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Reduction of Combustion Chamber Heating by Swirl Shield flow in Liquid Propellant Rocket Engine

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Abstract-Ina swirl shield combustion rocket engine theoxidizer is injected tangentially into cylindrical chamber which is closed at one end and which has a converging outlet at the other end. The flow is introduced into the interior of the chamber near the outlet end of the chamber and in a direction which is tangent to the inner wall of the chamber. This tangential injection causes the flow in the chamber to swirl and follow a spiral path up the inner wall of the chamber and carry away the generating heat due to combustion.

Index Terms-CFD, engine rich exhaust, heat transfer, inner vortex, outer vortex, rocket engine, swirl shield, vertical helix.

1 INTRODUCTION

THERE are many parts in a rocket, the Important among them are its payload system, guidance system, propulsion system, structure system.The rockets run with combustion temperatures that can reach ~3500 K (~3227 °C).Therefore temperatures used in rockets are very often far higher than the melting point of the nozzle and combustion chamber materials(~1200K). Two exceptions are graphite and tungsten although both are subject to oxidation if not protected .Here comes the importance of cooling system in the rocket. If it is not properly cooled it will be dangerous to the equipments in it,to the body of the vehicle.so the temperature should be controlled properly. Indeed many construction materials can make perfectly acceptable propellants in their own right. It is important that these materials be prevented from Combusting, melting or vaporizing to the point of failure.

Alternatively, rockets may use more common construction materials such as Aluminium, steel, nickel or copper alloys and employ cooling systems that prevent the construction material itself becoming too hot. Regenerative cooling, where the propellant is passed through tubes around the combustion chamber or nozzle. Dump cooling (a propellant, generally hydrogen is passed around the chamber and dumped), Curtain cooling (propellant injection is arranged so the temperature of the gases is cooler at the walls),Film cooling (surfaces are wetted with liquid propellant, which cools as it evaporates).

The object of the present invention is to provide an improved combustion chamber and method utilizing the above-described double vortex flow field. Another object of the present invention is to provide an improved combustion chamber and method utilizing the above flow field and to provide for increased fuel regression rates and increased travel distance and mixing to achieve complete combustion. A further object of the present invention is to provide a liquid rocket engine utilizing the above-described vortex flow field. A still further object of the present invention is to provide an improved hybrid rocket propulsion system that facilitates and promotes high and uniform fuel grain regression rates so that small combustion ports can be used in the propellant solid grain.

2 WORKING

A liquid rocket engine and a method for propelling a rocket utilizing a vortex flow field. The flow field includes an outer fluid vortex spiraling toward a closed end of the flow field generating apparatus and an inner fluid vortex substantially concentric with the outer vortex spiraling away from the closed end and toward an outlet opening in which the inner vortex spirals in the same direction as the outer vortex, but in the opposite axial direction. The flow field in accordance with the present invention is capable of providing separate regions or zones within and among one or more flowing fluids contained within a common chamber, without the need for diaphragms or other physical separators or barriers. Another embodiment is in the form of liquid rocket engine to prevent hot combustion products from contacting the chamber wall.

Virtually countless applications exist for a flow field Many devices depend upon vortex flows for their successful operation, such as combustion chambers, cyclone separators, classifiers and the like that are in common use. All of these devices introduce swirling flow at one end of a passageway in which the flow follows a generally helical path to exit at the opposite end. Such conventional vortex flows do not achieve zonal separation as does the unique flow field that is the subject of the present invention. it has particular application to the field of rocket engines and in one embodiment, specifically to hybrid rocket engines. Hybrid rocket engines denote a class of rocket propulsion systems in which one propellant is in fluid form and the other propellant is in the form of a solid grain. Typically, the fluid propellant is the oxidizer and the solid grain is the fuel. The oxidizer such as liquid oxygen is sprayed into the combustion ports in the solid fuel grain and caused to ignite. The hot combustion products sustain the combustion process until either the oxidizer flow is shut off or the fuel grain is depleted. The burn rate, often expressed as regression rate, is the rate at which fuel can be induced to vaporize the grain surface so it can participate which provides separate regions or zones of flowing fluids within a chamber. There is also a need in the art for a combustion chamber and method utilizing such a flow field, and particularly a combustion chamber and method for a hybrid rocket engine, which significantly increases the regression rate of the solid fuel grain and the effective chamber length and mixing within the combustion chamber. There is also a need for a combustion chamber and method utilizing such a flow field that prevents the hot combustion products from reaching the chamber wall.

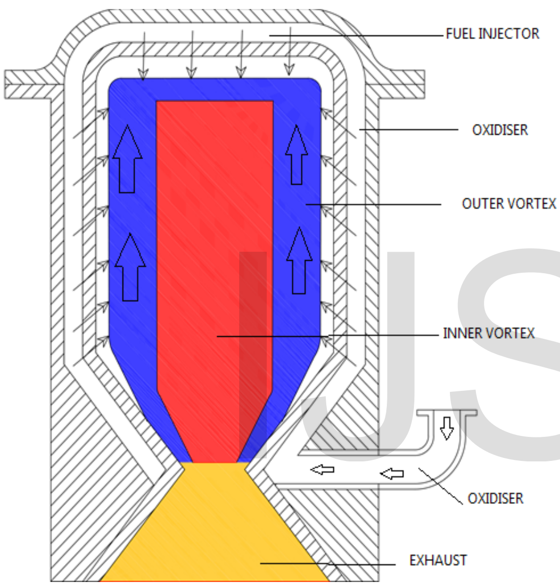

Figure 1; combustion chamber

In accordance with the present invention, a fluid flow field, and a structure and method for producing and sustaining the field, has been designed. This flow field provides for separate regions or zones of flowing fluids within a chamber without the need for physical barriers or other separators and without substantial mixing between the regions or zones. In a revolutionary departure from prior art the present invention introduces the incoming swirling flow concentric to the outlet passage and by this means establishes a new and unique flow field. The flow field inherently divides into an outer upwardly flowing vertical helix along a chamber wall, an inner downward flowing vertical helix along the center region of the chamber, a converging flow field at the head end where the outer vortex transforms into the inner vortex, a converging flow field as the flow approaches the exit nozzle, and less well defined regions of velocities and pressure gradients elsewhere throughout the chamber.

The flow field is produced by injecting flow tangentially into a cylindrical chamber which is substantially closed at one end and which has a converging outlet at the other end. The flow is introduced into the interior of the chamber near the outlet end of the chamber and in a direction which is substantially tangent to the inner wall of the chamber. This tangential injection causes the flow in the chamber to swirl and follow a spiral path up the inner wall of the chamber thereby establishing an annular vortex flow bounded by the inner wall of the chamber. When the spiral flow reaches the closed end of the chamber, the flow inherently translates inwardly to the center of the chamber to form the second vortex where the flow moves spirally away from the closed end, down the core of the chamber and out the chamber nozzle. This inner vortex or spiral flow through the center of the chamber rotates in the same direction as the outer vortex, pressure at the nozzle converging wall increases and pressure at the swirl axis decreases.

Accordingly, as the inner vortex flow approaches the nozzle, it enters the converging section of the nozzle, thereby increasing the swirl or angular velocity and thus producing an enhanced radial pressure gradient that blocks the outflow of the fresh incoming stream .The above-described flow field has several unique characteristics. First, the flow path of the injected fluid before reaching the outlet is quite long and highly convoluted. Thus, it provides an opportunity for intense and extensive mixing along the flow path, particularly in the core or inner vortex where the angular velocity of the swirl is greater. Secondly, the outer and inner vortexes are individually discrete. Thus, the fluid flow in the inner vortex does not mix significantly with the fluid flow in the outer vortex.

This enables the inner vortex to support burning or other chemical reactions to some significant degree independent of the outer vortex. Because of this, materials such as propellant or other chemicals, can be added to the inner vortex by injection at the conjunction of the two vortices at the closed end of the chamber and cause combustion or other chemical reaction to occur and be sustained wholly in the inner vortex if so desired The ability to produce and sustain the above-described double vortex field flow has countless potential application and several immediate practical applications.

Object of the present invention is to provide a hybrid propulsion system that inherently cools the case walls whenever fuel is not present to insulate the wall from hot combustion products. A more specific object of the present invention is to provide a hybrid rocket propulsion system that creates and uses a unique internal combustion vortex flow field to enhance grain regression rate and to increase the efficiency of the combustion process. Another object of the present invention is to provide a combusting flow field that allows the use of a single grain port for the combustion process. A further object of the present invention is to provide an injection means for the fluid propellant that induces the double vortex flow field in the grain combustion port. A further object of the present invention is to provide a combustion process that inhibits combustion instability. Another object of the present invention is to provide a double helix flow field in which an outer helix flows upwards along the grain surface inducing combustion, and an inner combustion helix flows down the port centerline and out the nozzle to produce thrust.

To achieve the foregoing and other objects and in accordance with the purpose of the present invention, a self- contained propulsion system is provided with a motor casing that houses a solid propellant grain. A first fluid propellant that will combust when in the presence of the solid propellant in the presence of an ignition source, is stored separately from the solid propellant in a fluid tank. A delivery means supplies at least a portion of the said fluid propellant in either liquid or gaseous state to the combustion port of the solid grain. An ignition means initiate’s combustion with the combustion port of the solid propellant grain. A fluid injection means that will cause the fluid propellant to enter the solid propellant grain case in such a manner as to form an up flowing helix along the surface of the combustion port in the solid propellant grain and then a down flowing helix along the centerline of the combustion port, said down flowing helix to eventually exit the chamber via the discharge nozzle.

The fluid propellant can be provided to the entrance to the fuel grain case by any of various common means, including delivery from pressurized tanks, or by pumps of suitable designs. The fluid can be either the liquid or gaseous state. Commonly the fluid propellant is the oxidant. In one embodiment, the oxidant is burned in a highly oxidizer-rich combustor (termed a "pre-burner") and the resulting oxidizer-rich combustion products are used to drive a turbo pump that pressurizes the liquid oxidizer for delivery to the pre-burner. After driving the turbine, the oxidizer-rich combustion products leave the turbine and flow to the injection ports of the fuel grain high pressure casing.

The oxidant enters the fuel grain ports in a fluid phase that may be at high enough pressure to be supercritical. The injector elements are positioned and designed such that the injected flow develops the co-axial vortex flow field within the chamber in the manner that is the subject of this invention. In another embodiment, the oxidizer in liquid state is carried in a high pressure tank. Pressure is supplied by a conventional tank pressurization system well known to those acquainted with the profession. The liquid oxidant is expelled from the tank and delivered at high pressure to the injection ports of the fuel grain high pressure casing.

2.1 Combustion Chamber

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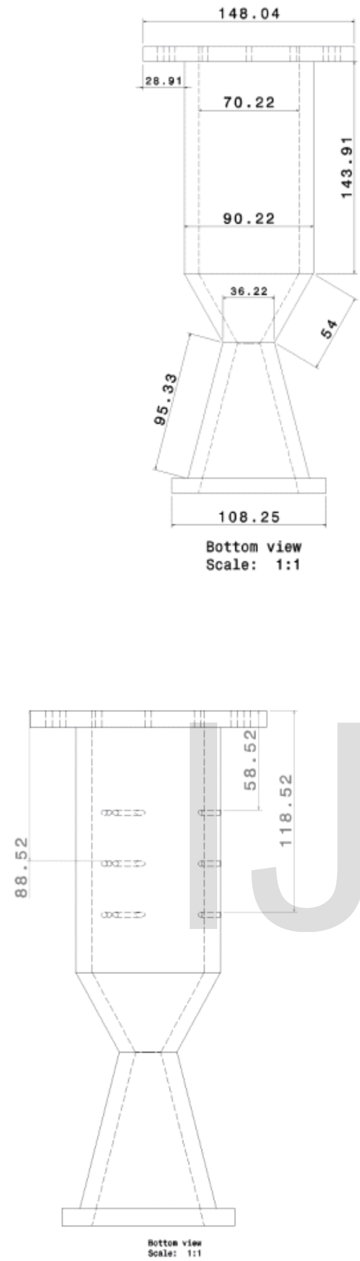

Figure 2; Dimensions of combustion chamber.

This is the bottom view of the combustion chamber .diameter for each holes are shown in the diagram itself. All dimensions are in mm.

2.2 Fuel Injector

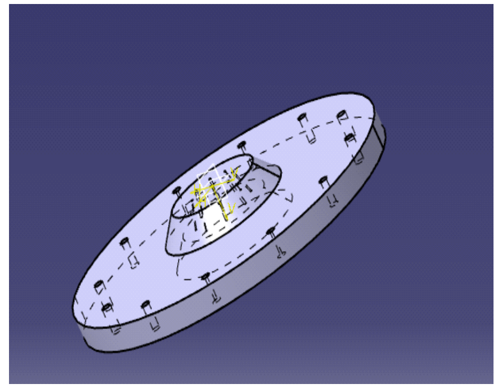

Figure 3; Fuel injector

This is the figure of the fuel injector where fuel is injected into the combustion chamber. It consists of small minute holes in order to get maximum atomization of the fuel. The holes are inclined in such a way that it enables the fuel to coincide at the center ,which help to strike the fuel coming from each holes at center and splash it to get the maximum atomization.

Solid Works Flow Simulation uses Computational Fluid Dynamics (CFD) analysis to enable quick, efficient simulation of fluid flow and heat transfer. Inlet mass flow rate of fuel is 0.3 lb/sec, which is indicated on the top portion of the combustion chamber, inlet mass flow rate of the oxidizer is 0.547lb/sec and the outlet environment pressure is 101325 Pascal.

3 RESULT

First, the high velocity outer vortex scrubs the burning fuel grain surface, causing enhanced heat transfer to the surface. Combustion near and on the surface is also able process because fresh oxidizer is carried directly to the surface by turbulent transport mechanisms in addition to the usual molecular diffusion process. Second, the vortex also sustains radial pressure and density gradients that cause hot, low density combustion products to be buoyed out of the combustion zone so their presence does not hinder the combustion process. Third, because the flow path of the injected fluid (the oxidizer) to reach the outlet is very long and highly convoluted, it provides an opportunity for intense and extensive mixing and combustion with the fuel grain vapor, particularly in the core or inner vortex. Accordingly, in the above application, the outer vortex flow causes rapid burning of the fuel grain on the wall of the cylinder, and the inner vortex causes combustion to proceed rapidly, by providing intense mixing and combustion travel distance to allow combustion to reach completion, thereby achieving high combustion efficiency.

3.1 Visualizing Results

After running the analysis, the software generates customizable default result plots.

Other plots can also be defined by right-clicking a result folder and selecting Define. When defining plots, you can use reference coordinate systems. For example, you can view radial and tangential stresses by selecting an axis when defining stress plots. You can associate result plots with named views.

Result viewing tools include fringe plots, section plots, iso plots, animation, probing, and exploded views. For sections plots, you can choose planar, cylindrical, and/or spherical cutting tools. A clipping utility is provided for convenient viewing of section and iso plots.

Solid Works Flow Simulation provides advanced easy-to use tools to visualize the results: Cut, 3D-Profile and Surface Plots (contours, isolines, and vectors), Isosurfaces, XY plots, Flow and Particle Trajectories, Animation of Results. Solid Works Flow Simulation provides advanced tools to process the results: Point, Surface and Volume Parameters, Plots of Goals, MS Word Report.

This figure below shows the temperature distribution inside the combustion chamber. The temperature is varied at each place in the combustion chamber. From the figure it is clear that the temperature at the wall of the combustion chamber is considerably low. High temperature is obtained at the core portion as well as at the top of the combustion chamber. The table at the left side of the figure shows the variation of temperature along the combustion chamber. Near the wall of the combustion chamber a very low temperature is developed, which is seen in green color in the figure.

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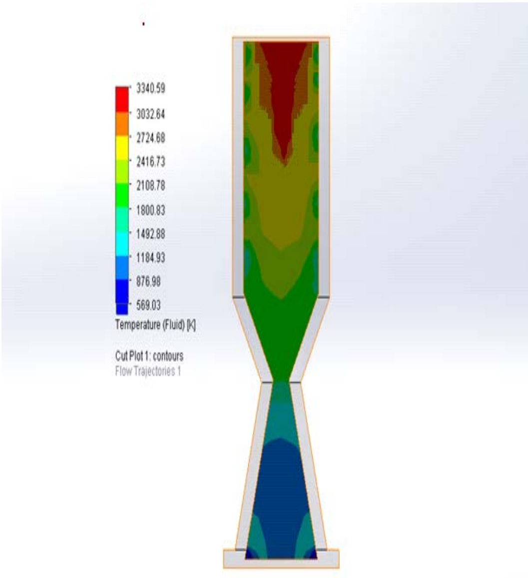


Figure 4: temperature distribution inside the combustion

The high intense temperature is at the core, which has red color. When the flow comes to exit its temperature is considerably low and having a color of blue. From this figure we can understand that the wall of the combustion chamber is protected from developing a high temperature by the swirl shield effect. So here the prevention of generating heat in the combustion chamber wall is done rather than curing it after the heat generation. The temperature value of each color is indicated in the left side table.

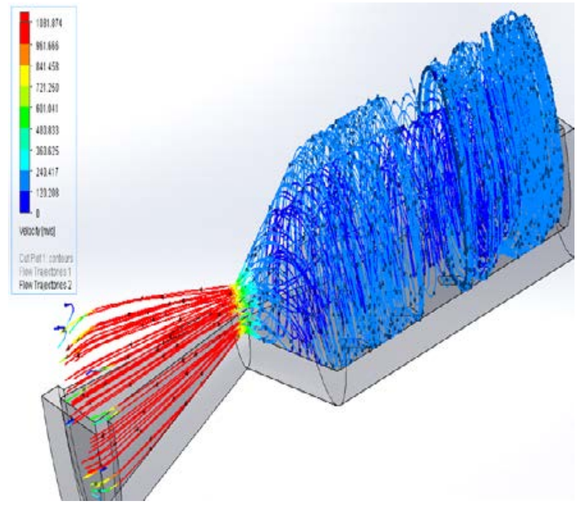


Figure 5**: velocity distribution inside the combustion**

In the above figure, the velocity distribution of oxidizer flow inside the combustion chamber .The corresponding values of velocity for different colors is shown in the left side table. The velocity of oxidizer at the outer vortex is different from that of inner vortex. The outer and inner vortexes are represented in sky-blue and dark blue color respectively. At the throat region velocity is reaches to match velocity, which can be identified by the color and velocity value combination from the table. Because of the convergent divergent nozzle the velocity of flow after the throat is supersonic; this is represented by the red color flow lines. The arrow marks on each flow line shows its direction.

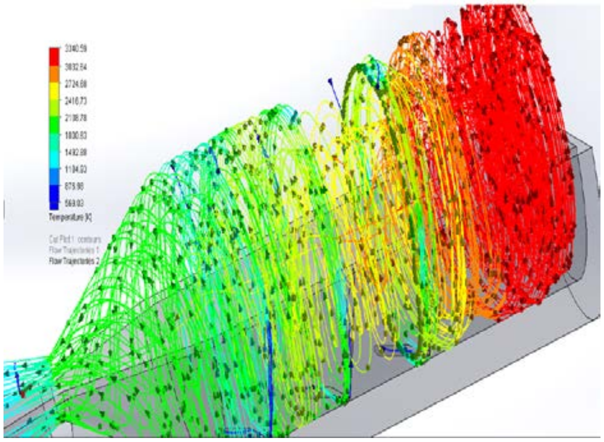
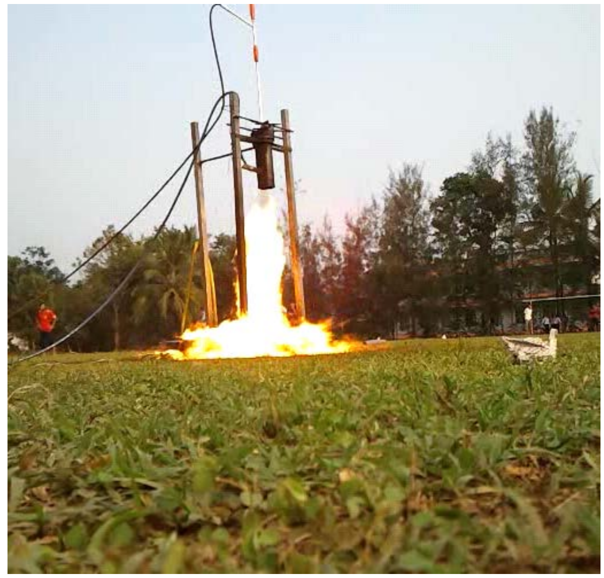


Figure 6: **temperature distribution inside the combustion**

This figure shows the temperature distribution of the gas flow lines, inside the combustion chamber. The temperature is reduced when it goes from top to bottom and also towards the core region from the periphery. The intensity of temperature is increased from the blue color to red color, which is shown in the left table. The arrow mark on each flow line indicates its direction.

3.2Experimentaltest

At the time of ignition



After 5 seconds

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After 15 seconds

after 30 seconds

4 CONCLUSION

The present invention relates generally to a vortex flow field and the apparatus and method to produce and sustain it and more particularly to a hybrid rocket engine and a method of propelling a rocket utilizing such vortex flow field. The flow field in accordance with the present invention is capable of providing separate regions or zones within and among one or more flowing fluids contained within a common chamber, without the need for diaphragms or other physical separators or barriers. It is evident and believed that the flow field of the present invention has utility to a wide range of applications. One general field of application is that of combustion chambers, and more particularly, that of combustion chambers and methods for rocket engines or the like and hybrid rocket propulsion systems. A combustion chamber and method in accordance with one embodiment of the present invention utilizes the unique flow field of the present invention to improve hybrid rocket fuel regression and increase mixing length in a rocket or other engine. Another embodiment is in the form of liquid rocket engine to prevent hot combustion products from contacting the chamber wall. By this new innovative idea we developed a new rocket engine which has 20% weight reduction than the conventional rocket engine. This is accomplished by avoiding the extra cooling mechanism that is used in conventional engines. Here we prevent the formation of heat on the wall of the combustion chamber rather than cooling it after it become hot.

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