JERZY WEHR

JERZY WEHR, 54, professor, for many years the scientific worker of the Institute of Fundamental Technological Research, Polish Academy of Sciences, lost his life in the prime of his creative forces, as a member of a climbing expedition in Hindu Kush at the altitude of 6000 m on August 10th, 1977.

This tragic event put an end to the activities of a man of unusual versatility, a scientist known in the milieu of acousticians who has managed to assemble around him not only the closest co-workers, but also many other scientists from all over Poland.

Professor Jerzy WEHR started his scientific career at the Warsaw Technical University, initially in the field of electronics. Since 1952 he has dealt with acoustics, working in the Vibrations Research Department and, subsequently, in the Institute of Fundamental Technological Research of the Polish Academy of Sciences. In 1954 he published his first paper on the application of transversal and standing waves to the detection of flaws. In 1961 he obtained his Ph. D. degree after presenting a thesis on "The use of non-reflective transducers in the measurements of ultrasound". In 1969 he obtained the title of assistant professor, after presenting the paper "Ultrasonic method of the determination of density and compressibility of liquids". He was nominated professor in 1975. In the recent years he performed the function of the deputy director for scientific matters in the Institute of Fundamental Technological Research of the Polish Academy of Sciences. He has also been a coordinator of the interdisciplinary problem of the application of acoustic methods in engineering and medicine, involving all the acoustic research centres in the country.

As a member of the Committee on Acoustics of the Polish Academy of Sciences, Professor WEHR greatly contributed to the rapid development of acoustics studies in Poland. He pointed to the main perspective directions of investigations which he was carryingo ut with his own team. He also stimulated the research work of other Polish research centres.

The scientific contribution of Professor Jerzy WEHR comprises a total of 58 publications including 2 books, 10 patents on the ultrasonic detection of flaws, the ultrasonic methods of measuring mechanical properties of solids and liquids, the piezoelectric transducers and ultrasonic probes, with special attention given to the ceramic materials and plastics, and also to the methods of dimensional analysis and electro-mechanical analogy. In his last works Professor WEHR attacked the difficult problem of the measurements in dispersive media.

The results of longstanding and consistent investigations, regarding the methods of physical acoustics, were published in numerous Polish and foreign periodicals. Many of these papers were presented by Professor WEHR at acoustical meetings in Poland and abroad.

Apart from his scientific activities Professor Jerzy WEHR has developed a number of measuring devices based on his own patents. The achievements in this field not only distinguish him as a talented designer but also demonstrate his ability to take advantage of his own theoretical considerations in the construction of the above-mentioned devices.

Vast scientific production of Professor WEHR, concerning the development of the methods of measuring the velocity and damping of ultrasonic waves, was recapitulated in an extensive monograph under the title "The measurements of the velocity and damping of ultrasonic waves" published in 1972. It presents briefly his numerous achievements in this field and constitutes a valuable item in the world's literature, being based on rich experimental material and due to the clear and concise formulation. The book was to be translated into foreign languages.

Professor Jerzy WEHR's scientific achievement has placed him amidst the world's best and not numerous scientific authorities on ultrasonic measurements. Over the 25 years of his scientific work he has developed and used ingeniously a number of experimental methods intended primarily to obtain the information about the material structure. Special mention deserves not only his mastery elaboration of diverse experimental techniques but also a thorough knowledge and understanding of the physical phenomena being the subject of his investigations. He possessed an unusual ability of seeing and presenting complicated problems in a clear and simple way. In 1966 he was awarded the Collective Scientific State Prize of the 2nd degree. He also received many Polish and foreign medals.

Being for many years the head of the Physical Acoustics Department, he took care of the young scientific workers and despite of his numerous duties — always amicable and friendly — he found the time to render advice to those needing his assistance. He has left a group of disciples who will continue his work. A humanist and erudite, speaking fluently six languages, he maintained contacts with scientists in many countries. He worked in scientific institutions in the United States, the USSR, England, Italy, France, Switzerland

and Cuba. On his return from Hindu Kush he was to deliver a series of lectures in recognized acoustic centres in France.

He had many passions. His knowledge of the fine arts, history, politics, literature and music was amazing. He was an excellent sportsman and ardent traveller — the mountains were part of his life. He took part in scientific research expeditions organized by the Polish Academy of Sciences to Vietnam and Spitsbergen. He climbed the peaks in the Tatra Mountains, the Alps and the Rocky Mountains, he was also a successful climber in the mountains of Spitsbergen, Hindu Kush and the Caucasus.

Full of creative forces, he set out every year for subsequent ascents in the high mountains. This time he did not return, remaining for ever on the slope of Nadir Shak summit. Polish acoustics has suffered a severe and painul loss.

ARCHIVES OF ACOUSTICS
3,2, 79-84 (1978)

OPENING TRANSIENTS AND THE QUALITY OF CLASSIC GUITARS

A. JAROSZEWSKI, A. RAKOWSKI, J. ŻERA

Laboratory of Musical Acoustics, Academy of Music
Okólnik 2, 00-368 Warszawa

Analysis of the correlation between opening transients of guitar sounds and the guitar quality as determined by the subjective assessment by music experts is presented.

1. Introduction

Earlier attempts, carried out in various laboratories, to find out which of the easily measurable physical characteristics of guitars could well represent their quality were not very successful. These attempts pertained mostly to the frequency response of guitar resonators [1-3].

As a rule, the frequency response of a guitar resonator is rather complex and cannot be approximated by simple functions. Therefore for a pragmatic type of analysis only the most pronounced resonances or the general features of the integrated frequency responses are usually taken into account. To add to the complexity of the problem, the frequency responses depend significantly on the type of excitation of the resonators, i.e. on the nature of the signal, the point of application of the transmitting and receiving transducers or the location and distance of the microphone, if used. In addition, it is well known that the frequency response depends on the brand of the strings and their tension.

Although various experiments in our laboratory produced a vast amount of data, the analysis often showed only slight correlations between easily distinguishable resonances in the frequency response and the subjective quality ranking.

Further work was directed to the measurement of the frequency spectrum of guitar sounds. For some purely technical reasons, in these experiments the amplitudes of partials of the sounds analysed, were recorded on the spectrum charts at the time instants always corresponding to the maximum of signal amplitude. Unfortunately the sound spectra recorded in such a way were very similar for the worst and the best guitars tested, and could hardly be used for a comparison of instrument quality. The natural solution in such a situation would be to measure the running spectrum of the subsequent guitar sounds. This method, however, appeared to be very troublesome.

The differences in the subjective quality assessment pertained particularly to the initial transient of the sounds. Sounds characterized by a very rapid initial transient were often defined as "hard", "flat" or "noisy" and were scored low. On the contrary, high scores were mainly assigned to sounds rising slowly in loudness and usually defined as "soft" or "pleasant". Thus the next step in the research programme was the measurement of the opening transient (attack or onset) times of the subsequent sounds of various guitars, and a comparison of the results with the subjective quality assessment. This part of the programme is covered briefly in the present report.

2. The examined instruments

The experiments were performed using thirteen classic guitars well differentiated as regards their quality. It must be emphasized, however, that these instruments ranged from quite poor inexpensive student instruments to average master-class hand-made guitars. No instruments of a very superior quality were included in the tests. All these instruments were tuned to A4 = 440 Hz prior to the quality assessment by expert guitar players and sound temporal analysis. All sounds up to the fourth position were examined, except for the E4 string on which the fifth position was also used. In such a manner, the onset times were determined for all the chromatic scale sounds from E1 to A4, for each guitar tested.

3. Subjective quality assessment

Three well recognized professional guitar players who were experienced in similar tests served as experts in the quality assessment. The assessment sessions were distributed over six months and lasted from 30 min to 1,5 h each, depending on the spare time of the musicians. Instruments were compared in pairs by playing single sounds or chords (but not tunes) on each of the two instruments, using sounds from E2 to A4. The expert's final task in each comparison was to decide which of the two guitars sounded better. The time limit for the comparison of one pair was approximately 30 min. Usually one or two, but never more than three judgements were made in one session. The tests were carried out in a typical classroom.

4. Onset time measurements

The experimental arrangement used for the tests was very simple. The strings in all tested instruments were activated using a small piece of plastic material with a very thin metal layer thickness $0,3 \cdot 10^{-2}$cm covering one side of the plastic. Plastic strings were used. Bass strings had usual metallic winding, the remaining strings obtained a short, very thin, copper wire winding. Both the strings and the metal layer on the piece of plastic used for string activation were connected to the electronic circuit, which, at the instant of opening the circuit, produced an electric pulse of about 10^{-5} sec duration at its output. This pulse was fed to the synchroscope and used to trigger the time base.

The sound signal was picked up using a Brüel & Kjaer 4331 condenser microphone located 50 cm from the top plate in the direction approximately normal to its center. This signal was fed via a Brüel & Kjaer 2604 amplifier to the synchroscope and photographed. The onset times were determined as the time between the detectable beginning of the signal and the moment at which the amplitude of the signal reached its maximum. In cases where this procedure could not have been used (i.e. for sounds which increased in loudness firstly rather rapidly and then only slowly) the time to reach a value of 90 % of the maximum amplitude value was taken as representative.

Preliminary measurements showed that in low quality instruments the opening transient envelope usually depended strongly on the force applied to sound the string, particularly at low sound intensity levels. For higher levels this dependence was determined to be insignificant and could have been neglected. For this reason all the onset time measurements and the subjective quality assessment were carried out at loudness levels proximal to mezzo-forte forte.

5. The results

The results are presented in Figs. 1, 2 and 3 which show the correlation between the onset times and quality assessment in the 13 instruments investigated. In Fig. 1 the distribution of all of the 30 onset time values for each instrument is shown, the histograms being ordered according to the quality assessment of the instrument: from 1 (the worst guitar) to 13 (the best one). The median values and interquartiles of all the 13 distributions are shown in Fig. 2. To evaluate the relative value of the dispersion of the results the ratio $2Q/M$ was computed for each distribution and the results are presented in Fig. 3. The following additional observations were made:

Sounds with longer onset times had generally a shorter decay and were often described as "pleasant" and "soft".

Sounds with shorter onset times had generally a longer decay and were often described as "flat", "hard" and "less tonal".

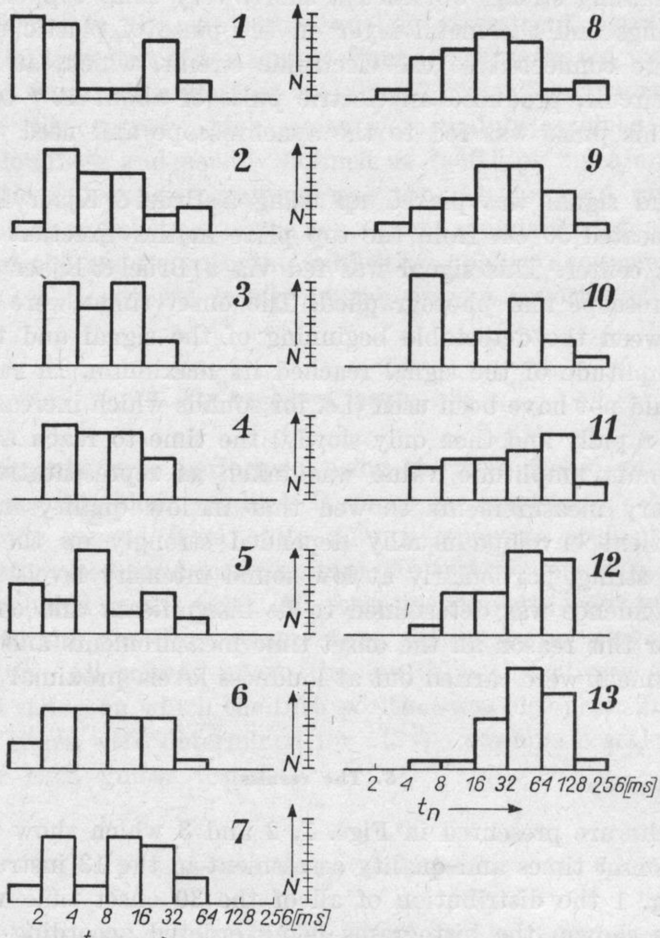


Fig. 1. Onset time histograms for 13 guitars of various quality, ranging from very low quality (1) to very high quality (13)

t_n – onset time, N – number of sounds within each t_n class

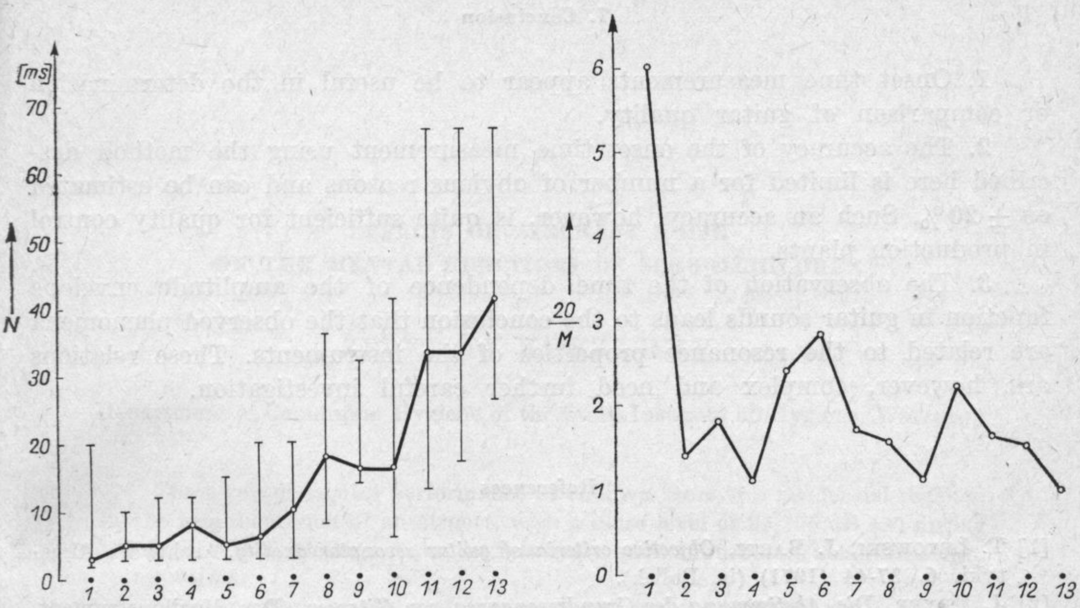


Fig. 2. Median values and interquartiles of the onset times of sounds for 13 guitars ranged as in Fig. 1

Fig. 3. Ratio of interquartile ranges and medians of the onset times of 13 guitars ranged as in Fig. 1

6. Discussion

The results presented in Figs. 1 and 2 show a rather pronounced correlation between the subjective quality scores and the onset times. The presentation of the results in Fig. 3 shows also that the higher scored instruments show a smaller relative dispersion of the values of the onset times. For example the instrument scored 1 (lowest subjective quality) had the longest onset time – 40 ms; and the shortest – 1 ms (ratio 40 : 1) while the best scored instrument (13) had the longest onset time of 132 ms whereas its shortest time was only 16,5 ms (ratio 8 : 1). However it must be emphasized that in the instrument scored 13 only D3 sharp had such a short onset time, the remainder were all above 30 ms whereas in the instrument scored 1 most of the sounds over the whole range of the scale, tested from E2 – E4, had onset times ranging from 1 to 3 ms.

It should be also emphasized that in revealing the relations between the amplitude envelope form and the quality scores a large amount of information is ignored. The shape of the envelope changed dramatically and it is believed that apart from the onset time, the shape of the envelope may have influenced the quality scoring.

7. Conclusion

1. Onset time measurements appear to be useful in the determination or comparison of guitar quality.

2. The accuracy of the onset time measurement using the method described here is limited for a number of obvious reasons and can be estimated as ± 20%. Such an accuracy, however, is quite sufficient for quality control in production plants.

3. The observation of the time dependence of the amplitude envelope function in guitar sounds leads to the conclusion that the observed phenomena are related to the resonance properties of the instruments. These relations are, however, complex and need further careful investigation.

References

[1] T. Łętowski, J. Bartz, *Objective criteria of guitar resonator quality*, Archiwum Akustyki, **6**, 37-44 (1971) (in Polish).

[2] J. Meyer, *Die Abstimmung der Grundresonanzen von Gitarren*, Das Musikinstrument, **23**, 179-186 (1974).

[3] J. Meyer, *Das Resonanzverhalten von Gitarren bei mittleren Frequenzen*, Das Musikinstrument, **23**, 1095-1102 (1974).

Received on 29th September 1977

ARCHIVES OF ACOUSTICS
3, 2, 85-105 (1978)

EFFECTS OF AIRCRAFT NOISE ON THE MENTAL FUNCTIONS OF SCHOOLCHILDREN

ZBIGNIEW KOSZARNY

Department of Communal Hygiene of the State Institute of Hygiene, Warszawa

The levels of mental performance of children from two residential regions: in the neighbourhood of an airport, with a noise level of 95-105 dB (A) during the flight of a single aircraft, and a relatively quiet suburban Warsaw areas were appraised.

A comparative analysis of the results of the investigations has revealed a considerable difference in the psychomotoric performances and attention level.

For the inhabitants from the intensive noise area the lengthening of the time of a simple reaction, reduced visual and motoric coordination, disorder of psychomotoric control, and reduced ability of the concentrated and divided attention were observed.

Experiments on the effects of intense noise have also revealed the detrimental influence of this noise upon all the aforementioned psychological processes for all people regardless of their acoustic environment. However, stronger effect of the experimental noise was found for children from the quiet areas and for children with an increased neuroticity.

1. Introduction

Former investigations of the influence of noise upon man have been devoted to the biological and psychological consequences of noise affecting the human organism engaged in professional work. The results of investigations conducted in laboratories and in manufacturing plants have been reviewed, inter alia, by BINASCHI and PELFINI [6], BROADBENT [7], and JANSEN [17]. In recent years new, more systematic investigations on the influence of industrial noise on workers have been carried out [9-13, 22, 23, 28, 31]. Despite some doubt and controversy in the interpretation of the obtained results, these investigations point to disadvantageous and complex relationships between the performance level of various psychological human functions or the performance and quality of certain types of professional work, and the types and duration of acoustic stimuli. However, it is hard to foresee to what extent the effects found under conditions of intense industrial noise can be related to the influence of noise at the place of residence.

The few papers published so far on this subject reveal a particularly disadvantageous effect of noise at the dwelling-place. This mainly applies to aircraft noise which, owing to its nature and intensity, constitutes a serious health hazard for the people living in the neighbourhood of an airport. The results of these investigations indicate that psychical diseases occur more frequently in the proximity of airports [1]; the weight of newborn children is reduced under the effect of aircraft noise [3]; the reactions of children to noise become modified as a result of their mothers' stay in a noise-affected area during pregnancy [2]; and a reduced mean level of speed of mental work of schoolchildren occurs [4, 19].

The present paper analyses similar problems. The investigations attempted to evaluate some of the psychological processes of pupils born and living in an airport neighbourhood. Attention has been focussed on learning the differences in the way the children exposed to different noise intensities at their dwelling-places react to a standard noise level. Attempts have also been made to establish the relation between the disorder caused by noise and some personal features. Initially the following hypotheses were formulated:

(a) aircraft noise unfavourably affects the psychological processes of children living in an airport neighbourhood;

(b) the performance of mental functions deteriorates during noisy periods;

(c) certain differences in the reaction to the noise intensity can be observed in the children from the acoustically different regions;

(d) a relation exists between the degree of disorder in mental performance and certain personal features.

2. Subjects and methodology

The characterization of the examined persons. The investigations involved 138 children from the 6th and 7th forms of a primary school who were born and living in an area affected by aircraft noise from the Warszawa-Okęcie airport, and 147 children who have lived since their birth within a zone of relative tranquility, in the Zielonka area near Warsaw.

When choosing the groups to be examined, the following variables were taken into consideration: age, sex, socio-economic status, and the professional education group of the main supporter of the family. The analysis showed that both populations were comparable as regards the above-mentioned variables. The average age of the children was about 13 years (12.5 in the 6th form; 13.5 in the 7th form). A factor essentially differentiating between the groups was the acoustic conditions prevailing at their dwelling-places, notably in respect of aircraft noise.

The children from the Warszawa-Okęcie area live in a zone affected by aircraft noise at a level of 95-105 dB (A), as produced by a single flying aircraft. The actual intensity of the noise obviously depends on the volume of the air traffic, which increases with every passing year (in 1975 more than 44 000 flights were recorded). In the area around Zielonka aircraft noise essentially does not occur. There is no railway noise in either region. Apart from the aircraft noise, measurements of noise along traffic routes point to more favourable acoustic conditions in the Zielonka area. The volume of the automobile traffic in this region is insignificant, while equivalent noise levels on the two thoroughfares of the traffic system do not exceed 58 dB (A). In the other streets, which have the character of approach roads to homes, the measured noise level varied between 45 and 50 dB (A).

In the Okęcie residential district the intensity of traffic noise is especially noticeable along the Krakowska Avenue, attaining a value for the equivalent level of 74 dB (A). This noise affected 16 % of the examined persons. In the remainder of the Okęcie area, the traffic noise levels vary from 47 to 55 dB (A). In both regions the buildings are similar, being mainly low, detached houses.

In addition to the above differences in the acoustic conditions at the dwelling-places, it might also be expected that contacts with the noisy centre of Warsaw are more frequent for the children from the Okęcie residential district than for the children from Zielonka. Consequently, the acoustic conditions in Okęcie are less favourable than those in Zielonka. The Okęcie area will, therefore, in the following pages of this paper be referred to as the noisy region, the area around Zielonka as the quiet one.

Description of the methods used. For appraisal of the psychological processes and the verification of the hypotheses we used devices for psychologic examinations and "paper" tests for the determination of psychomotoric performance, attention, perception and neurotic tendencies of children.

The choice of the above-mentioned variables was dictated by both practical and other commanding reasons. Previous investigations on the effect of noise have determined the suitability of many relevant tests and the conditions for their application and their limitations.

The tests have been selected in such a way as to obtain the most comprehensive picture of motoric performance and to estimate various forms of attention. These processes are related to the disposition to mental work [33] and may be of importance in assessing the state of the nervous system [18, 30]. The description of the tests according to the sequence of their application in the investigations is given below.

1. "Attention test by Poppelreuter". The test consists in ordering, during a strictly defined time, the numbers placed at random in various fields of the test tables. The measure of the test is the number of ordered numbers. The test is used for the investigation of the divisibility of attention.

2. "Two-crossing test" in the ZAZZO system [32] serves for the comparison of the performance at two levels of difficulty of the task which com-

prises the crossing of one sign followed by the crossing of two signs. The test provides an estimation of the degree of adaptation of the examined child to easy but monotonous work which requires a strong will and concentrated attention. Thanks to precisely defined indicators it is possible to measure precisely the potential of a child as regards the rate and accuracy of the performed work, and to estimate its ability in terms of psychomotority control.

3. The "Piórkowski device" permits assessment of visual and motoric coordination, the division of attention, and perceptivity; it also examines the reaction speed at a prescribed rate. In the investigations three rates of light stimuli, of 93, 107 and 125 pulses per minute, were used. The time of the examination at each rate was 1.5 min. The results were recorded automatically.

4. "Reaction time meter". This is a set of devices comprising an electronic digital time meter, programming equipment to control the exposure to stimuli, and a generator of optical and acoustic stimuli. The time is measured to an accuracy of 0.001s. The reaction time is determined by measuring the time period between the moment of visual stimulus and the moment of pressing by the school-child an appropriate key. The stimuli were generated at random intervals. A series of 28 stimuli was used for each examination. The measurement of the reaction time is used for investigation of the motivation, attention and, especially, the reactivity.

5. "Couvé's test". The test consists in crossing, during a prescribed time, 40 precisely determined numbers out of the 100 three-digit numbers in the table. The Couvé test is used for examining the concentration of attention.

6. "Evident anxiety test". This test serves [25] to examine the neurotic tendencies of children at school age (9-16). The Polish adaptation comprises two scales: the 40-question scale of neurosis and the 9-question scale of falsehood. The neurosis scale measures the mental state of a child as expressed by uneasiness, anxiety, fear or concern, and by psychosomatic symptoms. The falsehood scale is a control scale permitting estimation of the frankness of those answers of the child which might present him in an unfavourable light.

The conditions and methods of performing the investigations tests. The investigations were carried out from November to March in the school year 1975/1976. They took place at a time intended for school teaching in a specially prepared school room. A 4-person group took part in the investigations. Prior to each test, the pupils had been encouraged to put maximum mental effort into solving individual tasks.

According to the assumptions and the purpose of this paper the children from both regions were examined twice.

The first examination was intended to estimate the performance level of some of the mental functions of the children from the different acoustic regions. This investigation was carried out under normal acoustic conditions in the school.

During the second examination an experiment was carried out to discern the reaction of the children to the noise emitted by a loudspeaker system. In the experiment two groups were formed by the method of random choice (including pupils from both acoustic regions). One group was examined during exposure to the noise while the other was examined in the quiet and constituted a control group. In order to check the correct choice of groups for a planned experiment, the results of the first investigation were used.

The interval between the first and the second examination was about two months for each child.

Each series of investigations was carried out using the same set of tests and under similar external conditions. The equivalent level during the performance of the tests in the quiet varied from 38 to 43 dB (A). The upper levels were mostly recorded at Zielonka. The less favourable acoustic conditions found in the test room at Zielonka rather support the hypothesis of this paper, since a possible reduction of the mental performance of the children from the airport neighbourhood can be related with a higher likelihood to the effect of aircraft noise.

In analyzing the noise stress during the second examination, the noise emitted from a loudspeaker system was an imitation of a starting aircraft recorded on magnetic tape with a noise level equivalent to 85 dB (A). The spectrum of this noise is shown in Fig. 1. The distribution of the sound pressure level indicates that the maximum amount of energy generated by the loudspeaker system is at low and medium frequencies.

The moment of transmitting the noise was random, the time of a single exposure was 30 s. During each investigation the noise was emitted about

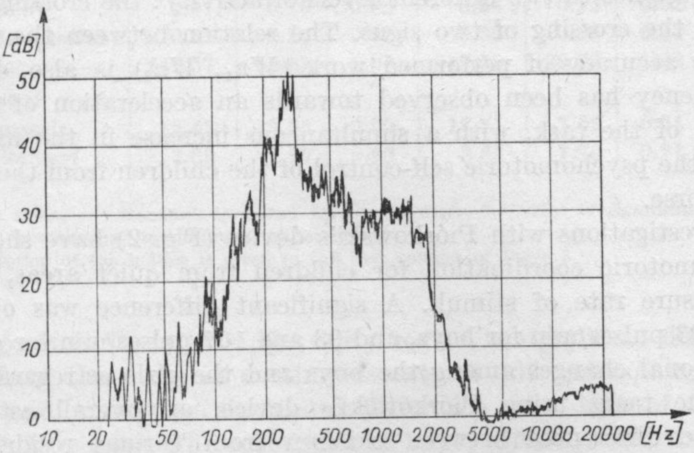


Fig. 1. The spectrum of the noise generated by the loudspeaker system

150 times. Prior to each investigation the noise level was controlled by means of a noise level meter (Brüel-Kjaer). The investigations lasted from 9 to 12 o'clock a. m., thus being the period of time which is most favourable for mental work.

3. The appraisal of the mental performance of children from the different acoustic regions

The investigations carried out have revealed considerable differences in the psychological processes of children living under favourable and unfavourable acoustic conditions. The results of the investigations are shown in Table 1 and Fig. 2.

The analysis of the results shows a lower level of performance of mental functions for the children living in the area affected by aircraft noise. This applies also to motoric performance and attention. A considerable slowing in psychometric reaction, the deterioration of visual and motoric coordination, reduced psychomotoric self-control and the disorder of attention processes were observed.

The most remarkable differences could be observed in the examination of the reaction time. Mean values of the reaction time of pupils from noisy regions are longer for boys by 0.013 s., and for girls by 0.024 s. Also the standard deviations of the reaction times are considerably larger for the children living in an airport neighbourhood. Probably the noise induces not only a reduction in the rate of psychomotoric reaction, but also a variation in its process.

Similar conclusions can be drawn from the analysis of the results of the "two-crossing tests". Both the speed and performance of work, and the accuracy of its execution are much worse in the case of the children from the noisy region. This applies to two different levels of activity: the crossing of one sign and then to the crossing of two signs. The relation between the velocity (V_1, V_2) and the accuracy of performed work (Wn_1, Wn_2) is also disadvantageous. A tendency has been observed towards an acceleration of the speed of performance of the task, with a simultaneous increase in the inaccuracy indices. Thus the psychomotoric self-control of the children from the noisy region was also worse.

The investigations with Piórkowski's device (Fig. 2) have shown a higher visual and motoric coordination for children from quiet areas, independent of the exposure rate of stimuli. A significant difference was obtained only at a rate of 93 pulses/min for boys, and 93 and 107 pulses/min for girls. In view of unidirectional changes among the boys and the girls as regards the performance of the tasks using Piórkowski's device, an overall estimation was made of the differences between children from various residential regions [14]. Apart from the above-mentioned data the analysis has revealed, to the

Table 1. Comparison of the results of the psychological testing of children under various acoustic conditions

Name of test	Noisy region			Quiet region			t	P
	M	σ	E_x	M	σ	E_x		
1	2	3	4	5	6	7	8	9
Boys								
Poppelreuter's test	14,50	3.30	0.41	16.33	3.93	0.43	2.94	0.01
Two-crossing test ([a]):								
speed, V_1	188.26	29.70	3.77	208.30	41.82	4.64	3.20	0.01
performance, W_1	225.68	37.90	4.81	250.36	50.63	5.62	3.21	0.01
inaccuracy, Wn_1	4.59	3.73	0.47	3.95	2.77	0.30	1.18	*n.s.*
speed, V_2	90.48	15.32	1.94	95.73	16.42	1.88	1.96	0.05
performance, W_2	209.22	39.21	4.98	224.89	41.50	4.61	2.29	0.05
inaccuracy, Wn_2	9.52	6.28	0.79	7.33	4.57	0.51	2.39	0.05
speed quotient	0.97	0.16	0.02	0.94	0.15	0.02	1.41	*n.s.*
performance quotient	0.94	0.17	0.02	0.91	0.15	0.02	1.03	*n.s.*
Reaction time	226.84	48.39	1.08	214.17	40.86	1.05	8.41	0.0001
"How are you?"								
scale of neurosis	15.49	6.69	0.85	15.20	6.39	0.82	0.25	*n.s.*
scale of falsehood	3.72	1.69	0.21	3.32	1.58	0.20	2.38	*n.s.*
Girls								
Poppelreuter's test	17.03	4.04	0.46	17.75	3.65	0.44	1.43	*n.s.*
Two-crossing test:								
speed, V_1	205.40	36.25	4.15	222.90	38.53	4.74	2.78	0.01
performance, W_1	221.49	40.46	4.64	268.85	47.66	5.86	6.40	0.01
inaccuracy, Wn_1	5.74	4.48	0.50	3.84	2.89	0.35	2.96	0.01
speed, V_2	98.45	16.23	1.86	103.16	15.42	1.89	1.76	*n.s.*
performance, W_2	224.55	39,54	4.53	241.28	38.95	4.79	2.53	0.05
inaccuracy, Wn_2	11.23	9.30	1.06	7.48	4.99	0.61	2.92	0.01
speed quotient	0.97	0.16	0.02	0.94	0.14	0.02	0.93	*n.s.*
performance quotient	0.93	0.14	0.02	0.90	0.13	0.02	1.08	*n.s.*
Reaction time	241.57	49.61	1.04	217.59	39.78	1.02	16.46	0.0001
"How are you?"								
scale of neurosis	16.43	7.88	0.90	17.71	7.62	0.94	0.94	*n.s.*
scale of falsehood	3.99	1.97	0.23	3.65	1.70	0.21	1.09	*n.s.*

M – arithmetic mean, σ – standard deviation, E_x – mean error, t – value of significance factor, P – probability, *n.s.* – statistically insignificant difference

(a) description of the indices is given in the first column of Table 3.

disadvantage of children from the noisy region, a significant difference in the performance of the tasks at a stimulus rate of 107 pulses/min ($\chi^2 = 10.599$; $P = 0.05$), and almost as significant difference at a rate of 125 pulses/min ($\chi^2 = 9.228$; $P = 0.06$). The occurrence of larger differences in the performance of the tasks at lower rates is to some extent a surprise since it might be expected that, with objectively more difficult and more complicated operations, the differences in the task performance by children from the different acoustic regions would be higher. Perhaps, the difficulty of the intelligence task has encouraged the subjects from both regions and, because of the strengthened motivation, the differences in achieving the visual-motoric coordination have become insignificant.

Fig. 2. The psychomotoric performance of children living in different acoustic conditions (Piórkowski's device)

Clear columns – from the noisy region; dashed columns – from the quiet region.

The results obtained by Poppelreuter's test (Table 1) have confirmed the above trends of differences in psychological processes resulting from acoustic conditions at the dwelling place. Although a marked difference was observed only for the boys, nevertheless the tendency observed for the girls is in agreement with the assumed hypothesis.

The investigations of evident uneasiness as a symptom of neurotic tendencies have shown no difference between the children residing in the different acoustic environments. The level of neurosis among the tested groups was similar, and the distribution of results agreed with the distribution observed for the population of children [25].

4. The reaction of children to acoustic stress

One of the aims of the described investigations was to learn about the disturbances of the mental processes during experimental exposure to noise and to determine the differences in the reactions of children from different acoustic environments. It seemed likely that the children exposed to aircraft noise at their place of residence for many years would react to the acoustic stress differently from the children living in a quiet region. An additional task was to explain the role played by neurosis in the development of disorders of psychological functions under the influence of noise.

Results of investigations of psychological processes in the quiet and in noise. The results of investigations of the effect of noise in the experimental conditions upon the mental processes of children are shown in Table 2. Besides statistical inference arising from differences between the mean values – a more comprehensive comparison was performed using such factors as the differences in reactions in the experimental groups compared to those in the control group, in both investigations [15]. This factor is assumed as a basis for drawing conclusions.

The analysis of the results of tests performed in the initial stage of the investigations indicated a lack of significant differences between the experimental and control groups in all the tests, thus confirming the correct choice of the examined groups.

The investigations of the pupils reactions to the high level of noise (85 dB (A)) revealed a number of significant differences, concerning both psychomotoric performance and attention. The highest disorders in performance occurred during the examination of simple motor-reflex operations and during the examination of higher degrees of difficulty of visual-motoric coordination.

The extension of the reaction times in the presence of noise was averaged to 0.19 s and 0.024 s for boys and girls, respectively. This means that the slowing of the reaction times with respect to those obtained when children were tested in the quiet amounts to 9.2 % and 11.4 % for boys and girls, respectively. The deterioration of the results appears not only with respect to the control group, but also to the rest results obtained prior to testing the effect of exposure to acoustic stress. In the control group a considerable shortening of the reaction time and smaller scatter of the results were observed. Thus acoustic stress not only affects the reaction time, but also increases variations in the speed of execution.

The comparison of the curves depicting the differences between the reaction time in the quiet and in noise during consecutive exposures to stimuli throws additional light on the trends of the analyzed relations (Fig. 3). Taking the sequence of stimuli into consideration permits the differences in the reaction rate as a function of time to be estimated approximately. Although the time intervals between individual stimuli (according to the assumptions of the investigations described in the section about the methods) are not equal, it is obvious that the earlier and the later stimuli are related to the earlier and the later period of the test, respectively. The time required for the exposure to the whole series of 28 stimuli is about 6 min.

The analysis of the presented graphs points to a difference in the reaction rates in the quiet and in noise. For the boys, the reaction times in the quiet undergo an initial extension, but as time passes, the results improve systematically and uniformly. For the girls the curve is somewhat different.

In the initial stage the results oscillate around the average results from the whole series, but beginning with the 20th stimulus an extension of the

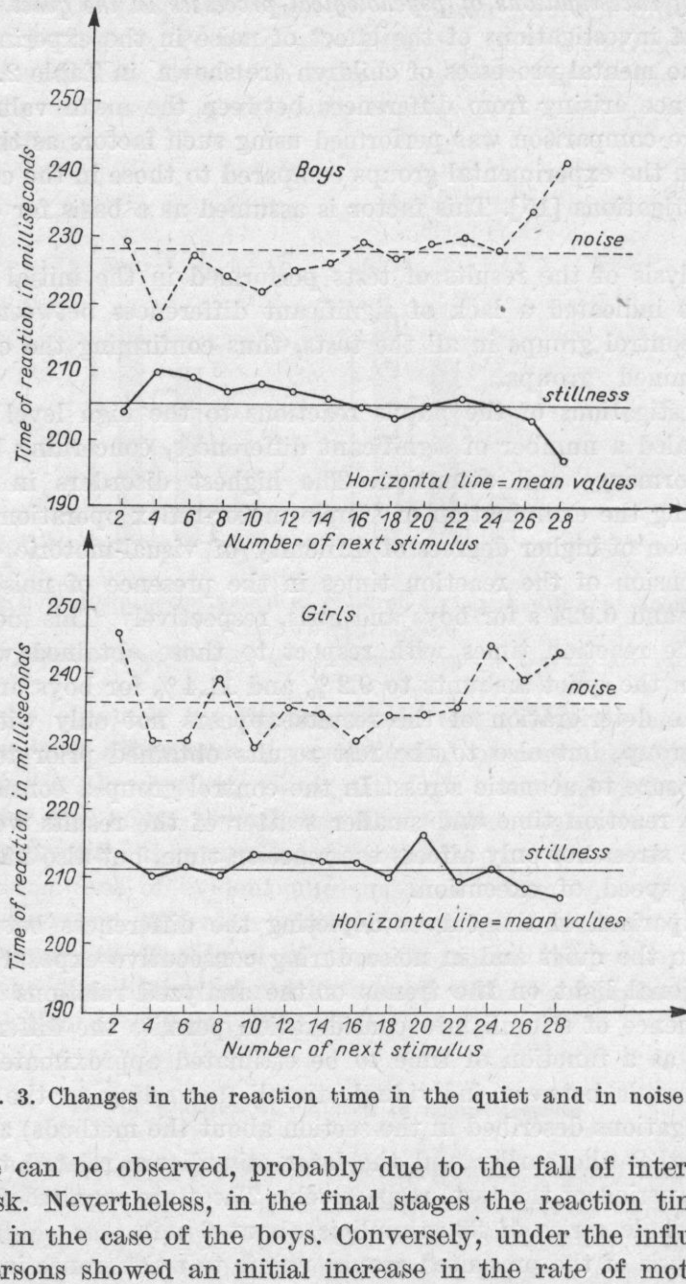


Fig. 3. Changes in the reaction time in the quiet and in noise

reaction rate can be observed, probably due to the fall of interest in performing the task. Nevertheless, in the final stages the reaction times are much shorter – as in the case of the boys. Conversely, under the influence of noise all tested persons showed an initial increase in the rate of motoric reaction, the reaction times extending slowly thereafter until, at the end of the experiment, a considerable deterioration of the reaction rate has taken place. The oscillations of the reaction time are also larger. Initial mental concentration in noisy conditions is reduced after some time, bringing about a considerable deterioration in performance.

The investigations performed by means of Piórkowski's device (Table 2) indicate a considerable improvement in the results of the successive tests both in the experimental group, tested in the noise, and in the control group, tested in the quiet. However, the improvement of the results of the control group in comparison with the experimental group, is considerably higher for both sexes. The largest changes were observed at rates of 107 and 125 pulses/min. The above differences are statistically significant. At a rate of 95 pulses/min a significant change has occurred only for the boys and, although a distinct tendency in favour of the persons tested in the quiet was observed for the girls, it did not attain significant level.

The noise stress also disadvantageously influenced the processes of attention, the degree of disorder being dependent on the kind of the attention engaged. The less severe disorders occurred when the concentration and the resistance to distracting stimuli were examined; while the most severe occurred for the tasks requiring divided attention. Thus a comparison of the results of the investigations by means of Couvé's test indicates only insignificant differences between the children tested in the quiet and in the noise (for boys $t = 1.30$; for girls $t = 1.01$), whereas the results obtained by means of Poppelreuter's test, and also the results of the "two-crossings test" show very significant differences between the investigations in the different acoustic conditions. Binaschi and Pelfini [5] came to a similar conclusion. They stated that the noise affects more strongly the performance of the tasks which require the divided attention than the tasks requiring greater concentration.

The investigations also indicated that with a lengthening of the acoustic stress the disorders of the attention processes intensify. This can be clearly seen from the graph shown in Fig. 4. Improved skill in solving Poppelreuter's test after 6 min. could only be observed when testing the children in the quiet. On the other hand in the conditions with noise, the deterioration of the execution of this test, in comparison with the results obtained during earlier examinations (after 3 min. of work) could be observed. This regularity occurred both for the boys and for the girls.

In addition to the previous data the analysis of the "two-crossings test" also confirms the disadvantageous effect of noise upon the tasks performed. The comparison of the speed and accuracy of work at two levels of activity indicates reduced speed and performance in both tests, and an increase of errors in the second test. At the same time an excessive accuracy in the test of crossing one sign at execution rates that are too slow, and the sacrifice of accuracy in favour of speed in the test of crossing two signs are observed. For the girls, excessive accuracy in performing the work with a simultaneously decreased speed was present in both types of activities. Also the difference in the quotients of speed and performance, chiefly for the girls, points to the disturbances between the two levels of activity. The above lack of concentration in performing both tests, and the change in the behaviour for each of them,

Table 2. Psychological processes of the children examined in quiet and in noise; during the test II the experimental group was exposed to noise

Name of test or trial	Groups	Test I M	Test I σ	Test II M	Test II σ	t_z	P
1	2	3	4	5	6	7	8
			Boys				
	experim.	16.04	4.43	15,93	4,57		
Poppelreuter's test	t		1.15		3,78***	5.63	0.001
Table I	control	15.14	4.84	18.78	4.40		
	experim.	16.00	4.01	15.61	4.27		
Table II	t		1.05		4.53***	7.78	0.001
	control	15.27	3.54	18.72	3.87		
Two -crossing test:	experim.	200.19	36.02	235.36	36.52		
speed, V_1	t		0.20		1.93	3.43	0.001
	control	198.90	40.84	249.91	46.17		
	experim.	241.26	44.88	285.02	45.09		
performance, W_1	t		0.42		1.88	3.36	0.001
	control	237.94	49.51	301.86	50.61		
	experim.	4.04	2.86	3.07	2.31		
inaccuracy, Wn_1	t		0.42		0.01	0.89	*n.s.*
	control	4.28	3.52	3.07	2.82		
	experim.	93.48	15.42	117.00	18.71		
speed, V_2	t		0.02		2.70**	4.22	0.001
	control	93.42	16.84	126.78	24.17		
	experim.	219.17	40.28	277.90	47.89		
performance, W_2	t		0.31		3.26**	5.57	0.001
	control	217.01	42.18	307.89	51.09		
	experim.	7.85	5.36	7.14	4.57		
inaccuracy, Wn_2	t		0.93		3.26**	5.62	0.001
	control	8.70	5.55	4.98	4.52		
	experim.	0.94	0.16	1.01	0.16		
speed quotient, *I.V.*	t		0.11		0.90	1.06	*n.s.*
	control	0.95	0.14	1.02	0.16		
	experim.	0.92	0.17	0.98	0.17		
performance quotient,	t		0.11		1.62	1.85	*n.s.*
I.W.	control	0.93	0.15	1.03	0.16		
	experim.	220.44	47.49	226.51	48.13		
Reaction time	t		0.39		19.22***	20.11	0.0001
	control	220.86	45.57	207.44	36.42		
Piórkowski's device:	experim.	91.98	24.58	119.01	20.69		
P_1 – 93 p/min	t		0.74		1.67	2.37	005
	control	88.60	29.56	124.23	16.08		
	experim.	91.22	28.31	113.38	25.38		
P_2 – 107 p/min	t		0.74		3.18**	5.14	0.001
	control	86.55	33.73	126.91	25.25		
	experim.	52.35	28.60	73.97	37.00		
P_3 – 125 p/min	t		0.19		3.47***	5.18	0.001
	control	53.34	31.13	95.98	38.41		

c.d. Table 2

1	2	3	4	5	6	7	8
		Girls					
Poppelreuter's test:	experim.	17.56	5.34	18.81	5.81		
Table I	*t*	0.64		3.14**		3.57	0.001
	control	18.10	4.35	21.48	4.12		
	experim.	16.84	4.06	17.33	5.42		
Table II	*t*	0.07		3.62***		5.22	0.001
	control	16.90	3.86	20.35	4.38		
Two-crossing test:	experim.	212.08	40.29	254.68	49.76		
speed, V_1	*t*	0.45		1.16		1.32	*n s.*
	control	215.04	36.19	263.38	38.30		
	experim.	252.79	50.26	306.86	57.68		
performance, W_1	*t*	0.16		1.41		1.74	*n.s.*
	control	254.74	46.40	319.28	45.62		
	experim.	5.06	4.53	4.47	3.96		
inaccuracy, Wn_1	*t*	0.67		2.61**		0.46	*n.s.*
	control	4.61	3.33	2.97	2.73		
	experim.	101.80	14.55	129.33	20.30		
speed, V_2	*t*	0.87		1.54		2.73	0.01
	control	99.44	17.35	134.54	19.64		
	experim.	233.40	37.57	308.16	52.30		
performance, W_2	*t*	0.32		1.46		3.46	0.001
	control	231.22	42.61	321.31	54.16		
	experim.	9.77	7.67	6.78	5.60		
inaccuracy, Wn_2	*t*	0.91		1.28		0.15	*n.s.*
	control	8.82	5.76	5.54	5.89		
	experim.	0.98	0.17	1.01	0.13		
speed quotient, *I.V.*	*t*	1.76		0.53		2.03	0.05
	control	0.94	0.14	1.03	0.13		
	experim.	0.94	0.15	1.01	0.13		
performance quotient,	*t*	1.55		0.57		2.21	0.05
I.W.	control	0.90	0.13	1.02	0.14		
	experim.	229.40	46.89	234,34	45.57		
Reaction time	*t*	0.33		26.01***		26.89	0.001
	control	229.76	46.63	210.54	32.61		
Piórkowski's device:	experim.	92.27	27.94	120.16	17.72		
P_1 – 93 p/min	*t*	0.09		1.25		1.24	*n.s.*
	control	92.71	26.64	123.68	15.44		
	experim.	86.87	30.58	112.09	28.26		
P_2 – 107 p/min	*t*	0.19		3.01**		4.33	0.001
	control	85.82	31.80	125.57	24.88		
	experim.	50.12	29.74	70.19	35.27		
P_3 – 125 p/min	*t*	1.08		3.39***		6.82	0.001
	control	44.88	27.77	91.91	40.54		

t – value of the significance factor between the means,
t_z – value of the parameter of significance between changes,
n.s. – a statistically insignificant difference,
* – differences significant at a level of 0.05,
** – differences significant at a level of 0.01,
*** – differences significant at a level of 0.001

reveal considerable disturbance of the control of the psychomotoric functions under the influence of noise.

Adaptation to noise. In addition to the above discussed effects of noise attempts were made to acquire an understanding of the differences in the reactions of the children from various acoustic conditions to the standard noise stress. The problem was to find a means of detecting the phenomenon of the possible adaptation of the children to the acoustic conditions prevailing at their place of residence.

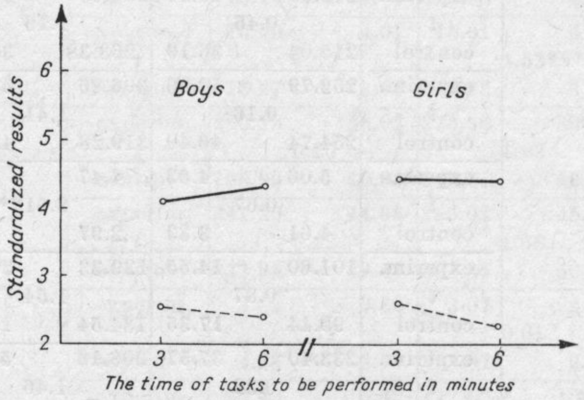


Fig. 4. Improving performance in the solution of Poppelreuter's test under various acoustic conditions: ——— in the quiet, ----- in the noise

A comparative analysis of the results of the investigations is shown in Fig. 5. It presents the level of disturbance of mental functioning under the influence of the experimental noise stress. The dashed columns give the levels of decreased performance of the execution of tasks in particular tests in the group of children living in more favourable acoustic conditions; the blank columns present similar decreased performance in the group of children from the area affected by aircraft noise. It can be clearly seen from the figure that the degree of disturbance of the mental processes, caused by the noise is considerably higher for the group from more favourable acoustic conditions. This applies both to psychomotoric performance and to the processes of attention. However, the largest difference occurred in the speed and accuracy of the execution of various psychomotoric operations. In the processes of attention, differences were only noted in the examining of its divisibility, while a similar level of disturbance occurred in the range of concentration of attention for the children from both regions. Only the index of speed at 93 pulses/min using Piórkowski's device for the boys, and the inaccuracy in crossing one sign in the "two-crossing test" of all the persons examined, point to a somewhat higher disturbance due to the noise effect in the group of children from unfavourable acoustic conditions. These are probably accidental differences.

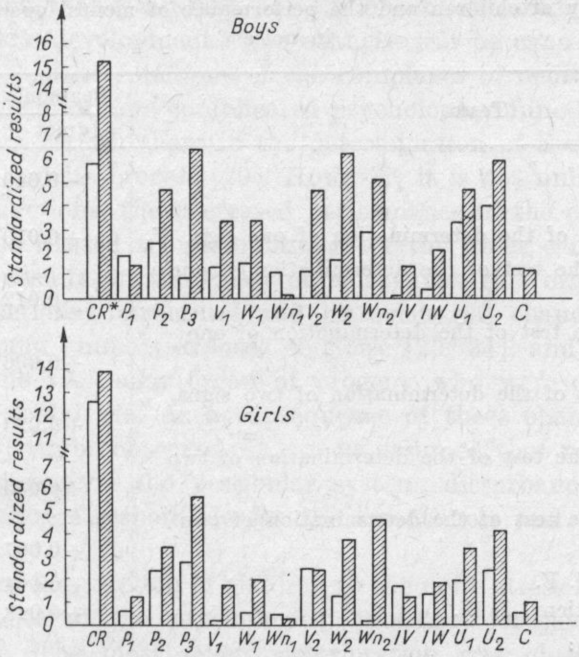


Fig. 5. The level of disturbance of mental processes of the children from different acoustic regions under the effect of an experimental noise stress; clear columns – from the noisy region; dashed columns – from the quiet region; the indices are presented at Tables 1, 2, 3.

Generally, it can be said that noise at the place of residence has reduced the sensitivity of the pupils to the acoustic stress, particularly in terms of psychomotoric operations and the divisibility of attention.

Neuroticity and the performance of mental operations in noise. In the investigations concerning the effect of noise it has been found that some children were more susceptible to its negative influence [5, 8, 16]. The reasons for this are not sufficiently known. In this paper attempts have been made to establish the interrelation between the performance of mental operations in the quiet and in noise, and the neuroticity of the examined children. The results of these investigations are given in Table 3. The obtained results show no relation between the psychological processes in the quiet and the neuroticity. It should be suggested that neuroticity in the normal conditions for the pupil's mental work, without any physical or mental stresses, does not significantly influence the performance of the executed operations. The situation is different during noise stress. The absence of a relationship between the neuroticity and the determined psychological processes occurred only in relation to psychomotoric performance, but the process of attention was disturbed.

The children exhibiting higher levels of neurosis showed a greater decrease in the results of both tests of attention.

Table 3. Neuroticity of children and the performance of mental operations in quiet and in noise

Tests	Pearson's correlation factor[1]	
	quiet	noise
Poppelreuter, U	−0.040	−0.181
Two-crossing test:		
speed in the test of the determination of one sign, V_1	+0.010	−0.022
performance in the test of the determination of one sign, W_1	+0.012	−0.041
inaccuracy in the test of the determination of one sign, Wn_1	+0.006	−0.012
speed in the test of the determination of two signs, V_2	+0.023	−0.064
performance in the test of the determination of two signs, W_2	+0.035	+0.012
inaccuracy in the test of the determination of two signs, Wn_2	+0.007	−0.006
speed quotient, *I. V.*	+0.064	−0.008
performance quotient, *I. W.*	+0.043	−0.011
Piórkowski's device:		
93 p/min, P_1	+0.021	−0.121
107 p/min, P_2	−0.062	−0.143
125 p/min, P_3	−0.040	−0.071
Reaction time, *CR*	+0.133	−0.021
Couvé's test, *C*	+0.031	−0.222

[1] – value of correlation factor $\geqslant 0.171$ significant at a level of 0.05 and $\geqslant 0.228$ significant at a level of 0.01.

5. Discussion

The above results indicate a decreased performance of some psychological functions for the children living in the area affected by aircraft noise. The largest differences involve the simplest destination (target) motions. Nevertheless there was some decrease in the performance of other types of mental operations and disorder of the attention processes was also noted.

Similar results were obtained by Ando et al. [4], who investigated the effect of the aircraft noise on the concentration of attention for the children aged from 7 to 10 years. These authors have found that short periods of a decreased average level of the speed of work occur more frequently for the children from noisy regions than for their counterparts from quiet regions. This decrease can be observed in the investigations performed in the quiet, but was not noticed for the work in noise.

The relation between aircraft noise at the place of residence and the mental processes is poorly recognized. However on the basis of the previous data it can be concluded that if aircraft noise is one of the elements in the environment of a child's development some changes will be caused in the formation of the multi – stage functions of the complexes of neuron groups taking part in both simple and more complicated psychological functions. Consequently, the noise has a certain share in the determination of the structure of the function, its rate and its process [29]. However, it is not unlikely that in the case of motoric functions, the decreased performance of the children from the noisy area may be related to micro-damage of the inner ear. Many authors, in discussing the results on the effect of noise upon this organ, describe the occurrence of functional, structural and histochemical changes in the vestibules of humans and animals exposed to noise [20, 24], and also disorder of the function of the vestibular organ of progeny who were exposed to noise [26] during their foetal life. As a consequence of these changes, disturbance of equilibrium [21] can be observed. It can be assumed that noise at the place of residence produces, via the vestibular system, disturbance in the coordination of the analyzers responsible for the smoothness and precision of movements.

The analysis of the reaction of children to the noise stress has shown a considerable disturbance of the psychological processes for persons from both residential regions. The most severe deterioration was observed when examining reaction times, in accordance with the previously observed disturbance of the reflex functions [6, 11, 12, 31]. Disturbances of other psychomotoric functions and of the attention process also occurred. The disturbances occur primarily in difficult or complex functions that require precise action or great concentration. At simpler functions no marked effect of the noise was observed. At the same time an aggravation of the disturbance of the psychological functions with prolonged noise was found to occur. Mostly, these disturbances did not occur at once; but the negative effect of the noise stress becomes evident only after some time. It is likely that the same interpretation would be valid for the greatest deterioration of the results observed when investigating the reaction times in the initial phase.

The investigations also exhibited to some extent the phenomenon of adaptation to noise as a result of the effect of a noisy environment. ANDO et al. [4], in similar investigations, did not reach the same conclusion. This divergence of the results is caused probably by the investigation of different psychological functions. From the results of the investigations described in this paper it can be concluded that noise at the place of residence reduces the resistance of the organism to the disturbing action of acoustic stress mainly in terms of psychomotoric functions. On the other hand, Ando also investigated the concentration of attention which in our investigations also did not differ for the children from the two residential regions. The noise disturbed the attention of the children from the quiet and noisy regions in similar ways.

Probably the possibility of adaptating to noise is smaller for the more complicated psychological functions.

The analysis of the relation between neuroticity and the performance of mental operations in noise has shown a deteriorated performance for children liable to excessive sensitivity, timidity and psychological breakdown. An additional noise stress causes disorder mainly in neurotic persons performing complicated and difficult operations, while disturbance of the performance of tasks carried out automatically or requiring relatively simple motoric coordination were not observed. Probably the excessive anxiety characterizing the persons with a high level of neuroticity does not cause the disturbances of the psychological processes, under normal conditions but the increased excitation caused by noise stress produces an accumulation of the tension and the deterioration of performance. This phenomenon of the increased susceptibility of neurotic persons to the disturbing action of noise is probably one of the decisive factors in the so-called subjective sensitivity to noise.

6. Conclusions

From the results of the investigations and the discussion the following conclusions can be drawn:

1. Aircraft noise exerts a negative influence on the psychological processes of children living in the neighbourhood of an airport.

2. During an acoustic stress of short duration, a reduced mental performance was observed for all examined children.

3. The direction and range of disturbances are dependent on the type of functions examined, the difficulties of the tasks, and personal traits. The largest changes appear in the execution of the simplest destination motions. A decreased psychomotoric performance of other types of functions, and disorder of the attention processes were also observed. Particular susceptibility to the disturbing influence of noise was observed when examining functions that require a divided attention and, to a lesser extent, when examining the functions related to attention concentration.

4. The children from the noisy region exhibit adaptation to the noise. This adaptation applies mainly to the psychomotoric functions. When examining more complicated psychological processes, the effects of the adaptation to noise are less evident and in some cases are virtually non-existant.

5. The susceptibility to the disturbing influence of noise is related to the level of neuroticity. A high level causes a decrease in the performance of higher forms of the mental functions under conditions of noise. No relationship was found to exist between the level of neuroticity and the psychomotoric performance.

References

[1] I. ABEY-WICKRAMA, M. F. A'BROCK, F. E. G. GATTONI, C. F. HERRIDGE, *Mental hospital admissions and aircraft noise*, Lancet, **12**, 1275-1277 (1969).

[2] Y. ANDO, H. HATTORI, *Reaction of infants to aircraft noise and effect of the noise on human fetal life*, Practica Otologica, **67**, 2, 129-136 (1974).

[3] Y. ANDO, H. HATTORI, *Statistical studies on the effects of intense noise during human fetal life*, J. Sound Vibr., **27**, 1, 101-110 (1973).

[4] Y. ANDO, Y. NAKANE, J. EGAWA, *Effects of aircraft noise on the mental work of pupils*, J. Sound Vibr., **43**, 4, 683-691 (1975).

[5] S. BINASCHI, C. PELFINI, *Gli effetti del rumore sui tempi di reazione: rapporti tra rendimento e personalitá*, Bolletino di Psicologia Applicata, **67/68**, 51-64 (1965).

[6] S. BINASCHI, C. PELFINI, *II problema degli effetti del rumore nella psicologia applicata al lavoro: rassegna di letteratura*, Securitas, **3**, 79-94 (1965).

[7] D. E. BROADBENT, *Effects of noise on behavior*. In: Handbook of noise control, McGraw-Hill, New York **1957**.

[8] D. E. BROADBENT, *Effect of noise on an intellectual task*, J. Acoust. Soc. Am., **30**, 9, 824-827 (1958).

[9] J. M. FINKELMAN, D. C. GLASS, *Reappraisal of the relationship between noise and human performance by means of a subsidiary task measure*, J. Appl. Psychol., **54**, 3, 211-213 (1970.)

[10] I. FRANASZCZUK, *The investigation of changes in the performance of mental operations during work in noise* [in Polish], CIOP Works, **16**, 49, 122-141 (1968).

[11] I. FRANASZCZUK, *The effect of disturbing acoustic stimuli upon some psychological functions* [in Polish], CIOP Works, **21**, 71, 335-344 (1971).

[12] I. FRANASZCZUK, *The effect of a disturbing noise of a definite frequency upon the simple and compound reaction*. CIOP Works, **20**, 64, 55-64 (1970).

[13] W. H. GLADSTONES, *Some effects of commercial background music on data preparation operators*, Occupational Psychol., **43**, 3/4, 213-222 (1969).

[14] A. GÓRALSKI, *The methods of description and statistical conclusions in psychology* [in Polish], PWN, Warszawa 1976.

[15] A. GUILFORD, *Fundamental statistical methods in psychology and education* [in Polish], PWN, Warszawa 1976.

[16] H. W. HEPNER, *Psychology applied to live and work*, Prentice Hall, New York 1966.

[17] G. JANSEN, *Lärm in Arbeitsraum*. In: *Handbuch der Psychologie*. V. **9**. Betriebspsychologie, Göttingen 1963.

[18] H. E. KING. *Psychomotility: a dimension of behavior disorder*, Proc. Amer. Psychopath. Ass., **58**, 1, 99-131 (1969).

[19] H. KODAMA, *Psychological effect of aircraft noise upon inhabitans of an airport neighborhood*. Proceeding of the XVII International Congress of Applied Psychology, Liége 1971.

[20] A. LAUDAŃSKI, B. CHOTECKI, W. SUŁKOWSKI, *The effect of factory noise on the balance organ* [in Polish], Proceedings of the 27th Congress of Polish Otolaryngology in Katowice 1968, PZWL, Warszawa 1970.

[21] V. LITVINENKOVÁ, J. LISKA, M. KONIKOVÁ, L. STACHOVÁ, *Vplyv hluku na reguláciu postoja*, Čs. Hyg., **20**, 5, 236-239 (1975).

[22] C. NOSAL, *Effect of noise on performance and activation level*, Polish Psychol. Bull., **2**, 1, 23-29 (1971).

[23] B. ROGACKA-TRAWIŃSKA, *The investigation of the performance of the perceptibility function of workers employed in difficult acoustic conditions* [in Polish], Pol. Tyg. Lek., 25, 27, 1023-1025 (1970).

[24] H. Sienkiewicz, *The investigation of the effect of intense noise on the pigeon vestibule* [in Polish], Proceedings of the 27th Congress of Otolaryngology in Katowice, 1968, PZWL, Warszawa 1970.

[25] E. Skrzypek, *Provisional handbook for the test of evident disorder "How are you?"*, Warszawa 1968 (duplicated typescript).

[26] Z. Szmeja, H. Sowiński, E. Białek, *The status of hearing and the inner ear of animals exposed to the action of intense noise in foetal life* [in Polish], Otolaryng. Pol. **29**, 1, 11-16 (1975).

[27] S. Szuman, *On attention* [in Polish], PZWS, Warszawa 1965, p. 18.

[28] G. C. Theologus, G. R. Wheaton, E. A. Fleishman, *Effects of intermittent, moderate intensity noise stress on human performance*, J. Appl. Psychol., **58**, 5, 539-547 (1974).

[29] T. Tomaszewski, *An introduction to psychology* [in Polish], PWN, Warszawa 1963.

[30] A. T. Welford, *Performance, biological mechanisms and age: a theoretical sketch. Behavior, aging and the nervous system,* Springfield, Illinois 1965.

[31] K. Witecki, *The investigation of the time of a simple reaction to visual and aural stimuli under disturbing noise conditions* [in Polish], Pol. Tyg, Lek. **25**, 27, 1012-1015 (1970).

[32] R. Zazzo, *Psychological methods in the examination of a child* [in Polish], vol. 2, PZWL, Warszawa 1974.

[33] L. Zdunkiewicz, *Selected hygienic and health factors and their importance as variables affecting the results of the mental work of pupils in primary schools* [in Polish], PZH, Warszawa 1970.

Received on 6th January 1977

ARCHIVES OF ACOUSTICS
3, 2, 105-119 (1978)

VARIATIONS OF THE FUNDAMENTAL FREQUENCY IN POLISH VOICED CONSONANTS*

OLGA MATUSZKINA

Department of Acoustic Phonetics of the Institute of Fundamental Technological Research, Polish Academy of Sciences, Poznań

The aim of work described in this paper was to verify and confirm the general thesis regarding the Polish language that the variations of the fundamental frequency in voiced consonants can sometimes agree with and sometimes differ from the global tone line plotted on a tonogram for the sequence of the vowels. The evolutions of this line are considered to be critical in the perception of the intonation contour. Qualitative and quantitative descriptions of the character of variations of the fundamental tone in the voiced consonants */b/, /d/, /g/, /ɟ/, /v/, /z/, /ʒ/, /γ/, /m/, /n/, /ŋ/, /r/,* and */l/* are given.

The relation between these changes and the type of articulation of the consonant was investigated. The results of the investigations support the assumption that such a relationship exists. In many respects this fact is in agreement with the data given in the relevant literature, and its explanation can be sought in the articulatory and physiological properties of the individual consonants.

1. Introduction

It is known that certain features of speech, known as prosodic features, are related to variations of the fundamental frequency. These include various types of intonation, accent, the methods of indicating the completion of the sentence, etc. However, it is also known that the variations of the fundamental tone in segments that correspond to the individual speech sounds are important. The "microvariations" of F_0, analyzed in the voiced consonants, are brought about by many factors, both articulatory and physiological. One of the most important factors are the fluctuations in sub- and supraglottal pressure,

* The paper was prepared as a contribution to the fundamental project 10.4. "Systems and elements of biocybernetics".

related to the occurrence of the articulatory barrier in the upper part of the vocal tract and the variations of the frequency of the vocal chord vibration.

Although the significance of variations of the fundamental frequency in particular voiced consonants for the perception of the functional intonation units is problematic (various viewpoints on this problem are presented by JASSEM [7], WITTING [19], PIKE [17]), the results of a series of psychophysical experiments indicate that a listener can discern variations of the fundamental frequency over a comparatively short segment (HEINZ [6], LUBLINSKAIA [10]) and indeed uses them, in addition to other features, for distinguishing the phonemes (ČISTOVIČ [3], HAGGARD [5]).

Speech synthesis tests concerned with intonation contours (MATTINGLY [11], ÖHMAN, LINDQUIST [15], ÖHMAN [16], MEHNERT [13]) show the value of information about the "microvariation" of F_0 as regards the distinctness and natural sound of synthetic speech.

The papers by MOHR [14], MEHNERT [13], and STEFFEN-BATÓG [18] are concerned with a direct investigation of the variation of F_0 in consonants; the latter paper is the only, known to the authoress, investigation of the microvariation of the fundamental tone in Polish voiced consonants. The data concerning such microvariation in addition to their purely cognitive character may also be used in experiments concerning the synthesis, the automatic recognition and the automatic segmentation of the Polish language.

This paper is devoted to the qualitative and quantitative description of the variation of F_0 in some voiced consonants of the Polish language, with special attention being paid to the relation between these variations and the type of consonant articulation. A well-known thesis of the decrease of F_0 in voiced consonants or, in other words, of the decreasing effect of the voiced consonants on the F_0 contour has been verified on Polish sounds. A more complete description of the investigations carried out is published separately [12].

2. Material and methods of investigations

The analysis of F_0 variations was performed by using a tape recorder, oscillograph and "Tonograph"[1]). A newspaper text read four times by four people was used for this study giving a total of 48 sentences.

The segmentation of the oscillogram provided the basis for further investigations. The segmentation of the tonogram was performed in agreement

[1] The principles of operation of the device are described by KUBZDELA [8]. Fig. 1 shows by the way of an example one of the analyzed segments.

with this segmentation, with the delay of the tonometer indication by one period with respect to the oscillograph taken into account.

In some important but ambiguous cases the segmentation was checked with the aid of a spectrograph and an audio-monitoring device separator. F_0 contours were plotted on the tonograms and the values of F_0 were measured on them at the beginning, in the middle and at the end of each voiced consonant, by means of hyperbolic scales drawn separately for each voice.

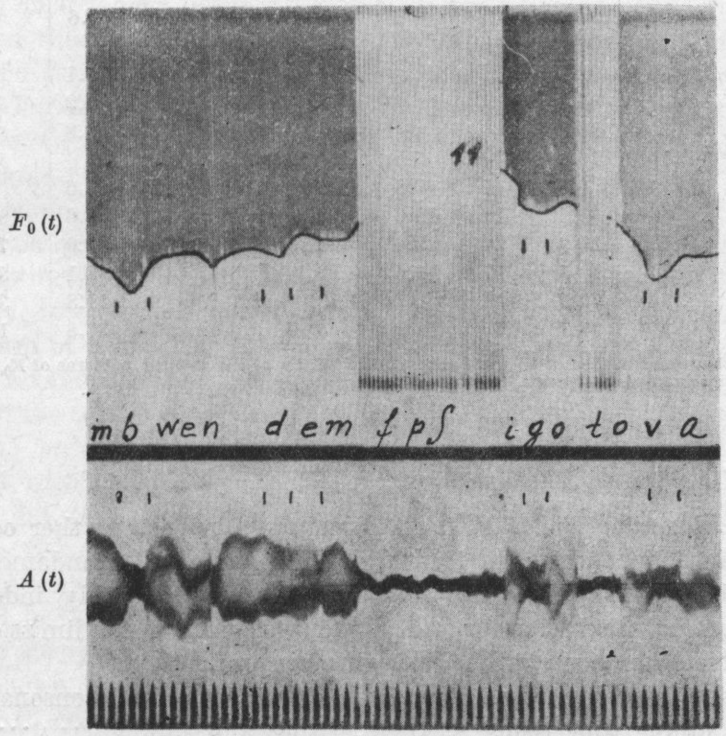


Fig. 1. Evolution of F_0 in the utterance: "błędem w przygotowaniach "(Female voice)

The method of plotting the contour on those segments of the tonogram that have irregularities in F_0 changes was chosen separately for each individual case, depending on the source of the irregularity.

The analyzed material contained different numbers (Table 1) of the following voiced consonants:

stop consonants	/b/, /d/, /ɟ/, /g/,
fricative consonants	/v/, /z/, /ʒ/, /γ/,
liquid consonants	/m/, /n/, /ŋ/, /r/, /l/.

Table 1. The frequency of the occurrence of typical patterns of variations of the fundamental frequency in voiced consonants. Male and female voices

Voiced consonant	Number of the cases considered	Pattern of variations of the fundamental frequency									
		… ∨ …		… ∧ …		… / …		… \ …		… — …	
		Quantity	%	Quantity	%	Quantity	%	Quantity	%	Quantity	%
/b/	45	44	97.8					1	2.2		
/d/	161	152	94.4			8	5.0	1	0.6		
/ɟ/	13	13	100								
/g/	42	39	92.9					3	7.1		
/v/	260*	222	85.4			18	6.9	16	6.2	1	0.4
/z/	34	30	88.2			1	2.9	3	8.8		
/ʒ/	13	10	76.9			3	23.1				
/ɣ/	15	1	6.8	1	6.8			13	86.6		
/m/	87	4	4.6	11	12.6	12	13.8	51	58.6	9	10.3
/n/	106	12	11.3	24	22.6	29	27.4	34	32.0	7	6.6
/ŋ/	105	11	10.5	17	16.4	29	27.6	40	38.1	8	7.6
/r/	102	74	72.5			13	12.7	12	11.8	3	2.9
/l/	53	20	37.7	7	13.2	5	9.4	20	37.8	1	1.9

* 3 cases of the pronunciation of /v/ were not included in any of the typical patterns of $\overline{F}_0$, but lack of space prevents their detailed discussion in this paper.

3. Qualitative analysis of the typical microvariations of F_0

Types of microvariation of F_0. As a starting-point for further considerations the assumption was made that the evolution of the fundamental frequency can be described as the resultant of two relatively independent transients: a general pitch contour and smaller variations in the limits of voiced consonants which are superimposed on this contour.

Initially the following types of variation of F_0 in voiced consonants were distinguished: falling and rising ···∨···, rising and falling ···∧···, falling ···\..., rising .../···, flat ...—.... Numerical data describing the frequency of occurrence of these patterns are given in Table 1.

Stop consonants /b,/, /d/, /ɟ/, /g/. It results from the data contained in Table 1 that for this group of consonants the variation of F_0 according to the pattern ∨ prevails. Also some utterances included in the pattern groups \ and /(purely because the variations of F_0 are analyzed strictly between the consonants limits determined from the oscillograms) represent in fact versions of the pattern ∨. This occurs because the fall of F_0 in voiced consonants sometimes occupies the entire consonant segment, more rarely, only a part of this segment, but usually it extends into adjacent segments thus indicating that even in the case of the micro-variation of F_0 a kind of coarticulation occurs.

Another reason for the transformation of the pattern ⋁ into the pattern ⁄, ∖ or — is related to the phenomenon which is conventionally referred to as the "subordination" of the pattern of F_0 in one particular consonant to the general variation of F_0 in a larger fragment determined by all vowels. This is closely connected with the assumption of the resolvability of the F_0 variations into two independent elements. The phenomenon observed in this case can be described briefly as follows: the variation of F_0 in the consonant (e. g. a decrease in F_0) is subjected to a "deformation" due to the large rise or decrease of F_0 occurring in a longer fragment of the utterance.

When the variation of F_0 in the consonant itself is insignificant, the effect of the superposition of the patterns is even more evident. This is clearly shown in Fig. 2*a*, where the variation of F_0 in the consonant /*d*/ (which in other circumstances would mean a distinct decrease in F_0) is subordinated to the general large rise of F_0 from /*o*/ to /*e*/ in such a way that the beginning and the extremum are almost at the same level.

Fig. 2b presents an example in which the F_0 contour in the consonant /*g*/ is distinctly decreasing. This figure shows that as F_0 decreases from /*e*/ via /*g*/ towards the middle of /*z*/, one sees a microvariation in F_0 in /*g*/ in the form of a small bulge somewhat different from the generally decreasing contour. Examination of this point on the separator shows that this /*g*/, when cut out of the text, sounds like a liquid consonant, somewhat similar to /*ł*/. The consonant /*g*/, cut for a comparison out of the same segment of another recording (but with a marked ⋁ pattern), had the sound of a kind of voiced stop impulse and was quite different from the previous /*g*/.

Thus the evolution of F_0, presented in Fig. 2b, cannot be reduced to the same ⋁ pattern, presumably because of the specific combination of physiological and acoustical factors. It is not unlikely that the proximity of /*z*/ and the rapid decrease of the fundamental frequency had a decisive influence on the /*g*/ shown in Fig. 2b. It is possible that a combination of two successive drops in F_0 occurred with the "prevalence" of the drop in /*z*/. The difference in levels of the amplitude of /*z*/ in the above recording and in the same segment of another recording (in which the ⋁ pattern was observed for /*g*/), is also worth noting. It is not unlikely that the "local" increase of F_0 in /*g*/ was due to the increase in the intensity over a given segment (the occurrence of the pattern ∖ instead of the expected ⋁ pattern can be interpreted in this case as a "local" increase of the pitch).

Fricative consonants /*v*/, /*z*/, /*ʒ*/, /*j*/. According to the articulation of the fricative consonants, their pattern of F_0 should be similar to that in the stop consonants. The analysis has shown that this is the case only for /*v*/, /*z*/ and /*ʒ*/ for which, as for the stop consonants, the most typical variation in F_0 is the ⋁ pattern (Table 1).

In some of the pronunciations the phenomenon which has already been described for stop consonants was observed, namely the fall and subsequent

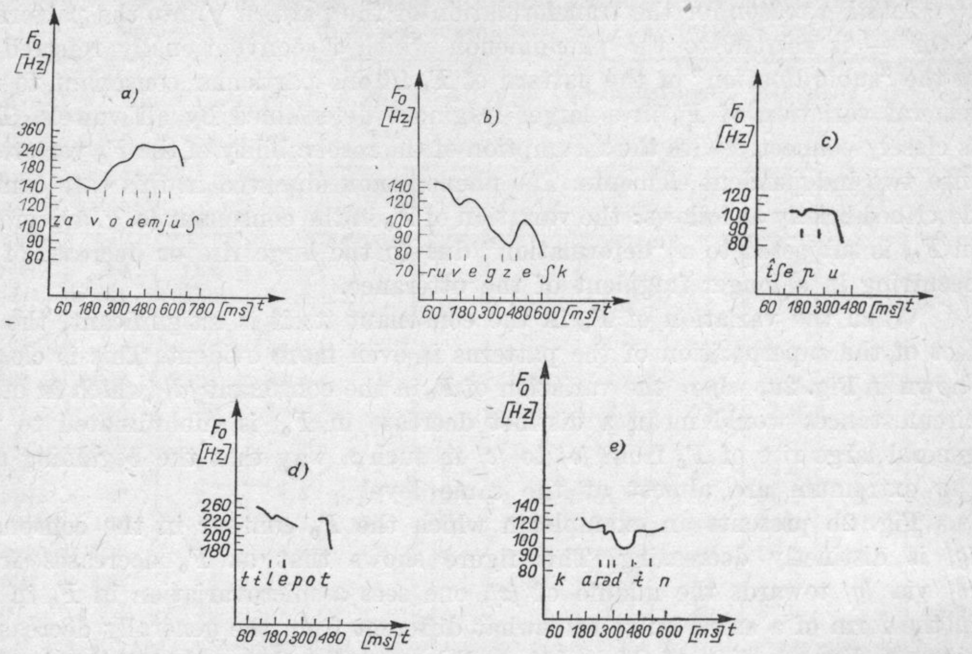


Fig. 2. Changes of F_0 in some utterances
a) "zawodem już" (male voice); b) "wędrówek do szkoły" (male voice); c) "po ukończeniu" (male voice); d) "tyle potem (female voice); e) "kardynalnym "(male voice)

rise of F_0 over a segment somewhat longer than the consonant itself, while the lengths of the part of the F_0 contour and the limits of the consonants are so related to one another that the pattern of F_0 within limits of the consonant may be increasing (if the fall has taken place before the consonantal limit) or decreasing (if the rise occurred only after the consonantal limit).

As in the case of the stop consonants, the examination of the fricative consonants reveals minor variations of the fundamental frequency which are "subordinated" to the pattern of F_0 over longer segments.

The sound /γ/ within the system of phonemes of the Polish language, is an allophone of the phoneme /x/ spoken in the position before a voiced consonant. Out of 15 utterances of /γ/ 13 featured a decreasing pattern of F_0, and this suggests that this consonant differs from the other fricative consonants as regards the variation of the fundamental frequency. In fact, the falls of F_0 which were noticed were mostly insignificant and did not deform the general contour of the melody. Such falls were not observed at all in some of the pronounciations.

A third group of utterances was identified in which fairly distinct or even considerable falls of F_0 displaced towards the left limit of /γ/ occur. (In Table 1 these utterances were included in the pattern groups ↘, ⋁ or ⋀ of F_0 depending on the combination of the fall in F_0 with the general pattern of F_0.) Although the reason for this phenomenon is unknown, it can be said, ahead of next paragraphs that similar falls in F_0 in the proximity of the boundary of the consonantal segment were frequently observed in the liquid consonants, particularly the nasal ones.

Nasal consonants /m/, /n/, /ŋ/. The majority of utterances of these consonants are included in one of three patterns: increasing, decreasing, or flat F_0. The typical patterns actually coincide with the pattern of F_0 for a segment longer than the consonant itself. Nevertheless, in some of the utterances of the nasal consonants, larger or smaller deviations of the patterns from the F_0 contour in the longer segments can be observed. Among others there is a fall of F_0 on transitional segments from vowel to nasal consonant, or more rarely from nasal consonant to vowel (Fig. 2c).

In addition several utterances of the nasal consonants with a distinctly decreasing increasing pattern of F_0 were observed, but the magnitude of these changes is smaller than for the stop and fricative consonants.

The occurrence of $\wedge$ type patterns in the nasal consonants (Table 1) is not, as it appears in the case of the other consonants, a feature of the consonant itself. The occurrence of such a pattern is often associated with the consonant position being either in front of the pause in the phonation before which the fall of F_0 took place, or before a voiced fricative consonant in which an independent fall in F_0 occurs and this, for example in conjunction with a preceding rise of the fundamental frequency, led to the $\wedge$ pattern, or finally to a melodic breakdown.

Lateral consonant /l/. In many utterances of /l/ the tone fell. Close to this group are a number of utterances of /l/ with a pattern of F_0 of ╱,╲ or – which, as in the resonant consonants, can be considered as versions of the pattern *V*. There were also utterances of /l/ in which independent changes on F_0 could not be observed. A fall in F_0 over transient segments was also observed in some cases, as for instance in Fig. 2d where a drop at the boundary *v/l* in conjunction with the subsequent drop of the pitch before stopping results in the $\wedge$ pattern.

Vibrating consonant /r/. An analysis of the pattern of the fundamental frequency in this sound encountered difficulties related to the fact that /r/ is very short and the analysis could thus not comprise more than 2 to 4 periods. Out of 102 cases only 74 revealed any fall in F_0. An example of the pattern of F_0 for this consonant is presented in Fig. 2e.

Similar changes of F_0 were also observed in the majority of utterances which were originally assigned to the pattern groups ╱,╲ and –.

Since the variations were insignificant and occurred over a short segment, it was not possible within consonantal boundaries to read from the scale the magnitude of the fall or rise in F_0. The number of such cases totalled 18. In the other cases the pattern of F_0 appeared to coincide with the general pattern of the fundamental frequency.

4. Statistical analysis of the F_0 variations in voiced consonants

In addition to the qualitative analysis of the presented material quantative investigations were also carried out. For this purpose the differences in pitch between the initial point and the central peak were measured for all F_0 variations of the ⋁ pattern. The difference was expressed as a percentage of the value of F_0 of the preceding vowel.

The data of the relative fall in tone were grouped into 2.5 % intervals. An example of the histogram of the percentage fall in tone for the stop consonants determined for all the voices is presented in Fig. 3, while the arithmetic averages and standard deviations of all the empirical distributions are given in Table 2.

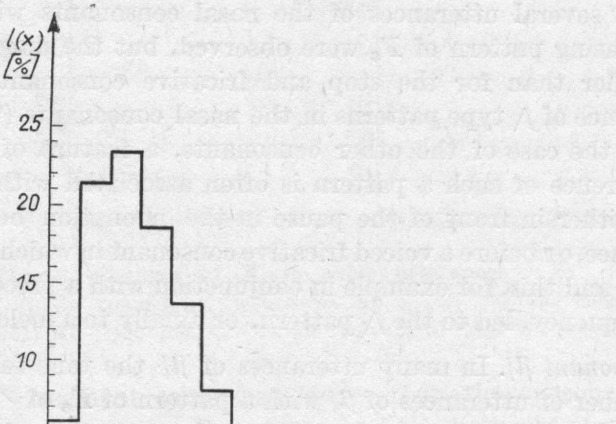


Fig. 3. Histogram of relative falls of F_0 in stop consonants. All voices included

From the data in Table 2 it can be seen that the mean relative fall of F_0 is the largest in stop consonants, smaller in fricative consonants and the smallest in nasal consonants. The lateral consonant /*l*/ and the vibrating consonant /*r*/ occupy an intermediate place between the stop and fricative consonants. In all likelihood the type of the articulation barrier plays the most important role for these cases.

In the group of stop and fricative consonants this regularity is confirmed in the data for the male and female voices considered separately. In both cases the mean relative fall in the stop consonants is higher than in the fricative ones. If the sounds /*d*/ and /*v*/ are to be considered as representatives for the stop and fricative groups (the numerical data were most numerous for these two consonants) one sees that for each individual voice the same sequence for the mean relative fall of F_0 is maintained.

Table 2. The parameters of empirical distributions of relative falls of F_0

Consonant or group of consonants	WJ		ZK		KD		MB		Male voices		Female voices		All voices together	
	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
/*b*/									10.0	6.12	6.3	2.85	8.2	5.13
/*d*/	11.5	7.09	7.7	3.67	5.9	3.46	10.4	7.48	9.6	5.94	7.7	5.85	8.8	5.93
/*g*/													8.6	3.90
/*b, d, ɟ, g*/									9.3	5.46	7.2	5.15	8.5	5.40
/*v*/	8.5	5.05	5.6	4.63	4.3	2.73	5.7	4.07	7.2	5.07	5.1	3.52	6.2	4.51
/*z*/													9.6	6.65
/*v, z, ʒ, γ*/										5.06	5.5	3.94	6.4	4.58
/*m, n, ŋ*/													4.6	3.73
/*l*/													6.9	
/*r*/	8.4	7.20	5.8	3.19					7.0	5.56	6.2	3.49	6.7	4.97

In the series of histograms of the percentage fall of F_0, it can be clearly seen that all the empirical distributions have a marked asymmetry. The hypothesis is set forth, that the magnitude of the relative fall of F_0 in voiced consonants has a lognormal distribution. By treating the data obtained from the examined material as random samples from the population of all possible cases of a fall of pitch in voiced consonants, this hypothesis has been verified statistically.

For a preliminary verification of the validity of this hypothesis, and for the estimation of the parameters of theoretical distributions, the graphical method described, for example, in [1], § 4.5 was used. For this purpose the empirical distributions were marked on the lognormal paper. It was found that the distribution functions could be approximated by straight lines. This feature supported the hypothesis of a distribution for the fall in F_0 in voiced consonants. Fig. 4 shows the graphs plotted for the 3 fundamental groups of consonant and for /r/.

In addition to its simplicity and demonstrativeness the graphical method has another advantage since it enables to estimate directly the parameters of the theoretical distributions. Table 3 contains the estimates obtained for the parameters μ and δ, as well as for the expected values a, and standard deviations β of the theoretical distributions[2]).

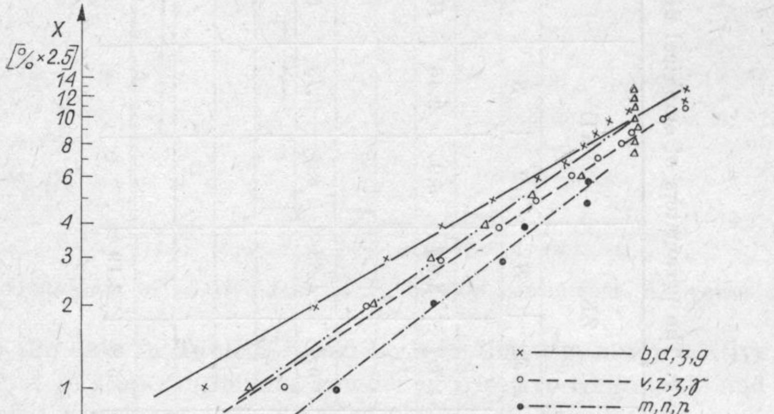


Fig. 4. Values of the relative falls of F_0 in voiced consonants on a lin-log scale

[2] It is known that the probability density function of a random variable with a lognormal distribution $\Lambda(\mu, \sigma^2)$ is described by the formula

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2\sigma^2}(\ln x - \mu)^2\right].$$

The expected value of the random variable $a = \exp(\mu + \frac{1}{2}\sigma^2)$, while the variance $\beta^2 = \exp(2\mu + \sigma^2)(\exp\sigma^2 - 1)$.

Table 3. Estimations of the parameters of the theoretical distributions of relative falls of F^0

Voices	Consonant or group of consonants	μ	σ	a	β
all	/b/	1.99	0.501	8.33	4.42
all	/d/	1.94	0.572	8.17	5.14
all	/g/	1.99	0.447	8.09	3.81
male	/b, d, g, ɟ/	2.04	0.503	8.76	4.65
female	/b, d, g, ɟ/	1.80	0.636	7.39	5.18
all	/b, d, g, ɟ/	1.96	0.523	8.17	4.53
all	/v/	1.61	0.650	6.17	4.46
all	/z/	1.93	0.588	8.17	5.32
male	/v, z, ʒ/	1.76	0.649	7.17	5.19
female	/v, z, ʒ, γ/	1.44	0.685	5.31	4.14
all	/v, z, ʒ, γ,/	1.59	0.665	6.11	4.55
all	/m, n, ŋ/	1.25	0.775	4.71	4.28
all	/r/	1.66	0.737	6.89	5.84

It is worth noting that the estimated theoretical parameters of the distributions of the relative fall of F_0 in voiced consonants exhibit the same regularity as regards the mean magnitude of the fall for the groups of homogenous consonants as it was mentioned above., i. e., the expected value of the distribution is highest for the stop consonants (8.17 %), smaller for the fricative consonants (6.11 %) and smallest for the nasal consonants (4.71 %). From these estimates it can also be seen that the distributions of the relative

Table 4. Values of the Kolmogorov test statistics for verification of the hypothesis of the lognormal distribution of the relative falls of F_0

Voices	Test	Sample size	Empirical value of the test statistics	Critical value of Kolmogorov test statistics *
all	/b/	44	$D_{44} = 0.0835$	$D_{44}(0.05) = 0.2006$
all	/d/	152	$\lambda = 0.986$	$\lambda_{0,05} = 1.358$
all	/g/	39	$D_{39} = 0.0997$	$D_{30}(0.05) = 0.2127$
male	/b, d, g, ɟ/	149	$\lambda = 0.7483$	$\lambda_{0.05} = 1.358$
female	/b, d, g, ɟ/	99	$D_{99} = 0.376$	$D_{99}(0.05) = 0.1347$
all	/b, d, g, ɟ/	248	$\lambda = 0.6913$	$\lambda_{0.05} = 1.358$
all	/v/	222	$\lambda = 1.229$	$\lambda_{0.05} = 1.358$
all	/z/	30	$D_{30} = 0.0515$	$D_{30}(0.05) = 0.2417$
male	/v, z, ʒ/	146	$\lambda = 0.611$	$\lambda_{0.05} = 1.358$
female	/v, z, ʒ, γ/	117	$\lambda = 0.784$	$\lambda_{0.05} = 1.358$
all	/v, z, ʒ, γ/	263	$\lambda = 1.0801$	$\lambda_{0.05} = 1.358$
all	/m, n, ŋ/	27	$D_{27} = 0.0219$	$D_{27}(0.05) = 0.2544$
all	/r/	74	$D_{74} = 0.0387$	$D_{27}(0.05) = 0.1554$

* From [20] (Tables 47 and 48)

fall of the pitch in stop and fricative consonants differ considerably in terms of this parameter for male and for female voices (in stop consonants the respective values of a are 8.76 % and 7.39 % while in fricative consonants 7.17 % and 5.13 %, respectively).

After graphical estimation of the parameters of the individual distributions the hypothesis that the observed values of the fall of F_0 originate from the lognormal populations with the same parameters, was verified by means of the Kolmogorov test.

The verification was performed at the significance level $p = 0.05$. The results of the verification procedure are presented in Table 4. In all cases the empirical values of the proper statistics (Dn for small n and λ for $n > 100$) are smaller than the critical value, and thus the Kolmogorov test provides no basis for rejecting the assumed hypothesis in all cases under investigation, at 5 %-significance level.

5. Conclusions

Stop and fricative voiced consonants in the majority of cases exhibit local falls of the fundamental frequency. The patterns of F_0 in the other utterances (that is those which are not of the V pattern) can be frequently regarded as variants of this pattern, resulting from the influence of many factors. The analysis has shown (although it did not raise any doubts previously) that the form and magnitude of the fall of pitch in a consonant are affected by such factors as the accent on the syllable with a given consonant, the accent of the neighbouring syllables, the character of the melody over segments longer than a syllable (e. g. in a word). Another important factor influencing the pattern of the pitch in a consonant is the phonetic environment of a consonant (in the form of the neighbouring sounds and pauses in the phonation).

In the investigated material one can find examples of the effects of all the above factors. Amongst others it would be of interest to investigate the consonantal combinations for which, according to our observations, a cumulation of the falls of F_0 is possible, as this would result in a single joint fall forming a considerable deviation from the level of F_0 determined by the vowels. It would be also worth -while to investigate the relation between the nature of the variations of F_0 in consonants and the accent. It appears that an accent on the preceding vowel favours an increase of F_0 in the following consonant (it might well be the result of the remanent tension of the vocal cords on the accented syllable).

Generally one can talk of suprasegmental factors (accent, general melody contour) and segmental factors (phonetic environment of a consonant) influencing the character of the pitch variations in individual consonants. In the case of the latter factors a co-articulation in the field of the fundamental frequency can be observed, and this is evidenced by the fact that the fall of F_0 related to the presence of a consonant frequently starts on a tonogram before the moment at which the initial boundary of a consonant can be determined from the oscilloscope trace. The subsequent rise of the pitch often extends through the boundary between the consonant and the next vowel.

The mean fall of F_0 for stop consonants calculated from the data contained in this paper is 8.5 % of the fundamental frequency of the preceding vowel. For fricative consonants /v/, /z/, /ʒ/, /γ/, the corresponding value is 6.4 %. This does not agree with the data contained in previous papers, [18] and [9], p. 176, according to which the fall of F_0 for fricative consonants is higher than the fall of F_0 for stop consonants.

It seems reasonable to suggest that the difference of the mean values of the fall in stop and fricative consonants is related to the character of the articulatory barrier — a complete occlusion in the first group of consonants, and a gap through which air coming out of the lungs is partly exhaled in the second group.

From the viewpoint of the variation of F_0 occurring in the voiced consonant /γ/ the latter occupies an intermediate position between the fricative and nasal consonants, since in the majority of utterances, the pattern of the pitch changes in the consonant /γ/ coincided with the general contour of F_0.

A fall of F_0 occurs in the vast majority of utterances of the vibratory consonant /r/ (with a mean value of 6.7 %), and places this consonant, in terms of the nature of the variations, in one group with stop and fricative consonants. Local falls of the fundamental frequency in the lateral consonant /l/ also occurred frequently, the mean fall in the investigated sample being 6.96 %. Sometimes the frequency pattern of the pitch in the two last sounds agrees (more frequently for /l/ than for /r/) with the general contour of F_0.

For the nasal consonants /m, n, ŋ/ the pattern of F_0 in the consonants themselves is most typically superposed on the pattern of the tone over longer segments, in agreement with other reports on this subject. However, a fall of F_0 also occurs, the relative mean value of the fall being 4.65 % for the investigated material. A number of utterances of the nasal consonants include an insignificant boundary fall of F_0 (on the vowel/consonant and, more rarely, consonant/vowel boundaries).

Without additional investigation it is difficult to formulate a hypothesis about the origin of these boundary falls of F_0. They may, for example, be related to the articulation of the nasal consonants or to the nasalization of particular segments[3]. However, it is known that in the perception of synthetic sounds the boundaries between vowels and liquid consonants are the worst to be recognized [2], thus it may well be the case that the falls of F_0 observed

---

[3] S. Smith in his list of the distinctive features of "opened nasality" points to the absence of essential variations of fundamental frequency ([4], p. 146).

at boundaries of the nasal consonants, even though insignificant, are essential for perception.

The frequency of the occurrence of local falls of F_0 in the analyzed consonants and the relative magnitudes of these falls, decrease in the order in which particular groups of consonants have been mentioned here, namely: stop — fricative — nasal. It would appear that the conclusion may be drawn that the smaller the constriction (the degree of occlusion) of a consonant, the smaller is the mean value of the fall of F_0 in the consonant. The conclusions drawn for /r/ and /l/ need further confirmation because of the small statistics of the results.

It seems that the use of information on the behaviour of F_0 at the transitions between particular sounds would have a beneficial effect on the quality of synthetic speech.

The statistically verified hypothesis of a lognormal distribution for the magnitude of the relative fall in F_0 for consonants, throws some light on the mechanism of these falls, since it may give evidence of the function of the vocal chords being subject to a law of proportionality in the cases under discussion. It would appear that use can be made of the estimated parameters of the theoretical distributions in speech synthesis when one is anxious to obtain speech with a highly natural sound. In this case one should define the fall of F_0 at the end of a consonant by means of a random numbers generator, modulating the lognormal distribution with parameters that correspond to a particular group of consonants (stop, fricative or liquid).

References

[1] J. Aitchinson, J. A. C. Brown, *The Lognormal Distribution*, 4.5 Cambridge 1957.

[2] W. M. Belawski, L. W. Jeżowa, *Spektralno-vremennyje priznaki dla segmentacii reči na zvuki*, ARSO, 8, 2, 36 (1974).

[3] L. A. Čistovič, *Metod issledovanija rešajuščich pravil, primenjajemych pri vosprijatii reči.* Proceedings of the Sixth International Congress of Phonetic Sciences (Prague, 7-13 Sept. 1967), Academy of Sciences, Prague 1970, p. 23-34.

[4] G. Fant, *Acoustic Theory of Speech Production*, S'Gravenhage, 1960.

[5] M. Haggard, St. Ambler, McCallow, *Pitch as a voicing cue*, JASA, 47, 2, 613-617 (1970).

[6] J. M. Heinz, B. E. F. Lindblom, I. Ch. Lindqvist, *Patterns of Residual Masking for Sounds with Speech—Like Characteristics*, In: Conference on Speech Communication and Processing, Boston 1967, p. 246-251.

[7] W. Jassem, *Fundamentals of acoustic phonetics* (*in Polish*) Warszawa, 1973.

[8] H. Kubzdela, *Automatic extraction of the fundamental frequency and of the first three formants of a speech signal*, (in Polish) IPPT Reports, n° 51 (1973).

[9] R. P. Léon, Ph. Martin, *Prolégomènes à l'Etudes des Structures Intonatives*, Studia Phonetica, II-Ottava 1970.

[10] W. W. Lublinskaja, *Vosproizvedenije prostych konturov izmenenija častoty osnovnogo tona zvukov*, In: Problemy fiziologičeskoj akustiki, 7, Analiz rečevych signalow čelovekom, Leningrad 1971, s. 66-74.

[11] I. G. MATTINGLY, *Synthesis by Rule of Prosodic Features*. Language and Speech, **9**, 1, 1-13 (1966).
[12] O. MATUSZKINA, *Effect of consonantal articulation on the pattern of the fundamental frequency in the Polish language* IPPT Reports n° 37 (1976).
[13] D. MEHNERT, *Untersuchungen zur Feinstruktur der Grundfrequenz bei der stimmhaften Anregungsfunktion*, In: 14, akusticka konferencia "Akustika reči a vnimanie zwuku", Bratislava 1976, p. 114-118.
[14] B. MOHR, *Intrinsic Variations in the Speech Signal, Phonetica,* **23**, 65-93 (1971).
[15] S. ÖHMAN, J. LINDQVIST, *Analysis-by-synthesis of prosodic pitch contours,* STL QPRS, 4, 1-6 (1965).
[16] S. ÖHMAN, *Word and sentence intonation: a quantitative model,* STL QPRS, 2-3, 20--54 (1967).
[17] K. L. PIKE, *The Intonation of American English,* Ann Arbor (1945).
[18] M. STEFFEN–BATÓG, *The effect of consonants articulation and intonation on fundamental frequency,* In: Speech Analysis and Synthesis, 3, Warszawa 1973, p. 121-134.
[19] C. WITTING, *A method of evaluating listeners transcription of intonation on the basis of instrumental data,* Language and Speech, **5**, 3, 138-150 (1962).
[20] R. ZIELIŃSKI, *Statistical tables* (in Polish), Warszawa 1972.

Received on 15th June, 1977

ARCHIVES OF ACOUSTICS
3, 2, 121-139 (1978)

A STUDY OF THE UNDERWATER ACOUSTIC DISTURBANCES PRODUCED BY A SHIP PROPELLER

EUGENIUSZ KOZACZKA

Naval College, Gdynia

The paper discusses briefly the problem of the generation of underwater acoustic disturbances by hydrodynamic sources (e. g. a ship propeller).

The results of the investigations carried out in a hydrodynamic channel are presented. They refer to the following characteristics: the amplitude spectrum of the disturbances, the propeller performance (characteristic), and the acoustic pressure level as a function of the propeller speed at given velocities of movement relative to the undisturbed water. The results of investigations performed in an anechoic basin are described . They are illustrated by the amplitude spectra of the acoustic disturbances recorded using a narrow-band analyser with a bandwidth of 3.16 Hz. In addition, the level of the acoustic underwater disturbances as a function of the propeller rotational speed is discussed.

Having in mind certain limitations imposed upon the experiments performed in a hydrodynamic channel and an anechoic basin the measurements of acoustic underwater disturbances at the marine conditions were carried. The electrically driven ship propeller was used. The results discussed in this paper concern a propeller operating in the presence of cavitation.

In addition to the results of these investigations a method is also presented for studying the acoustic effects produced by a ship propeller working under various conditions.

Notation

A/A_0 – area coefficient,
A – area of the ship propeller blades [m²],
A_0 – area of the propeller disc [m²],
c – sound velocity [m/s],
D – ship propeller diameter [m],
H/D – propeller pitch factor,
F_i – i-th component of the volume force density,
H – propeller pitch,
f – frequency [Hz],
i – index $i = 1, 2, 3$,
J – effective pitch propeller advance coefficient,
j – index $j = 1, 2, 3$,
J_{mz} – Bessel function of the first kind order mz,

K_m – propeller torque coefficient,
K_T – propeller thrust coefficient,
M – torque applied to the propeller [Nm],
m – order of harmonic,
n – propeller speed r. p.s.,
η – ship propeller efficiency,
p – sound pressure,
p_m – sound pressure of the m-th harmonic [N/m^2],
m – order of harmonic of the sound pressure,
Q – volume rate of the mass source [kg/m^3 · s],
R_0 – radius of the ship propeller [m],
R_e – effective radius of the ship propeller [m],
ϱ – density of the medium [kg/m^3],
ω – angular velocity i/s,
T – thrust of the ship propeller,
T_{ij} – tensor of stress [kg/m · m^2],
t – time [s],
v – velocity of the stream flowing on to the propeller [m/s],
Z – number of blades of the ship propeller,
X_i – coordinates,
V – volume of a propeller blade.

The generation of acoustic underwater disturbances by a ship propeller received little attention in the literature on underwater acoustics. The problem is complicated and has not as yet been comprehensively described either theoretically or experimentally.

The papers on the generation of acoustic disturbances by systems of the "propeller type" are well known, but mostly refer to a gaseous medium.

Among the more interesting papers in this field the publications by GUTIN [1, 2], LIGHTHILL [3, 4], GARRICK and WATKINS [5, 6] and other authors [7, 8, 9, 14, 15] should be mentioned. As regards experimental work, there is virtually no publication on the generation of acoustic disturbances by a ship propeller. The paper by ALEKSANDROV [10] deals only in a fragmentary form with this problem.

The process of the generation of underwater acoustic disturbances can be divided into two ranges. The first range is concerned with propeller operation without cavitation, while the other range is concerned with propeller operation in the presence of cavitation.

The mechanics of the generation of acoustic disturbances in the first range is related to the hydrodynamic effect of a propeller upon the ambient medium. The acoustic radiation is related, inter alia, to such phenomenon as the action of the propeller blades on the medium, which generates the thrust force. The effect of the generation of the thrust force and the periodic changes in the volume (section 1) define the value of the acoustic pressure produced by the propeller.

It should be stressed that even in the absence of cavitation, the propeller operation produces phenomena which are very complex hydromechanically.

A precise analysis of the flow around the propeller has not yet been made even for an incompressible fluid model. The formation of swelling and detachment areas, the formation of vortices and vortex lines make the interpretation of the phenomena observed during propeller operation rather difficult. In addition, the mutual effect of the propeller blades (the blade cascade effect) also contributes to the complexity of the phenomena. It is for these reasons that it is not easy to give an exact mathematical description of the acoustic phenomena encountered during propeller operation. Under actual conditions the ship propeller is working in non-uniform fluid velocity field and this, in the author's opinion has a fundamental influence on the magnitude of the acoustic effects. It is worth to mention that even for a uniform field velocity the theoretical description is rather hard to formulate.

Thus an experimental study of the acoustic effects related to ship propeller operation is at present more attractive.

Cavitation on a propeller constitutes an additional source of underwater acoustic disturbances which, by their nature, differ from those which exist in the sub-cavitation range.

The growth and collapse of air or gas bubbles produce acoustic effects. The bubbles, when distributed within the area of propeller operation, can be considered as point sources of shock waves. Furthermore, the formation of air bubbles brings about a rapid growth of non-uniformity in the velocity field, and also in the medium (two-phase medium). This makes the description of the phenomenon investigated even more difficult.

Sometimes there is also a strong hydroelastic effect which induces strong torsional vibrations of the propeller blade. These vibrations are the source of the acoustic disturbances commonly referred to "propeller singing". This phenomenon occurs only for some propellers over certain ranges of speed. This paper presents the results of investigations of propeller operation in the subcavitation range. They constitute a particular part of the study of the underwater acoustic effects associated with the operation of ship propellers.

1. The mathematical and physical description of the generation of underwater acoustic disturbances by ship propeller

A mathematical description of a ship propeller operating under normal conditions has not so far been elaborated. The mathematical model of an aircraft propeller operating in a uniform velocity field developed by Gutin [1] can be used only for the qualitative description of the operation of a ship propeller. Although the problem considered in this paper would appear similar, the results obtained by calculating the sound pressure are several orders of magnitude smaller than the values obtained experimentally [9]. Since no formulae have so far been derived which would permit a clear and simple interpretation of the phenomena, the results obtained by Gutin are presented below to explain some of the mechanics of sound generation by a ship propeller.

The problem of the radiation of sound by a hydrodynamic source is described by a non-uniform partial differential equation of hyperbolic type (sometimes referred to as the Lighthill equation) which is of the form:

$$\frac{\partial^2 p}{\partial x_i^2} - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = -\frac{\partial Q}{\partial t} + \frac{\partial F_i}{\partial x_i} - \frac{\partial^2 T_{ij}}{\partial x_i \partial x_j}, \tag{1}$$

where p is the sound pressure, Q is the volume rate of the mass source, F_i is the component of the body force acting in the i-th direction, T_{ij} is the tensor of the stress, and c is the sound velocity.

The third term on the right-hand side of Eq. (1) describes sound generation by turbulent flow and will not be extensively considered here, since such effects are not perceptible in the investigations carried out.

However, the first term characterizes the time changes of the mass velocity in the space of the action of the propeller blades upon the surrounding medium. It is related to the periodical displacement, by the propeller blades, of a certain volume of fluid which in turn fills the space left by the blades. The resulting radiation is monopolar in its character (this means that a source of such a type can be replaced with a source of zero order). Such disturbances generated by a screw propeller are sometimes called the "volumetric noise" of the screw [16].

The second term of equation (1) is related to the change of body forces accompanying propeller operation. The body forces occurring in the field of a ship propeller are primarily the thrust force and the force from the propeller torque. During rotation there is a periodical change of the body forces in space. This type of generation results in dipole radiation and is called the „propeller force noise" [16].

Since equation (1) is too general to be useful in studying a relationship between the sound pressure and the quantities describing an acoustic field source, we shall use the relationship derived by Gutin [2, 9] for a clearer interpretation of the propeller action. This relation defines, for a given observation point, the value of the sound pressure associated with the parameters of propeller operation:

$$|p_m| = \left\{\frac{m\omega z}{2\pi c R}\left| -T\frac{x}{R} + M\frac{c}{\omega R_e^2}\right| + \frac{\varrho (m\omega z)^2}{2\pi R} V\right\} J_{mz}\left(\frac{k_m R_e}{R}\,y\right), \tag{2}$$

where p_m is the pressure of the m-th harmonic component of the sound pressure induced by the propeller, ω is the angular velocity of the propeller, z is the number of propeller blades, T is the thrust of the propeller, X is the coordinate along the axis of revolution of the propeller, R is the distance of the observation point from the centre of the propeller, M is the torque applied to the propeller, R_e is the effective radius of the propeller $R_e = (0.7-0.8)R_0$, R_0

is the radius of the propeller $R_0 = D/2$, Y is the coordinate axis perpendicular to the X axis, J_{mz} is a Bessel function of the first kind of order mz, k_m is the wave number, $k_m = m\omega z/c$, x, y are the coordinates of the observation point, V is the volume of the propeller blades, ϱ is the density of medium and c is the velocity of sound in the medium.

Formula (2) is obtained from the solution of equation (1) by substituting appropriate expressions for the first and second terms on the right-hand side of the equation. These terms are related to the working conditions of the propeller and to its geometry [9]. The method of solving the equation is given in the Appendix.

Formula (2) describes the propeller operation for a water stream flowing on to the propeller with a uniform velocity field. It can be seen from formula (2) that the value of the sound pressure is related to the rotational speed of the propeller and the number of blades. It also depends on the load of the propeller in terms of thrust and torque and on the radius of the propeller. As it has already been stated, this formula describes ship propeller operation only qualitatively, since the numerical results are not in quantitative agreement with the experimental data [9].

More complex mathematical models of the generation of acoustic underwater disturbances by a ship propeller use the circulation model of propeller operation [9]. However these models are very complicated, and their practicability is limited because the actual distribution of the velocity of the stream flowing onto the propeller is not always known. Consequently it is not possible to determine the circulation of the velocity on the propeller blades.

The investigation of the acoustic underwater disturbances generated by propellers can be carried out under the following conditions:

1. in hydrodynamic channels with models of propellers;
2. in anechoic water basins with the propeller operating but stationary;
3. in anechoic water basins with the propeller operating but in motion;
4. at sea, on real propellers.

2. Investigations of propeller operation in a hydrodynamic channel

The propeller operation is, in principle, described by the three following coefficients:

1. The propeller thrust coefficient

$$K_T = \frac{T}{\varrho n^2 D^4}, \tag{3}$$

where T is the propeller thrust, n is the rotational speed, D is the propeller diameter, and ϱ is the density of the medium.

2. The coefficient of propeller torque load

$$K_M = \frac{M}{\varrho n^2 D^5}, \tag{4}$$

where M is the torque applied to the propeller.

3. Advance coefficient

$$J = \frac{v}{nD}, \tag{5}$$

where v is the velocity of the undisturbed water stream.

The so called efficiency coefficient, of the form

$$\eta = \frac{K_T}{K_M} \cdot \frac{J}{2\pi} \tag{6}$$

is also often used.

The characteristics of the investigated propeller are shown in Fig. 1. The parameters of this propeller are summarized in Table 1.

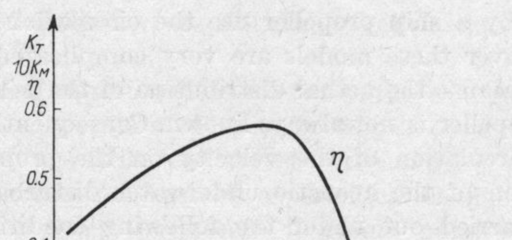


Fig. 1. Characteristics of ship propeller No. 1

Table 1

Propeller No.	Outer diameter D[m]	Number of blades z	Surface coefficient A/A_0	Pitch coefficient H/D	Direction of revolution
1	0.17	5	0.75	0.7	left

The investigations were carried out in a hydrodynamic channel on a model of a five-blade propeller [1, 12, 13].

The measuring system is shown schematically in Fig. 2

A number of measurements were made (Fig. 3) to determine the spectra of the acoustic underwater disturbances produced by the propeller rotating at a speed of $n = 20$ r. p. s. One can see here a distinct band centred at a frequency of $f_0 = 100$ Hz.

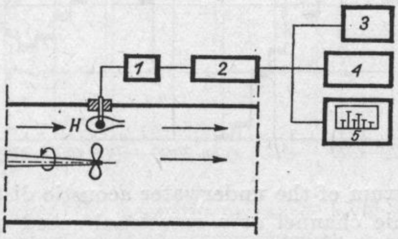


Fig. 2. Diagram of the system for measuring the acoustic disturbances produced by a ship propeller in a hydrodynamic channel

H – the measuring hydrophone; 1 – type 2626 charge amplifier; 2 – type 2606 measuring amplifier; 3 – type 2010 spectrum analyser; 4 – type 7001 magnetic tape recorder; 5 – type 3347 Brüel & Kjaer real time 1/3 octave analyser with display unit

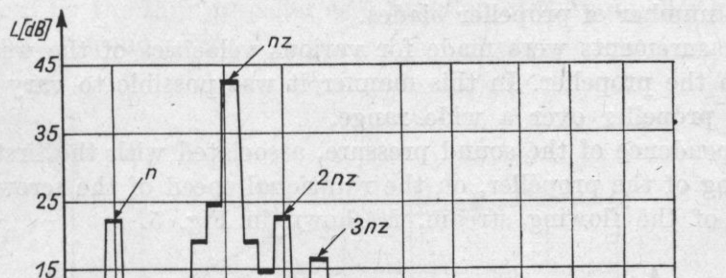


Fig. 3. The amplitude spectrum of the underwater acoustic disturbances of propeller No. 1, operating in a hydrodynamic channel at a rotational speed $n = 20$ r. p. s. Flow rate of water stream, $v = 1.2$ m/s

The spectra of acoustic underwater disturbances generated by the ship propeller rotating at a speed of 40 r. p. s. are shown in Fig. 4.

It can be seen from Figs. 3 and 4 that the level in the frequency band corresponding to the fundamental driving has a considerable effect on the total level of the acoustic underwater disturbances which are generated by the ship propeller. The frequency of this driving can be related to the parame-

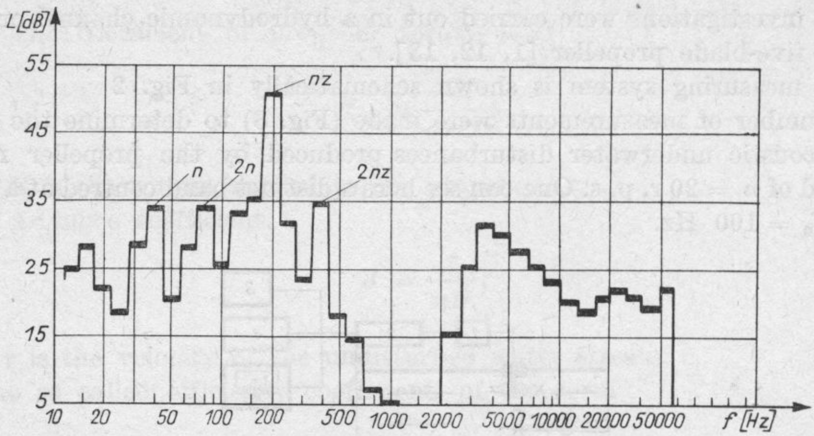


Fig. 4. The amplitude spectrum of the underwater acoustic disturbances of propeller No. 1 operating in a hydrodynamic channel at a rotational speed of $n = 40$ r. p. s. Flow rate of water stream, $v = 2.4$ m/s

ters of the propeller operation by the following formula

$$f_m = m\, n\, z, \tag{7}$$

where m is the number of the harmonic 1, 2, ..., n is the propeller speed [r.p.s.] and z is the number of propeller blades.

The measurements were made for various velocities of the water stream flowing onto the propeller. In this manner it was possible to vary the thrust load of the propeller over a wide range.

The dependence of the sound pressure, associated with the first harmonic of the driving of the propeller, on the rotational speed of the screw, for high velocities v of the flowing stream, is shown in Fig. 5.

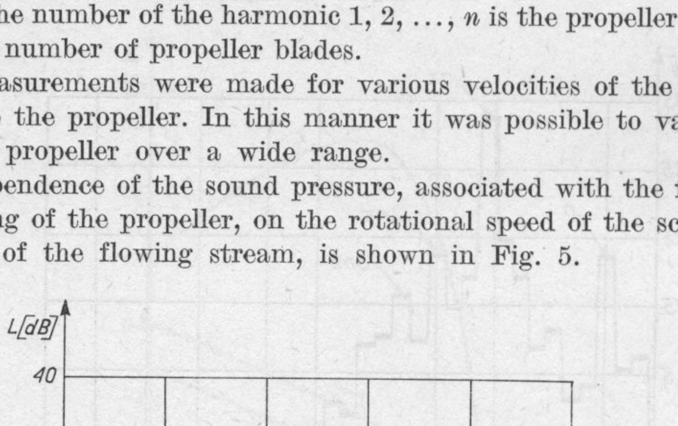


Fig. 5. The relationship between the acoustic pressure level and the rotational speed of the propeller. Flow rate of water stream, $v = 1$ m/s

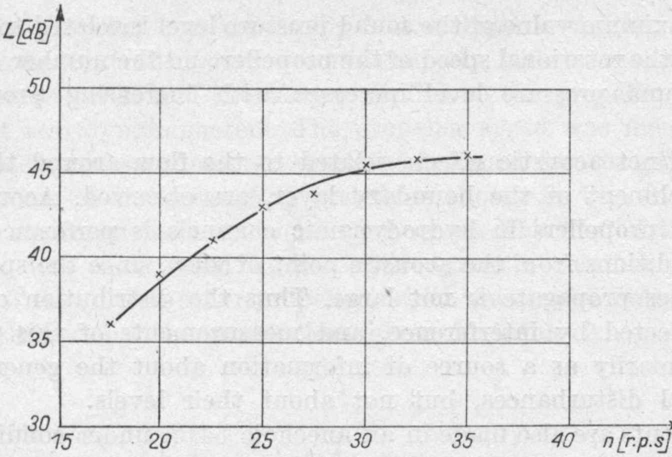


Fig. 6. The relationship between the acoustic pressure level and the rotational speed of the propeller. Flow rate of water stream: $v = 2$ m/s

In order to relate the acoustic effects to the load of the propeller, that is to the thrust and torque, use has been made of relations (3) (5), and of the graph presented in Fig. 1. On this basis a graph was plotted of the sound pressure produced by the ship propeller as a function of the propeller load in terms of thrust and torque (Fig. 7).

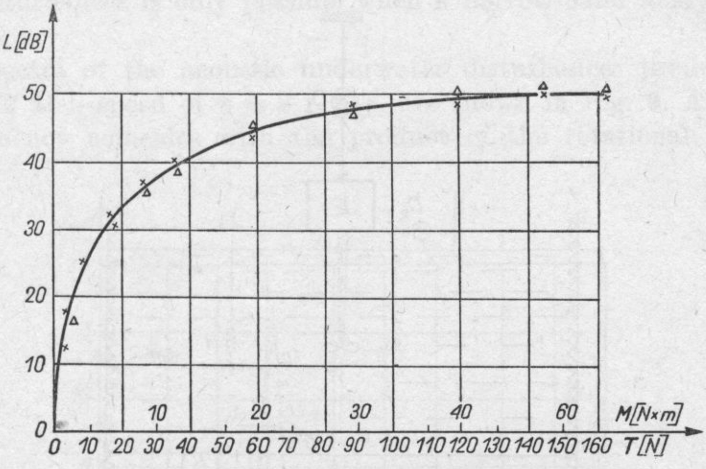


Fig. 7. The relationship between the acoustic pressure level L and the propeller load. T is the thrust propeller and M — the torque

On the basis of the investigations carried out on the generation of acoustic underwater disturbances by a model of the ship propeller in a hydrodynamic channel the following conclusions can be drawn.

1. The maximum value of the sound pressure level is related to the driving determined by the rotational speed of the propeller and the number of its blades.

2. The sound pressure level increases with increasing propeller speed and load.

3. No distinct acoustic effects related to the flow around the propeller, e. g. the detachment of the boundary layer, are observed. Acoustic investigation of ship propellers in hydrodynamic channels is performed under unfavourable conditions from the acoustic point of view, since the space in which the disturbances propagate is not large. Thus the distribution of the sound pressure is affected by interference, and measurements of this type can be considered primarily as a source of information about the general structure of the spectral disturbances, but not about their levels.

Measurements are also made in an anechoic basin under conditions of stationary propeller operation. The conditions in the anechoic basin are more favourable acoustically, but less favourable from the point of view of the propeller dynamics (as compared to the investigations carried out in a hydrodynamic channel), since the flow rate of the water is too low.

3. Investigation of a propeller in an anechoic basin

Investigations of the acoustic effects associated with ship propeller operation in an anechoic basin were carried out with the propeller operating but stationary.

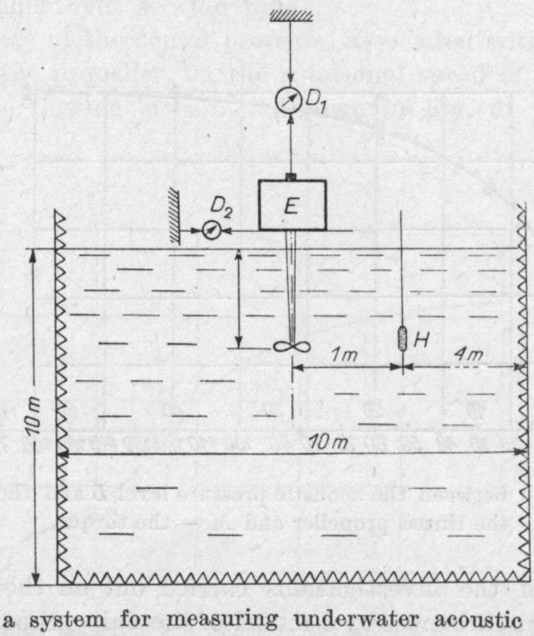


Fig. 8. Diagram of a system for measuring underwater acoustic disturbances produced by a ship propeller in an anechoic basin

D_1 – dynamometer for measuring the thrust force, D_2 – dynamometer for measuring the torque, E – eletric motor, H – hydrophone

The ship propeller was driven by a d. c. electric motor, which enabled the speed to be controlled over a comparatively wide range. The thrust produced by the propeller and the torque applied to the propeller were measured by means of two dynamometers. The propeller speed was measured with the aid of an electronic speedometer specially designed for the purpose.

The scheme of the measuring system is shown in Fig. 8. Two ship propellers were tested on the same measuring stand. The first of them is the propeller which was also tested in the hydrodynamic channel. Its parameters are given in Table 1. The other propeller, which was tested only in the anechoic basin is described by the parameters given in Table 2.

Table 2

Propeller No	Outer diameter D[m]	Number of blades Z	Surface coefficient A/A_0	Pitch coefficient	Direction of revolution
2	0.5	3	0.35	0.45	left

The spectral analysis of the underwater acoustic disturbances was carried out using a heterodyne analyser, with a bandwidth of $\Delta f = 3.16$ Hz.

It should be noted that for this type of investigation a fixed bandwidth narrow-band analyser should be used. This results from the fact that the disturbances have a discrete character and exact identification of the frequencies related to these disturbances is only possible when a narrow-band analysis is performed.

The spectra of the acoustic underwater disturbances produced by propeller. No. 2 at a speed of $v = 8$ r. p. s. are shown in Fig. 9. A spectral line whose frequency coincides with the product of the rotational speed of the

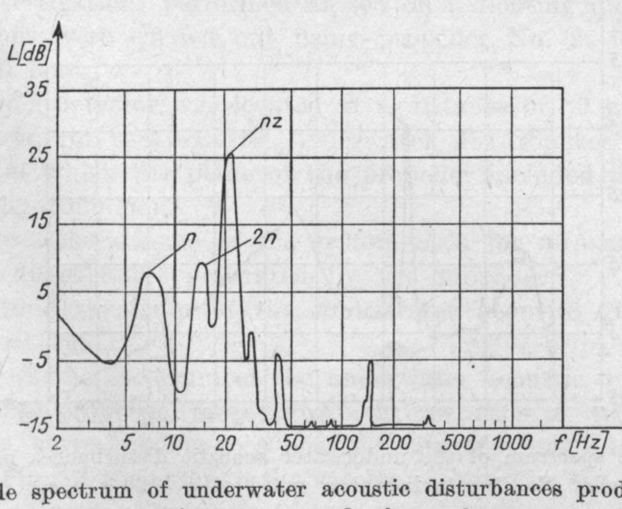


Fig. 9. Amplitude spectrum of underwater acoustic disturbances produced by propeller No. 2 rotating at a speed of $n = 8$ r. p. s.

propeller and the number of blades can be clearly seen. This line has a level which predominates over the whole spectrum. The level defines the total level of the disturbances generated by the propeller.

Fig. 10 shows the dependence of the sound pressure produced by propeller No. 2 as a function of the propeller speed. The level increases with increasing propeller speed, until the cavitation bubbles begin to appear on the propeller.

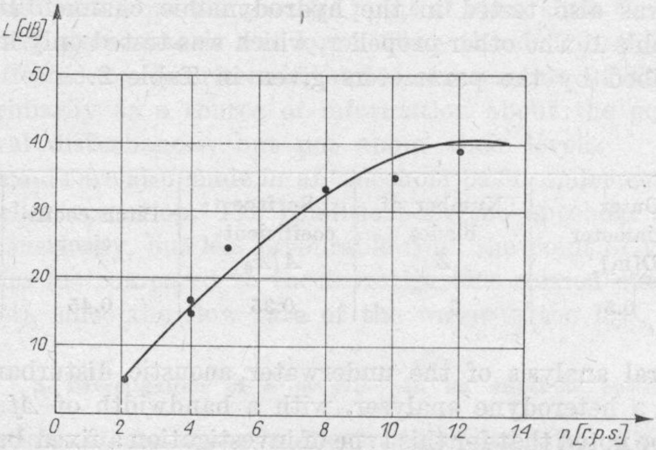


Fig. 10. The level of underwater acoustic disturbances produced by propeller No. 2, vs. the rotational speed

The spectrum of the acoustic underwater disturbances produced by propeller No. 1 is shown in Fig. 11.

Fig. 11. clearly shows the existence of a spectral line with a frequency equal to $f = 150$ Hz. This frequency, as it has already been pointed out is equal to the product of the number of blades of propeller No. 1 ($Z = 5$), and

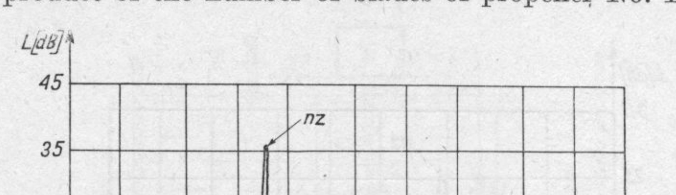


Fig. 11. Amplitude spectrum of the underwater acoustic disturbances produced by propeller No. 1 rotating at a speed of $n = 30$ r. p. s.

the rotational speed $n = 30$. This figure also shows a range of the continuous spectrum which is associated with the cavitation bubbles.

The interpretation of this part of the spectrum is very difficult. The distinct character of cavitation does not permit these effects to be described in greater detail.

It follows from the investigations carried out on the underwater acoustic disturbances generated by a ship propeller in absence of cavitation in an anechoic basin, that the total level of the acoustic disturbances is related to the level of the spectral line of a frequency equal to the product of the propeller speed and the number of propeller blades.

4. Investigations of the propeller at sea

Investigations carried out on the basis of measurement of the acoustic effects produced by a ship propeller in a hydrodynamic channel and in an anechoic basin have certain drawbacks.

In the case of investigations carried out in an hydrodynamic channel, where the free space is comparatively small, the occurrence of a strong water stream produces intense internal noises. It was therefore difficult to measure the magnitude of the acoustic disturbances generated solely by the propeller. On the other hand, the acoustic effects of the propeller in stationary operation in an anechoic basin may be somewhat "deformed" because of the unfavourable hydromechanical conditions for the propeller. Investigations carried out in the two conditions mentioned above are more favourable from the point of view of the practicality and the costs involved, but they provide only general data on the disturbances generated by the propeller. The most realistic ones are investigations performed at sea on a floating object.

Investigations were carried out using propeller No. 2, which was used to drive a small boat.

The measuring detector was located at a distance of 30 m from the propeller. The spectra of the acoustic underwater disturbances were recorded at the moment at which the plane of the propeller included the point of observation (the hydrophone).

Fig. 12 shows the scheme of the system used for measuring the underwater acoustic disturbances generated by the propeller.

The amplitude spectrum of the underwater acoustic disturbances was measured in real time.

Fig. 13 shows the spectrum of the underwater acoustic disturbances produced by the ship propeller (propeller No. 2) operating at a rotational speed of $n = 15$ r. p. s. corresponding to a boat velocity of about 3.1 m/s. The spectrum shown in Fig. 13 is similar to the spectrum shown in Fig. 9, although the component corresponding to the driving input 3 *nz* is significantly enhanced. Besides, the spectrum shown in Fig. 13, is more complicated. This results mainly from the fact of the propeller operating near a rigid body (boat hull), and this causes an increase in the disturbance amplitude, and also introduces certain additional disturbances. Furthermore, the driving system of the pro-

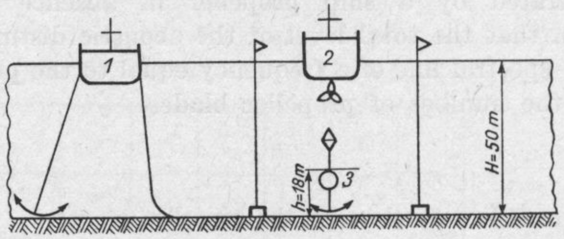


Fig. 12. Diagram of a system for measuring the underwater acoustic disturbances produced by a ship propeller under marine conditions

1 – measuring station; *2* – motor boat driven by an electric motor; *3* – measuring hydrophone

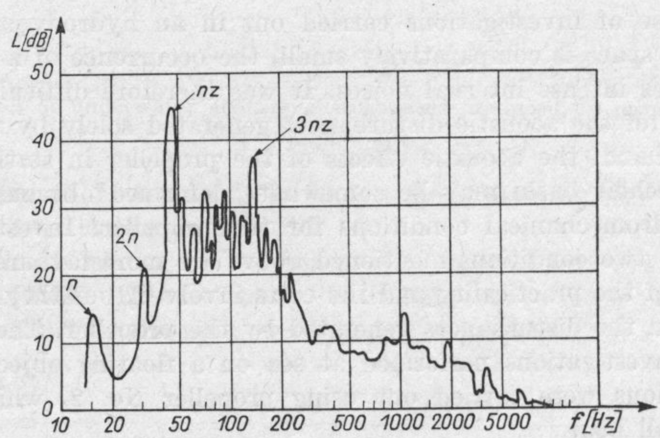


Fig. 13. Amplitude spectrum of the acoustic underwater disturbances produced by ship propeller No. 2, rotating at a speed of $n = 15$ r. p. s.

peller, operating in the interior of the boat hull, produces vibrations of the hull plating which also have some effect on the structure of the composite spec. trum of the underwater noise of the propeller operating near the boat hull. The non-uniform distribution of the water stream flowing onto the screw has a substantial effect on the disturbance spectrum. Fig. 14 shows the relative changes of the thrust force as a function of the angle of rotation of the propeller induced by the non-uniformity of the velocity field of the water stream flowing onto the propeller.

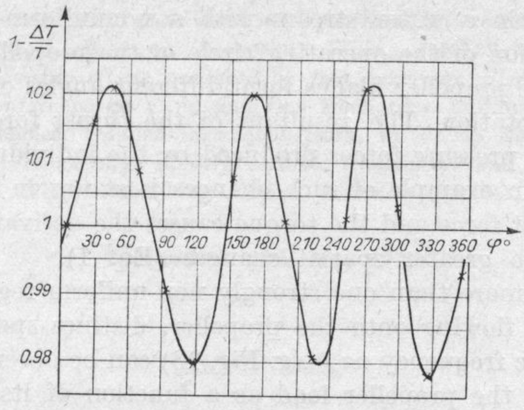


Fig. 14. The relative changes of the loading of the propeller as a function of the angle of rotation

5. Discussion of the results of the acoustic investigations on the ship propeller operation

The investigations of the acoustic effects carried out under different experimental conditions permit one common conclusion to be drawn. The spectrum of the underwater acoustic disturbances produced by a ship propeller, in the subcavitation range, depends on the rotational speed of the propeller and the number of its blades. The level of the disturbance near the frequency nz predominates in all the spectra presented and defines the overall value of the sound pressure level.

The level of the acoustic disturbance produced by the propeller increases as its speed is increased. This level increases with increasing loading of the propeller, as does the acoustic pressure of the m-th harmonic, according to Gutin's formula for aircraft propellers (formula 2). Nevertheless the substitution in that formula of the actual values of the thrust force and the torque, of the geometrical parameters of the propeller and of the medium properties, gives values of the acoustic pressure, e. g. for the first harmonic, which are several tens of decibels smaller than the data obtained experimentally. Thus this formula is not useful for the analytical determination of the acoustic pressure produced by a ship propeller, but may only be used for the qualitative interpretation of the phenomenon.

In the Lighthill equation (formula (1)) the first two terms on the right-hand side of the equation correspond to zero and first order sources. Obviously, this equation is related to the Gutin formula (see Appendix).

In experimental investigations an increase in the sound pressure level can be observed when the ship propeller is operating in fluid stream with a non-uniform velocity field. This applies mainly to the angular distribution,but the changes of fluid velocity with propeller radius have also some effect on the magnitude of the acoustic effects related to the propeller operation. A screw propeller operating in a water stream with a nonuniform velocity field distribution in the region of the operating circle of the propeller, is distinquished by the fact that the propeller blades form different angles of attack depending on the angle of rotation. The resultant of the thrust forces, being the geometrical sum of the pressure forces produced by the individual blades is a fluctuating quantity. An example of such changes is shown in Fig. 14. The fluctuation of the thrust force and the torque causes the derivative of the density of force to undergo greater spatial changes (Eq. 1).

When there is more than one strongly non-uniform region in the velocity field of the stream flowing onto the propeller, distinct spectral lines at multiples of the acoustic frequency *nz* (e. g. Fig. 13) can be observed. Thus it seems that the change of the propeller load as a function of its angle of rotation, (this results from the non-uniform character of the velocity field of the water stream), is an essential factor in determining the overall level of the sound pressure of the underwater acoustic disturbances produced by a screw propeller.

The effect of a rigid body near the propeller e. g. a plate in a plane parallel to the propeller axis causes an additional increase in the acoustic pressure level produced by the propeller.

It was found in the course of the investigations that third octave spectral filters (Fig. 3 and 4) are less useful than narrowband, fixed bandwidth spectrum analysers (Figs. 9, 11, 13.)

References

[1] L. J. Gutin, *O zvukovom polie vraščajuščego vozdušnego vinta,* Žurnał techničeskoi fiziki, 6, 5, 899-909 (1936).

[2] L. J. Gutin, *O zvukie vraščenia vozdušnogo vinta,* Żurnał techničeskoi fiziki, 12, 2-3, 76-33, (1942).

[3] M. J. Lighthill, *On sound generated aerodynamically,* General Theory. Proceedings of Royal Society, A 221, 564-578 (1952).

[4] M. J. Lighthill, *Sound generated aerodynamically,* The Bakerian Lecture, 267, A 5 (1962).

[5] T. E. Garrick, C. E. Watkins, *A theoretical study on the freespace sound-pressure field around propellers,* NACA, TN 3018 (1953).

[6] V. T. Bavin, M. A. Vashkerich, I. Y. Miniovich, *Pressure field around a propeller operating in spatially non-uniform flow,* Seventh symposium on naval hydrodynamics, Rome 1968.

[7] J. P. Breslin, *A new interpretation of the free space pressure field near a ship propeller,* Stevens Inst. Technol. Davidson Lab. Rept. No 689 (1968).

[8] S. Tsakonas, C. V. Chen, W. P. Jacobs, *Acoustic radiation of a cylindrical bar excited by the field of ship propeller,* JASA, 36, 1959-88 (1964).

[9] I. A. Minowicz, A. Piernik, W. C. Pietrowskij, *Gidrodinamičeskije istočniki zvuka,* Izd. Sudostrojenie, Leningrad 1972.

[10] I. A. Aleksandrov, *Physical nature of the rotation noise of ship propellers in the presence of cavitation,* Soviet Phys. Acoust., 8, i, 123-128 (1962).

[11] E. Kozaczka, *Investigation of underwater noise generated by a rotating propeller (in Polish)* Proc. XXIII Open Seminar on Acoustics, Wisła, 128-129 (1976).
[12] E. Kozaczka, *Acoustic effects produced by free screw propeller in non-uniform flow.* 2-nd National Conference on Fluid and Gas Mechanics. Summary of lectures, Polish Academy of Sciencies, Gdańsk-Jastrzębia Góra, in Polish 49 (1976)
[13] J. Morawiec, E. Kozaczka, *Modern ceramic transducers and some of their applications (in Polish)* WSP. Publishing House, Rzeszów (1977).

Received on 18th May 1977

APPENDIX

THE DERIVATION OF THE GUTIN FORMULA

Relation (2) used by Gutin [2], which enables the value of the acoustic pressure produced by a blade system to be determined, is obtained by solving equation (1), with the third term of the right-hand side of the equation being neglected.

We shall give the method which permits the determination of the "force noise", the basic component of the sound pressure produced by the propeller. Equation (1) for this problem takes the form

$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)p = \mathrm{div}\vec{F}. \tag{1a}$$

If we present the sound pressure in the form

$$p(x, y, z, t) = p(x, y, z)e^{i\omega t} \tag{2a}$$

and the density of forces as

$$F(x, y, z, t) = F(x, y, z)e^{i\omega t}. \tag{3a}$$

then equation (1a) assumes the form of the non-uniform Helmholtz equation

$$(\nabla^2 + k^2)p(x,y,z) = \mathrm{div}\vec{F}(x,y,z). \tag{4a}$$

When the forces act within a limited area V_0, the solution of equation (4a) can be written in the following form:

$$p(x,y,z) = -\frac{1}{4\pi}\int\left(\frac{\partial Fx}{\partial x_0} + \frac{\partial Fy}{\partial y_0} + \frac{\partial F_2}{\partial z_0}\right)\frac{e^{-ikR}}{R}\,dx_0dy_0dz_0, \tag{5a}$$

where

$$R = \sqrt{(x-x_0)^2+(y-y_0)^2+(2-z_0)^2}.$$

If we have a concentrated force acting at the origin of the system, as is the case of a propeller, then formula (5a) is expressed as follows:

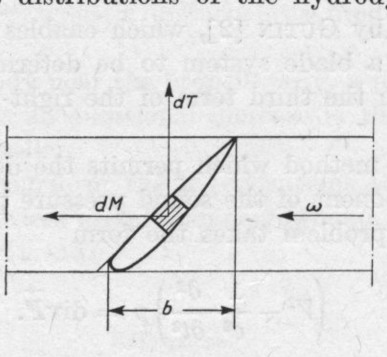
$$p(x,y,z) = -\frac{1}{4\pi}\left(F_x\frac{\partial}{\partial x}+F_y\frac{\partial}{\partial y}+F_z\frac{\partial}{\partial z}\right)\frac{e^{-ikR}}{R}. \tag{6a}$$

Taking into consideration the distribution of the forces acting upon an element of the propeller surface, in the system shown in Fig. 15, we obtain:

$$dT = \frac{A(r)rd\Theta r}{b}, \tag{7a}$$

$$dM = \frac{B(r)rd\Theta}{b}dr, \tag{8a}$$

where $A(r)$, $B(r)$ are the distributions of the hydrodynamic load along the blade radius.



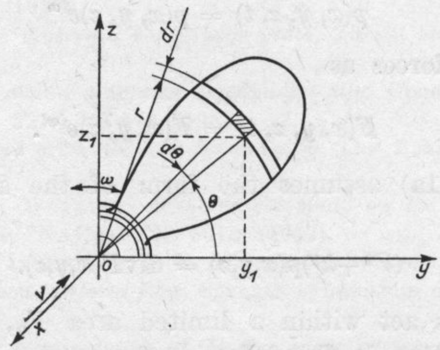


Fig. 15. Scheme of the influence of the propeller blade on the ambient medium

The thrust force and the torque are acting on the medium for the time equal to $\tau = b/r\omega$.

In view of the fact that the action of the forces upon the medium is periodic, equations (5a) and (6a) can be expressed as trigonometric series.

After simplification we obtain the components of the elementary forces acting upon the medium:

$$dF_{mx} = -\frac{1}{\pi}\frac{dT}{dr}e^{i(mz\omega t - mz\Theta)}drd\Theta, \tag{9a}$$

$$dF_{my} = -\frac{1}{\pi r}\frac{dM}{dr}e^{i(mz\omega t - mz\Theta)}\sin\Theta drd\Theta, \tag{10a}$$

$$dF_{mz} = -\frac{1}{\pi r}\frac{dM}{dr}e^{i(mz\omega t - mz\Theta)}\cos\Theta drd\Theta. \tag{11a}$$

Substituting (9a), (10a) and (11a) into (6a) under the assumption that the velocity of the water stream flowing on to the propeller satisfies the relationship $v \ll c$, and after some tedious transformations, we obtain the GUTIN formula for the value of the sound pressure of the n-th harmonic in the following form:

$$|p_m| = \frac{m\omega z}{2\pi c R}\left| -T\frac{x}{R} + M\frac{c}{\omega R_e^2}\right| J_{mz}\left(\frac{k_m R_e}{R}y\right). \tag{12a}$$

This schematic presentation of the method shows the relationship between equation (1) and the GUTIN formula (2). Equation (12a) constitutes part of the relationship (2), and defines the dependence of the sound pressure on the load of the propeller in terms of torque and thrust force.

A similar method is used for the determination of the levels of the harmonics of the sound pressure of the "volume noise" that results from the finite volume of the blades of the ship propeller.

An exact derivation of both formulae is given by MINOVICH et al. [9].

C H R O N I C L E

XXIV-th OPEN SEMINAR ON ACOUSTICS

The XXIV-th Seminar on Acoustics was held at Władysławowo at Gdańsk, September 19-24. The seminar was sponsored by the Gdańsk Section of the Polish Acoustical Society in cooperation with the Committee on Acoustics of the Polish Academy of Sciences, the Institute of Telecommunication of Gdańsk Technical University and the Institute of Physics of Gdańsk University.

360 persons, participated in the seminar including from abroad. There were acousticians from Czechoslovakia, Denmark, France, GDR, Japan, Netherlands, Spain, Switzerland, USSR. Out of the 322 home participants nearly half were members of the Polish Acoustical Society.

There were 40 people from the Warsaw section, 38 from Wrocław, 29 from Gdańsk, 21 from the Upper Silesian section, 19 from Poznań, and 7 from the Rzeszów section.

A fortnight before the beginning of the Seminar participants were sent the following printed material: a detailed programme of the sessions, and a two-volume book entitled: "Prace XXIV Otwartego Seminarium z Akustyki – Proceedings of the XXIV-th Open Seminar on Acoustics" which included 163 four-page lectures submitted for the seminar. It should be noted that out of 172 papers, only those accepted by the reviewers were printed.

The evaluation of the papers was performed, as from the XIX-th Open Seminar on Acoustics, with the cooperation of the Section Boards of the Polish Acoustical Society, and the assistance of the Editorial Committee of the XXIV-th Open Seminar on Acoustics.

The timely sending of the lectures permitted the assumption that they were known to the participants concerned. Thus 10 or 15 minutes out of the 25 assigned for each lecture, were devoted to an introduction and to the presentation of complementary or illustrative material; the remaining 15 or 10 minutes were used for discussion. The breaks between lectures lasted 5 min. thus permitting sufficient time for moving between the different lecture halls.

The choice of lecture–hall was facilitated by an audio-visual monitoring system installed in all session rooms. Two remotely switched cameras and microphones in each room permitted the observation of the sessions from a centrally situated and easily accessible foyer with installed monitors, and also a simultaneous viewing of the sessions in the technical dispatch room.

The monitoring system of the sessions and the selective announcement system from the dispatch room to the loudspeakers in the individual rooms, hall, dining-room and corridors proved their effectiveness in ensuring the punctual realization of the programme without the need for frowning over-running sessions with music, as has been done at several previous Seminars. Furthermore, the awareness that in addition to the participants assembled in the room, other spectators were watching the lecturers and the participants in the discussion, stimulated the activities of the participants, and contributed to the high level of the debates and discussions.

A multi-channel earphone system was also installed for the synchronous translation of lectures into foreign languages and vice versa. Three cabins located in the technical dispatch room in front of the monitors permitted the interpretators to observe the lecturer, thus facilitating a synchronous translation of the text. Plenary lectures were translated simultaneously into English, French and Russian. The translation of the session lectures was reduced to a minimum because of the lack of available funds.

The opening session was attended by representatives of the municipal authorities of Władysławowo and of the institutions engaged in the organization of the Seminar.

Occasional speeches were delivered. The Chairman of the Main Board of the Polish Acoustical Society prof. H. Ryffert opened the session. The audience paid homage to the memory of prof. Jerzy Wehr, an eminent Polish acoustician, who had lost his life on a expedition in the Hindukush mountains in the summer of this year.

During the Seminar 3 plenary lectures and 156 session lectures, including 143 published in the "Prace XXIV Otwartego Seminarium z Akustyki" and 10 amongst papers destined for poster session were orally presented. The lectures were divided into the following subject groups:

Musical acoustics – Chairman L. Pimonov – 8 lectures,
Psychological acoustics – Chairman H. Ryffert – 5 lectures,
Speech acoustics – Chairman J. Kacprowski – 22 lectures,
Interior acoustics – Chairman W. Straszewicz – 11 lectures,
Electroacoustics – Chairman Z. Żyszkowski – 19 lectures,
Medical ultrasound diagnostics – Chairman J. Zieniuk – 7 lectures,
Ultrasonic techniques – Chairman J. Ranachowski – 14 lectures,
Ultrasonic transducers – Chairman W. Pajewski – 7 lectures,
Underwater acoustics – Chairman Z. Jagodziński – 14 lectures,
Molecular acoustics – Chairman A. Śliwiński – 22 lectures,
Noise sources – Chairman S. Czarnecki – 25 lectures,
Lectures not foreseen in the program – Chairman G. Budzyński – 2 lectures.
Poster session – Chairman L. Lipiński – 30 works.

The poster-session consisted of contributions related formally, but not in terms of subject-mater to the Seminar. As it has already been mentioned, ten of these contributions were included as lectures in the programme sessions while the others were the subject of free discussion.

The problem of environmental acoustics was discussed at a special plenary meeting under the chairmanship of prof. S. Czarnecki.

Twenty two young authors submitted their papers for the Marek Kwiek competition. Twenty one of these presented their lectures, and were evaluated by the members of a jury set up by the Competition Committee. It should be noted that the competition took place according to the rules as altered last year.

Discussion sessions, summing up the results of the deliberations in a given group were held in each of the subject groups. The chairman of these groups presented the results of these sections at a final plenary meeting. These sessions, under the chairmanship of prof. I. Malecki, brought out many valuable remarks and observations for future use in the organization of the next Seminars. The advisability of organizing the recapitulatory sessions was stressed. It was found that the annual seminars organized by the Polish Acoustical Society have gained importance in fulfilling their functions as a review of the actual achievements of Polish acoustics, as a platform for the exchange of experience and views, as a school for the younger generation of acousticians and as an opportunity of establishing and strengthening links with acousticians from all over the world.

There was a general feeling that the use of the highly efficient equipment for the service and organization of the Seminar has saved much time for the participants for individual contacts and discussion, and informal group discussions. Coach excursions were organized during the conference. The location of the conference centre near the beach facilitated the establishment of direct contacts, especially with the many foreign participants. The importance of the party for lla participants at one table, on the evening of September 21 was stressed.

In brief, the proceedings of the XXIV Open Seminar on Acoustics included 199 scientific papers of which 159 were delivered as lectures. The proceedings are published in Polish with the summaries in English.

Every evening films on acoustics were shown, totalling 12 films: 5 French, 4 English, 2 American and 1 Polish. Full-length film and a short-feature film were also projected.

The Brüel & Kjaer exhibited their measuring instruments during the Seminar. The "3M" displayed audio and visual equipment. The publishing house "Ultrasonics" provided a comprehensive information about its publications.

The sponsors of the Seminar also displayed large-scale illustrations depicting the development of the Seminars organized by the Polish Acoustical Society and graphic proposals for the mark of this Society.

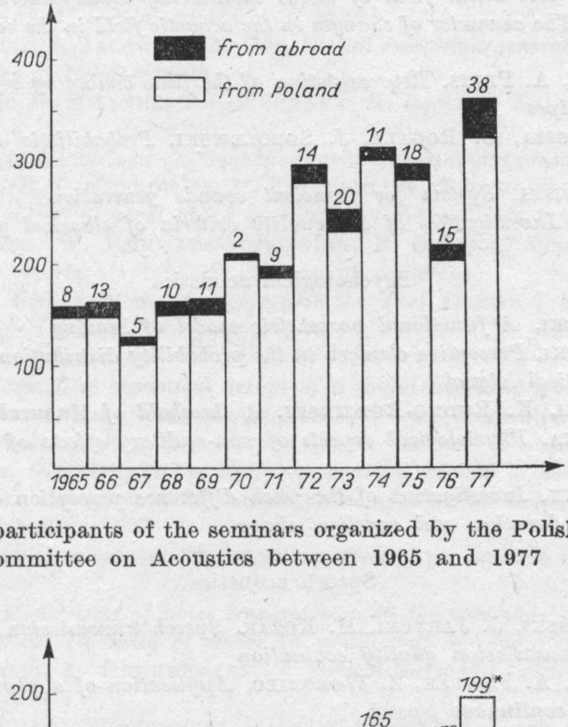


Fig. 1. Number of participants of the seminars organized by the Polish Acoustical Society and the Committee on Acoustics between 1965 and 1977

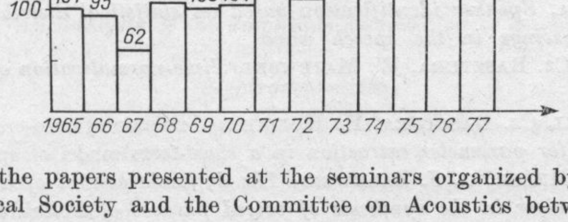


Fig. 2. Number of the papers presented at the seminars organized by the Polish Acoustical Society and the Committee on Acoustics between 1965 and 1977

LIST OF PAPERS DELIVERED AT THE SEMINAR

Plenary papers

1. G. Budzyński, *Phonic problems of acoustics*
2. A. Śliwiński, *Problems of molecular acoustics*
3. Z. Jagodziński, *Ultrasonic echolocation*

Section papers

Musical acoustics

1. G. W. Papanikolaou, *Microphone systems for tetraphonic recordings*
2. E. Lieber, *Tune of pianos, causes and properties*
3. J. Geisler, *Acoustical field of stereo monitoring loudspeakers*
4. J. Regent, *The character of changes in the acoustic field in the sound due to frequency correction*
5. H. Ryffert, A. Preis, *Representation of the flute timbre by reference to the timbre of selected organ pipes*
6. R. W. Kulesza, B. Rogala, J. Sobolewski, *Probabilistic structure of musical signals*
7. K. Muzalewski, *System for transient sounds generation*
8. M. Meinel, *Investigation of the quality criteria of classical guitar strings*

Psychological acoustics

1. S. Hlibowicki, *A functional parametric model of hearing*
2. S. Hlibowicki, *Perceptive changes in the probability distribution of the instantaneous value of an acoustical signal*
3. J. Renowski, K. Rudno-Rudziński, *A threshold of binaural sound image*
4. M. Konarska, *Physiological aspects of non-auditory effects of low-frequency ultrasound*
5. J. Konieczny, *Investigation of the pitch difference perception of selected sounds as a function of their duration and envelope shape*

Speech acoustics

1. S. Brachmański, J. Jarycki, M. Kozak, *Speech transmission as a predictive measure of a speech transmission quality evaluation*
2. E. Tyburcy, A. Pawlak, Z. Worobiec, *Application of a phonetic speech function to segmentation of continuous speech*
3. J. Jarycki, S. Brachmański, M. Kozak, *The measurement of skin vibration acceleration during speech production*
4. Cz. Basztura, *Speaker identification based on statistical distributions of time intervals between zero-crossings in the speech wave*
5. A. Pawlak, Cz. Basztura, W. Majewski, *Time-normalization of utterances in speaker identification*
6. W. Majewski, Cz. Basztura, H. Hollien, *Analysis of zero-crossings in the speech wave as a technique for parameter extraction in a short-term model of speaker recognition*
7. M. Gos, W. Myślecki, J. Zalewski, *The dynamic control of a computer simulated series formant synthesizer in the synthesis of voiced phrases of Polish speech*

8. W. Mikiel, P. Żarnecki, W. Tłuchowski, P. Maniecka-Aleksandrowicz, A. Szewczyk, *Acoustic parameters of children's speech signal*

9. R. Gubrynowicz, P. Żarnecki, *An on-line minicomputer system for processing some parameters of the speech signal*

10. W. Mikiel, R. Gubrynowicz, W. Hagmajer, *Intonograf – a system for the measurement and visualization of speech signal intensity and melody*

11. J. Kacprowski, *A simulation model of the vocal tract including the effect of nasalization*

12. J. Zalewski, J. Jurkiewicz, H. Hollien, *An application of the Itakura measure for the estimation of predictive coded pattern similarity*

13. Cz. Basztura, J. Jarycki, Zb. Worobiec, *Application of multiple regression analysis for quality classification of larynx transducers*

14. J. Jurkiewicz, J. Zalewski, W. Myślecki, *A formant contour analysis of Polish speech short phrases by means of the linear prediction method*

15. E. Tyburcy, J. Zalewski, *The distinctive features of vowel junctures described by a phonetic speech function*

16. G. Kiełczewski, *Digital synthesis of speech*

17. W. Myślecki, J. Zalewski, A. Gos, *Glottal excitation generation rules for the synthesis of short phrases of Polish speech*

18. R. Millner, M. Millner, R. Grossmann, H. J. Hein, *Evaluation of the US-TM-glottogram*

19. O. Matuszkina, *Fundamental frequency variations in voiced consonants of spoken Polish*

20. W. Mikiel, R. Gubrynowicz, P. Żarnecki, W. Tłuchowski, A. Komorowska, A. Szewczyk, *Evaluation of vocal chord paralysis by the analysis of the $F_0(t)$ function*

21. B. Adamczyk, W. Kuniszyk-Jóźkowiak, E. Smółka, *Synchronization of speaking with echo and reverberation in the therapy of stuttering*

22. T. van der Graaf, *Vowel analysis with the Fast Fourier Transform*

Building acoustics

1. E. G. Tzekakis, *The acoustical design of a sound-recording studio in Athens, Greece*

2. E. Bromberg, J. Zalewski, *An approach to some applications of digital analysis technique for characterising properties of "the speaker-listener" acoustic path in auditoria*

3. M. Tajchert, *Directivity in the digital geometrical method of acoustical field analysis*

4. St. Czarnecki, *An effect of diffraction phenomena on the acoustic conditions in concert and industrial halls*

5. M. Vogt, *How to maximize the cancelling effect of an acoustic resonator acting as an insulating element*

6. S. Weyna, *Model tests of noise transmission in the accomodation of sea-going ships*

7. B. Makarewicz, *Intensity of waves in media with screening obstacles*

8. B. Piwakowski, L. Dunkelmann, *A vertical/horizontal tapping machine with adjustable tapping frequency*

9. A. Kulowski, A. Witkowski, *Acoustical correction of a vaulted room*

10. H. Ryffert, E. Ozimek, *Perceptibility of changes of the spectral structure of sound propagating in a room*

11. E. Ozimek, *An analysis of the amplitude deformation of sound propagating in enclosure.*

Electroacoustics

1. A. Gabor, J. Zarzycki, *The minimization of loudspeaker system nonlinear distortion by proper bandwidth division*

2. S. Hlibowicki, J. Renowski, K. Rudno-Rudziński, *An enlarged equivalent electrical circuit of a loudspeaker*

3. A. Puch, R. Wyrzykowski, *The effect of rotor and stator port shape on the acoustic parameters of a dynamical generator*

4. J. Zarzycki, A. Gabor, *The optimization of the multidimensional functions describing nonlinear distortion*

5. K. Musialik, W. Majewski, W. Myślecki, *The rules for the generation of a limited set of messages by means of the three channel computer voice response system (CVRS)*

6. K. Somla, *Fast Fourier Transformation and tracking filter capability*

7. Z. Sołtys, Z. Wąsowicz, *Measurement of loudspeaker responses by means of noncoherent signals*

8. C. Szmal, *Loudspeaker quality factor correlated with subjective evaluation*

9. A. Dobrucki, *The influence of the constructional properties of a conical loudspeaker membrane on its vibration and radiation*

10. S. Nuckowski, B. Rogala, R. Zmonarski, *Some problems in the optimization of the spectral method of nonlinear distortion measurements in the electroacoustical part of radio receivers*

11. M. Glabisz, B. W. Kulesza, R. Szkop, *Investigations of the electroacoustical properties of radio receivers using impulse methods*

12. T. Zamorski, R. Wyrzykowski, *The radiation of an acoustic horn below the cutoff frequency*

13. B. Bogusz, *Applications of spectral analysis in infrasound measurements*

14. J. Kamiński, J. Jurkiewicz, *Investigation of cooperation signals in kinematic pairs*

15. S. Nuckowski, J. Szymbor, *A nonlinear network with memory for measuring technique optimization*

16. A. Defevre, J. Pouliquen, M. Chastagner, *Measurement of the propagation velocity of acoustic waves*

17. M. Rabiega, B. Rudno-Rudzińska, J. Zalewski, *An application of digital techniques to the analysis of the signal obtained in the measurements of the reflection coefficient using a tone-burst method*

18. R. Dyba, B. Żółtogorski, *On the application of the Peltier effect in metal-semiconductor junctions to the generation of sound waves*

19. A. Kulik, J. Ryll-Nardzewski, *Determination of elastic constants in circular discs*

Ultrasonic medical diagnostics

1. M. Petzold, H. Pein, *Koordinatendarstellung für mechanische Scanner ohne Funktionspotentiometer*

2. A. Grospic, Q. Vo, I. Prerowski, J. Fąbian, A. Belan, L. Hejhal, *Noninvasive ultrasonic examination of aortacoronary bypass*

3. J. Etienne, *Spectral analysis of ultrasound doppler signals in obstetrics*

4. P. Kwiek, *Application of double exposure hologram interferometry to the investigation of ultrasonic field distributions in the liquids*

5. P. Kwiek, *Theoretical background of time averaged hologram interferometry applied to ultrasonic field observation*

6. A. Markiewicz, *Transients in ultrasonic probes used in medical diagnostic equipment*

7. T. Maruk, *Electronic focusing of the ultrasonic beam in medical diagnostic systems*

Ultrasonic techniques

1. W. Kołtoński, P. Jaroszewski, *Geoacoustic apparatus – petroscope PS-20*

2. W. Kołtoński, B. Zienkiewicz, *Sonic detection and localization of cracks in bore hole casings*

3. H. GAJDA, *The attempt at applying pulsed ultrasonic method for testing the elastic properties of the stalks of cereal plants*

4. M. KOWALEWSKI, S. WACHOWICZ, *Ultrasonic disintegration of ceramic materials*

5. Z. SIWKIEWICZ, *Ultrasonic vibration in powder element pressing*

6. L. LIPIŃSKI, *The change of hardness of ultrasonically excited polycrystalline Al samples*

7. R. KUKULSKI, B. NIEMCZEWSKI, *Ultrasonic cleaner with liquid degassification*

8. B. KURELLA, *Ultrasonic joining of metal inserts and plastic*

9. A. GACA, *Application of ultrasonic vibration to the plastic working process of metals*

10. Z. PAWŁOWSKI, A. PILARSKI, *Longitudinal ultrasonic wave techniques for measuring bond strength in adhesive bonded joints*

11. J. MAZUREK, Z. PAWŁOWSKI, *Research in inhomogeneous media using the spectral analysis of acoustic emission*

12. R. SUWALSKI, *Sound power levels of airborne noise emitted by ultrasonic cleaners UM-4 and ATH-1117/TW*

13. A. SKRZYNECKI, *Some problems of ultrasonic wire cleaning system construction*

14. Z. KACZKOWSKI, S. RÓŻAŃSKI, *Ultrasonic device for fatigue tests*

Ultrasound transducers

1. Z. KACZKOWSKI, E. MILEWSKA, *The piezomagnetic flexibility of Alfer transducers*

2. Z. KACZKOWSKI, *The impedance of Alfer transducers working with acoustic waves*

3. E. TALARCZYK, *Ultrasonic aerolocation transducer with a vibration plate used in flexural modes*

4. Z. KLESZCZEWSKI, A. MLECZKO, *The study of acoustic field distribution of piezoelectric transducers using the Bragg diffraction method*

5. I. WOJCIECHOWSKI, *The application of hologram interferometry to ultrasonic transducer investigation*

6. W. NASALSKI, *Synthetic aperture as a method for increasing the lateral resolution in ultrasonic visualization*

Underwater Acoustics

1. T. OTANI, Y. URABE, *Effet non linéaire à la surface limite entre l'eau et l'air*

2. J. C. SOMER, *Real-time improvement of both lateral and range resolution by optical signal processing*

3. E. WASILTSOW, *Metody rasčeta antennych reszetok*

4. J. TABIN, *Diffraction of an ultrasonic wave by an elongated target*

5. C. RANZ GUERRA, R. CARBO FITE, *Echo formation by dioptric systems with high acoustic impedance mismatch*

6. L. KILIAN, *On some problems of sonar echo normalization and dynamic range compression*

7. H. LASOTA, *On a method of target echo extraction from reverberation background*

8. A. STEPNOWSKI, M. LAMBOEUF, J. C. BRETHES, *The application of the echo integration technique to the acoustic estimation of trumpet fish stock off the Atlantic coast of Marocco*

9. E. T. KOZACZKA, J. MORAWIEC, *Investigation of piezoelectric hydrophones*

10. B. KIBORT, *The errors in measurements on an underwater transducer in a closed acoustic system*

11. W. Martin, *Hydroacoustic system for position fixing of freerunning ship models*

12. Z. Klusek, *Influence of seasonal changes of the speed of sound profile in the Baltic on some properties of ambient sea noise*

13. M. Brzozowska, *Statistical properties of acoustic signals in the sea scattered by its rough surface*

14. R. Salamon, R. Gudelewicz, E. Niedziałkowska, *Digital depth meter.*

Molecular acoustics

1. D. Sette, *Acoustic emission in liquid crystals*

2. W. F. Kunigelis, *Akustoelektričeskije wzaimodiejstwie pri naličii dwoch tipow nositelej toka i koniečnom wremieni ich žizni*

3. M. Blukis, C. J. Lewa, S. Łętowski, M. Roeding, A. Śliwiński, *Piezoelectric properties of some polymers*

4. F. M. Mazzolai, R. Franco, *Effect of oxygen impurities on the diffusion coefficient of hydrogen in niobium*

5. W. Szachnowski, B. Wiślicki, *Acoustical study of association phenomena in hydrocarbon fractions of petroleum*

6. L. Werblan, L. Skubiszak, *Ultrasonic absorption in polar-butyrolactone-water mixtures*

7. E. Drescher, *Length of selective attenuated waves due to structural changes in early stages of the hardening process*

8. Z. Tylczyński, *Determination of domain wall thickness in TGS crystals from measurements of longitudinal ultrasonic wave propagation*

9. A. Drzymała, H. Herba, M. Cieślak, *Ultrasonic investigation of the temperature dependence of the viscosity coefficient in cholesteric liquid crystals*

10. M. Cieślak, A. Drzymała, *An attempt to estimate the relaxation time in cholesteryl mirystyate on the basis of the attenuation of dispersion of ultrasonic waves*

11. A. Juszkiewicz, Z. Bartynowska, *Second ultrasonic relaxation region in acetic acid esters*

12. W. Nozdriev, *Investigation of carbohydrate solutions by an optical ultrasonic method*

13. M. Szustakowski, *Acoustooptic interaction development and applications*

14. M. Łabowski, O. I. Zinowjew, *Fine structure of the Rayleigh line of light scattering in critical mixture*

15. M. Łabowski, A. Artykow, *Study of the acoustical properties of some liquids over a wide range of frequencies*

16. P. Sladky, P. Lokaj, *Laser induced acoustic waves in some liquids*

17. D. Ciplys, A. Domarkas, *Generacja akusticzeskogo szumowego potoka w n-InSb w otsutstvije magnitnogo pola*

18. M. Nowicki, E. Niechoda, W. Woliński, G. Gackowska, *Acoustooptic Q-switches for Nd: YAG lasers*

19. H. Swół, J. Małecki, *Measurements of the Young modulus of natural crystal of gypsum by resonance method*

20. J. Lewandowski, *The acoustical field angular distribution of a wave scattered in a random inhomogeneous medium*

21. E. Soczkiewicz, *Propagation of ultrasonic waves and the hole theory of liquids*

22. B. Niemczewski, *The cavitation intensity of liquids*

Sound-proof and vibration-proof protection

1. J. Stenička, *Prediction of structure-borne noise transmission from machines to constructions*

2. W. Rybarczyk, *Methods of establishing optimum set of technical solutions for reducing noise in working room*

3. M. Frączyk, L. Kałmucki, J. Regent, *Designation method of noise source location in industrial spaces*

4. W. Rybarczyk, *Cost analysis and effects of noise abatement in different production rooms*

5. L. Rutkowski, *Evaluation of short-time changes of acoustic diagnostic signals*

6. M. Mirowska, *Investigations of the propagation parameters of acoustical waves in sound absorbing fibrous materials*

7. J. Degórski, H. Kaczmarek, W. Łańczak, *Transverse vibration test stand foundation for marine diesel engines*

8. J. Kozłowski, K. Somla, A. Sowiak, *Real-time measurement and analysis of a ship-hull vibration*

9. T. Deloff, *The selectivity of chamber mufflers*

10. B. Rudno-Rudzińska, M. Rabiega, J. Zalewski, *A mathematical model of road traffic noise*

11. A. Podsędkowski, *Methods of reducing the efficiency of siren noise radiation in axial fans*

12. M. Słomski, *The application of the relative acoustic pressure level to the determination of the sound field distribution of a non-stationary acoustic source*

13. J. Kaźmierczak, *The vector representation of the noise spectrum in constructional research on machines using acoustic methods.*

14. Z. Dukiewicz, W. Ziółkowski, *Determination of space correlation function of structure-borne sound propagation in the beam-plate system*

15. Z. Stepaniak, C. Cempel, *Spectral and correlation analysis in ball bearing diagnostics*

16. C. Cempel, M. Golec, *Vibroacoustical processes similarity measures and their application in the diagnostics of machinery*

17. W. Bandera, *An experimental method of complex propagation constant determination in viscoelastic materials*

18. W. Bartelmus, *Coherence method of diagnosing machines*

19. H. Chmieliński, D. Nitecki, *Analysis of acoustical signal of drifter drills for acoustical diagnosis*

20. H. Chmieliński, J. Motylewski, *Measuring method and stand for acoustical diagnosis of drifter drills*

21. H. Kusek, W. Birecki, W. Jankowski, *The perception of acoustic signals against the background of factory noise*

2. A. Jaroch, H. Idczak, J. Renowski, *Influence of rotating diffuser parameters on the diffusion of the sound field*

23. J. Jakubczak, M. Mielcarek, W. Tyrchan, *The influence of the silencing of the inlet pipe installation of piston compressors on the sound level in the neighbourhood of the compressor hall*

In the conclusion of this report it is instructive to include some data about the development of the Polish Acoustical Society which was provided on the information stand during the XXIV Open Seminar on Acoustics (See Fig.).

Gustaw Budzyński (Gdańsk)