ACOUSTIC METHOD OF AIRPORT FOG PRECIPITATION

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Abstract. The influence of an acoustic field on the dispersed phase of a fluid has been studied in connection with the application of acoustic coagulation for the precipitation of gases. An acoustic field, depending on the intensity and frequency of the wave, as well as the physical condition of the medium, may cause coagulation, i.e. the joining of small particles into larger aggregates. This paper gives an example of the applications of dispersed phase acoustics, with particular emphasis on recent developments, e.g. the acoustic method of airport fog precipitation. This innovative technology is based on the fact that water can be collected from fog under the influence of acoustic waves. This work presents the new results of the analysis of the action of the acoustic field on the fog.

Key words: acoustical field, fog dispersal, acoustic coagulation, and cleaning gases.

Introduction

Air transport in great part depends on the weather conditions. It is known that fog significantly reduces visibility, making orientation difficult or simply impossible. In foggy conditions, special difficulties are encountered in the field of aviation. These factors can make the take-off and landing of aeroplanes impossible. Airports covered in fog, for security reasons, often cancel take-offs and refuse to accept aeroplanes [15]. The unusual essential and important thing is the possibility of eliminating fog artificially in a short time from the airport region i.e. an assigned area on land, in the water, or on board an aircraft carrier adapted and designed for the take off and landing of aircraft [16]. An airport consists of an airstrip, road system, buildings, aerodrome facilities and airspace.

An airstrip is defined as an airport designed for aircraft traffic on land (taxi track, take off and landing).

It is composed of runways, wheeling tracks, and parking-places.

Various methods to eliminate fog over airports are well-known and in use [11]:

1) thermal–heating the air up to the temperature at which fog droplets evaporate;

2) spraying into fog hygroscopic substances, which absorb air moisture and cause the condensation of fog droplets (used in San Diego, California);

3) spraying into fog overcooling crystal substances that cause the formation of new nucleuses of moisture condensation and water solidification around themselves;

4) introducing into fog special smoke that becomes the nucleuses of moisture condensation and water crystallization [11].

In the first two methods of precipitating fog, the improvement in visibility is obtained by eliminating droplets, and in second two the improvement is obtained by enlarging their sizes.

Practice has showed that these methods of precipitating fog possess numerous defects that significantly limit their application. For example, the thermic method requires the use of an enormous amount of thermal energy and spraying hygroscopic substances in fog requires the use of a considerable amount of these substances, which can make visibility even worse.

The discovery of the effect of an acoustic field on the process of aerosol coagulation has resulted in a new chance to solve the problem of fog at airports [1, 2].

Light dispersion through fog

Fog is defined as a mass of water vapour condensed into small water droplets [17]. The size of the fog droplets is usually bigger than length of visible light waves, ($\lambda = 0.40\ 10^{-6} - 0.76\ 10^{-6}$ m), which is why light dispersion occurs according to the laws of geometric optics. The coefficient of the dispersion of light through fog, *a*, depends on the gravimetric concentration of droplets, *K*, and on the radius, *r*, of droplets. The smaller the radius of the droplet and the bigger the gravimetric concentration are, the bigger the coefficient of dispersion, *a*, is [11]:

$$\alpha = \pi r^2 n = \frac{const \cdot \mathrm{K}}{\rho_p r}, \qquad (1)$$

where *n* – numerical concentration of droplets, while ρ_p – density of droplets.

If $r << \lambda$, then the coefficient of dispersion, *a*, is proportional for:

$\frac{\mathrm{K} r^3}{\lambda^4}$ (i.e. the other dependence of droplet size).

Flow of light intensity, J, going through fog diminishes with exponential distance [11]:

$$J = J_0 e^{-kx}, \qquad (2)$$

where J_0 – initial magnitude of the flow of light intensity, *x* – distance, while the coefficient of light weakening, *K*, is proportional to the coefficient of light dispersion through fog, *a*.

The clarity of the atmosphere obtained by the precipitation of fog is bigger:

– the smaller the relative coefficient of light dispersion is:

$$\frac{\Delta\alpha}{\alpha} \quad \text{marked in [\%]} \qquad (3)$$

– and the bigger relative distance, at which the initial magnitude of light intensity is kept, is:

$$\frac{\Delta x}{x} \quad \text{marked in [\%].} \qquad (4)$$

Bibliographical study

The acoustic method of fog precipitation was first suggested in the 40s of the 20th century in the USA A few years later early experiments, which involved the elimination of fog with Hartman's ultrasonic whistles were carried out in Germany. A clear rise in atmospheric limpidity was observed within a radius about 10 m around the source of the acoustic waves [11].

In the following years, others in the USA and France carried out further research (chiefly experimental) about the acoustic method of eliminating fog. Experimental research was carried in laboratories, closed spaces (tunnels), and open spaces e.g. airports.

In the USA, in a laboratory at the University of Columbia, a vertical tube with a size of $15 \cdot 10^{-2} \times 1$ m that contained droplets with radius (average magnitude) about $4 \cdot 10^{-6}$ m, while their gravimetric concentration was $14 \cdot 10^{3}$ kg/m3 was experimented on.

The source of the acoustic wave was a loudspeaker operating at a frequency of 0.5 kHz and able to produce 150 dB. In the field of the stationary acoustic wave obtained in the tube, the precipitation of fog within about 15 s was observed.

In later experiments, static hooters and dynamic hooters with more and more power and higher frequencies (up to 30 kHz) were used as sources of acoustic waves. Depending on the size of the area in which precipitation took place and on the parameters defining the acoustic field, precipitation occurred in several minutes.

In open spaces (experiment carried out at an airport in Ohio) dynamic hooters working at a frequency of 0.44 kHz and generating running waves were used. In about one minute, these caused the precipitation of fog in area of more than 5000 m^3, where at first there was fog with a gravimetric density of 10^3 - $2 \cdot 10^3$ kg/m^3 and the radius of droplets was 10^{-5} m. Experiments making use of stationary waves for fog precipitation were also carried out in the USA.

Basing on an analysis of the findings of the experiments carried out, the following conclusions were expressed:

– an improvement in atmospheric clarity connected with the coagulation of fog droplets occurs in a few seconds to several minutes according to the size of the area tested;

– to improve the effectiveness of the acoustic method of fog precipitation, it is important to select wave frequency according to the size of the fog droplets: the bigger the radius, the smaller the frequency; for smaller radiuses, higher frequency acoustic waves must be used.

– in open spaces, considering the absorption of acoustic waves, increased visibility was obtained at a distance of no more than 30 m in the direction of the propagation of the acoustic waves. To precipitate fog in large areas, it was therefore suggested that a system of acoustic wave sources instead of a single source should be used;

– the amount of energy needed to precipitate fog in open spaces with the acoustic method is large but smaller than e.g. the amount need for the thermic method.

It was observed that under the influence of acoustic waves, an acceleration in the process of fog coagulation followed.

Influence of acoustic field on process of fog precipitation

Requires frequencies appropriate to particle size so that the forces of the acoustic field move the particles towards one another and facilitate coagulation [4–13, 18]. In the process of acoustic precipitation, the mean particle size (rain) increases [3, 14]. We present new results of the analysis of the action of the acoustic field on the fog. In aerosols with a liquid dispersed phase (e.g. fog), both the original and the coagulated particles are spherical [14]. We estimate particle acceleration caused by various types of drifts:

- in the current wave field,
- in the standing wave field.

The main reasons for the movement of particles (fog droplets) in an acoustic field (known as drift) are the pressure of wave radiation on a particle (R-type drift), periodical changes in the viscosity of a vibrating medium (L-type drift), and deformation of the shape of the acoustic wave (Z-type drift).

To compare the effectiveness of the action of various types of drift forces in an acoustic field on the water particles, the acceleration amplitude B_D) has been calculated. The particle acceleration amplitude of R-type drift in a current wave field (B_{DR}) is as follows:

$$B_{DR} = 3\pi k^4 r_p^3 \rho_P^{-1} G\left(\frac{\rho_g}{\rho_p}\right)\overline{E}\ , \tag{5}$$

where: k – wave number, r_p – radius of water droplets, ρ_p – density of water droplets, ρ_g – air density, E – acoustic wave energy density, G – density function:

$$G\left(\frac{\rho_g}{\rho_p}\right) = \left[1 + \frac{2}{3}\left(1 - \frac{\rho_g}{\rho_p}\right)\right]\left(2 + \frac{\rho_g}{\rho_p}\right)^{-1} \tag{6}$$

The particle acceleration amplitude of L-type drift in a current wave field (it denotes B_{DL}) is as follows:

$$B_{DL} = \frac{9}{4}(\kappa - 3)\frac{\eta_0}{\rho_g c}\frac{\mu_g^2}{r_p \rho_p}\overline{E} \tag{7}$$

where κ – adiabatic coefficient, c – speed of acoustic sound in air, η_0 – medium viscosity, μ_g – water droplet flow-around coefficient.

The particle acceleration amplitude of Z-type drift in a current wave field (it denotes B_{DZ}) is as follows:

$$B_{DZ} = -\frac{9}{2}\frac{h_2 \sin\psi \mu_g^2}{\pi r_p \rho_p}\overline{E} \tag{8}$$

where h_2 – relative amplitude of second harmonic, ψ – phase angle.

Quantitative analysis of the effects described is assumed by following values of numerical parameters that characterize an acoustic field, dispersed phase, and medium:

– particle density (water): 1.000 kg/m^3;
– medium density (air): 1.249 kg/m^3;
– acoustic sound speed in air: 340 m/s;
– density of wave energy: 1000 J/m^3;
– range of particles size: 10^{-8} – 10^{-4} m;
– frequency: 10–200 kHz.

Results of calculations

The results of calculations are given in figures 1–6.

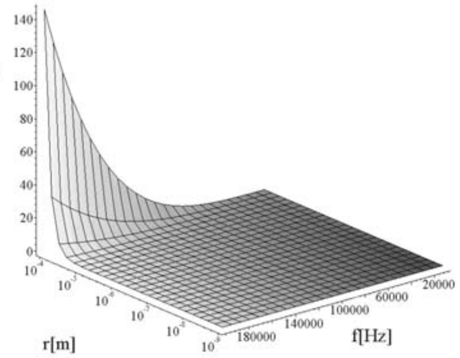

Fig 1. Amplitude B_{DR}, of the acceleration of the particle of water suspended in air (fog) affected by type R drift forces as a function of particle radius and frequency

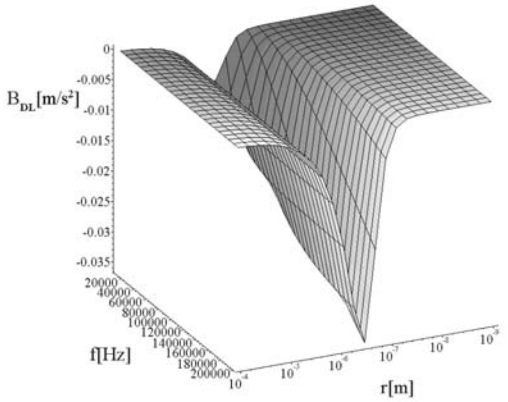

Fig 2. Amplitude B_{DL}, of the acceleration of the particle of water suspended in air (fog) affected by type L drift forces as a function of particle radius and frequency

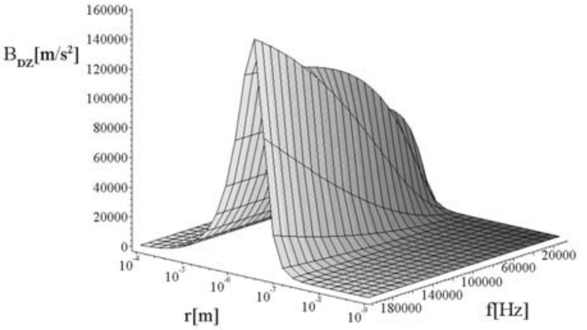

Fig 3. Amplitude B_{DZ}, of the acceleration of the particle of water suspended in air (fog) affected by type Z drift forces as a function of particle radius and frequency

Comparative studies of different types of drifts conducted for various types of fog prove that the aforementioned types of drift are not mutually competitive since they dominate within different, mutually complementary variability ranges of the parameters of the water particles and the acoustic field.

For the largest particles, with radiuses of the order of 10^{-4} m, the radiation drift acceleration is the strongest. For the smallest particles, with radiuses of the order of 10^{-6} [m], the Z-type drift acceleration dominates. The values of the L-type drift acceleration are minimal.

We take also into account the A-type drift acceleration related to the asymmetry of motion of fog droplets in a standing wave field.

The particle acceleration amplitude of R-type drift in a standing wave field (it denotes A_{DR}) is as follows:

$$A_{DR} = 2k\rho_P^{-1}\mu_g^{2}\overline{E}, \tag{9}$$

The particle acceleration amplitude of L-type drift in a standing wave field (it denotes A_{DL}) is as follows:

$$A_{DL} = \frac{9}{4}(\kappa - 3)\eta r^{-2}(\rho_p\rho_g c)^{-1}\mu_g^{2}\overline{E}, \tag{10}$$

The particle acceleration amplitude of A-type drift in a current wave field (it denotes A_{DA}) is as follows:

$$A_{DA} = -\frac{1}{2}\rho_g^{-1}k\mu_p^{2}\overline{E}, \tag{11}$$

where ρ_p – water droplet entrainment coefficient. Figures 4–6 show the influence of an acoustic standing wave on small particles of water in air (fog) as a function of the droplet radius and frequency.

In an acoustic standing wave, for the largest particles with radiuses of the order of 10^{-4} m, the radiation drift acceleration is the strongest, and for the smallest particles with radiuses of the order of 10^{-8} m, A-type drift acceleration dominates. In the intermediate interval, L-type drift acceleration dominates.

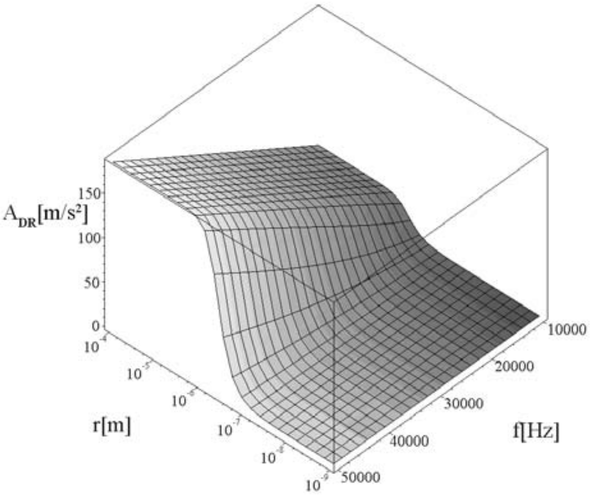

Fig 4. Amplitude A_{DR}, of the acceleration of the particle of water suspended in air (fog) affected by type R drift forces as a function of particle radius and frequency

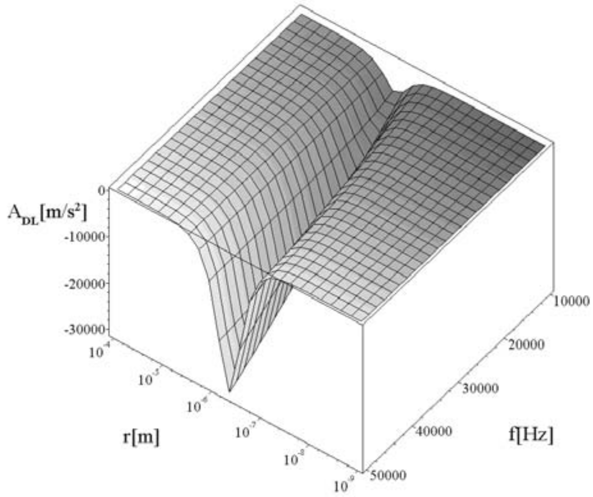

Fig 5. Amplitude A_{DL} of the acceleration of the particle of water suspended in air (fog) affected by type L drift forces as a function of particle radius and frequency

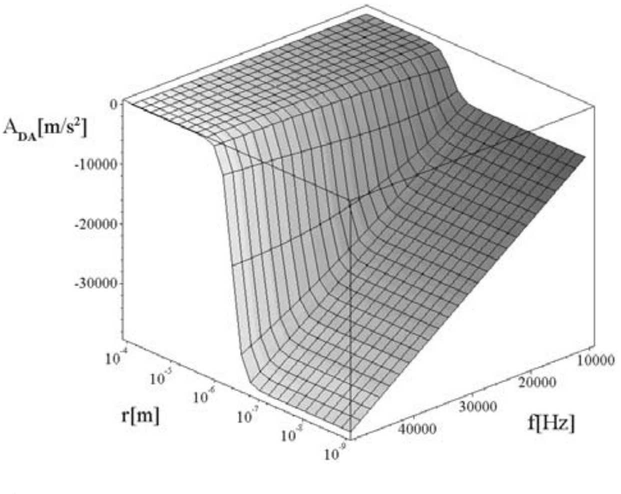

Fig 6. Amplitude A_{DL} of the acceleration of the particle of water suspended in air (fog) affected by type L drift forces as a function of particle radius and frequency

Conclusions

The phenomena causing transportation of the particles dispersed in air result:

– in coagulation and acoustic precipitation of suspended particles. Water particles can be produced from fog under the influence of acoustic progressive waves.

– in local changes in particle concentration and thus, under particular circumstances, in coagulation and acoustic precipitation of suspended particles.

In summing up the considerations, it can also be stated that particular kinds of drift dominate various intervals of the variation in the radius of the water particles.

If the air is sufficiently saturated with water vapour, under the influence of an acoustic field an increase in the size of fog droplets occurs.

Under the specified conditions, these processes cause the precipitation of fog. It is therefore possible to use an acoustic field as a method to cause the precipitation of fog.

Like other methods, the acoustic method of fog precipitation is not versatile, but it presents a new chance to solve the problem of fog precipitation effectively in open spaces, e.g. at airports.

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