TSF012

An Investigation of the Ignition of Surface-to-Surface Missiles

Chirachaya Srikhao[1,2,*], and Lerkiat Vongsarnpigoon [2]

[1] Research and Development, Defence Technology Institute (Public Organization), Ministry of Defense Changwattana Road, Pakkred, Nonthaburi 11120, Thailand
[2] Master Program in Engineering Technology, Faculty of Engineering, Thai-Nichi Institue of Technology Pattanakarn Road, Suanluang, Bangkok 10250, Thailand
[*] Corresponding Author: chirachaya.s@dti.or.th, Telephone Number 087-4976459

Abstract

A type of Surface-to-surface missiles used by the Thai military mainly used solid propellant in a relatively simple propulsion system. Ignition of the propellant is initiated by hot gases passing through holes drilled at an angle along the surface of an embedded ignition case. This paper considers the effect of the angle of these holes on the flow and pressure of hot gases impacting on the solid propellant. Both cases of constant angle of the holes and varying angle are considered. The investigation has been carried out by the finite volume method using the program ANSYS FLUENT.

Keywords: solid propellants, ignition, pressure, velocity, finite volume

1. Introduction

Missiles of various types, e.g. surface-to-air missiles (SAM), surface-to-surface missiles (SSM), are used by practically all military forces in the world. They are actually an ancient weapon dated back at least a thousand year to ancient China [1]. Modern missiles are of course much more sophisticated but still basically rely on the same propulsion concept. The missile moves as a result of hot gas escaping from its exhaust end pushing it forward as a consequent of the conservation of linear momentum.

One type of surface-to-surface missiles used by the Thai military has a relatively simple propulsion system that lends itself to investigation and modification. On this missile, the propulsion system relied on an ignition of solid propellant which forms a hollow cylinder inside the body behind the missile head. Within the hollow cylinder sits an igniter which consists of an igniter case and igniter propellant. The igniter case is a solid composite cylinder with holes drilled at an angle along the surface to allow hot air to escape out and ignite the solid propellant. The igniter propellant is usually a cylindrical sack of solid propellant pellets with a primer inserted [2]. A schematic diagram of an SSM is shown in Fig. 1.

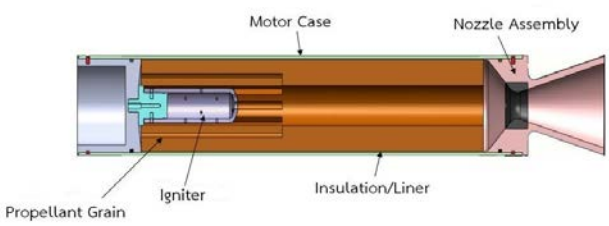


Fig.1 A schematic diagram of an SSM

To operate the SSM, the primer in the igniter is lit usually by electricity causing the igniter propellant to burn. This creates a rush of hot air out through the holes of the igniter case. The hot air in turn creates high pressure and temperature at the inner surface of the solid propellant cylinder leading to ignition. Clearly, it is desirable that the solid propellant is evenly ignited and burns uniformly along its length to create high thrust and stability. Hence, burning of the igniter propellant should lead to uniform high pressure and temperature along the surface of solid propellant.

Many studies have been made on the burning and ignition of solid propellants [3,4,5]. It was found that the ignition of the propellant depended very much on the surface temperature and pressure. There is a critical temperature and also a critical pressure which must be reached for ignition. However, the role of the igniter case has not been looked into much. This paper considers the effects of variation of the holes on the igniter case.

2. Investigation of the igniter case

As mentioned above, an igniter case is a small composite cylinder with regular holes through its length and a small amount of propellant packed inside. Hence the ignite case is modeled as a hollow cylinder inside another larger hollow cylinder with small space separating the two. One end of the nested cylinder is closed; this is the end next to the missile head. For simplicity, the nozzle assembly is ignored and the outer cylinder is assumed to be open to air at atmospheric pressure. Upon ignition, the propellant in the igniter turns into hot gas which escapes out through the holes in the case. Since hot gas is actually created. For calculation purpose, the burning propellant inside the igniter case is therefore modeled as a row of velocity inlet in the middle of the igniter case. Velocity and temperature of the gas coming out of the inlet are specified arbitrarily to be 100 m/s and 1000º K, respectively. The flow of the hot gas from the inside of the igniter case out through the holes in the case into the space inside the solid propellant can be calculated using the program ANSYS (FLUENT).

For the gas flow, k-ϵ model is used. The choice is based on a successful usage of this model to calculate for gas flow in 10 MW premixed gas burner [6]. The wall of the igniter case between holes and the surface of the propellant, i.e. the wall of the outer cylinder, are treated as standard walls so that the velocity of the gas necessarily vanishes there. Since it is desirable for the solid propellant to be uniformly ignited, the flow should give rise to relatively uniform velocity, pressure and temperature at the surface of the solid propellant.

For the sake of simplicity and ease of calculation, some assumptions are made to simplify the problem. The igniter case has holes drilled along its length at regular interval. This effectively makes the problem a three-dimensional one since there is also a variation in the circumferential direction. However, if the holes are closed together along the circumference, the circumferential variation should not be much. Therefore, the holes are assumed to be axisymmetric although this is indeed physically impossible, i.e. the igniter cylinder cannot maintain its shape with an axisymmetric opening. Furthermore, the actual solid propellant does not really form a cylinder with a smooth inner surface (see Fig.1). There are grooves along the length to increase its surface area. The grooves will be ignored in the calculation and the inner surface is assumed to be smooth so that the problem can be treated as axisymmetric.

The purpose of the present investigation is to see if different angles of the hole will make any difference in terms of velocity, pressure and temperature distribution along the propellant surface. Three cases of hole geometry are considered. The first is when the holes are drilled at 45º to the surface of the igniter. This is in fact the actual geometry of the holes presently used in the missile. The second case is when the holes are drilled at 90º, i.e. perpendicular, to the igniter case. Finally, the angles of the holes are allowed to vary from 90º near the base to 45º next to the tip. Admittedly, the nature of the problem under consideration is a transient one. When the hot gas that escapes from the holes impact upon the propellant surface, ignition will occur and move along the surface of the propellant. Such situation would be very difficult to model and investigate. Here, a more modest aim is chosen and the emphasis is placed on the distribution of the holes on the igniter case, and its effect on the flow. Hence, steady state situations are sought and presented here rather than transient ones.

3. Results

In each of the three cases of the hole geometry, the program ANSYS FLUENT is used to find the steady state solution of the flow. Since the two cylinders are coaxial and the problem is treated as axisymmetric, calculation is needed only for one half of the problem. The number of element in each calculation is 180,000. The figure of a typical mesh is shown in Fig. 2.

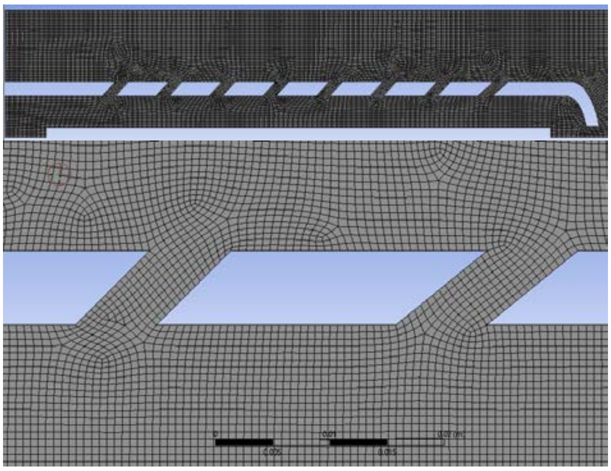
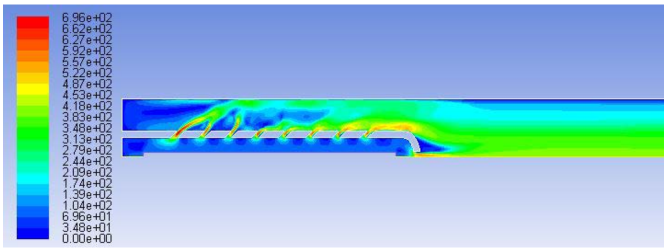
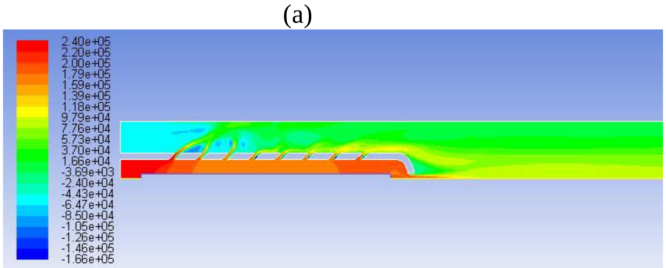


Fig.2 A typical mesh for the calculation

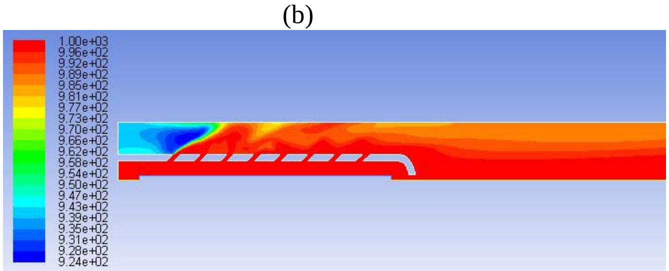
Fig. 3a, b and c show the velocity, pressure and temperature distribution of the hot gas in the space between the two cylinders, respectively, for the first case in which the holes are at 45º throughout the igniter case. The values of pressure and temperature along the inner surface of the outer cylinder, i.e. the solid propellant, are shown in Fig 4a, and b, respectively.



(a)



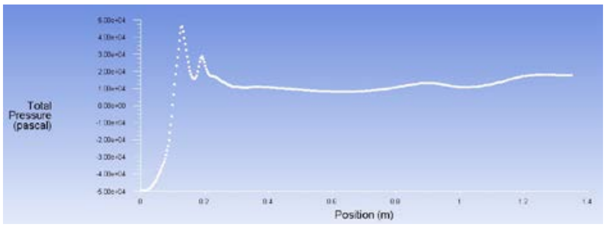
(b)



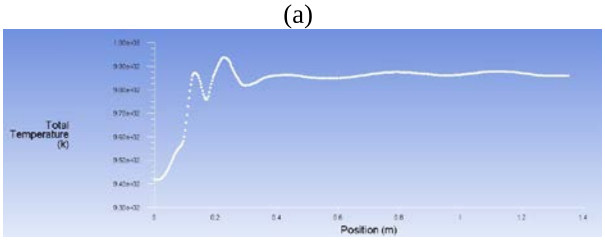
(c)

Fig.3 (a) velocity distribution, (b) pressure distribution, and (c) temperature distribution in the space between the two cylinders for 45º holes

Since the hot gas is treated as a viscous thermos fluid, the velocity at the inner surface of the solid propellant is necessarily zero



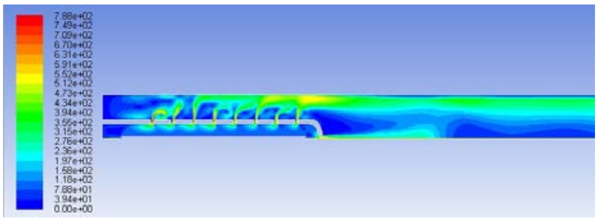
(a)



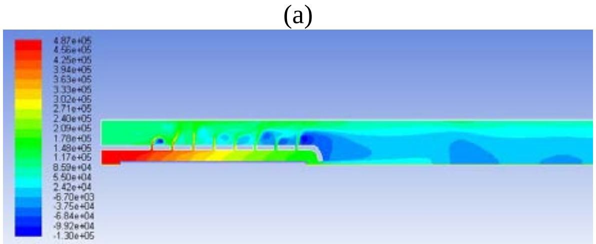
(b)

Fig.4 (a) pressure value, (b) temperature value along the inner surface of outer cylinder for 45º holes

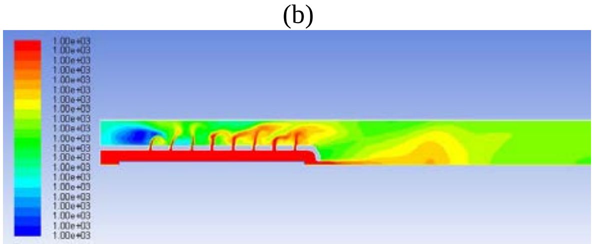
It can be seen from Fig. 3 and 4 that in this case in which the holes are at 45º, the flow of hot gas is quite smooth and the velocity, pressure and temperature do not vary much at the surface of the solid propellant except near the closed end of the structure. Thus, the present arrangement of holes on the igniter case can be somewhat justified although the low pressure near the closed end may be an indication of difficulty in propellant ignition at that point.



(a)



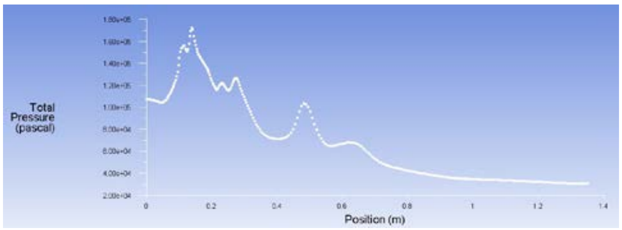
(b)



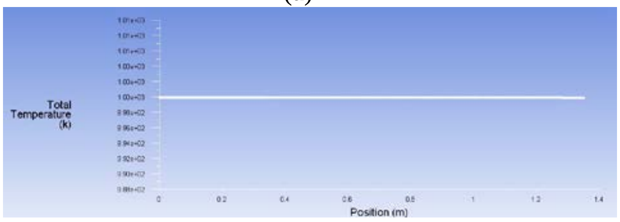
(c)

Fig.5 (a) velocity distribution, (b) pressure distribution, and (c) temperature distribution in the space between the two cylinders for 90º holes

Fig. 5a, b and c show the velocity, pressure and temperature distribution of the hot gas in the space between the two cylinders, respectively, for the second case in which the holes are at 90º throughout the igniter case. The values of pressure and temperature along the inner surface of the outer cylinder, i.e. the solid propellant, are shown in Fig 6a, and b, respectively.



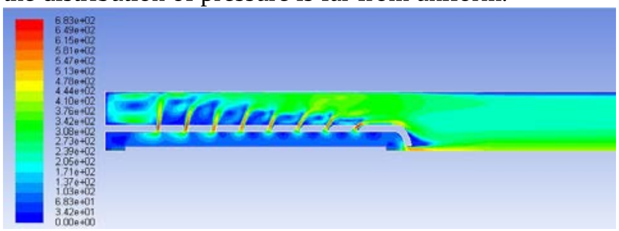
(a)



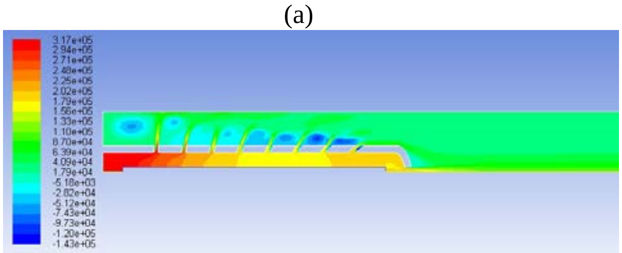
(b)

Fig.6 (a) pressure value, (b) temperature value along the inner surface of outer cylinder for 90º holes

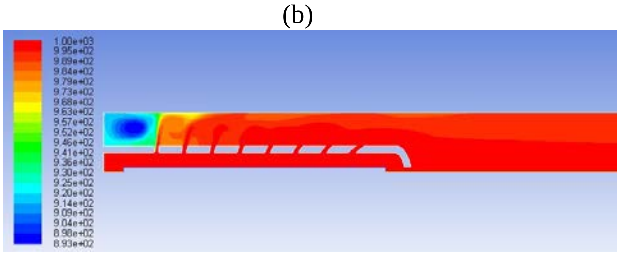
As should be expected, since the hot gas comes out perpendicular to the igniter case, the flow will quickly hit the inner surface of the solid propellant and the distribution of pressure is far from uniform.



(a)



(b)

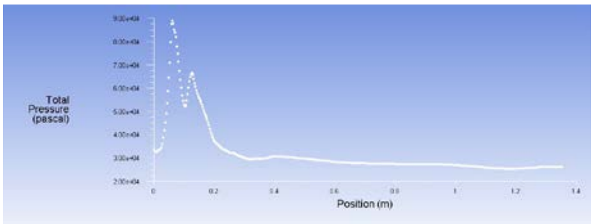


(c)

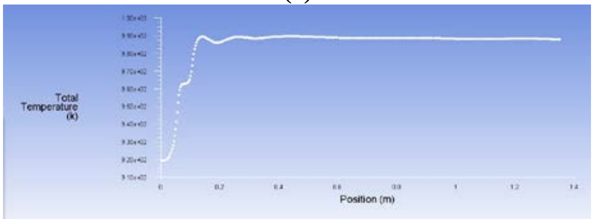
Fig.7 (a) velocity distribution, (b) pressure distribution, and (c) temperature distribution in the space between the two cylinders for vary angle holes

However, it should be noted that the pressure at the inner surface, especially that at the region further downstream from the igniter is much higher than that of the first case. The temperature at the inner surface, however, is very uniform and this is definitely desirable.

Fig. 7a, b and c show the velocity, pressure and temperature distribution of the hot gas in the space between the two cylinders, respectively, for the third case in which the angle of the holes varies gradually from 90º at the close end to 45º at the other end which is near the open end of the cylinder. The values of pressure and temperature along the inner surface of the outer cylinder, i.e. the solid propellant, are shown in Fig 8a, and b, respectively.



(a)



(b)

Fig.8 (a) pressure value, (b) temperature value along the inner surface of outer cylinder for vary angle holes

While the overall distributions of pressure and temperature in this case do not differ much from the first case, it should be noted that in this case the values near the closed end are somewhat smoother. However, the overall pressure is lower than the second case.

4. Conclusion

It can be seen from the previous section that the case in which the holes are at 90º to the igniter case lead to uniform temperature and highest pressure along the inner surface. Since ignition of the solid propellant depends on critical temperature and pressure, the solid propellant should ignite quite evenly. The arrangement presently in used in which the holes are at 45º lead to acceptable distributions of velocity, pressure and temperature except near the closed end. Therefore, some delay ignition may occur in this area. The best distributions of pressure and temperature seem to be the case in which the angle of the holes varies from 90º near the closed end to 45º at the other end. The solid propellant could expect to ignite most uniformly in this third case if the pressure is indeed higher than the critical pressure. The overall pressure is, however, lower than the 90º case. Judging from the high pressure and very uniform temperature, it must be concluded that the case in which the holes are at 90º is the best choice. There is also an added benefit that the construction can be carried out easily and automatically.

It is possible that a wider range of variation of angle, say from 90º to 10º, may lead to even better distributions of pressure and temperature. This will be explored further in the future. However, the cost of construction should be considered carefully. An igniter case with varying angle of holes is certainly more difficult and expensive to make than one with a constant degree. The cost-benefit should be carefully considered by the owner of the system.

5. References

[1] P. Kuentzmann. (2002). Introduction to Solid Rocket Propulsion, paper presented in *the RTO/VKI Special Course on "Internal Aerodynamics in Solid Rocket Propulsion"*,
Rhode-Saint-Genèse, Belgium.
[2] George P. Sutton. (2001). Rocket Propulsion Elements Seventh Edition, John Wiley
& Sons, Toronto.
[3] G. Lengellé, J. Duterque and J.F. Trubert. (2002). Combustion of Solid Propellants, paper presented in *the RTO/VKI Special Course on "Internal Aerodynamics in Solid Rocket Propulsion"*, Rhode-Saint-Genèse, Belgium.
[4] Kenneth K. Kuo and Glen R. Coates. (1977). Review of dynamic burning of solid propellants in gun and rocket propulsion systems, *Symposium (International) on Combustion*, Volume 16, Issue 1, 1977, Pages 1177–1192.
[5] A. Di Mascio, E. Cavallini, B Favini and A. Neri. (2014). Numerical Simulation of 3D Unsteady Flowfield in Aft-Finocyl Solid Rocket Motor, Paper presented in *50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference*, At Cleveland , Ohio, USA.
[6] Weibo Chen and Guixiong Liu. (2015). Numerical Investigation on the Flow, Combustion and NOx Emission Characteristics in a 10 MW Premixed Gas Burner, *The Open Fuels & Energy Science Journal*, vol. 8, 2015, pp.1-13.