

as a result of making use in the approximation of the first and second terms only, when we expand the perturbing acceleration due to the moon.

Figures 5 through 9, for a moon satellite, are graphs showing the dependence on the revolution number of the osculating elements of the satellite orbit at a minimum distance from the moon. The relations determined by numerical integration of the differential equations are shown by solid lines. The relations obtained with the approximation (broken lines) were entered for purposes of comparison. The approximate calculation was done with an interval of one revolution, using Euler's method for the integration of system (91) with recomputation.

The initial minimum and maximum distances from the moon for five variants are given in Table 1.

The angular elements in the calculation and on the graphs are measured from the plane of the earth's equator. The first two variants (Figs. 5 and 6) represent a satellite orbit with inclination to the plane of the moon's orbit close to 90°. Here we estimate the special case in which the pericenter height shows, basically, a monotonic deviation in the course of a complete revolution around the earth. The graphs in Figs. 7 through 9 refer to orbits the planes of which are close to the plane of the orbit of the perturbing body (the earth). In this case the pericenter height has oscillations with a period generally equal to half a lunar month.

The comparison is made over 20–30 orbits of the satellite. For all orbits considered, this number of revolutions represents a time longer than a lunar month.

For the moon satellite orbits considered, the basic factor determining the error in the approximate method should be the large value of the perturbing acceleration (with infraction of the assumption that the orbital elements be invariable through one revolution) and the long revolution periods resulting from calculating only the first approximation in the motion of the perturbing body in one revolution of the satellite).

On the basis of the estimates made, we can conclude that for exploratory purposes and for purposes of preliminary computations, the approximate method can be used for a fairly broad class of satellite orbits.

In conclusion the author wishes to thank D. E. Okhotsimskii for his comments on this study.

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# Methods of Estimating the Quality of Jet Fuels

V. N. ZRELOV

**T**HE development of work on jet fuels is accompanied by the development and use of new methods of estimating their quality. Fundamental attention is given to methods of estimating the quality of high-boiling fuels.<sup>1</sup>

Raising the boiling limits of the fuels causes an increase in their aromatic-hydrocarbon content, the total amount of which can go as high as 28%. Aromatic hydrocarbons cause a considerable increase in the deposit-forming tendency of the fuels.

In order to estimate the deposit-forming tendency, small laboratory devices have been developed, in which a weighed portion of fuel is burned and the quantity of deposit is measured. The device proposed by Ya. M. Paushkin et al.<sup>2</sup> measures the quantity of deposition in the upper conical part of a vertically positioned metal tube.

The device proposed by Starkman, Cattaneo, and McAllister<sup>3</sup> operates according to the same principle. However, in this case the combustion tube is horizontally positioned, and the deposition occurs on the walls of the tube.

Common to both of these devices is the possibility of estimating not the total solids-forming tendency but the partial tendency related to the determination of the deposition on the walls of the device. These methods do not take into account the solids that are not deposited on the walls and which are carried out of the tubes. The total quantity of solids forming during the burning of the fuel is estimated by a tubular-type quartz device, in which the solids are trapped in special absorbers containing porcelain filling and then are weighed (Fig. 1).<sup>4</sup> In comparison with other methods, the quartz device gives a true estimate of the solids-forming tendency of jet fuels.

A test formerly used for estimating the qualities of lamp kerosenes is used at the present time in the United States for estimating the deposit-forming tendency of jet fuels.<sup>5</sup> According to this method, the deposit-forming tendency of the fuels is estimated in millimeters over the height of the sootless flame (smoke point), which in the case of jet fuels must be no less than 20 mm.<sup>6</sup> With an increase in the quantity of aromatic hydrocarbons the height of the sootless flame decreases.<sup>7</sup> However, the deposits formed in a jet engine depend not only on the height of the sootless flame but also on the vaporizability of the fuel. Therefore the index of deposit-formation is used also for estimating the deposit-forming tendency of jet fuels. The index of deposit-formation is equal

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to the smoke point multiplied by 0.42% of the distillate up to 204°C during fractionization of the fuel. A direct relationship between this index and the deposit-forming tendency has been established, and the index has been introduced into the specifications for JP-5 fuel. The index of deposit-formation should be no less than 54. Recently it was found advisable<sup>8</sup> to use the index of deposit-formation for estimating the deposit-forming tendency of fuels of wide fractional composition and to use the smoke point for high-boiling fuels of kerosene and gas-oil type.

For scientific research purposes the estimation of the deposit-forming tendency of jet fuels is done on installations with small jet engine combustion chambers. For this purpose the fire tube of the combustion chamber is weighed before and after the tests. From the difference in weight we determine the quantity of deposit on the walls of the fire tube, from which we can estimate the deposit-forming tendency of the fuel.

Installations of this type, developed by Ye. R. Tereshchenko<sup>9</sup> and Williams,<sup>10</sup> have many structural features in common. In addition to estimating the deposit-forming tendency, these installations are also used for estimating the completeness of combustion of jet fuels. Ye. R. Tereshchenko's installation (Fig. 2) is used widely for estimating other characteristics of the combustion of jet fuels,

When high-boiling fuels were used abroad in jet engines, special cases of burnout of the combustion chamber were noted. A study of this problem showed that the cause of burnout of the combustion chamber is the great increase in the brightness of the flame during the burning of high-boiling fuels. The bright flame, as a result of an increase in radiation, increases the flow of thermal energy to the walls of the fire tubes, increases their temperature, and causes burnout. Therefore, in order to estimate the ability of the fuels to cause burnout of the fire tubes of the combustion chamber, a laboratory device was developed for estimating this from the brightness of the flame.<sup>8</sup> It was established from studies that the brightness of the flame depends on the amount of bicyclic aromatic hydrocarbons of the naphthalene series in the fuel. Proceedings from this fact, the Pratt & Whitney Company limited the amount of bicyclic aromatic hydrocarbons in the experimental high-boiling fuel PWA-522 to not more than 3%.<sup>8</sup>

The determination of the total quantity of aromatic hydrocarbons in jet fuels and the separate determination of the amount of bicyclic aromatic and unsaturated hydrocarbons is accomplished by the chromatographic method. Thus, in 1956 a fluorescent indicator, Sudan III, was standardized in the United States for determining the aromatic hydrocarbons in jet fuels.<sup>11</sup> This method enables us to determine rapidly on small laboratory chromatographic columns the amount of aromatic and unsaturated hydrocarbons, using a 1-ml sample for analysis.

Of great importance in evaluating modern fuels for supersonic planes is their insoluble-gum-forming tendency. Under conditions of supersonic flight the fuel is heated to above 100°; this process is accompanied by formation of solid precipitates and clogging of the fuel filters.<sup>12-15</sup>

The insoluble-gum-forming tendency of jet fuels is determined under static and dynamic conditions. Thus, under static conditions the estimate is made with the aid of two devices: a bomb, which was formerly used for determining the induction periods of gasolines, and the LSA apparatus, which is used also for determining the stability of ethylated aviation gasolines.

The determinations of the insoluble-gum-forming tendency in these devices differ essentially, both with respect to the amount of the sample being tested and with respect to the ratio between the liquid and vapor phases.<sup>16-18</sup> Therefore the quantity of insoluble gum obtained in the determination in the bomb is greater than that obtained in the determination in the LSA apparatus. The maximum gum formation occurs

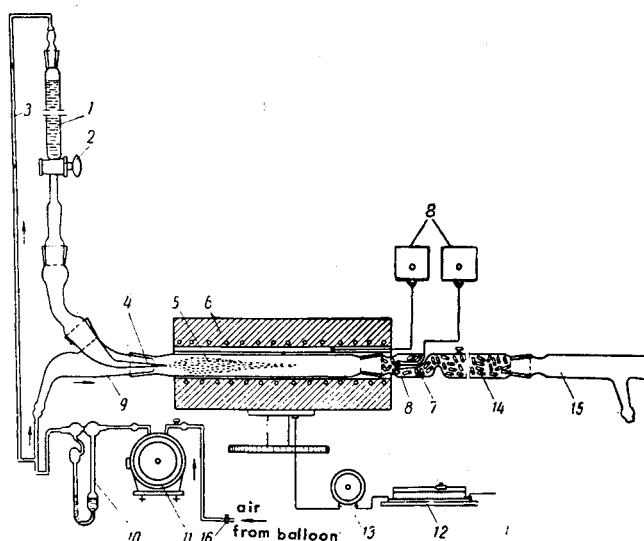


Fig. 1 Quartz device for estimating the deposit-forming tendency of jet fuels: 1) burette for fuel; 2) stopcock for regulating the fuel intake; 3) pressure compensator; 4) capillary; 5) fire tube; 6) tubular furnace; 7) recess for thermocouple; 8) thermocouple with galvanometer; 9) T-bend; 10) rheometer; 11) gas clock; 12) rheostat; 13) voltmeter; 14) absorbing tube with filling; 15) outlet tube with branch pipe for removing samples of gas; 16) stopcock for regulating the air intake.

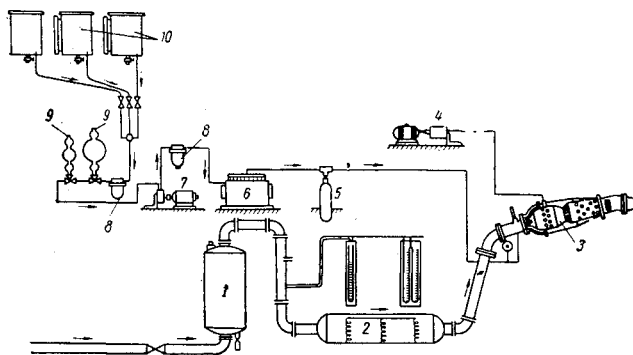


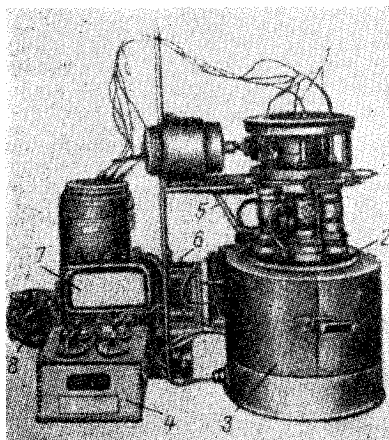
Fig. 2 Design of single-chamber installation for estimating the deposit-forming tendency and the completeness of combustion of jet fuels: 1) receiver; 2) electrical air heater; 3) miniature combustion chamber; 4) starting magneto; 5) fuel receiver; 6) fuel pump; 7) fuel pump; 8) fuel filters; 9) samplers; 10) fuel tanks.

at 200° in the LSA apparatus and at 150-180° in the bombs. The introduction of these two methods into the GOST (All-Union State Standard) for fuel T-5 results from the necessity of accumulating experimental data, which will give us the possibility of singling out one method.

In addition to these methods, the complex "KOS" method is known also; it enables us to determine simultaneously the insoluble-gum-forming tendency and the corrosive power of fuels.<sup>19, 20</sup>

The KOS method (Fig. 3) is superior to the other laboratory methods for estimating the insoluble-gum-forming tendency, since it enables us to determine the insoluble-gum-forming tendency and the corrosive power of jet fuels. This fact is of particularly great importance when analyzing fuels at 200-250°, when the quantity of gum is small and corrosion of bronze increases significantly.

In order to estimate the coarseness of the gums forming in the fuel, Ya. B. Chertkov and V. M. Shagin<sup>21</sup> developed a screening analysis that makes it possible to classify gums from 5 to 120  $\mu$ . The structure and the coarseness of the gums are controlled also with the aid of ordinary and electronic microscopy.<sup>21, 22</sup> The chemical composition of the gums is deter-



**Fig. 3 KOS device for combined determination of the insoluble-gum-forming tendency and the corrosive power of jet fuels:** 1) thermocouples; 2) aluminum heat-control unit; 3) heating casing; 4) resistance bridge; 5) contact thermometer; 6) relay; 7) galvanometer; 8) thermocouple switch.

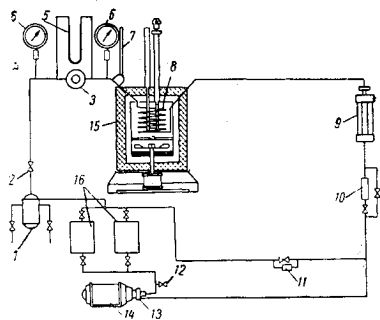
mined on the basis of an elementary analysis of the organic part and a spectral analysis of the ash components.

Laboratory pumping apparatus are of great significance in estimating the insoluble-gum-forming tendency of jet fuels. On these apparatus the insoluble-gum-forming tendency of the fuels is determined under dynamic conditions directly from the intensity with which the fuel filter is clogged with sediments; for one test from 20 to 300 liters of fuel are consumed; the measurements are made in the temperature range from 150 to 250°; in the majority of apparatus the fuel is heated by means of an external source; a screen with openings of 15–20  $\mu$  is used as the filter. Fig. 4 shows a laboratory apparatus developed by A. A. Gureyev and Z. A. Sablina<sup>23</sup> for estimating the insoluble-gum-forming tendency. A comparison of the results of pumping fuels T-1 and TS-1 on this apparatus with data obtained on the LSA apparatus proposed by G. S. Shimonayev, Ye. S. Churshukov, and I. V. Rozhkov showed a good agreement between the results.<sup>24</sup> The same picture is observed when we compare the results of pumping the fuels on Ye. R. Tereshchenko and M. Ye. Tararyshkin's apparatus with the data obtained from the KOS method and in the bomb.

Methods have also been developed for estimating the insoluble-gum-forming tendency and the corrosive power of fuels by circulation pumping through the fuel apparatus of a turbojet engine.<sup>25, 26</sup> These methods enable us to obtain results comparable to the results of testing the engine under stand conditions and to the laboratory determinations of the insoluble-gum-forming tendency of the fuels.

The insoluble-gum-forming tendency of jet fuels is measured abroad at the present time on a standard Erdco pumping apparatus from the intensity with which the fuel filter is clogged.<sup>25</sup>

On this apparatus at a heater temperature of 149° and a fuel-filter temperature of 204° the pressure drop on the filter



**Fig. 4 Design of the apparatus for estimating the insoluble-gum-forming tendency of jet fuels:** 1) radiator; 2) but-tress stopcock; 3) filter; 4) manometer damper; 5) differential manometer; 6) manometers; 7) thermometer for measuring the fuel temperature; 8) heater coil; 9) rotameter; 10) preliminary purification filter; 11) reduction valve; 12) starting valve; 13) gear pump; 14) electric motor; 15) air thermostat for heater; 16) fuel tanks.

after 5 hr of operation should not exceed 300 mm Hg in the case of fuel PWA-522.<sup>8</sup> In the case of fuel JP-6 according to specification Mil-F-25656 the pressure drop should not be more than 250 mm Hg at a heater temperature of 204° and a filter temperature of 260°.<sup>27</sup> In evaluating the thermal stability on the Erdco apparatus the formation of a small quantity of deposit in the heater is allowed.

The stability of jet fuels under storage conditions is estimated from the change in the amounts of actual insoluble gums and the change in the acidity.

In order to determine the actual gums in jet fuels, a new, widely recognized method proposed by I. P. Budarov is used at the present time. The determination of the gums is done in a standard POS-01 device by steaming the fuel with water vapor.<sup>28, 29</sup> Vacuum distillation in combination with molecular distillation also is used to determine gums in jet fuels.<sup>30</sup>

It has been suggested that the stability of jet fuels containing cracked components be determined under laboratory conditions in a PK device based on the measurement of the absorption of oxygen by the fuel in a thin layer at 120°.<sup>31, 32</sup> On the basis of the values obtained the admissible storage time of the fuel is determined from a nomogram.<sup>32</sup>

The stability of jet fuels is determined abroad from the value of the potential gums.<sup>33</sup> Z. A. Sablina and A. A. Gureyev<sup>34</sup> suggested estimating the stability of fuels from the rate of formation of potential gums determined in an LSA device at 110°. In this case it was also suggested that the amounts of soluble and insoluble gums be evaluated.<sup>35</sup> The potential gums are determined from the increase in the actual gums after 16 hr of oxidation of the fuel in a bomb at 100° in an oxygen medium. In order to insure long-term storage of jet fuels, the potential gums according to the specifications Mil-F-5616 C (United States), D. Eng. R. D.-2482 (England), and Air 3405 (France) should not exceed 8 mg/100 ml and should not exceed 14 mg/100 ml according to Mil-F-5624 C (United States) and D. Eng. R. D.-2488 (England).<sup>36–39</sup>

The foaming tendency of jet fuels is of great importance in evaluating their operational properties under conditions of high-altitude flight and can be determined by means of a laboratory device proposed by Poulston and Thomas.<sup>40</sup> This device consists of a cylindrical chamber with a stirrer. The fuel is poured into the chamber; the necessary vacuum is created, and the fuel is stirred intensely. The foaming tendency of the fuel is determined from the height of the column of foam that forms.

Water contained in dissolved form in jet fuels facilitates corrosion of the parts of the fuel apparatus and is the cause of formation of ice crystals in fuel at negative temperatures.

In order to determine the amount of dissolved moisture in fuel T-1, a calcium hydride method was developed; it is based on the change in the volume of the hydrogen liberated during the interaction between calcium hydride and water.<sup>41</sup> A comparison of this method with methods based on measuring the change in pressure in a vessel, when calcium hydride is introduced into it, showed that the volume method proposed by VNI I NP (All-Union Scientific Research Institute for the Processing of Petroleum and Gas and for Production of Synthetic Liquid Fuel) and TsIAM (Central Scientific Research Institute of Aircraft Engines) gives more reliable results.

An index characterizing the ability of a fuel to dissolve moisture was introduced into the specifications for jet fuels in the United States and England. No more than 2 ml/liter of water should be dissolved in jet fuels. This index is determined from the increase in the volume of the fuel after it is shaken with water.

The calorific value of jet fuels usually is determined by the calorimetric method—by burning a weighed portion of fuel in a bomb. However, this analysis is complicated and time consuming and can be carried out only by qualified laboratory workers; therefore a method of calculating the calorific value of jet fuels JP-3, JP-4, and JP-5 has been standardized in the United States.<sup>42</sup> The calculations are made on the basis of the

values for the density, the aniline point, and the total sulfur according to empirical tables. The discrepancies between parallel determinations of the calorific value by the calculational method in one laboratory do not exceed 1 kcal and do not exceed 4 kcal in different laboratories.

Among the operational characteristics of jet fuels the corrosive power is of great significance. Several methods have been developed for estimating the corrosive power of jet fuels differing from each other with respect to temperature regime, test length, metal assortment, etc.

In practice the corrosive power of jet fuels usually is estimated from the amount of hydrogen sulfide, mercaptan sulfur, and elementary sulfur contained in them.

For determining the hydrogen sulfide, a method previously used in determining the hydrogen sulfide in diesel fuels was used. For determining the mercaptan sulfur in straight-run jet fuels, the Adams method<sup>43</sup> was used. It is based on the ability of the mercaptans to form copper mercaptides when interacting with an ammonia solution of copper sulfate. Z. N. Moguchaya<sup>44</sup> suggested that fuels containing cracked components be treated before determining the amount of mercaptan sulfur in them.

The presence of elementary sulfur is determined from the change in color of a copper plate. In fuels not containing or possessing traces of elementary sulfur, the copper plate should not change its original color. However, at the present time a method of determining the elementary sulfur in type-T fuels has been developed by A. Ya. Rysanyanskaya and V. P. Muzychenko.<sup>45</sup> It is based on the ability of the elementary sulfur to react with caustic soda, when a weighed portion of fuel is heated in isopropyl alcohol to form the end products sodium sulfide and sodium hyposulfide, which do not hydrolyze in the given medium. This method enables us to determine elementary sulfur to an accuracy of 0.0002%.

Only mercaptan sulfur in jet fuels is determined abroad quantitatively by potentiometric or conductometric titration.<sup>46</sup>

The fractional composition, the viscosity, and other indices are determined by the usual methods.

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### Reviewer's Comment

The article is basically a review of methods used to study the quality of jet fuels. Approximately 80% of the article is concerned with methods developed in the United States for determining fuel thermal stability and deposit-forming tendencies.