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HYDROPHYSIQUE

ON THE VOICE OF THE SEA

By W. W. ŠULEJKIN
Corresponding member of the Academy

The aerologists working on board ship and at maritime hydrometeorological stations have noted that on approaching a sounding-balloon filled with hydrogen to the ear one feels a certain pressuse upon the eardrum. This extremely painful feeling has its climax at the distance of one cm and utterly disappears if the balloon is removed to a distance of some ten centimetres.

My attention was drawn to this phenomenon for the first time in 1932 during the navigation on board of the s/s «Taimyr» by V. A. Berezkin, the meteorologist of the expedition.

On my return from the expedition I tried to observe this curious phenomenon in Moscow by filling sounding-balloons of different size with hydrogen, but no effect at all was to be obtained. It was perfectly evident that the observed effect had been caused by the sea.

This January I succeeded in repeating the experiment on the Black Sea coast (with a balloon 65 cm in diameter filled with hydrogen). Here again arose an effect of nearly the same force as was observed by the «Taimyr» expedition in the open (Kara) sea.

However, when in my experiments at the Black Sea Hydrophysical Station I substituted air for hydrogen, the effect disappeared. Hence, we may draw conclusion that the second indispensable condition for the effect is the presence of hydrogen in the balloon.

Yet, the pain in the ear could be avoided even in the experiments with hydrogen: it was sufficient to place a wooden plank between the ear and the balloon; the plank could even have a small hole (1 mm in diameter). Consequently, the painful feeling was caused by no excess pressure (for the latter would have passed through the hole), but by some oscillations of the air near the cover of the balloon. The amplitude of these oscillations must have been very great, as could be judged from the pain in the ear.

As concerns the range of the oscillations, it has to be classified among the subsonic, for at the time of the first observation in the Kara Sea no sounds were to be heard around (at the Black Sea Hydrophysical Station was heard a faint noise of the surf). The supersonic oscillations were out of the question, because the effect would have been quite different (as is known from the experiments of Wood and others, supersonic oscillations cause a thermic effect).

Thus, we have here subsonic oscillations. But in such a case, it must be possible to record them by means of some simple device connected to the cover of the balloon.

Such a record has been realized at the Black Sea Hydrophysic Station. The general view of the apparatus is shown in Fig. 1. A balloon filled with hydrogen was fixed into a certain trihedral angle in order to prevent any oscillations which might be produced by accidental air currents inside the laboratory. The angle was formed by three planks mounted upon a carriage which could be micrometrically moved along the horizontal plane.

In the original design of the apparatus the balloon was put into touch with a thin rubber membrane stretched on a round box, which is to be seen in the figure (the box was turned 180° around its vertical axis as compared with its position in Fig. 1). In its turn, this membrane was connected to a small moveable mirror. The second variant is represented in Fig. 1. Here the balloon was put into contact with a very thin aluminium pin acting upon the mirror, which is seen in the centre of the box. Consequently, the apparatus responded directly to the oscillations of the rubber balloon cover. A ray from the light source (not shown in the diagram) fell on the mirror and was reflected by the latter upon the sensitive paper encircling the drum of a kimogragh seen in the foreground of Fig. 1.

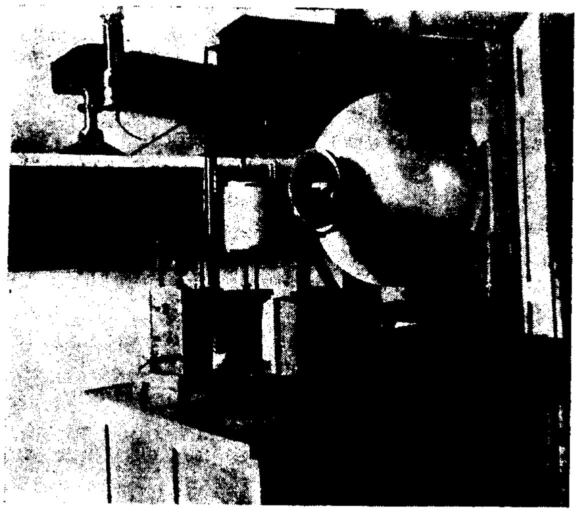

Fig. 1.

On starting the latter and switching on the light, the sensitive paper quite destinctly recorded the balloon cover oscillations of a rather complex nature. Oscillations of a frequency of 12—13 Hertz were the most pronounced; but besides these, some lower oscillations (about 2 H) and some hygher ones were to be observed, the latter being seemingly caused by the noise of the surf.

It is to be noted that, in designing the recording device, all precautions had been taken to exclude the details which might have a period close to that of the oscillations under investigation (about 0.1 seconds). That is why we had to make the mirror and all the other details rather heavy, thus con-

Fig. 2.

sciously diminishing the oscillation amplitude. This was compensated by the fact that all the recorded oscillations with the period we were interested in could cause no more doubts as to their authenticity.

What is then the origin of the subsonic waves which we have discovered in the air above the sea?

At the present time, it may be safely said that this is a genuine v o i c e o f t h e s e a: the air passing over the agitated surface of the sea suffers the effect of the unevenness which always characterizes a wind wave covered with three-dimensional «hills». If we assume that the distance between the latter is about 1 metre and the wind velocity is about 10 m/sec. (with regard to the water), it is evident that the same air mass will meet with the «hill» summits every tenth of a second. Therefore, it is easy to show that there must arise not only transverse oscillations (usually considered by the classic theories of the sea wave) but also l o n g i t u d i n a l ones caused by the fact that the air is a c o m p r e s s i b l e m e d i u m.

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where V is the wind velocity, s
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Therefore, the oscillation amp
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Now we have only to explain why this voice of the sea is made audible by means of a rubber balloon filled with hydrogen, without which the former would remain quite inaccessible to our ear.

The solution of the problem is prompted by the fact that a similar balloon filled with air produces no effect at all. Indeed, it is perfectly obvious that a balloon filled with hydrogen may be regarded as a Rayleigh's particle with a refraction index different from unit, which produces a d i s p e r s i o n of waves around itself. But as is known, under certain ratios between the constants of such a particle and the wave length, the energy of the waves produced by the particle may considerably exceed the amount of the energy falling on the area of its equatorial section. For the first time this was shown by Mie for the particles of colloidal suspensions of gold placed in a field of light waves and commeasurable with their length. At certain ratios between the diameter of the particles and the length of the wave there arose a regular optical r e s o n a n c e.

In our case of subsonic waves, apparently, a similar phenomenon of resonance between the falling waves and the balloon takes place. Its result is the voice of the sea we have overheard. No doubt, in this case the phenomenon of resonance must arise at entirely different ratios between the diameter of the balloon and the wave length, for besides the hydrogen inside the rubber cover of the balloon, the latter is also put into oscillatory motion. Without any calculations we can say that the oscillation period of the system, with the same diameter of the balloon, must considerably exceed the period of a sphere of hydrogen alone. That is why the resonance takes place when the diameter of the balloon is much less than the length of the corresponding subsonic wave. At the present time, this curious case of resonance is being investigated by the gifted mathematician L. N. Sretenski, and I make no doubt that very soon he will succeed in finding a perfectly exact solution of the problem.

It would be of interest to calculate the order of magnitude of the p o w e r of the voice of the sea. Unfortunately, at the present time it is impossible to make a more or less exact calculation to that effect, as the flow of the air around the three-dimensional waves running along the surface of the sea is extremely complicated. At all accounts, in accordance with Jeffreys (1), we may assume that the force of the air pressure on the surface of a three-dimensional sea wave is equal to

$$p = s \cdot \delta V^2 \cdot k \cdot h \cdot \sin kx \cos k_1 y \left(\frac{\text{dyne}}{\text{cm}^2}\right) \cdot \qquad (1)$$

where V is the wind velocity, s is the coefficient characterizing the area of the action of the wind on the wave, δ is the air density, h is the height of the wave, and k and k_1 are coefficients connected with the wave length L and its breadth L_1:

$$k = \frac{2\pi}{L}; \quad k_1 = \frac{2\pi}{L_1} \cdot$$

Therefore, the oscillation amplitude of the air pressure will be determined by the equation

$$P = 2\pi \frac{h}{L} \cdot s \cdot \delta \cdot V^2. \qquad (2)$$

As the energy flow of the subsonic waves, calculated for one cm² of the «radiating» surface of the sea, is connected with the amplitude P:

$$E = \frac{1}{2} \frac{P^2}{\delta \cdot c}, \qquad (3)$$

where c is the velocity of sound, we have

$$E = 4\pi^2 \left(\frac{h}{L}\right)^2 \cdot \frac{s^2 \cdot \delta \cdot V^2}{c}. \tag{4}$$

Here we must substitute the numeric values:

$$\frac{h}{L} = 0.1; \quad \delta = 0.0012; \quad c = 34\,000; \quad s = 0.3.$$

If we perform all the operations and if we express the energy flow in terms of watts per 1 square metre of the sea surface and the wind velocity in terms of metres per second, we shall get

$$E = \frac{1}{4}\left(\frac{V}{10}\right)^4 \tag{5}$$

At the velocity of the wind equal to 20 m/sec., the power of the voice of the sea would reach 4 W/m².

This value must be considered the upper limit, for in reality a certain acoustic «enthropy» is to be expected. Given turbulent motion of the air current over the agitated sea, only part of the whole air mass which had undergone compression at the meeting with the first wave, will meet the second one; a certain part of the oscillation energy will be dispersed in the atmosphere, without propagating in the form of subsonic waves.

At the present time, the Black Sea Hydrophysical Station has set about investigating this process of the energy dispersion, as well as that of the damping of subsonic waves. Even now it may be safely said that the process of damping is very slow: the above-mentioned painful effect is equally pronounced in the open air, in the laboratory with open windows, and in that where the windows and the doors are closed.

This fact gives grounds to suppose that the subsonic waves arisen in some remote zone of the sea where a storm is raging, will propagate very swiftly (with the velocity of sound) in all directions. Consequently, it is only necessary to design an appropriate receiver to get beforehand storm warnings. In all probability, the wave spectrum obtained by such a receiver will make it possible to judge of the velocity of the wind, and the power indicatrix (in different directions of the horizontal plane) will permit to determine the direction where the storm is to be expected from.

We have only to add that the periodic change of pressure with the amplitude, determined from (2), must set up subsonic waves not only in the air, but also in the water on whose surface the same pressure is acting, the only difference being in the power, which, according to (3), will be in the water as many times less as the sound velocity in the water multiplied by the water density exceeds the sound velocity in the air multiplied by the density of the latter. In other words, the power of subsonic waves in the water will be 3300 times less than that of waves arising in the atmosphere. In all probability, this difference in power will decrease with the propagation of the waves in the atmosphere, because the damping in the water medium will be still weaker than that in the air.

Black Sea Hydrophysical
Station.

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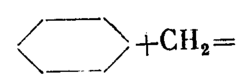

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