

attempted to answer by discussing fundamental but unsophisticated mathematical models that highlight all essential features (Ref. 1 of Dzung's comment). I have exposed the statement (Ref. 2 of Dzung's comment) that this material is the same as found in the countless applications of routine classical procedures. In addition, the false impression has been created that Dzung's Ref. 1 deals only with this subject. It contains many other items, including a variational approach to boundary-layer heat transfer which is of drastic simplicity and remarkable accuracy. This is in contrast with the extremely elaborate procedure of Dzung's Refs. 3 and 4, which are more suitable for dealing with the Schroedinger equation than with engineering problems.

[This paper (Dzung's Ref. 1) also prepared the ground for a companion paper that follows and deals with the more difficult problem of coupling between a solid and a moving fluid in transient heat flow.

## Spontaneous Ignitability of Nonhypergolic Propellants under Suitable Conditions

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**B**IPROPELLANTS used in rockets are classified as hypergolic (self-igniting) and nonhypergolic (non-self-igniting). Ignition usually is preceded by exothermic chemical reactions. If the heat generated is not enough to raise the temperature of the vapor or gaseous reaction mixture to the ignition temperature, the flame will not be produced. Ignition will not take place if the vapor is intrinsically nonignitable. In general, the former factor is responsible for the inability of several bipropellants to ignite spontaneously. It appears, therefore, that, if the chemical reaction preceding ignition can be accelerated, spontaneous ignition can occur. Suitable additives can be employed for this purpose. It is the purpose of this comment to report the role of such additives.

The nonhypergolic fuels used in the investigation were m-cresol, furfural, cyclohexanol, anisole, and triethanolamine, which were of laboratory grade. For oxidizer, red-fuming nitric acid (density 1.5 g/cm<sup>3</sup>) containing 6% nitrogen oxides was used. These fuels did not ignite with it, but in few cases red-fuming nitric acid containing 5% potassium permanganate was used to make the fuel self-igniting. The ignition delay was measured by the cup-test method, as described earlier.<sup>1</sup> The fuel and the oxidizer were taken by volume. The volume of the oxidizer taken was 1.1 ml, and the volumes of m-cresol, furfural, cyclohexanol, anisole, and triethanolamine were taken as 0.6, 0.6, 0.6, 0.6, and 0.8 ml each time, respectively.

The results given in Table 1 show that the forementioned fuels become hypergolic when red-fuming nitric acid con-

taining potassium permanganate is used. Similar behavior of potassium permanganate is known for the gasoline/red-fuming nitric acid system.<sup>2</sup> The mechanism of action of potassium permanganate is under investigation.

### References

<sup>1</sup> Rastogi, R. P., Girdhar, H. L., and Munjal, N. L., "Ignition catalysts for rocket propellants with red-fuming nitric acid as oxidant," *ARS J.* **32**, 952 (1962).

<sup>2</sup> Warren, F. A., *Rocket Propellants* (Reinhold Publishing Corp., New York, 1958), p. 28.

## Comments on "Wing-Tail Interference as a Cause of 'Magnus' Effects on a Finned Missile"

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**H**AVING read Benton's paper<sup>1</sup> recently, the author finds that an additional description of the flow over a rotating wing is necessary in order to understand it. The author agrees with Benton's conclusions concerning wing-tail interference creating a side force but does not agree with his picture of the mechanism involved.

The angle of attack on a rotating wing varies linearly along the span of the wing according to  $\alpha = \omega r/U$ . Here  $\omega$  is the spin rate,  $r$  is the spanwise distance from the centerline of rotation, and  $U$  is the freestream velocity. In turn, the spanwise lift distribution is not only a function of the stationary wing factors but also the variation of angle of attack along the span. The spin changes the lift distribution on the wing and makes it necessary to integrate along the span in order to determine the resultant lift force and its center of pressure. The forementioned alters the flow and force pattern present on a stationary wing and must be considered in analyzing the conditions existing on a rotating wing.

It also is interesting to note that when free spin conditions exist on a cruciform wing plus body ( $\delta \neq 0$ ,  $\alpha = 0$ ), such as in Benton's paper, the resulting rolling moment on each wing must be zero ( $\int r dL = 0$ ). However, the lift force is not zero on all sections of the wing but varies from positive values (tends to increase spin) on inboard sections to negative values on outboard sections. Under free spin conditions the resultant lift on each wing, which must be located on the body centerline, is in the direction of the inboard lift. However, the resultant lift on a symmetrical configuration at  $\alpha = 0^\circ$  will be zero, for the lift on opposing wings will cancel.

From Benton's paper it is seen that, when the wing-tail configuration reaches  $\alpha = 10.5^\circ$ , the upper tail fin (fin  $d$ ) is clear of the wing vortices and is subject only to freestream conditions. In this case the lift (side) force on the fin can be computed from

$$L = q \frac{dC_L}{d\alpha} \frac{P_{WBT}}{U} \int_{r_1}^{r_2} r ds$$

Here  $r$  is the span distance from the body axis,  $r_1$  and  $r_2$  are the span distances to the root and tip chord, and  $ds$  is the incremental wing area. However, fin  $b$  at the same time is immersed fully in the vortex pattern so that it is no longer subject to freestream conditions. Instead, its lift (side)

**Table 1** Average ignition delay using red-fuming nitric acid

Fuel	With KMnO <sub>4</sub> , sec
m-cresol	0.30
furfural	10.0
cyclohexanol	8.0
anisole	erratic
triethanolamine	3.0

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