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THE FOAMING PROPERTIES OF LUBRICATING OILS FOR AIRCRAFT GAS TURBINE ENGINES

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Abstract

The paper represents results of experimental researches of foaming properties of lubricating oils for aviation gas turbine engines (GTE). It shows new approaches for evaluating the oils foaming properties and describes the foaming modes depending on airflow and temperature. The paper shows the effect of aviation oils foaming on it performance characteristics, operation of engine oil system and aviation GTE.

1 Introduction

The aviation oil foaming is one of the most important factors influencing to the flight safety. The deterioration of oil operating properties with an increased tendency to foaming is due to increased air content in this oil during an engine operation. Increased tendency to foaming can lead to a breach of the aviation GTE normal operation: heat sink worsening, overheating of friction units, accelerating of oil oxidation, reduction of lubricating efficiency [1-4].

In addition, the helicopter engines fuming may occur because of increased oil foaming (Fig. 1). The air-oil separator of GTE oil system cannot separate the oil-air mixture when oil is pumping out from rotor bearings. As a result, the foam surplus flows to the exhaust nozzle where the temperature is about 400°C. Under such conditions, the oil dispersed in gases evaporates resulting in fume from the exhaust of engine.

Fig. 1. The helicopter engines fuming
E – exhaust, OT – oil tank, AOS – air-oil separator, FP – feed-pump.

The foaming of oils during engine operation depends on the oil properties and other factors: operation mode, temperature, impurities, type of constructional materials, degree of oxidation, intensity of aeration, mixing, etc. In addition into the oil may fall a lubricants based on molybdenum disulfide and silicone fluid that significantly influences to foaming of oils and operation characteristics of GTE oil system [5].

Further, the results of foaming estimation obtained by the standard method GOST 21058-75 are difficult to interpret. For example, the column height of foam is 20 mm at 25ºC and 40 mm at 95ºC – is it high or low for GTE normal operation? Does it mean that if the column height of foam is higher at 95ºC, the oil foaming in GTE oil system at 95ºC will be higher also? It is difficult to compare results of foaming properties evaluation at 25ºC, 95ºC and 25ºC of two different oils by the standard method: the foam column height for the first oil is 40 mm, 10 mm and 20 mm, and for the second one – 20 mm, 10 mm and 40 mm. Is it possible to compare foaming properties of these oils? To answer these questions it was necessary to investigate the dependences of the foam formation properties from the temperature, the airflow and other factors.

The tasks of experimental researches were:

1. Investigate the influence of airflow, temperature, oxidation time and the concentration of additives on oils foaming.
2. Evaluate the dependence of characteristics of GTE oil system operation from oil foaming properties.

2 The method of oil foaming analyzing

2.1 The standard method of oils foaming analyzing

In Russia the main method for analyzing the aviation oil foaming is the standard method GOST 21058-75. The dried air passes through the oil sample in a thermostatic column. Definitions of the foaming parameters (the height and the column destruction time of foam) are performed successively at 25ºC, 95ºC and 25ºC again with a fixed air mass flow rate of 0.2 cm^3/s (Fig. 2). The last determination at 25ºC is different from the first two in method of pre-treatment - the oil sample is bubbled by gas at 95ºC. This method intended for the quality analyzing of aviation oils.

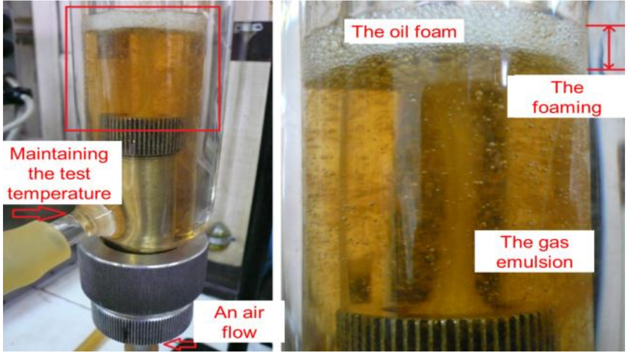

Fig. 2. The visualization of oil foaming

2.2 Methodology of determination of potential oils foaming

The authors made changes in the GOST 21058-75 method for a comparative estimation of the foam formation properties. The determination of foaming is carried out in the temperature range with 10°C interval, the sample preparation is regulated, and parallel and consistent definitions are conducted, the kinetics of foam development and destruction are studied, the impact of airflow and time of oil oxidation are estimated. The foaming and foam stability of oils are expressed in percentage relative to the level of foaming of the Russian LZ-240 oil, oxidized during 50 hours at 200ºC with additional lubricants, determined at 25ºC – which is average for oils from a fuming engines.

The sample preparation was the following: intensively mixing for the uniform distribution of compounds, heating and holding at 110ºC and then cooling to the test temperature. The heating of the oil reduces viscosity in 10 times for normalizing the sample before test. Preheating and following cooling up to test temperature simulates the oil-air mixture supply from the friction unit through a heat exchanger to the oil tank [6]. The effect of such samples preparation is show on Fig. 3 at determining of the foaming of TN-98 oil and B-3V oil from fuming engines. The increased foaming for these oils at 25ºC was determined after sample preparation only.

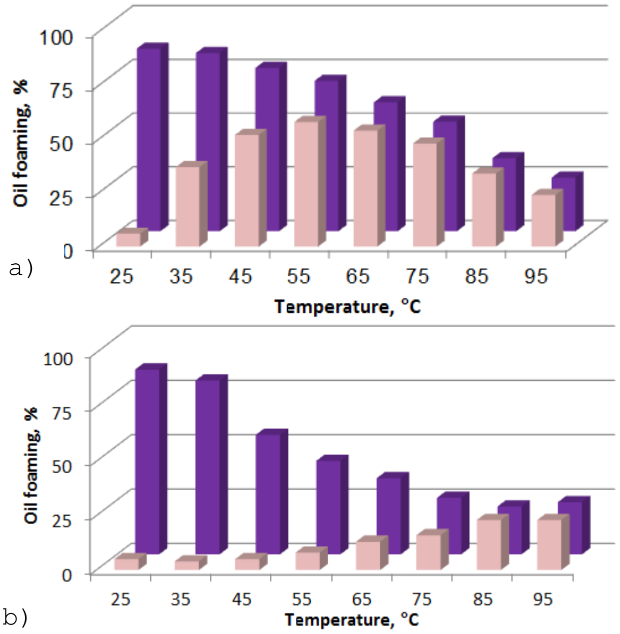

Fig. 3. Sample preparation effect on foaming of oils: a) TN-98; b) B-3V.

🟥 – No preparation;
🟪 – With preparation

These changes in the standard method allow in determining the potential level of oil foaming that is closer to GTE operation conditions.

3 Experimental investigation of oil foaming properties

Static and dynamic modes of foam formation have been determined during the research of airflow and test temperature influence to the foam column height for a synthetic (45 hours operating time) and petroleum (non-working) oils (Fig. 4).

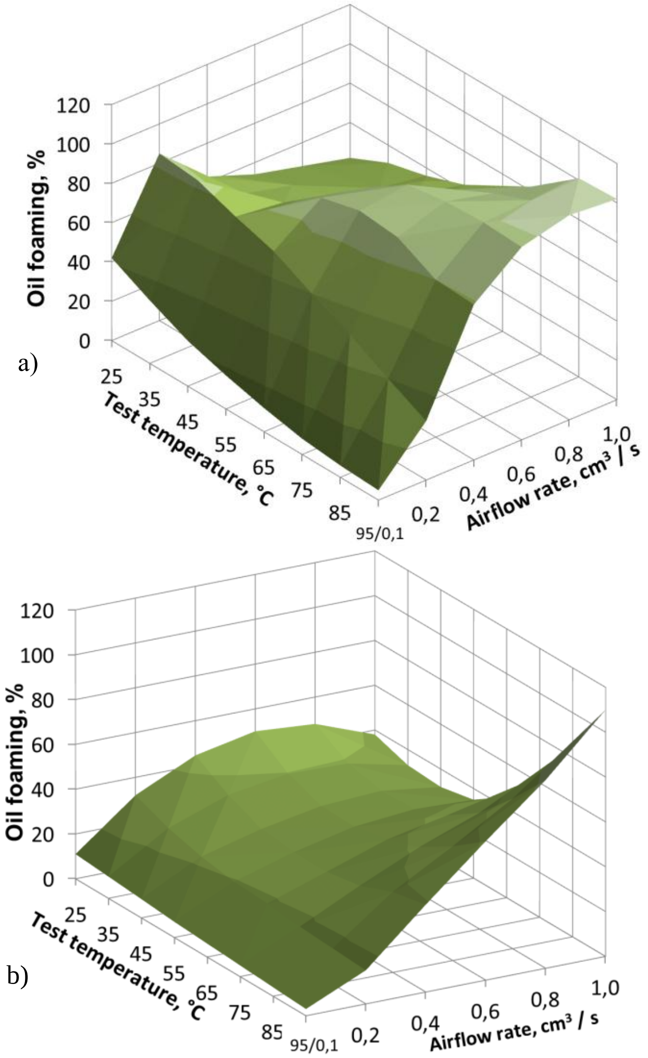

Fig. 4. Foam formation properties of oil vs temperature and airflow. Oil: a) MS-8P; b) TN-98

1. The static mode is at airflow 0.2 cm^3/s or less that corresponds to low Reynolds numbers. A gradual increase of foam in this mode passes without breaking the foam body by air stream. The growth of foam column occurring with airflow increase is due to increase a number of bubbles with the same dimensions. The foam column height is decrease when the temperature increases. In this mode the surface tension and solution density are determined the bubbles size. The surfactants type and concentration effects on formation rate of adsorption layers and the stability of formed foam [7].

2. At airflow more than 0.2 cm^3/s is the dynamic mode. The bubbles size and properties in this mode of foam formation are strongly depended from volumetric air velocity. Temperature increase lead to foam column height increase. The air after reaching a certain critical flow rate begins to leave the pore of dispersing device by continuous stream. Then a stream splits into separate bubbles. Turbulent flow and viscosity of solution have a significant influence on the bubbles size in this mode and surface tension have lower influence [8].

The column height of foam has extreme dependence from airflow (Fig. 5). The column height of foam is small at low flow rate, when flow rate increases the column height of foam is increases too, but at significant flow the foam is disappears.

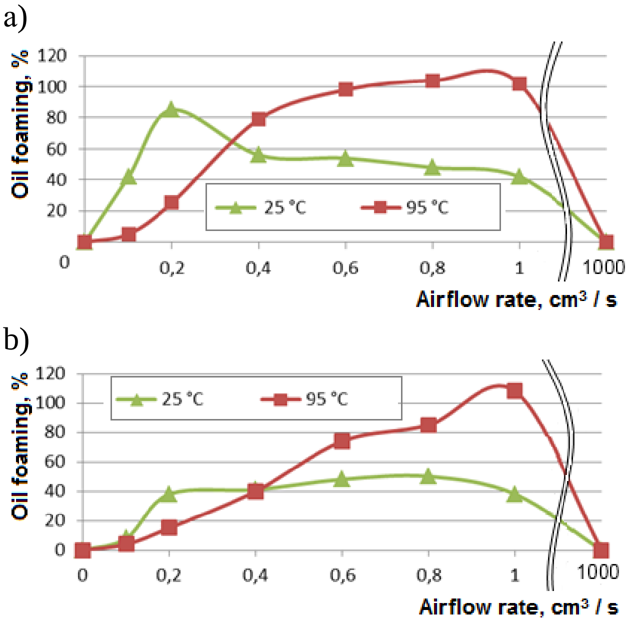

Fig. 5. Oil foaming vs. airflow. Oil: a) MS-8P; b) TN-98

The airflow passing through the oil prevents a foam formation on its surface and the oil becomes like a boiling water (Fig. 6).

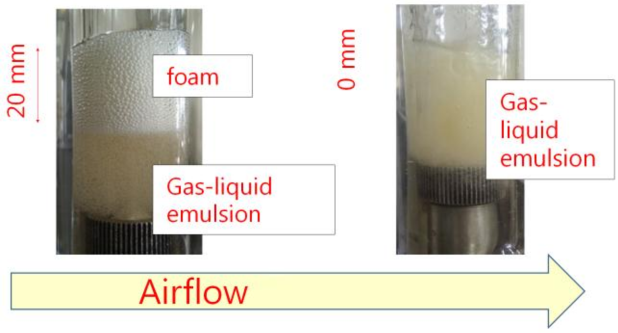

Fig. 6. Oil foaming with airflow increase from 0,2 to 1000 cm^3/s

As was shown above, the increased foaming of oils can lead to disruption of GTE normal operation. Injection of a silicone additive may lead decreasing of oil foaming. In addition, various silicone compounds that may fall to lubricating oils during engine operation can improve the oils performance properties. These include oligomethylphenylsyloxanes (OMPS), oligomethylsyloxanes (OMS). These compounds have high thermal stability, low saturated vapor pressure, well lubricating properties. However, tests have shown that foaming properties of OMPS may depend on changing the ratio of methyl (M) / phenyl (P) groups (Fig. 7).

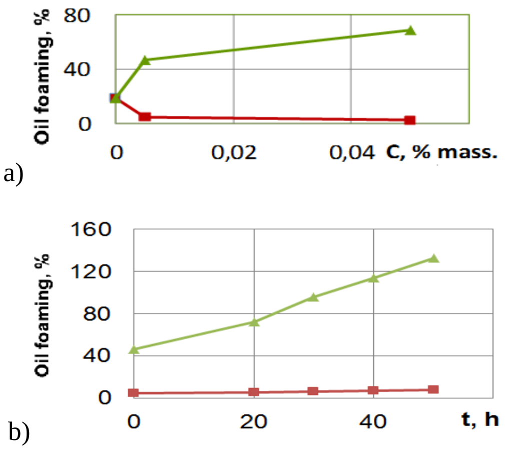

Fig. 7. Influence of factors on oil foaming: a) additive concentration, b) oxidation time (0,005 % mass.)
▲ – Initial oil + OMPS (M/P = 1)
■ – Initial oil + OMPS (M/P = 7); OMS

4 Oil foam vs oil-air emulsions

Foam is a collection of closely packed bubbles surrounded by thin films of oil that float on the surface of the oil. All other oil-air systems are oil-air emulsions.

Air in oils can be in entrained (dispersed) and dissolved states and according to it oils have different operational properties. In dissolved state content of air in oil varies within 7-10 % at 20ºC [9]. Dispersed volumetric air content in oil α is determined by the formula (1)

$$\alpha = V_{air}/(V_{air} + V_{oil}) * 100\% \qquad (1)$$

where α is dispersed volumetric air content in oil-air mixture, V_{air} is volume of air in oil-air mixture, V_{air} is volume of oil.

Intensive mixing of petroleum oil MS-8P in blender (10,000 rpm) lead to 9% vol. air content in oil-air mixture. The whole dispersed air exits from the oil after settling for 5 minutes (Fig. 8).

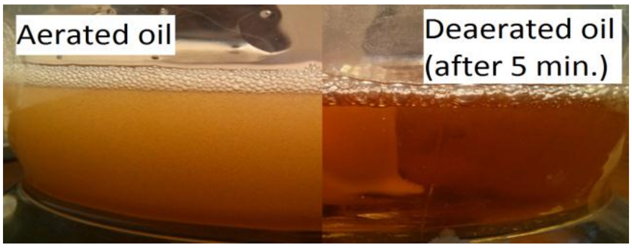

Fig. 8. Aerated and deaerated oils.

A content of dispersed air in oil may rise significantly during operation. This was confirmed by laboratory experiment when air was passed through the MS-8P oil: the α was 16.7 % after beginning of air passing through the oil and increased up to 50% after 15 minutes of passing (Fig. 9).

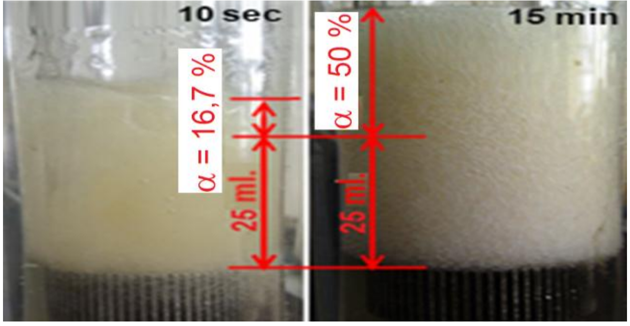

Fig. 9. The air involvement into oil after air passing. The sample volume 25 ml, airflow rate 1000 cm^3/s.

As was shown above, additives may be involved in oils for reduce foaming, however, these additives can deteriorate the oil deaeration. The reason is a difference between the surface tension of oil and additives, the last of which are concentrated on the surface of air bubbles in oil. It reduces the surface tension between the air and liquid phase. Based on the

Laplace equation [10], the reduction of surface tension at the "air-oil" boundary reduces the size of bubbles (2)

$$r = 2\sigma / \Delta P \qquad (2)$$

where r is the radius of the air bubble, m; σ is the surface tension, N / m; ΔP is the pressure difference between air and oil, Pa.

According to the Stokes equation [11] the lift speed of bubbles is proportional to square of radius (3), therefore, the lift speed of small bubbles is reduced.

$$\upsilon = 2\rho g r^2 / 9\eta \qquad (3)$$

where υ is a spherical bubble rise velocity, m / s; g is gravitational acceleration, m / s^2; η is viscosity of the fluid, Pa·s; ρ is density of the fluid, kg / m^3. Besides an additive density is higher and it also influence to the lift speed of little bubbles.

Fig. 10 shows air content in the oil for the stage of air passing and for the stage of oil settling for oils with and without silicone [11]. The oil with an antifoaming silicone additive involves less air at the stage of air passing (under the dynamic conditions). It is clearly that the bubbles colliding with each other become larger and rises faster to the surface in dynamic mode. However, the velocity of air release from this oil is also lesser during the settling [7, 8].

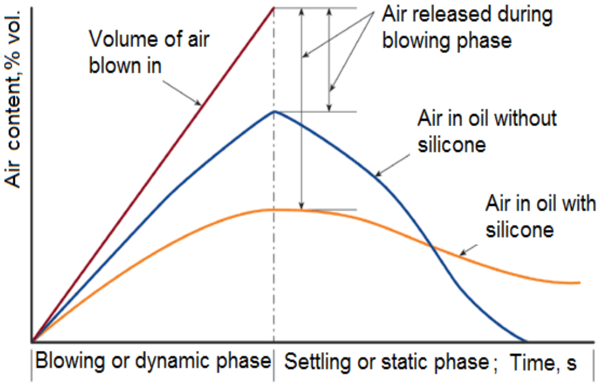

Fig. 10. Effects of silicone additive on air content in oil during and after air passing

Thus, it is very difficult to predict how will change the characteristics of aviation GTE oil system with an introduction of antifoaming additives in oil.

5 Oil foaming vs GTE oil system operation

Russian and foreign lubricating oils for aviation GTE are LZ-240, B-3V, TN-98, Royco 899 and others. These oils have different operational and foaming properties.

The standard method showed overestimated foaming only for one sample from oils samples from the fuming engines. The methodology described in paragraph 2.2 showed the increased foaming for other remaining samples of oils from fuming engines (Fig. 11).

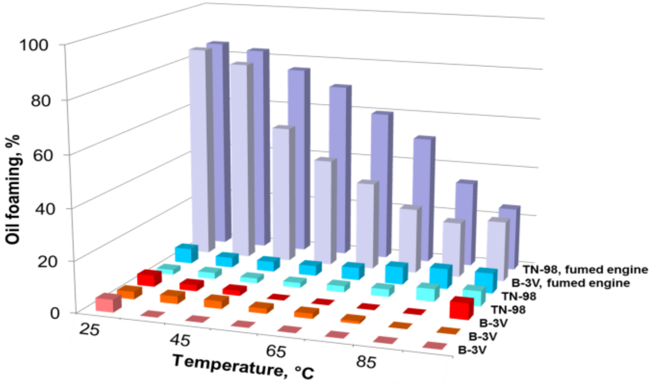

Fig. 11. Foaming of oils from fuming and non-fuming engines

As noted before the lubricant of high viscosity can get into the oil during GTE operation. Fig. 12 shows the oils foaming for GTE with adding the 0.005% wt. of lubricant based on organosiloxane fluid and molybdenum disulfide. The presence of such negligible amount of lubricant in oil increases the oil foaming significantly.

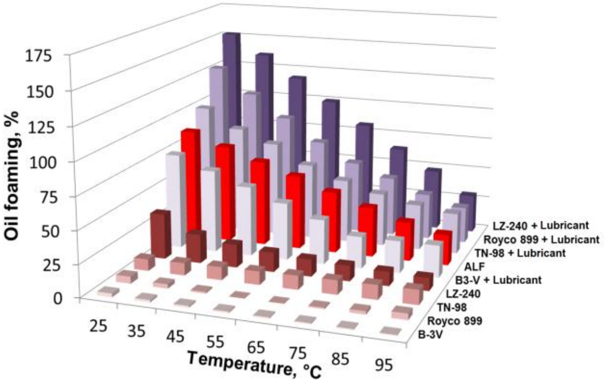

Fig. 12. Oils foaming after lubricant addition. Air flow rate 0.2 cm^3/s, oxidation time 30 hours; ALF – average level of foaming for oils from fuming engines

The lubricating systems are usually includes a gear pump. Flow characteristic of the pump determine oil-air mixture flow rate in oil system. The dependence of the volumetric flow rate at the pump outlet from rotation frequency of its shaft is choosing taking into account the calculated air content α. This specificity of pump operation caused by its design in which a pump pair of gears is pumping from the inlet to outlet the volume equaled to the volume of gears teeth cavities in the suction zone (Fig. 13). The volumetric flow rate at the outlet of pump at current rotation frequency characterizes its traffic capacity.

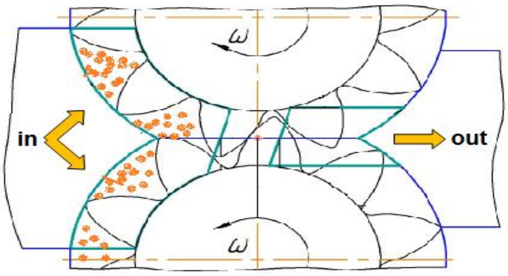

Fig. 13. Scheme of gear pump

As indicated above, increased oil foaming can influence the volumetric air content. Thus, the real volumetric air content in the oil-air mixture at pump inlet α can be changed at fixed rotation frequency of gear pump. In this regard, special tests with adding in MS-8P oil the silicone additive that reduced the oil foaming were necessary to conduct.

Fig. 14 shows the change in the electric drive power of the pump depending on the coefficient K_p for oils with and without silicone additive. The coefficient K_p is the ratio of flow rate from the oil chamber to flow into the chamber. During the tests the changing of K_p was conducted by increasing the rotation frequency of scavenge pump at a fixed frequency of feed pump. At such technology the volumetric air content increases with growth of K_p at the scavenge pump inlet, which leads to an increasing of their consumed power. As can be seen there is an positive effect of the additive, but it decreases with increasing of volumetric air content of mixture (increasing K_p) and it disappears at K_p=4.

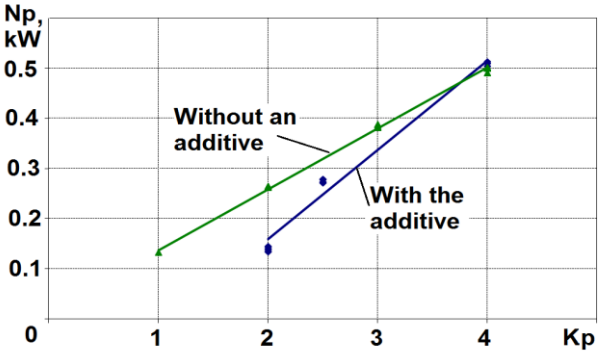

Fig. 14. Pump power vs. K_p with and without additive

The workspace of K_p changing in GTE oil system is in the range 2-3, where the influence of the additive is significant. The power consumed by the pump is reduced in 2 times under K_p =2.

Comparison of characteristics of demo electric lubricating oil system [12, 13] under operation with MS-8P oil showed that the adding of silicone additive:

- Decreases the pressure fluctuation at 23-40%;
- Lead to the harmonics shift in oils pressures frequencies from 110 to 80 Hz;
- Decreases of pump power consumption.

The reducing of oscillation amplitudes shows an increasing of the number of small bubbles and decreasing of the number of large bubbles in oil. Therefore, the bubble size reduction leads to improvement of the oil flow conditions.

Thereby testing of demo electric lubricating oil system of GTE at the gear pumps operation with fixed rotation frequency shows the necessity of considering the changes of oil foaming properties during operation.

Conclusions

1. The changes in the Standard 21058-75 allows to determine the potential foaming of oils in terms that are more closed to GTE operation conditions.
2. The increased foaming of oils can lead to disruption of engines normal operation.
3. OMPS (M/P = 1) may hit in the oil that even in small amount (0.005% wt.) rapidly increase oil foaming.

4. OMPS (M/P = 7) and OMS are recommended for decrease of foaming of aviation oils. Antifoaming adds improves oil-air feeding.
5. Study shows the two foam formation modes and establishes the dependences between foaming, airflow, temperature, oxidation time and the concentration of additives.
6. Bench tests of demo electric lubricating oil system with antifoaming additive have shown that the additive reduces the power consumed by the pumps and improves the performance of GTE lubricating system.

Acknowledgement

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