JOURNAL OF PROPULSION AND POWER
Vol. 17, No. 5, September–October 2001

Development of a Resonance Igniter for GO_2/Kerosene Ignition

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A resonance ignition system is attractive for rocket engines because of the igniter's simplicity and the possibility of multiple ignitions without additional mechanical complexities. In this work a resonance igniter to produce a torch from burning of gaseous oxygen and liquid kerosene was designed and tested. The oxygen is heated for 0, 1 s in the acoustic resonator cavity, and the ignition occurs instantaneously on kerosene injection. The preliminary tests under ambient conditions demonstrated the igniter's ability to ignite GO_2/kerosene mixtures over a wide range of pressures and mass flow rates. This opens new possibilities to create a compact and reliable ignition system for restarting rocket engines.

Nomenclature

$\dot{m}_f$, $\dot{m}_o$	=	mass flow rate of kerosene and oxygen, respectively, kg/s
O/F	=	$\dot{m}_o/\dot{m}_f$, mixture ratio
p_c	=	chamber pressure, bar
p_f, p_o	=	inlet pressure of kerosene and oxygen, respectively, bar
T_B	=	temperature of the igniter body, K
T_R	=	temperature of the outer surface of resonator, K
T_T	=	temperature of the torch, K
t	=	time, s
t_f	=	moment when the fuel valve is turned on, s
t_{ig}	=	moment of ignition, s
t_o	=	moment when the oxygen valve is turned on, s
t_{off}	=	moment when the fuel valve is turned off, s
Δt_{ig}	=	time delay of ignition, s
Δt_o	=	igniter preparation interval, s
Δt_{op}	=	igniter operation interval, s

Introduction

IN 1954 it was found that for specific conditions an underexpanded gas jet entering a deep cylinder cavity (resonator) can provoke fast and strong heating of gas inside the cavity.[1] Since that time a number of investigations in different aspects were fulfilled to understand the phenomenon and to check its applicability, for example, in the works of Thompson,[2] Brocher et al.,[3] and Sarohia and Back.[4] Through these investigations it was clarified that shock-wave oscillation was the predominant effect inside the resonator, although the theoretical description of this effect was not completed.

Phillips and Pavli[5] made the first attempt to apply this phenomenon in a LOX/LH_2 rocket engine. They investigated the resonance igniter operating with gaseous oxygen-hydrogen mixture at low pressures and temperatures, similar to those levels available in the ullage of propellant tanks. They found experimentally that the heating period of GO_2/GH_2 mixtures up to the ignition temperature was excessively long. After this period research on resonance igniter for application in rocket engine ceased.

Recently, taking into account that LOX/kerosene as well as LOX/LH_2 are propellant options that will find application in future space missions and considering that they are nonhypergolic combinations, new interest arose on engine ignition.[6] Among all of the different ignition methods available today, the resonance ignition is attractive because of the extremely simple igniter configuration and the possibility of multiple ignition.[7–9]

Received 11 October 2000; revision received 14 March 2001; accepted for publication 23 March 2001.

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In the present work, instead of the low-pressure concept, the igniter scheme with high-pressure feeding is proposed. The modified configuration of resonance igniter, operating with GO_2 and kerosene, was tested to confirm the feasibility of the concept and to explore its main operational characteristics.

Igniter Configuration and Features

The working principle of the resonance igniter, operating with GO_2/GH_2 mixture,[5] is the following: GO_2 and GH_2 are piped into the mixer whence the propellant mixture is directed through the sonic nozzle into the resonator cavity, exciting the shock-wave oscillations. As a result of these oscillations, a part of the propellant mixture inside the resonator is heated and ignited. The flame leaves the resonator and ignites the whole mixture delivered through the sonic nozzle. This type of igniter configuration, using premixed oxidizer and fuel, cannot be used for gas-liquid combination, such as GO_2/kerosene, because the liquid introduced into the resonator through the nozzle can fill up the cavity and affect the ignition. Moreover, configuration with premixed oxidizer and fuel presents a safety problem because the mixture can be ignited upstream of the nozzle, destroying the device.

Figure 1 depicts schematically the proposed GO_2/kerosene resonance igniter free of these drawbacks. In this scheme oxygen is used as an oxidizer and a carrier of power to initiate ignition, whereas kerosene is injected separately. The operation sequence is the following: compressed oxygen is accelerated through the nozzle and directed into the resonator as an underexpanded jet. Once the oxygen temperature in the resonator is increased to a level for ignition to occur, kerosene is injected into the igniter chamber. It is expected that the drops of kerosene will be partially entrained by the oxygen jet and enter the resonator. On contact with the hot oxygen, ignition takes place, the flame is forced out from resonator to the igniter chamber, and issued from the igniter as a torch.

The scheme of GO_2/kerosene igniter, compared with the scheme of GO_2/GH_2 igniter, has some advantages. First, only a small amount of liquid is entrained by the oxygen jet into the resonator; therefore, possibility of cavity clogging is reduced. Second, the igniter can be operated with lower values of kerosene inlet pressure because the kerosene is injected independently of GO_2. Third, because part of kerosene can be sprinkled on the chamber wall it can help to cool the downstream wall. Finally, the GO_2/kerosene igniter scheme is free of prohibitively sized GH_2 tanks.

The definition of the geometry of the GO_2/kerosene igniter was based on an existing theoretical consideration[10] to obtain fast oxygen heating inside a resonator. In this case the total pressure of the oxygen jet should be around six times higher than the pressure in the igniter chamber before ignition occurrence.

Experimental Apparatus and Procedure

Figure 1 shows a schematic drawing of the experimental apparatus. The igniter has a body made from copper in a cylindrical block

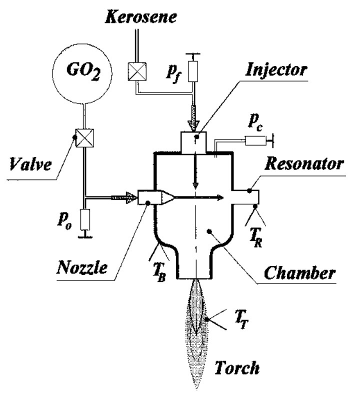

Fig. 1 Scheme of GO_2/kerosene resonance igniter.

of 60 mm diam and 30 mm height. Within the igniter body there is a combustion chamber, 20 mm diam, with an outlet hole 10 mm diam. On the chamber inner wall there is a kerosene injector provided with three injection holes of 0.6 mm diam, a sonic nozzle of 4 mm diam, and a resonator of 2 mm diam with conical entrance, placed on the opposite side of the sonic nozzle.

The setup for measurements and control is also shown in Fig. 1. The transducers p_c, p_o, and p_f are used to measure the pressures in the combustion chamber, the oxygen line, and the fuel line, respectively. The thermocouples T_R and T_B are used to check the temperatures of outer surface of the resonator and the igniter body, respectively. The thermocouple T_T is used to detect the presence of torch.

The following procedures were adopted in all of the experiments: opening of GO_2 valve to start the heating process and opening of kerosene valve after a predefined time interval. The computer-controlled measurement system recorded continuously information about parameters of interest and also controlled oxygen and kerosene valves operations. To stop igniter operation, the kerosene valve was turned off before oxygen valve.

All of the experiments were done under ambient conditions at an initial temperature of 303 K. The experimental setup allowed changing the inlet pressures of oxygen and kerosene within the following limits: $p_o = (5.0 \text{ to } 20.0)$ bar and $p_f = (1.0 \text{ to } 20.0)$ bar.

The following definitions were adopted throughout the experiments: the igniter preparation interval Δt_o as the difference between t_f and t_o; the moment of ignition t_{ig} as the instant when sudden temperature rising is detected in T_T; the time delay of ignition Δt_{ig} as the difference between t_{ig} and t_f; and the igniter operation interval Δt_{op} as the difference between t_{ig} and t_{off}. Under these conditions the following aspects were investigated: ability of igniter to produce a torch by the adopted scheme of injection; effect of p_o on Δt_o; ignition limits when O/F is varied; and behavior of T_R and T_B during the igniter operation.

Results and Discussion

Preliminary calibrations of the sonic nozzle and the fuel injector, without ignition, established a correspondence between p_o and $\dot{m}_o$ and p_f and $\dot{m}_f$. Mass flow rates changed in the following ranges: $\dot{m}_o = (13.0 \text{ to } 50.0) \cdot 10^{-3}$ kg/s and $\dot{m}_f = (5.0 \text{ to } 20.0) \cdot 10^{-3}$ kg/s. Besides the calibration, the effects of p_o on chamber pressure and on heat release inside the resonator were investigated. For this purpose measurements of p_c and T_R were conducted for several values of p_o. Results showed that p_c changes proportionally to p_o in the ratio $p_c/p_o \approx \frac{1}{6}$. Thus, for becoming feasible the fuel injection into the chamber p_f must be adjusted for the conditions $p_f > p_o/6$.

Figure 2 shows typical results from measurements of T_R, where t refers to the time elapsed from t_o. As the thermocouple T_R measures the temperature of the outer surface of resonator, it only gives a qualitative estimation of the temperature inside the resonator. However, the results are useful to show that the heat release increases with p_o.

The behavior of Δt_o was investigated in the experiments involving ignition because this parameter gives one of the most important characteristics of a resonance igniter: a long Δt_o requires a large amount of oxygen and, consequently, a heavier structure for the tank, which is undesirable for practical application. Figure 3 illustrates how Δt_o changes with p_o for a fixed value of p_f. For p_o between 16 and 11 bar, Δt_o equal to 0.1 s is enough to provide ignition; for p_o between 11 and 10 bar, Δt_o increases steeply, but the ignition is still possible; however, bellow 10 bar no ignition is observed. This example shows that for a given combination of p_o and p_f it is possible to reduce Δt_o up to a minimum value. In the present work such a minimum value, equal to 0.1 s, was dictated by the dynamics of feeding lines. To achieve the real minimum value associated only with the igniter, some improvement should be introduced in the experimental setup. However, for the purpose of the present igniter investigation $\Delta t_o = 0.1$ s was adopted.

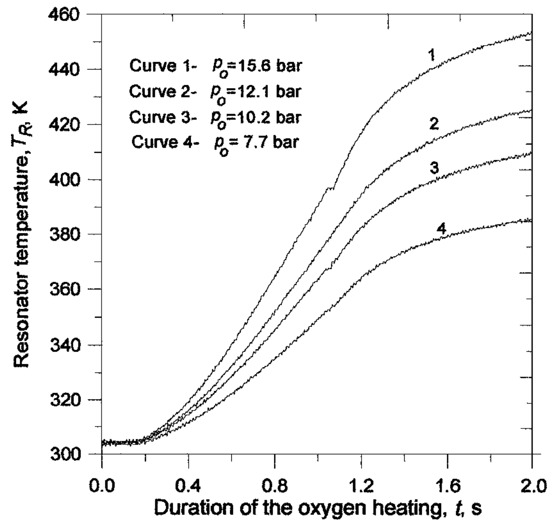

Fig. 2 Behavior of T_R during the resonator heating, for different values of p_o.

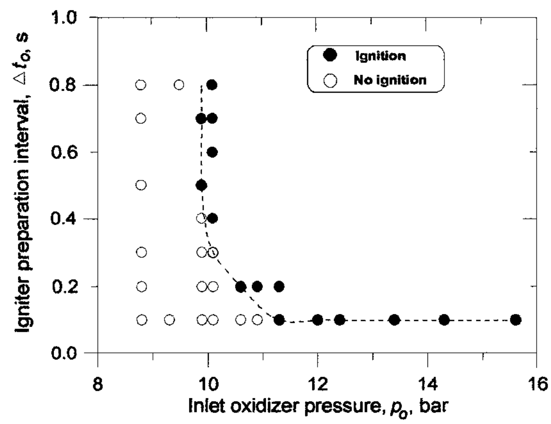

Fig. 3 Effect of Δt_o and p_o on ignition for p_f = 14.0 bar.

Figure 4 shows a detailed mapping of p_o and p_f combinations to obtain an ignition zone for $\Delta t_o = 0.1$ s. For these experiments Δt_{op} was limited to 0.5 s, enough to confirm ignition. On the plot of Fig. 4, a line is drawn between "ignition" and "no ignition" points. Calculations show that this line coincides with the line of constant value of the torch mixture ratio $O/F = 1.2$ at the ignition instant. Hence the $O/F = 1.2$ is the lower limit for igniter operation. The line that corresponds to the oxygen-kerosene stoichiometric ratio $O/F = 3.4$ is also drawn on the plot. Additionally, the experimental points of p_c, obtained with no combustion condition, are indicated on the graph.

As shown in Fig. 4, the plot is divided into four zones. Zone I corresponds to conditions that the igniter cannot operate because $p_f < p_c$. Just above the line of p_c, in zone II, for p_f in the range (3.0 to 4.0) bar pressure oscillations were detected in the chamber without torch breakdown; for p_f above this range, the igniter operation is stable without oscillation. Zones II and III correspond to the conditions that the igniter presents a Δt_{ig} lower than 0.05 s and

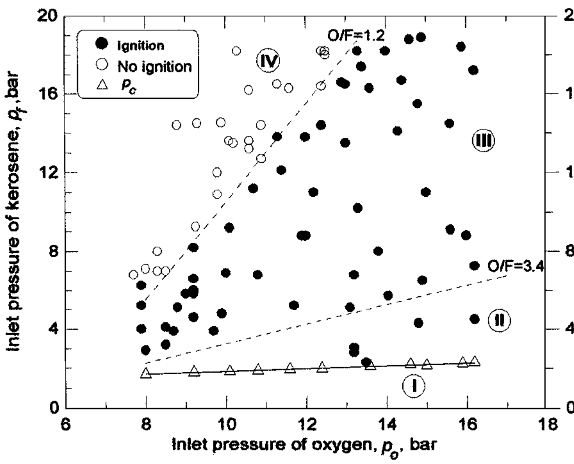

Fig. 4 GO_2/kerosene ignition zones for Δt_o = 0.1 s.

can operate respectively with excess of oxidizer and excess of fuel. The igniter operation is stable in both zones, except at pressures just above p_c line. Zone IV corresponds to the conditions where ignition is not achieved. However, it must be stressed that for $\Delta t_o > 0.1$ s ignition can be achieved, depending on the conditions, as shown in Fig. 3.

The results of Fig. 4 confirm that the resonance igniter presents some attractive characteristics for practical application. First, the igniter can produce either a fuel-rich torch or an oxidizer-rich one, a characteristic that makes the task of propellants ignition in the combustion chambers easy.[11] Second, as the required pressure to inject the fuel is relatively low, kerosene can be fed directly from the fuel tank of LOX/kerosene engines, avoiding the use of additional tanks.

In the experiments the igniter operation pressure p_c is kept in the range 2.3 to 10.3 bar, depending on p_o and p_f, thus, the torch that is issued from the igniter sustains a supersonic speed and can be sufficiently strong to ignite the propellant mixture in combustion chambers.

Several additional experiments were conducted to verify the temperature evolution during the igniter operation. For $\Delta t_{op} = 2$ s both T_R and T_B were not higher than 500 K. The possibility of application of other liquid fuels, ethanol for example, was confirmed preliminarily.

Conclusions

In the experiments with developed resonance igniter, the following were established:

1) Resonance ignition of GO_2 and kerosene can be realized with liquid fuel injection into an underexpanded oxygen jet.

2) Time interval of 0.1 s is enough to prepare the igniter for reliable ignition.

3) Time delay of kerosene ignition is less than 0.05 s.

4) The lower limit of the mixture ratio for igniter operation is 1.2 with oxygen inlet pressure in the range (8.0 to 16.0) bar.

5) Ignition and stable torch can be produced for kerosene inlet pressure higher than 4.0 bar.

Presented preliminary results show that the modified resonance igniter is feasible for GO_2 and kerosene ignition and opens new possibilities to create a compact and reliable ignition system to restart rocket engines.

Acknowledgments

The first and the third authors would like to acknowledge the financial support of Fundação de Amparo à Pesquisa do Estado de São Paulo and Conselho Nacional de Desenvolvimento Científico e Tecnológico, during the conduction of present work.

References

[1]Sprenger, H. S., "Über Thermishe Effekte bei Resonanzröhren," *Mitteilungen aus dem Inst. für Aerodynamik der E. T. H.*, No. 21, Zürich, 1954, pp. 18–35.

[2]Thompson, P. A., "Jet Driven Resonance Tube," *AIAA Journal*, Vol. 2, No. 7, 1964, pp. 1230–1233.

[3]Brocher, E., Maresca, C., and Bournay, M. H., "Fluid Dynamics of the Resonance Tube," *Journal of Fluid Mechanics*, Vol. 43, Pt. 2, Aug. 1970, pp. 369–384.

[4]Sarohia, V., and Back, L. H., "Experimental Investigation of Flow and Heating in a Resonance Tube," *Journal of Fluid Mechanics*, Vol. 94, Pt. 4, Oct. 1979, pp. 649–672.

[5]Phillips, B. R., and Pavli, A. J., "Resonance Tube Ignition of Hydrogen-Oxygen Mixtures," NASA TN D-6354, May 1971.

[6]Hensel, C., Mattstedt, T. B., Oechslein, W., Vermeulen, E., and deWilde, M., "Ignition System Concept for the Cryogenic Upper Stage Engine of Ariane 5," AIAA Paper 99-2474, June 1999.

[7]Huzel, D. K., and Huang, D. H., *Modern Engineering for Design of Liquid-Propellant Rocket Engines*, edited by A. R. Seebass, Vol. 147, Progress in Astronautics and Aeronautics, AIAA, Washington, DC, 1992, pp. 120–126.

[8]Liang, G., Zhang, G., Cheng, X., Ma, B., and Zhang, Z., "Preliminary Investigation on Gas Dynamic Resonance Ignition for Liquid Propellant Rocket Engine," *Journal of Propulsion Technology*, Vol. 20, No. 4, 1999, pp. 13–16.

[9]Sergienko, A. A., and Semenov, V. V., "Gas Dynamic Igniter," *Izvestija vusov Aviationnaja Tekhnika*, No. 2, 2000, pp. 44–47 (in Russian).

[10]Kessaev, K. V., "Theoretical Model of Resonance Tube," *Izvestija vuzov Aviationnaja Tekhnika*, No. 2, 1990, pp. 49–52 (in Russian).

[11]Niwa, M., Santana, A., Jr., and Kessaev, K., "Torch with Oxidizer Augmentation for LOX/LH_2 Engine Ignition," AIAA Paper 2000-3169, July 2000.