2 \leq 0.60$					
51	Others					

250,000 profiles from the climatic regime of the Southeast of the United States this was quite satisfactory. It may not be permissible on a world-wide basis, if frequency for types 40 through 46 warrants a subdivision.

Type 50 is a collection of the remaining profiles, where the maximum correlation coefficient to any of the preceeding prototypes is less than 0.70. It was derived by classification of profiles into the 31 types introduced as numbers 1 through 46 and then printing out the remaining profiles whose maximum correlation was less than 0.70. It was discovered that these were profiles whose first six polynomial terms rendered a percentage reduction of less than 60 percent. Although a type number 51 was reserved for cases not yet covered, none appeared.

The introduced system of classification has several advantages. First, instead of correlating the individual points of the sound speed profile with the individual points of the prototype (idealized types), only the percentage reductions Z_{nX} need to be multiplied. This reduces the computer time for classification considerably. Second, the profile is associated with the type by its maximum correlation. No other prototype would fit the profile better. Third, the correlation with the prototype is always > 0.70 except for type 50. The latter is a relatively small group, where higher order terms than the sixth power may prevail. It includes further profiles with no dominance of any term. In more than 90 percent of the profiles, the maximum correlation coefficient is over 0.90. More details are presented in a forthcoming report.[4] In essence, the actual profiles never fall 100 percent in line with the prototypes, but are very close. This can be interpreted as the actual profiles consisting of predominant terms with some perturbations. Since the idealized type does not contain perturbations, the classification is based upon the dominant feature of the profiles.

It proved further advantageous in application to sound propagation to establish for the various types three notable subgroups, although not all three subgroups can be found in every type (Table II). These subgroups were selected for their property with respect to acoustic wave propagation. As described in detail in a recent report,[5] the first group does not render returning sound rays from the atmosphere to the ground. In the second group, returning sound rays can be expected but no focusing will happen. The third group comprises profiles with chances of focusing. Focusing is used as a tool to identify areas with generally high acoustic intensity. The objective determination by computer methods has been thoroughly described by the author in a recent report.[5]

Table II. Survey of Focusing Per Profile Type for the Climatic Regime in the Southeast United States

Profile Types	Profile Groups			Focusing of B	Focusing of Type	Type Frequency
	Nonreturning	Returning	B			
1	0	100	100	86	86.0	5.9
2	62	38	29	18	5.0	1.8
3	0	100	46	57	26.0	0.3
4	37	63	63	41	26.0	0.1
5	0	100	45	5	2.0	0.0
6	19	81	81	61	49.0	0.0
11	67	33	5	69	4.0	63.1
12	0	100	86	84	73.0	2.6
13	63	37	35	36	12.0	0.8
14	0	100	37	25	9.0	0.1
15	49	51	51	68	35.0	0.0
16	6	94	69	21	15.0	0.0
21	1	99	99	45	45.0	1.4
22	0	100	97	90	87.0	1.9
23	4	96	59	73	43.0	4.7
24	86	14	1	49	0.3	4.6
25	0	100	95	51	48.0	0.2
26	4	96	96	64	61.0	1.5
27	91	9	3	10	0.3	1.9
28	1	99	25	81	20.0	1.3
29	2	98	74	28	21.0	0.2
30	88	12	9	26	2.0	1.5
31	5	95	94	64	61.0	0.4
32	0	100	43	76	32.0	1.1
40	40	60	30	54	16.0	0.9
41	24	76	35	50	18.0	0.2
42	9	91	64	66	42.0	1.1
43	14	86	66	43	29.0	0.3
44	24	76	41	56	23.0	1.4
45	15	85	66	51	34.0	0.3
46	22	78	49	58	29.0	0.4
50	7	93	76	34	26.0	0.0

The frequency distribution over 250,000* sound speed profiles by types and groups for the climatic regime in the Southeast portion of the United States is presented in Table II. The first three columns next to the profile types represent the three groups as mentioned above with the difference that in the middle column all profiles with returning rays and with chances of focusing are combined. The third column lists the profiles with chances of focusing alone. If the frequency of profiles with returning rays only without chances of focusing is desired, the reader may substract column 3 from column 2.

The fourth column under heading "Focusing of B" contains the fraction of B profiles in percentage, when focusing occurred. Certain types display high chances of focusing for profile group B, others have lesser chances. The final two columns delineate information of focusing per type and the overall type frequency.

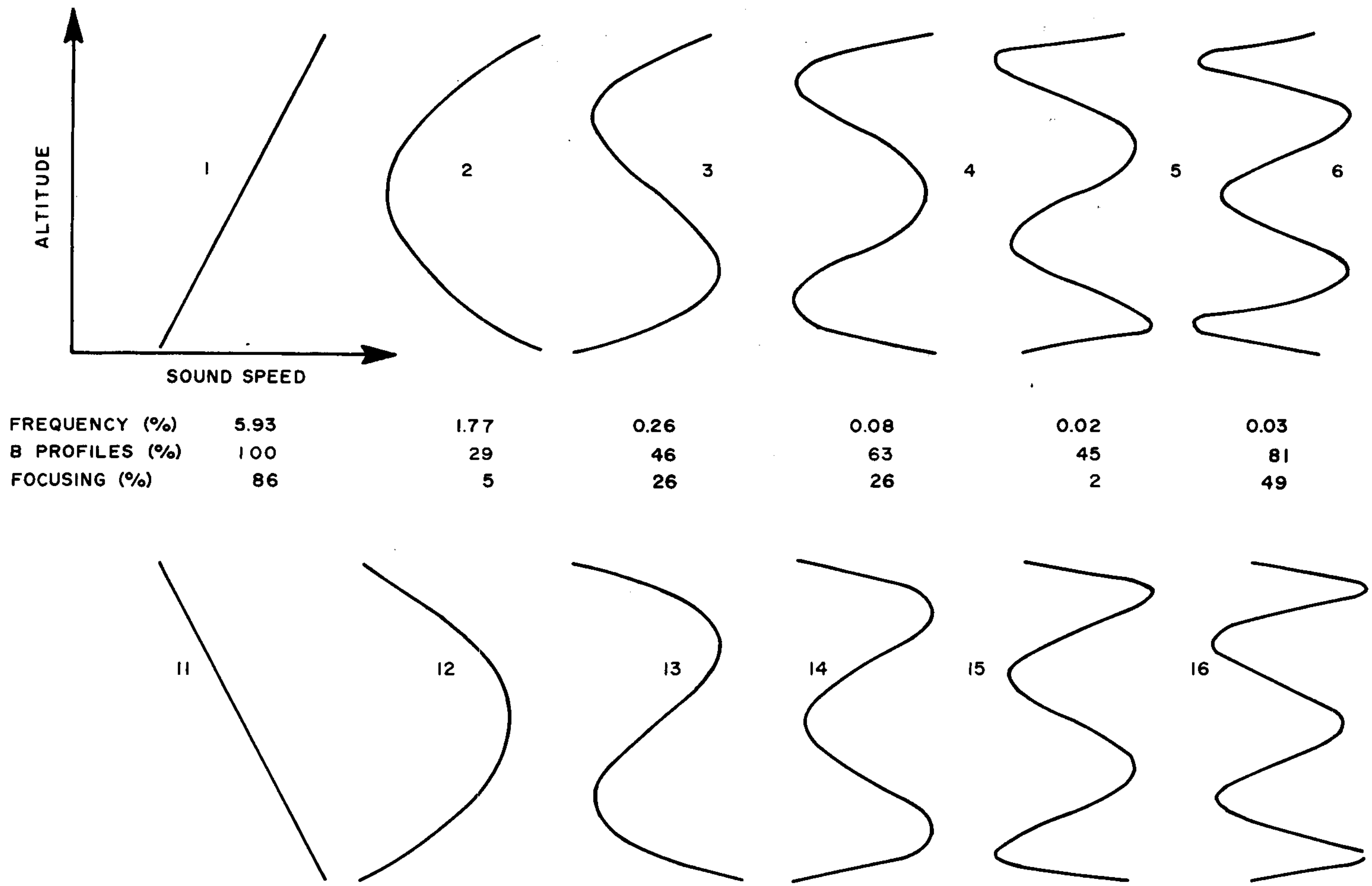
The result has been transferred into Figures 4 through 6, which picture 27 of the idealized types and associate the frequency of occurrence with them. The first line represents the overall occurrence of the type within the total material of 250,000 profiles. The second line gives the share of B profiles expressed in percentage of the type occurrence. The frequency of focusing per type can be seen from the bottom line.

It can be noticed that type 11 appears most frequent (in over 60 percent of the time) and represents the type with little chance of focusing. If empirical data were perfect and like the idealized type, no returning rays could be produced. One third of the empirical profiles, however, emerge with returning rays. This is caused by the perturbations.

Type 1 proves as the major type for focusing, again a contradiction to the idealized type. Although returning rays for that profile type must be expected, a straight linear increase of the sound speed would not create focusing. Again, the role of the perturbations can be seen.

These two examples already demonstrate the modification by the empirical profiles and with it the conversion into significant realistic types. It is the empirical profile which determines the profile type

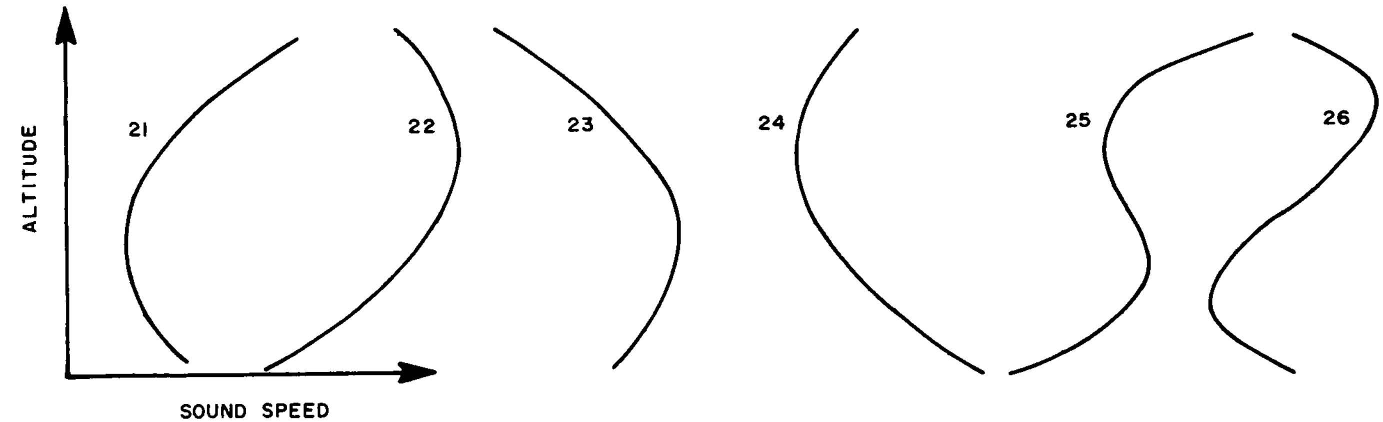
*Sound profiles have been computed for every 10-degree azimuth for meteorological ascents from Nashville, Tennessee; Huntsville, Alabama; and Mississippi Test Facility.



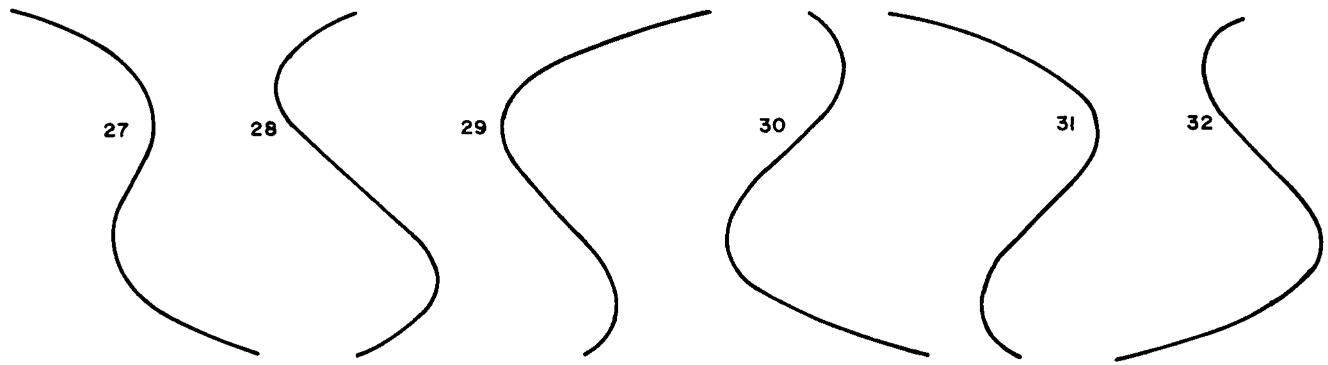
	1	2	3	4	5	6
FREQUENCY (%)	5.93	1.77	0.26	0.08	0.02	0.03
B PROFILES (%)	100	29	46	63	45	81
FOCUSING (%)	86	5	26	26	2	49

	11	12	13	14	15	16
FREQUENCY (%)	63.04	2.58	0.85	0.12	0.02	0.04
B PROFILES (%)	5	86	35	37	51	69
FOCUSING (%)	3.5	73	12	9	35	15

Figure 4. Idealized Sound Profile Types, Part I



	21	22	23	24	25	26
FREQUENCY (%)	1.37	1.88	4.70	4.59	0.22	1.46
B PROFILES (%)	99	97	59	1	95	96
FOCUSING (%)	45	87	43	0. 3	48	61



	27	28	29	30	31	32
FREQUENCY (%)	1.93	1.28	0.15	1.47	0.42	1.12
B PROFILES (%)	3	25	74	9	94	43
FOCUSING (%)	0.3	20	21	2.5	61	32

Figure 5. Idealized Sound Profile Types, Part II

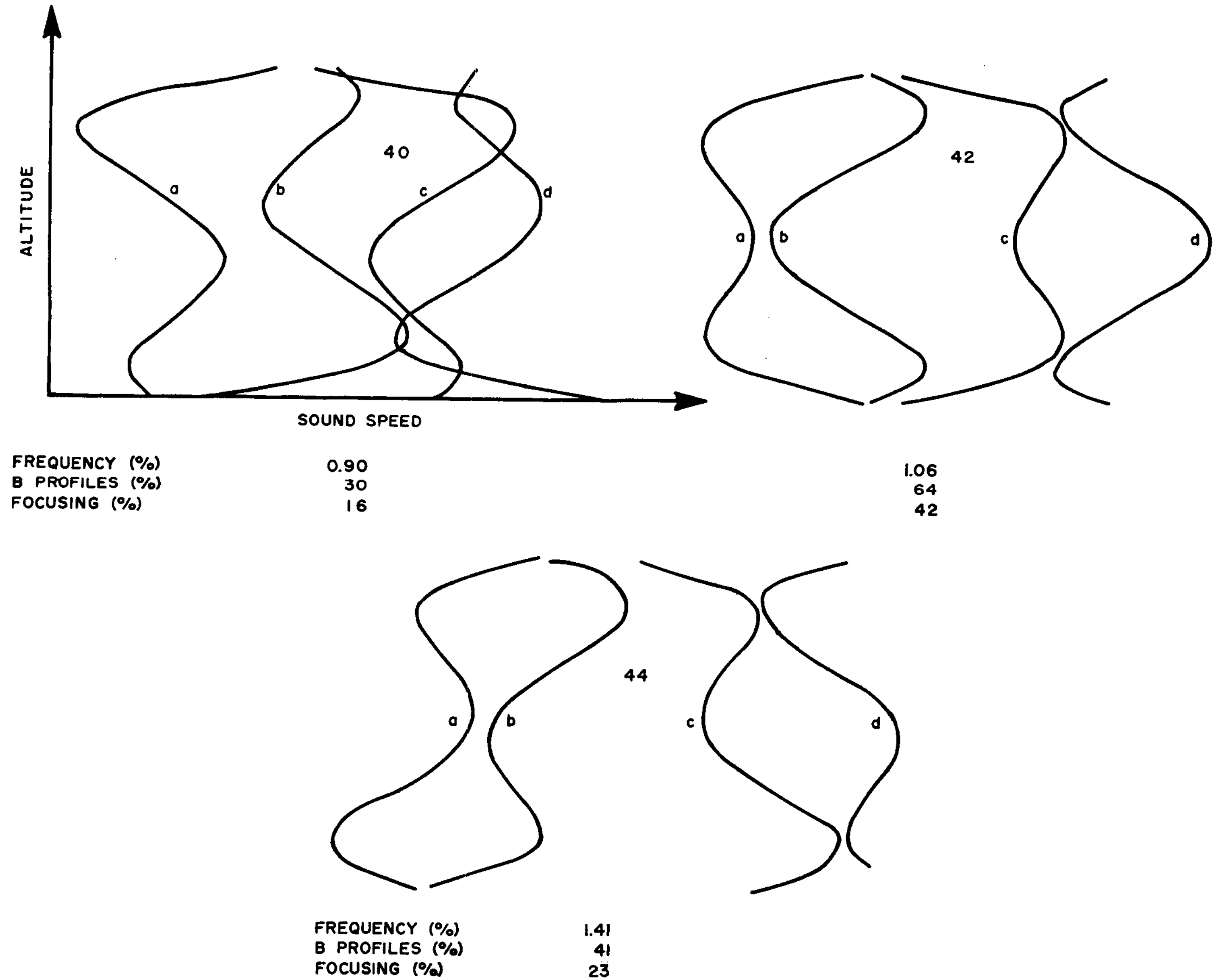


Figure 6. Idealized Sound Profiles, Part III

with respect to the acoustical behavior. Thus, the fixed framework of prototype becomes useful through the association of empirical profiles.

To further confirm the significance of the types, a similar statistical survey as in Table II has been established for a completely different climatic regime, namely Chateauroux in France. Table III extracts data from this study for comparison between the two climatic areas. The number of B profiles per type, the fraction of focusing per B profiles, and the focusing per type compare favorably for all profile types. Only a few cases of larger deviation can be noticed, whose frequency of occurrence is very small. Thus, no statistical significance can be given to those deviations.

It should be stressed that there is a climatic difference between the two areas. The focusing statistics show considerable change. This change is generated, however, by the variation of the type frequency and not by different acoustic behavior within the type. Thus, it may be concluded that the types can be used to adequately express the acoustical behavior of the atmosphere with respect to focusing and returning rays.

Figure 7 illustrates the three types with the highest focusing changes and the three types, when focusing is small. Comparison of these empirical mean sound speeds with the idealized types of Figures 4 through 6 reveals that types 12, 22, 24, and 27 are closer to the ideal model than types 1 and 11. The deviation from the model type in the lower 1000 meters explains the high chances of focusing.

4. Seasonal Variation of Types and Differences in Azimuth

Paragraph 3 of this report has described the types of sound speed profiles in the lower three kilometers of the atmosphere and their relationship to areas of high acoustic intensity (expressed by focusing). It was explained that focusing per type showed virtually no seasonal or climatic dependency. The seasonal variation must, therefore, be achieved by the variation of types with season.

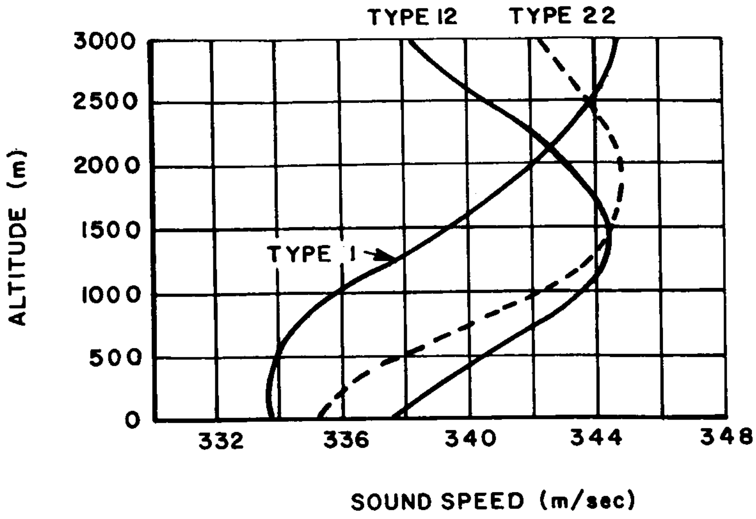
To begin with, Figure 8 displays the seasonal and azimuthal variation of focusing for Nashville, Tennessee, at 1700 hours local time. Focusing exhibits a peak at easterly azimuths and occurs more frequently in winter. Similar features can be found at Chateauroux, France (Figure 9). The peak in winter appears at southeasterly azimuths.

Table III. Comparison of Type Survey Between Southeast United States and Chateauroux, France

Profile Type	B Profiles		Focusing of B		Focusing of Type	
	SE US	Chat.	SE US	Chat.	SE US	Chat.
1	100	100.0	86	84	86.0	84.0
2	29	25.0	18	14	5.0	4.0
3	46	54.0	57	59	26.0	32.0
4	63	65.0	41	69	26.0	45.0
5	45	33.0*	5	0*	2.0	0.0*
6	81	100.0*	61	50*	49.0	50.0*
11	5	4.0	69	69	4.0	3.0
12	86	83.0	84	82	73.0	68.0
13	35	33.0	36	41	12.0	13.0
14	37	43.0	25	30	9.0	13.0
15	51	100.0*	68	100*	35.0	100.0*
16	69	69.0*	21	22*	15.0	15.0*
21	99	99.0	45	49	45.0	49.0
22	97	96.0	90	82	87.0	79.0
23	59	63.0	73	76	43.0	48.0
24	1	0.3	49	33	0.3	0.1
25	95	98.0	51	47	48.0	46.0
26	96	94.0	64	68	61.0	64.0
27	3	2.0	10	10	0.3	0.2
28	25	27.0	81	78	20.0	21.0
29	74	67.0	28	13	21.0	9.0
30	9	8.0	26	22	2.0	2.0
31	94	96.0	64	73	61.0	69.0
32	43	47.0	76	75	32.0	35.0
40	30	43.0	54	60	16.0	26.0
41	35	36.0	50	56	18,0	20.0
42	64	74.0	66	71	42.0	52.0
43	66	81.0	43	60	29.0	49.0
44	41	41.0	56	51	23.0	21.0
45	66	79.0	51	71	34.0	56.0
46	49	46.0	58	56	29.0	25.0
50	76	67.0*	34	50*	26.0	33.0*

*Type total is less than 10.

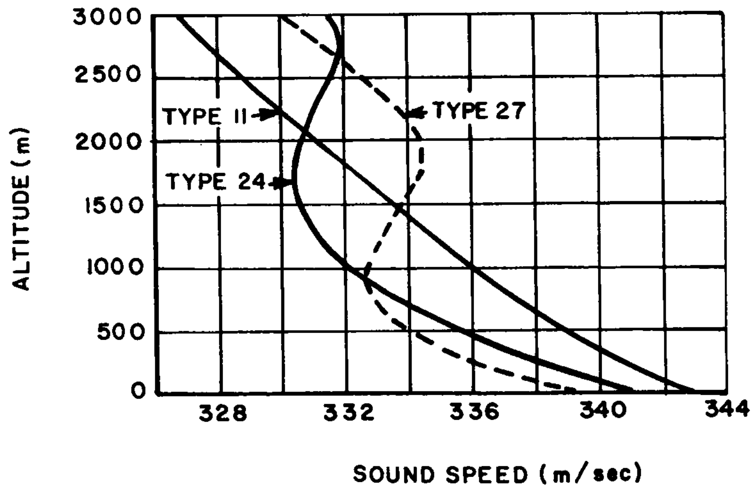
HIGH CHANCES OF FOCUSING



FOCUSING OF

TYPE	B	TYPE
1	86 %	86 %
12	84 %	73 %
22	90 %	87 %

SMALL CHANCES OF FOCUSING



FOCUSING OF

TYPE	B	TYPE
11	69%	4 %
24	49%	0.3%
27	10 %	0.3 %

Figure 7. Types with High Chances and Low Chances of Focusing

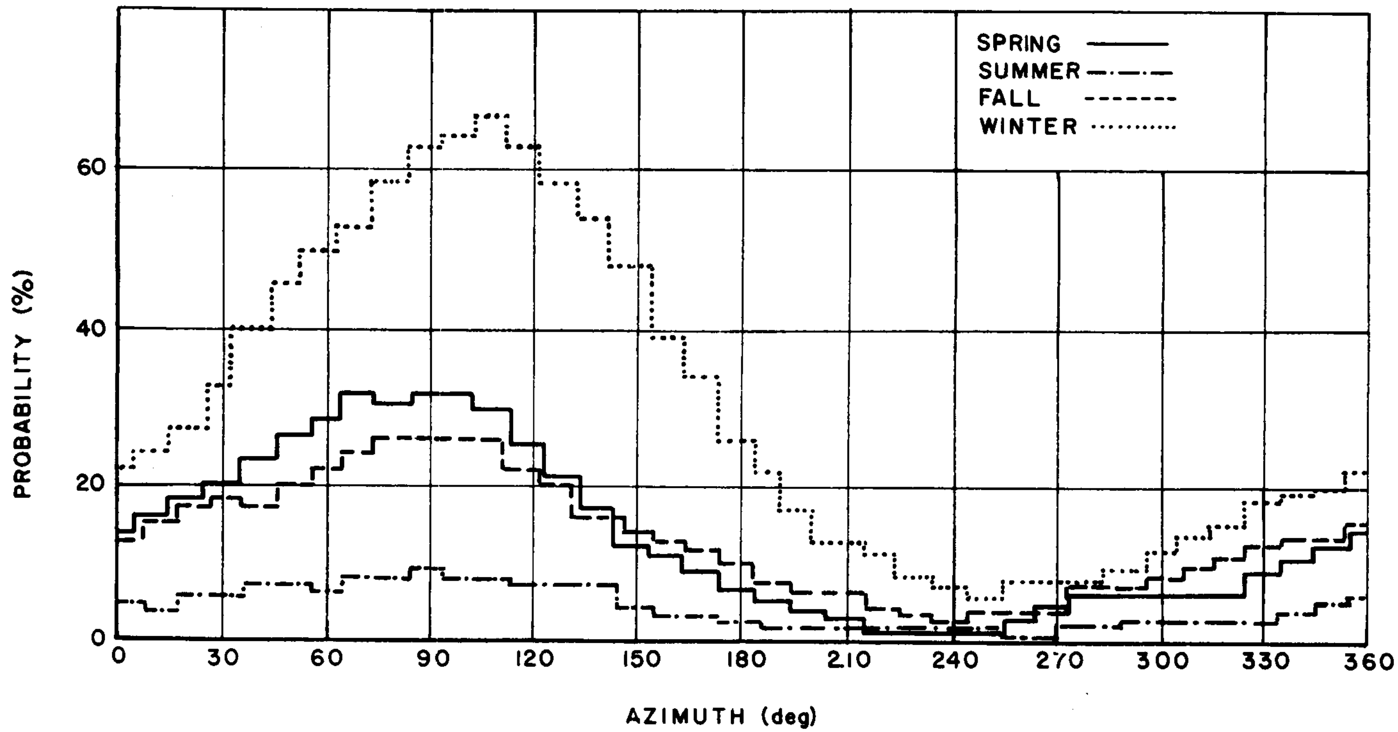


Figure 8. Probabilities of Sound Focusing by Azimuth, Nashville, Tennessee, 17:00 Hours, Local Time

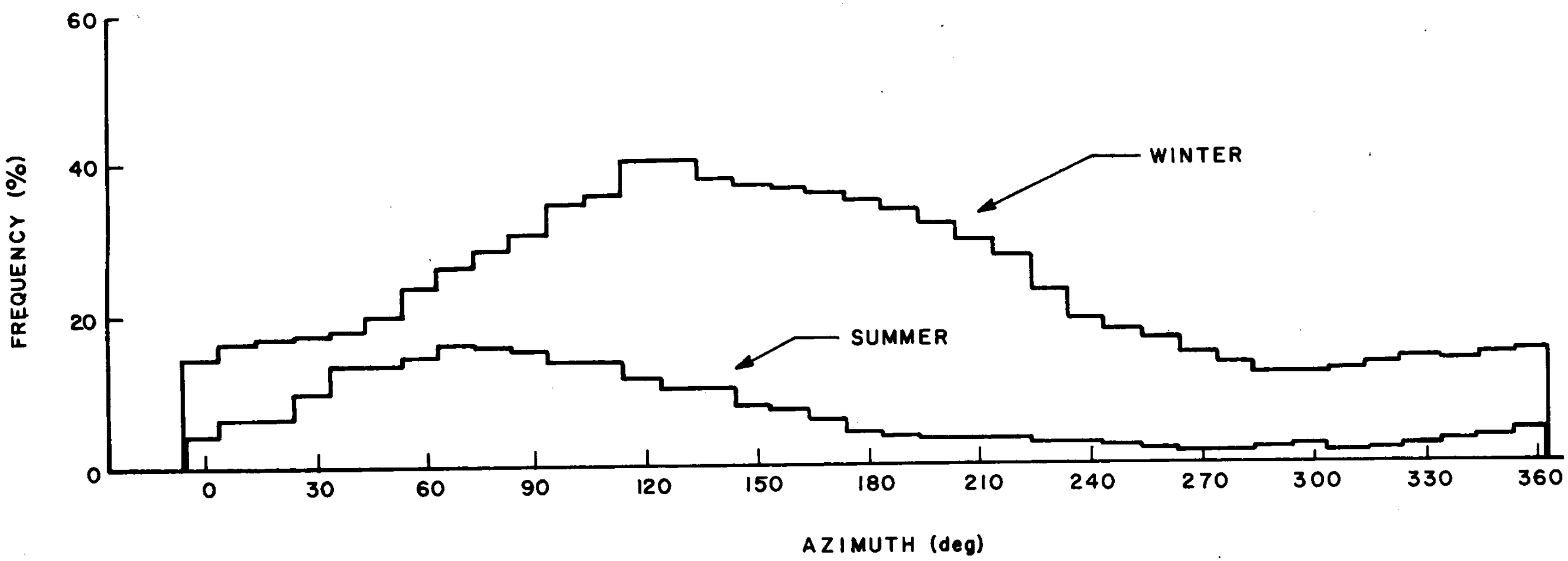


Figure 9. Probabilities of Sound Focusing by Azimuth, Chateauroux, France

The high amount of focusing during the winter months compared with the summer months is reflected in the seasonal variation of the types. Table IV provides data on the seasonal variation of profile types for Nashville and Chateauroux. The profile types have been combined into three groups, the first one with significant relationship to focusing, the second group with significant low focusing frequency. The remaining types could not be grouped into one or the other with statistical significance and were put into a third group.

The survey of Table IV indicates a remarked increase of the focusing types in winter and the reversed trend for the nonfocusing types.

Climatic differences become apparent in the following. Type 1 contributes most to focusing at Nashville, Tennessee, in winter. In contrast, types 12 and 23 are dominant for focusing at Chateauroux.

Although the nonfocusing types delineate the same seasonal trend, no clear climatic difference can be observed. This may be due to the large amount of profiles in type 11, which outnumbers all the other types together. Thus, a climatic change in the dominance of the nonfocusing profiles can hardly be expected.

Data presented in Table IV prove, however, that seasonal and climatic differences are created mostly by the variation of the type frequency. Likewise, the azimuthal difference is caused by appearance of differences in the types. As evidence, Table V is disclosed. Only the summary lines of the combined types as referenced in detail in Table IV are given. Table V contains the summary types for two separate ranges of azimuth, between 70 to 110 and 250 to 290 degrees. Focusing types appear more frequently at easterly azimuths in agreement with Figure 8.

5. Relationship Between Types and Atmospheric Profile

In Paragraph 4 of this report, a system of types of sound speed profiles has been discussed, the relationship to focusing derived, and the seasonal and azimuthal variation delineated. The study would be incomplete if no mentioning of the atmospheric profiles associated with the types were made.

A diversified investigation would have taken more time than was available for completion of this report. Therefore, only preliminary results were obtained for some specified conditions. First, two

Table IV. Seasonal Variation of Type Frequency

Profile Type	Nashville, 17^h Local Time				Chateauroux	
	Spring	Summer	Fall	Winter	Summer	Winter
Focusing						
1	4.4	0.4	4.5	14.2	1.1	4.2
12	1.5	0.6	2.0	4.3	0.8	7.3
22	1.3	0.2	1.3	3.9	0.4	3.2
23	2.9	2.1	3.5	4.5	1.9	9.4
26	1.6	0.4	1.8	2.9	1.0	1.5
31	0.3	0.2	0.4	0.6	0.4	0.7
Total	12.0	3.9	13.5	30.4	5.6	26.3
Nonfocusing						
2	3.7	1.0	2.4	2.5	2.5	1.1
11	66.0	85.2	66.6	46.1	75.8	52.4
14	0.1	0.02	0.1	0.1	0.1	0.2
24	6.5	5.6	5.7	4.7	6.2	3.9
27	1.8	1.5	1.7	2.1	2.4	2.1
30	2.0	0.9	1.8	1.9	1.7	1.4
Total	80.1	94.2	78.3	57.4	88.7	61.1
Others						
3	0.1	0.01	0.1	0.2	0.1	0.4
4	0.1	0.01	0.05	0.1	0.03	0.1
5	0.02	-	0.01	0.01	-	0.01
6	0.01	-	0.01	0.01	-	0.03
13	0.8	0.4	0.8	1.2	1.2	1.3
15	-	0.02	-	0.01	0.01	0.01
16	0.01	-	0.05	0.1	0.04	0.02
21	2.5	0.2	1.6	3.3	1.0	0.9
25	0.04	-	0.1	0.3	0.1	0.4
28	0.7	0.2	0.9	0.8	0.3	1.9
29	0.2	0.01	0.3	0.4	0.2	0.2
32	0.3	0.2	0.5	1.0	0.3	2.3
40	0.7	0.2	0.8	0.9	0.6	1.2
41	0.1	0.02	0.2	0.2	0.1	0.2
42	1.0	0.2	0.9	1.3	0.6	1.5
43	0.2	0.01	0.3	0.3	0.2	0.4
44	0.7	0.2	1.0	1.5	0.7	1.3
45	0.2	0.1	0.2	0.4	0.1	0.4
46	0.2	0.1	0.3	0.5	0.2	0.3
50	0.01	0.03	-	0.03	-	0.01
Total	7.9	1.9	8.2	12.2	5.8	12.6

Table V. Type Distribution for Easterly and Westerly Azimuths (Nashville, Tennessee, 17^h Local Time)

	70 to 110 Degrees	250 to 290 Degrees
Focusing	29.3%	2.4%
Nonfocusing	57.8%	96.7%
Others	12.9%	0.9%

azimuth ranges were selected, easterly and westerly, similar to the ranges for Table V. Further, a subdivision was made on B profiles (with chances of focusing, see Table II) being present or absent for the selected azimuth ranges. The resulting mean temperature, wind speed and direction profiles were computed. This is exhibited in Figure 10.

Although dispersion of the atmospheric conditions is disclosed for all three elements, the separation in the mean wind direction profiles is most striking. It expresses that B profiles (and associated acoustic focusing) appear for easterly azimuths, if the wind direction is westerly. B profiles for westerly azimuth, however, are more associated with northerly winds. This confirms again the influence of the wind upon acoustic focusing, discussed by the author in several other reports.[6,7,8] The mean wind direction was computed by methods derived by the author as published previously.[9,10] Compared with this mean difference, 60 to 90 degrees, the nonfocusing profiles show only a small separation in the mean wind direction.

The wind speed is from 2 to 5 meters per second higher for weather situations with focusing chances at easterly azimuths than it is for westerly azimuths. This result is reasonable since, in general, westerly winds are stronger than easterly winds and westerly winds create focusing conditions for easterly azimuths. The dispersion between the average wind speed for B and no B profiles in the range between 70 to 110 degrees azimuth can be interpreted to mean that stronger winds lead more to atmospheric conditions favorable to focusing than weaker winds. This is supplemented by the temperature profiles, whose gradient seems steeper in the cases of B profiles. Thus, wind and temperature profiles support one another to create sound speed profiles with an increase of the sound speed from the ground, which in turn lead to returning rays and focusing or vice versa to generate conditions for nonfocusing.

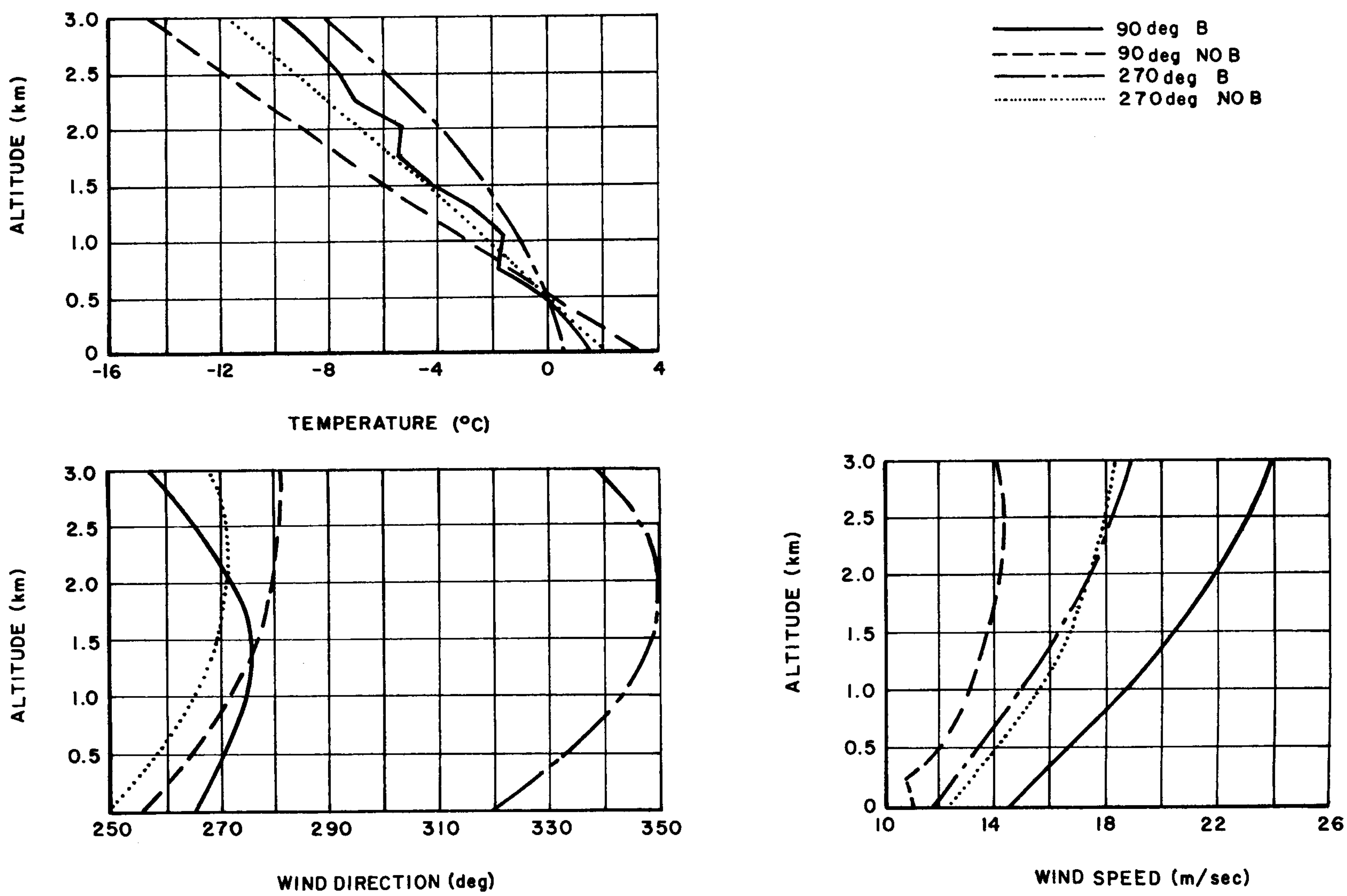


Figure 10. Mean Temperature, Wind Speed, and Direction Profiles for Profile Types B or No B at Easterly and Westerly Azimuths

6. Conclusions

In the preceeding study, it has been attempted to introduce a workable scheme of classifying sound speed profiles into characteristic types with an objective method where classes can be determined by electronic computers. It has been shown that an objective scheme can be developed based upon a representation of the sound speed profile by orthogonal polynomials, the utilization of the so-called "percentage reduction" (Equation 9) and the maximum linear correlation coefficient between the sound speed profile and the prototypes. A system of 32 types resulted for the climatic regime of the Southeast United States. It proved sufficient also for atmospheric conditions in France. The types were subdivided into three groups by their association with acoustic wave propagation, namely without and with returning rays from the atmosphere and with chances of acoustic focusing as a measure of areas with high acoustic energy. The survey in Table II relates the types and the three groups and provides data on frequency of occurrence in the climatic regime of the Southeast United States.

The introduced types show significant relationship to focusing with independence of focusing chances per type from azimuth, season, or climatic regime (Table III). Thus, seasonal, azimuthal, and climatic variations of focusing are associated with changes of types.

A preliminary survey of the relationship between the sound speed profiles with and without chances of focusing and the atmospheric profiles of temperature, wind direction, and wind speed was given. The results indicate a definite connection between the weather situation and focusing which is also supported by results established in a recently published report.[8]

The results would exceed the frame of this article if all details were presented which were investigated during the establishment of the classification system for sound speed profiles. More information can be obtained in a forthcoming report.[4]

Further, the present study refers only to acoustic focusing as a source of areas with high acoustic energy. The statistics can certainly be expanded to include other areas of high energy. Focusing was the phenomena, however, through which a relative simple objective tool could be developed in a reasonable time and which contains most of the high intensity area.[5]

More work is necessary to establish a closer relationship between the sound speed profiles and the weather situation with the final goal of relating acoustic parameters to the atmospheric profiles. The classification system of sound profiles can then be considered as one step towards that goal.

The object of this investigation was to develop a systematic classification scheme for sound speed profiles. Nothing speaks against the application of the method to other meteorological parameters as long as they can be fairly well represented by a limited number of orthogonal polynomial terms. The limited number is desirable only to restrict the sum of prototypes. Since the prototypes are based on the system of the percentage reduction, which in the case of the sound speed profiles seem sufficiently large for the first terms, a combination of smaller terms can be arranged which also makes the method applicable to classification of weather maps.

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The derivation of characteristic profiles for the sound speed is discussed and a classification system introduced. The system comprises 32 types of sound profiles with subsequent division into three groups, namely without and with returning rays and with focusing. The idealized 32 prototypes of the classification system are based on the percentage reduction for orthogonal polynomials and the sound speed profiles are classified by utilization of the maximum relationship with the prototypes.

The types show significant relationship with acoustic focusing and display practically no seasonal, azimuthal, or climatic variation for focusing. Therefore, seasonal, azimuthal, and climatic changes are caused by the occurrence of types. These seasonal, climatic, and azimuthal fluctuations of the types are presented.

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