DATA REPORT NO. 74

PROJECT NO. 510-001-08X

SPARKING HAZARDS OF STRUCTURAL MATERIALS

(A Preliminary Appraisal of the Problem of Frictional Sparking Ignition in Aviation)

by

John Marcy

National Aviation Facilities Experimental Center
Test and Evaluation Division
Aircraft Branch
Propulsion Section

September 1965

PROJECT 510-001-08X
SPARKING HAZARDS OF STRUCTURAL MATERIALS
(A Preliminary Appraisal of the Problem of Frictional Sparking Ignition in Aviation)

Introduction:

Interest in the subject of frictional sparking has to a great extent been stimulated by fear of the ignition hazard with which this phenomena has been associated. This particular hazard has been studied extensively in connection with safety precautions in mining. Incendive sparking in mining has occurred from sliding or impact frictional forces between magnesium/aluminum alloys and rusty steel surfaces. The thermite reaction which results from the combustion of the metals in the presence of oxides provides the energy for spark ignition. In contrast, sparking caused by metals rubbing on an abrasive surface such as a grinding wheel, while still capable of producing ignition, is much less intense without the benefit of a thermite reaction. Ordinarily, very high energy forces are required to produce incendive sparking. Such a situation occurs during a crash or wheels-up landing of an aircraft on a concrete surface.

NASA(1) and later NRL(2) have shown that frictional sparking under these conditions presented a serious fire hazard. Frictional sparks caused by dragging titanium and magnesium specimens along various runway surfaces were shown to be capable of igniting fuel sprays at relatively low bearing pressures (23 pounds) and speeds (20 mph). Fortunately, aluminum, which is the metal most commonly used in aviation, was found to be safe from spark ignition. However, with the increased use of titanium proposed for the SST, the importance of frictional sparking to the overall problem of fire protection has now become one of major concern and has assumed a new dimension. Thus, a need for conducting a study of the problem with the prime objective of minimizing the danger arising from the use of titanium is clearly indicated from past experience.

In addition to the possible use of less or non-sparking metals, the effect of the runway material and its condition on sparking need be considered. For example, NRL has attempted to reduce the possibility of spark ignition by covering the runway surface with a foam blanket. Although this was effective with steel, and to a lesser extent with magnesium, however, with titanium the ignition hazard still persisted because of the very severe sparking potential of this metal. Various other methods(3) have been proposed for reducing the sparking hazard. These include the possible use of new titanium alloys as well as cladding the surface of titanium with a non-sparking material such as aluminum or plastic.

Discussion:

For sparking to occur from frictional contact between two bodies, the right combination of mechanical and chemical factors must be present. Gerstein and Allen [4] in their report on the SST fire protection have listed fifteen factors which may affect the occurrence of incendive sparking. Only a few of these factors need to be considered to evaluate the sparking potential of any given metal. The mechanism of sparking in brief occurs as follows: (1) Abrasion between contact surfaces causes small particles to be detached and released in the air as a dust cloud; (2) Frictional energy imparted to the particles raises the temperature to their ignition point; (3) At this temperature, the heated particles react with oxygen to burn, thus releasing the heat of combustion of the metal and thereby increasing the intensity of the sparking. The significant properties of metals with regard to their sparking potential are listed in Table 1.

The most hazardous metals as shown in the table are characterized by their high degree of combustibility and low ignition temperatures. The U. S. Bureau of Mines [5] has determined the explosibility of metal dusts in a heated oven and by electrical sparks. On the basis of the test results, metals were graded under five different classifications. They are: severe, strong, moderate, weak and none. This classification is significant in that it applies to the sparking potential of metals. For example, only the metals listed in the severe and strong groups consisting of aluminum, magnesium, titanium, zirconium, uranium, thorium, iron carbonyl, plus alloys and hydrides of these metals, would be expected to produce sparks. Metals such as nickel, zinc, copper, lead, molybdenum, manganese, antimony, tungsten, beryllium, etc. listed under the weak group would not be expected to present a sparking hazard. Because of the lack of sufficient brittleness and hardness properties, not all materials assigned a severe or strong explosibility rating would necessarily present a sparking hazard. A prime example of this is aluminum which is normally a safe metal. This metal instead of abrading to form a cloud of dust particles smears on a rough surface such as grinding wheel or concrete.

A literature survey to obtain basic information on the nature of the problem of spark ignition was undertaken. The majority of the references quoted below pertained to work conducted by the Safety in Mines Research Establishment of Great Britain.

1. Reynolds [6] has measured the ignition temperature of small strips of metal and has shown that many of the metals melt before reaching the temperature at which they ignite and burn.

These metals include aluminum, nickel, copper, zinc, lead tin, molybdenum, etc. which are known to have either a low or no spark potential.

2. Bowden and Lewis[7] have shown that the heat released by burning metal particles was the major factor in spark intensity. Ignition by hot spots on metals resulting from sliding friction is not considered likely because of rapid heat transfer in metals. Brittleness of the metal as an essential factor in sparking is emphasized.

3. Margeson[8] has investigated the use of coatings to alleviate the sparking hazard of magnesium. Aluminum and plastic coatings applied to magnesium, although effective, were not considered practical when the metal was subjected to rough handling.

4. Titman and Wynn[9] [10] have obtained incendive sparking from the impact of one gram steel balls striking sandstone. The nature of the abrasive rock surface was found to be important. The possibility that highly reactive materials such as aluminum may react with oxides in some rock formations - similar to thermite reaction - is suggested.

5. Rae[11] has shown that relative humidity of the air from 15% to 85% is without any apparent effect on the spark ignition produced by the impact of light alloys against oxide coated surfaces. Suppression of spark ignition was not obtained by wetting the contact surfaces. Wetness of the surfaces increased the ignition hazard of aluminum and reduced that of magnesium. The incendivity of titanium sparks was found to be practically identical to that of magnesium, although the sparking mechanism is quite different in the two cases. Magnesium does not form discrete particles when abraded as does higher melting point metals. Instead, magnesium ignites as a vapor cloud almost instantaneously while titanium generates a shower of incandescent particles with a comparatively long life before these finally explode and flash.

6. Rae[12] has shown that steel, brass, aluminum, but not zinc, striking an aluminum smear on rusty steel are capble of producing incendive sparking from the thermite reaction between aluminum and iron oxide. Surface temperature of 750°F to 1100°F are required to initiate the thermite reaction. The low melting point temperature of zinc prevents the occurrence of the thermite reaction which could produce ignition.

7. Rae and Nield[13] have shown that the incendive sparking of aluminum is largely dependent on its mechanical properties. Increasing hardness of the alloys while maintaining the same ductility gives rise to greater sparking potential. Aluminum alloys containing zinc, copper and silver with more than 50% of aluminum are still capable of producing spark ignition when sliding over rusty steel. Alloying non-sparking metals to aluminum is not considered practical for alleviating the ignition hazard of this type of metal.

8. Rae[14] has shown that the cause of an oil tanker explosion could have been frictional sparking resulting from a brass object being dropped on a magnesium block used as an anode. However, no ignition could be obtained with a clean magnesium surface. It was surmised that the ship's magnesium anode material was contaminated with sufficient oxygen carriers to produce a thermite reaction.

9. Hill[15] has studied the possibility of ignition and burning of metals under high temperature flight conditions. When heated in an atmosphere of oxygen or when heated in air and plunged into a supersonic airstream, titanium, iron, carbon steel, and 4130 alloy were found to have spontaneous ignition temperatures in the solid phase below the melting point of the metal. Inconel, copper, 18-8 stainless steel, monel and aluminum did not ignite spontaneously in the solid phase. Magnesium ignited just above the melting point. Titanium burned in nitrogen.

10. Nagy[16] has shown in grinding wheel experiments that ignition of methane/air mixtures was easily obtained by sparks generated by rubbing friction (12 to 30 psi load and 12 to 94 fps speed) of sandstone against rotating sandstone, shale against rotating sandstone, and sandstone and shale against rotating steel. Ignition sparks were not obtained with the steel specimen stationary and the sandstone wheel rotating. The quartz-bearing sandstones present the greatest frictional hazard. Metal to metal contact is less hazardous than metal to rock contact.

Résumé

With the knowledge now available, means for reducing the sparking potential of titanium in aircraft to a safe level during a crash landing does not appear very promising. Unfortunately, titanium, along with magnesium, exhibits the most severe case of sparking potential and ignition hazard of any of the more common metals. Because of the tremendous impact forces and high speeds represented by an airplane crash on a concrete runway when compared with laboratory test conditions, the sparking potential would be very much greater than that demonstrated in past experiments. Therefore, only a very drastic reduction in the ability of titanium to produce incendive sparking would alleviate the ignition hazard. New alloys of titanium suitable to aircraft would not, it is believed, be expected to reduce sparking to acceptable levels. Coating or cladding titanium with a plastic or non-sparking metal would provide only temporary relief from sparking because of rough usage and would not be practical on thin gauge titanium sheet metal. The other approach to the problem of spark ignition, that of reducing the abrasive action of the runway surface by new materials, has not as yet been considered. A less abrasive covering material on a runway, such as asphalt without aggregates, would, no doubt, greatly reduce the sparking hazard. Also proposed is the use of a plastic covering for the runway, such as vinyl, which when decomposed by frictional heat would liberate chlorine gas or other extinguishing agents to suppress the ignition of the fuel/air mixtures. Foaming and wetting the runway surface to reduce spark intensity by cooling has not proved completely effective in eliminating the ignition hazard in tests already conducted by NRL which were intended to make crash landings safer.

References:

1. Campbell, John A., Appraisal of the Hazards of Friction-Spark Ignition of Aircraft Crash Fires. NACA TN-4024, 1957.

2. Peterson, E. J., et al, Studies on the Fuel-Ignition - Suppression Capability of Foam-Covered Runways for Aircraft, NRL Report 5492, 1960.

3. Eggleston, L. A., et al, A Feasibility Study of a Crash-Fire Prevention System for Supersonic Commercial Transport, Tech. Doc. Report ASD TDR - 63 - 478, 1963.

4. Gerstein, Melvin, et al, Fire Protection Research Program for Supersonic Transport, Tech. Doc. Report APL-TDR-64-105, 1964.

5. Nagy, John, Explosibility of Metal Powders, U. S. Bureau of Mines, RI 3722 (1943), RI 4835 (1951), RI 6516 (1964).

6. Reynolds, W. C., Investigation of Ignition Temperatures of Solid Metals, NASA TN D-182 (1959).

7. Bowden, F. P. and Lewis, R. D., Ignition of Firedamp (Methane) by Stationary Metal Particles and Frictional Sparks. Engineering, Aug. 22, 1958.

8. Margeson, S., Ignition Hazard from Sparks of Magnesium Base Alloys, SMRE Research Report No. 75 (1952).

9. Titman, H., The Ignition Hazard from Sparks from Cast Alloys of Magnesium and Aluminum. SMRE Research Report No. 90 (1954).

10. Titman, H., and Wynn, H. A., The Ignition of Explosive Gas Mixtures by Friction, SMRE Research Report No. 95 (1954).

11. Rae D., The Ignition of Gas by the Impact of Light Alloys on Oxide-Coated Surfaces, SMRE Research Report No. 177.

12. Rae D., The Ignition of Methane-Air by the Glancing Impact of Metals on Smears of Light Alloys Formed on Rusty Surfaces. SMRE Research Report No. 190 (1960.

13. Rae, D. and Nield, B. V., Incendive Frictional Sparking from Alloys Containing Aluminum, SMRE Research Report No. 192 (1960).

14. Rae D., The Ignition of Gas by the Impact of Brass against Magnesium Anodes and Other Parts of a Ship's Tank, SMRE Research Report No. 229 (1965).

15. Hill, Paul R., et al, High Temperature Oxidation and Ignition of Metals, NACA RM L55L23b (1956).

16. Nagy, John, et al, Frictional Ignition of Gas During a Roof Fall, U. S. Bureau of Mines, RI 5548 (1960).