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COMPARISON OF SPONTANEOUS IGNITION TEMPERATURES OF VARIOUS COMBUSTIBLE AIRCRAFT FLUIDS

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INTRODUCTION

The spontaneous ignition temperature of combustible fluids has been of great interest to the aircraft industry for a number of years now because of the fire hazard associated with operation of aircraft power plants. The primary concern is the accidental or inadvertent spillage of combustible fluids from any system onto hot engine surfaces or other hot surfaces under any aircraft operating conditions.

A preliminary literature survey revealed differences in testing techniques and spontaneous ignition temperatures; therefore, a more thorough literature survey was conducted in order to obtain a more complete picture of the problem. This report represents a compilation of information, test procedures, and results obtained from the references (Page 11) surveyed. Additional references were surveyed but are not included in the listing for one reason or another.

This survey was initiated in order to obtain a more complete overall picture of the problem of spontaneous ignition of combustible fluids and to further aid in minimizing the potential fire hazards that may exist in present or future aircraft designs.

There is no intent made to criticize the various test procedures, but merely to present the data obtained in each case for the benefit of the reader and to arrive at some general conclusions.

DESCRIPTION OF TEST PROCEDURES

1. The various test procedures utilized can be divided into two main groups: (1) Controlled laboratory procedure and (2) Simulated aircraft procedure. By controlled laboratory procedure, it is meant that the test apparatus is of a specific type, with specific equipment, well defined conditions, etc. The simulated aircraft procedure attempts to simulate a condition that could be encountered in an aircraft such as a heated duct, a duct with an internally heated plate or a heated pipe. The various techniques investigated would be divided as follows:

Controlled Lab. Procedure	Simulated Aircraft Procedure
(1) A.S.T.M. - (D286-30)	(1) C.A.A. - Duct with internally heated S.S. plate
(2) NACA - Modified A.S.T.M.	(2) Bur. of Mines - Heated S.S. pipe
(3) P & W - A.S.T.M. (D286-30)	(3) Douglas Airc. - Heated metal plate with shield
(4) P & W - Modified A.S.T.M.	(4) P & W - Heated steel plate (AMS-5504)
(5) Bur. of Mines--Laboratory	(5) C.A.A. - Cylindrical chamber
(6) NACA - Bomb type test	

2. The following brief description of each test procedure will serve to clarify the situation for the reader:

   (a) Simulated Aircraft Procedures

   (1) C.A.A. Procedure - utilized a 1/16" x 4" x 8" stainless steel heated plate, with the 1/16" x 4" edge facing upstream, located in an air chamber. For varying air flow velocity conditions the combustible fluids were discharged from a spray nozzle and then made contact with the heated plate. For static conditions, the fluids were discharged above the heated plate and allowed to fall on the plate. The size of the air chamber is unknown.

   (2) Bureau of Mines Procedure - utilized a 2" diameter heated stainless steel pipe, three feet long. Combustible vapor-air mixtures in the pipe were checked under static and varying velocity conditions.

   (3) Douglas Aircraft Company Procedure - utilized a heated metal plate to simulate the surface of an engine. For the static condition, the combustible fluids were dropped, poured, sprayed and squirted onto the heated plate. Under air flow conditions, a shield was placed above the heated plate and air of known velocity passed through the space in which spontaneous ignition occurred. The dimensions of the above plate and flow chamber are unknown.

DESCRIPTION OF TEST PROCEDURES (Cont'd.)

(4) Pratt & Whitney Aircraft Procedure - utilized a steel plate (AMS-5504) that was heated in a furnace until a temperature of 100°F above the desired temperature was obtained. The plate was then removed from the furnace and the temperature allowed to drop within 10°F of the desired test temperature. The combustible fluids were dropped, streamed and sprayed onto the steel plate. Static tests only were conducted. The dimensions of the steel plate are unknown.

(5) C.A.A. Cylindrical Chamber Procedure - utilized an 8.5 cubic ft. cylindrical chamber having an 18" diameter stainless steel panel at one end and a vapor-proof paper blowout panel at the other end. The stainless steel panel was heated externally by an oil burner until ignition of the fuel-air mixture in the chamber occurred. The vapor-air mixtures were held at 180°F and 200°F.

(b) Controlled Laboratory Procedures

(1) A.S.T.M. D286-30 Procedure - utilized a 125 milliliter pyrex Erlenmeyer flask supported in a molten metal bath (solder or other low-melting alloy) contained within a crucible. Heat is applied only to the bottom of the crucible by means of a gas burner. A cylindrical, asbestos metal-lined shield approximately 13" in diameter is provided to protect the solder bath from drafts. A pipette is used for delivering drops of fluid into the flask. The surface to volume ratio of the flask is 1:1.

(2) NACA Modified A.S.T.M. Procedure - utilized a 125 milliliter quartz Erlenmeyer flask resting on the bottom of a 2-5/8" diameter by 3" deep hole drilled axially into a solid 8" diameter by 5-1/4" deep Inconel block. The block was electrically heated around the 8" diameter of the block. Spontaneous ignition temperatures were determined by raising the temperature of the block and periodically dropping a few drops of the combustible into the flask until ignition was observed.

(3) P & W Modified A.S.T.M. Procedure - this procedure was similar to A.S.T.M. D286-30 except for size and material of the heating bath, size of the ignition flask and method of heating. A 25 instead of a 125 milliliter Erlenmeyer flask was placed in a large crucible filled with a molten low melting alloy to within 3/4" from the top of the flask. Heat was applied to both the bottom and wall of the crucible whereas A.S.T.M. stipulates bottom heating only. When the testing temperature was attained, the heat was removed and approximately four drops of sample fluid were placed in the flask by use of a pipette. The temperature was repeatedly dropped 25°F and the test continued until no auto-ignition resulted and the minimum temperature obtained was recorded as the spontaneous ignition temperature.

DESCRIPTION OF TEST PROCEDURES (Cont'd.)

(4) P & W - A.S.T.M. D286-30 Procedure - utilized the A.S.T.M. procedure as stipulated and as described above.

(5) Bureau of Mines Laboratory Procedure - This procedure known as I-8 consists of a commercial 1200-watt electric crucible furnace with a vertical, cylindrical well 5" in diameter and 5" in depth. Two auxiliary heaters, one at the neck of the 200 cc. pyrex glass Erlenmeyer flask and the second under the bottom of the flask, were added to the regular heater which encircled the 5" diameter wall. These heaters were added in order to eliminate a temperature differential along the axis of the test flask. After the desired flask temperature was obtained, the combustible fluids were introduced into the flask by means of a 0.25 or 1.0 milliliter hypodermic syringe. The minimum ignition temperature was determined with a given quantity of sample. Larger and smaller volumes were then tried in order to determine the critical volume which gives the lowest spontaneous ignition temperature.

(6) N.A.C.A. - Bomb Type Test Procedure - A cylindrical cast iron bomb or casing which had a 10-1/2" inside diameter and an 18" depth was utilized for containing the 125 cc. Erlenmeyer pyrex flask used as the ignition chamber. A glass-fiber insulated heating mantle which covered the outside of the flask was used as the heat source. Filtered air was supplied to the bomb at two points and the pressure within the bomb measured by a gage. The fuel line entered the cylinder near the top and discharged fuel through a 0.052 inch (I.D.) line about one inch above the flask mouth. An exhaust valve and rupture disk were located in the removable cover of the bomb. Two observation ports diametrically opposite were located in the bomb wall. Minimum ignition temperatures were ensured by injecting the fuel in a solid stream and by varying the amount injected. Stabilization of temperature and air pressure was permitted prior to injecting the fuel.

RESULTS AND DISCUSSION

1. The minimum spontaneous ignition temperature of a combustible fluid in air depends on a number of parameters. These are as follows: (a) pressure, (b) the nature of the contacting or igniting surface, (c) the combustible fluid to air or oxygen ratio, (d) the surface to volume ratio of the ignition vessel or chamber, (e) the movement of the combustible mixture relative to the surface, (f) the time allowed for spontaneous ignition to occur and (g) the temperature of the surface.

2. A comparison of the spontaneous ignition temperatures obtained for various aircraft combustible fluids which have been tested by more than one test procedure are shown graphically in Figure 1 (a) and 1 (b). These figures are practically self-explanatory, however, two points that might need clarification are as follows:

   (a) For the P&W hot plate test, the use of the words spray, stream and drops refers to the method used in bringing the combustible fluids in contact with the hot plate;
   (b) For the Bureau of Mines test, the use of Mg, Al, and Py refers to the flask material utilized in the test, and which respectively are Magnesium, Aluminum and Pyrex.

   The above information was included in the figures in order to show the effect of material and testing technique on the spontaneous ignition temperature.

   It will be noticed by the reader that JP-5 fuel is not included in Figure 1 (a). From all the references investigated, the only data that could be found was that given in Reference 12. Since no comparison could be made, this data was plotted separately in Figure 4.

3. A comparison of the spontaneous ignition temperatures for JP-4 fuel under varying airflow velocity conditions as tested by several investigators, is shown in Figure 2. Only two points were available from the Douglas data of Reference 4, however, from the appearance of the C.A.A. and Bureau of Mines curves, it appears that the Douglas hot plate technique would result in a curve falling between these two. The sharper drop in spontaneous ignition temperature at zero airspeed for the Bureau of Mines curve is due to the use of data from the laboratory static test procedure instead of the pipe procedure. The static ignition temperature with the hot pipe procedure was not evaluated.

   The curves are offset from each other but the general effect of airspeed on spontaneous ignition temperature of JP-4 fuel is evident in that the curves flatten out with increasing airspeed, thereby resulting in a decreased effect on the spontaneous ignition temperature.

RESULTS AND DISCUSSION (Cont'd.)

4. For combustible hydrocarbon fuels, the lower boiling hydrocarbons have higher self-ignition temperatures:

(a)	MIL-F-5624A (JP-4)	10% Point	191° F. Min.
(b)	MIL-F-5572 (100/130)	10% Point	167° F. Min.
(c)	MIL-F-5572 (115/145)	10% Point	167° F. Min.
(d)	MIL-F-5616 (JP-1)	10% Point	327° F. Min.
(e)	MIL-F-5624 (JP-3)	10% Point	116° F. Min.

This is evident from the results shown in Figure 1 (a) because in comparing the combustible fuels there is a definite increase in the spontaneous ignition temperature when checked against the 10% boiling points shown above.

5. From Figure 1 (a) and 1 (b), a comparison of the spontaneous ignition temperatures between those obtained by controlled laboratory procedures and those obtained by simulated aircraft procedures indicates that higher temperatures were obtained with the latter techniques. Based on the various parameters mentioned in paragraph one above, this would appear to be expected. The complete physical characteristics of the simulated aircraft procedure setups are not known but the differences in the results obtained between them could undoubtedly be attributed to variations encountered in these parameters.

6. An interesting fact brought out in Reference 1, is the relationship of injection pressure of a combustible fluid with respect to the spontaneous ignition temperature in a chamber having a pressure of one atmosphere. An MLO-54-540 commercial hydraulic fluid was injected with a Diesel injector at pressures between 0 and 4800 psig. at a distance of 4 inches from a hot pyrex surface. At 0 injection pressure the spontaneous ignition temperature was 70[illegible]° F, at 500 psig. the ignition temperature was 472° F and from 7[illegible]0 psig. up to 4800 psig. the ignition temperature remained constant at 4[illegible]8° F. The statement is made that similar effects were noted with other fuels, however, MIL-O-5606 hydraulic oil did not exhibit this effect under identical test conditions.

7. The effect of decreasing pressure alone on the spontaneous ignition temperature is adequately demonstrated by a test conducted on JP-4 fuel under static conditions by the Bureau of Mines laboratory controlled procedure. At -1- atmosphere pressure the ignition temperature was 468° F, while at 1/4 atmospheric pressure the ignition temperature increased to [illegible]° F. The 1/4 atmospheric pressure is equivalent to 35,000 ft. altitude. Figure 3, which was taken from Reference 1, graphically represents this effect.

RESULTS AND DISCUSSION (Cont'd.)

8. The effect of increasing pressure on the spontaneous ignition of JP-4 and JP-5 fuel as statically tested by NACA in Reference 12, is shown in Figure 4. As the pressure was increased from 1 to 9 atmospheres, the ignition temperature for JP-4 dropped from 522° F. to 410° F. while for JP-5 it dropped from 477° F. to 403° F. In addition, it was found that for similar quantities of fuel charges, injected into the flask in which spontaneous ignition occurred, the ignition lag time decreased with increasing pressure.

9. In the case of flowing vapor-air mixtures, shorter contact times are involved in which a mixture is in contact with a heated surface, therefore, higher temperatures are required for spontaneous ignition, than are required for static mixtures.

10. From a review of all the data surveyed, the lowest spontaneous ignition temperatures were obtained when liquid fuels were introduced into heated containers (controlled laboratory procedures). A similar effect was noted in the simulated aircraft procedure tests when comparing P & W data of Reference 9 and CAA data of References 2 and 10. The Bureau of Mines data in Reference 1, however, did not show any correlation in this respect.

11. The effect on spontaneous ignition temperatures of the material utilized for the combustion flasks in the controlled laboratory procedure tests is evident from the data given in Reference 1, in which pyrex, aluminum and magnesium flasks were used under similar test conditions. Pyrex and aluminum gave comparable, slightly higher and slightly lower temperatures interchangeably, whereas, magnesium consistently gave higher spontaneous ignition temperatures.

12. On Figures 1 (a) and 1 (b) a constant temperature line of 700° F. has been drawn. The line represents the U.S.A.F. (H.I.A.D. -- Volume I) hot surface maximum temperature limit for all shrouds and firewalls utilized to protect all aircraft components, equipment and structure that might be critically affected by fires occurring in or around the engine. This 700° F. limit corresponds to the lowest spontaneous ignition temperature for oil or fuel as tested by W.A.D.C.

13. The U. S. Navy Specification SD-24-G, Revision Nov. 30, 1954, titled "General Specification for the Design and Construction of Airplanes for the U. S. Navy" does not call out such a temperature limit and neither does the C.A.A. in their regulation. The U. S. Navy specification does reference the A.I.A. "Design Manual on Aircraft Fire Protection for Reciprocating and Gas--Turbine Engine Installations" in which a limit of 500° F. is given for reciprocating engine exhaust shrouds but none for gas turbine installations. The gas turbine chapter does generally mention that design considerations are to be taken into account with regard to spontaneous ignition temperature of combustible fluids.

RESULTS AND DISCUSSION (Cont'd.)

14. Comparing the U.S.A.F. 700° F limit with the survey results obtained on Figure 1 (a) and 1 (b), it can be seen that six out of the eight combustible fluids had spontaneous ignition temperatures above 700°F when tested under simulated aircraft procedures. The two fluids that had lower temperatures were JP-1 fuel and MIL-O-5606 hydraulic fluid. Unfortunately, only one simulated aircraft procedure test was conducted on these two fluids, therefore, no correlation can be made. Under laboratory controlled test procedures, four of the fluids, namely, JP-1, JP-3, JP-4 and MIL-O-5606 hydraulic fluid, had spontaneous ignition temperatures below 700° F while MIL-L-7808 lube oil and MIL-O-6081 (Grade 1010 lube oil) had values slightly above 700° F. Grade 100/130 and 115/156 gasoline had values well in excess of the 700° F figure.

CONCLUDING REMARKS

1. The higher the altitude of an aircraft, the higher is the spontaneous ignition temperature of a combustible fluid because of the reduction in atmospheric pressure. In conjunction with this, increasing the cooling or ventilating air flow velocity across any hot surface that is a potential ignition source also raises the spontaneous ignition temperature. Under these two conditions, the aircraft fire hazards from spontaneous ignition of combustible fluids decreases and the safety of the airplane increases.

2. Conversely, pressure areas greater than ambient atmospheric pressure in an aircraft will tend to decrease the spontaneous ignition temperature. In addition, the same effect can be encountered by decreasing the surface to volume ratio of the ignition chamber and/or increasing the percent of oxygen in the fuel-air mixture from the 20% found in air to 100%.

3. The spontaneous ignition temperature of combustible fuels was found to decrease sharply as the pressure at which ignition was made to occur was raised from one to three or four atmospheres. At higher pressures very little change in ignition temperature took place.

4. The difference in the spontaneous ignition temperature of two fuels at a low pressure cannot be used for estimating the respective spontaneous ignition temperatures at higher pressures, because differences are greatly reduced when the pressure in which ignition is made to occur is raised.

5. A lean or rich combustible fluid to air mixture will give higher spontaneous ignition temperatures above that obtained with a mixture giving the minimum spontaneous ignition temperature. The same is true where smaller or larger volumes than the so-called critical volume of a combustible fluid is used.

6. The time lag for spontaneous ignition of any combustible fluid is not an independent variable in testing. For a given combustible, the time lag increases as the temperature of a surface decreases. The time lag at the minimum spontaneous ignition temperature varies widely for various types of combustible fluid.

7. For similar combustible fluid quantities, the ignition time lag decreases with increasing pressure.

8. From all the spontaneous ignition tests conducted to date, it appears that a combustible fluid leak in an aircraft that is either a drip or a solid stream would be more dangerous from a fire hazard standpoint than a leak that is in the form of a fine spray. A high pressure spray over 300 psig., however, could result in it being just as dangerous, or more so, than a drip or solid stream.

9. The U.S.A.F. limit of 700° F appears to be a practical one when compared to the spontaneous ignition temperatures obtained with the simulated aircraft procedure tests. Establishing a lower limit on the basis of controlled laboratory procedure tests would be impractical since it would impose unnecessary design considerations for an aircraft and, in addition, the ideal test conditions utilized may never be realized in an aircraft because of the many variables involved as mentioned before.

RECOMMENDATIONS

1. It would appear that establishing a dimensionless Spontaneous Ignition Temperature Index Number for combustible fluids which would take into account the various parameters that affect the ignition temperature would aid in evaluating the safety, from a fire hazard standpoint, of various installations in an aircraft. To accomplish this, it would be necessary to establish some base line test data for each combustible fluid from a standardized test procedure such as ASTM D286-30 or a standardized simulated aircraft procedure against which the actual conditions that would be encountered in an aircraft could be evaluated so as to arrive at a dimensionless Index No. The parameters that would be involved are as follows: (1) pressure; (2) temperature; (3) air flow velocity; (4) material; (5) surface/volume ratio; (6) fuel/air ratio; (7) time.

2. To attempt this is beyond the scope of this report as it would entail a great deal of time and effort for determining the usefulness of such an Index No., checking out its practicality, establishing base line data, and actually applying it to sample aircraft installations.

3. The establishment of a standardized simulated aircraft test procedure that would be acceptable to the aircraft industry would be very desirable as the differences encountered in spontaneous ignition temperatures with the various test procedures utilized could be resolved. A common base line would then be established from which the aircraft industry could approach the problem of determining the potential fire hazards in their particular aircraft.

REFERENCES

1. Zabetakis, M. D., Jones, G. W., Scott, G. S., Furno, A. L., Research on the Flammability Characteristics of Aircraft Fuels. U.S. Bureau of Mines. Wright Air Development Center Contract No. AF 18(600)-151, Project No. 3048. W.A.D.C. Technical Report 52-35 Supplement 4, January 1956.

2. C.A.A. Technical Development Center. Hot Surface Ignition Studies (U.S.A.F.). Aircraft Fire Prevention Program, Progress Report, June 1956.

3. Jackson, J. L. Spontaneous Ignition Temperatures of Pure Hydrocarbons and Commercial Fluids. NACA RME50J10, Dec. 20, 1950.

4. Harvey, H. Fuels for Turbine Transports. S.A.E. Journal, June 1956.

5. Swarts, D. E. and Orchin, M. Vapor-Phase Oxidation and Spontaneous Ignition - Correlation and Effect of Variables, NACA TN 3579, April 1956.

6. Mecklenborg, K.T. Spontaneous Ignition Studies Relating to Lubricants of Reduced Flammability. NACA TN 3560, January 1956.

7. [illegible], B. Self-Ignition Temperature and Flash Points of Some High Energy Fuels, NACA RME56C16A, March 19, 1956.

8. Scull, W. E. Relation Between Inflammables and Ignition Sources in Aircraft Environments. NACA Report 1019.

9. Pratt & Whitney Aircraft. Auto Ignition Tests on Fuels, Oils, Hydraulic Fluids. J-57 Information Letter, WCO #27, August 31, 1953.

10. C.A.A. Technical Development Center Hot Surface Ignition Studies (U.S.A.F.) Aircraft Fire Prevention Program, Progress Report, March 1956.

11. General Electric Co. Installation Handbook for Turbojet Engines.

12. O'Neal, C., Jr. Effect of Pressure on the Spontaneous Ignition Temperature of Liquid Fuels. NACA TN 3829, October 1956.

13. Anon. Standard Method of Test for Autogenous Ignition Temperature of Petroleum Products and Lubricants. (D286-30). A.S.T.M. Standards on Petroleum Products and Lubricants, 1955, pp. 154-155.

14. Zabetakis, M.G., Furno, A.L., and Jones, G.W. Minimum Spontaneous Ignition Temperatures of Combustibles in Air. Industrial and Engineering Chemistry, Vol. 46, No. 10, October 1954, pp. 2173 - 2178.