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CFD Anaylsis of Improving Thrust in Afterburner By Configuration Changes

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ABSTRACT
The ever-widening spectrum of high-speed flight imposes new and greater demands upon turbojet aircraft propulsion systems. One of the propulsion system components affected is the afterburner. In designs where the use of an afterburner is considered, the specifications become quite rigid, not only in terms of performance required at severe operating conditions, but also in terms of geometrical changes often made necessary by space and structural limitations. Afterburner combustion performance is influenced by many individual factors and their mutual interaction. Fuel properties and reaction kinetics are some of the factors which are chemical in nature. Pressure, temperature, and velocity of the mixture approaching the afterburner combustion chamber are aero thermodynamic factors. Still other factors such as flame holder gutter dimensions and gutter arrangement are of a geometrical nature. These and other factors both singly and collectively affect the performance of a given afterburner. Usually due to unstabilized combustion inside the afterburner most of oxygen is escaped remaining unburned. The aim of the project is to utilize maximum amount of the available unburned oxygen from the primary combustor inside the afterburner to achieve more combustion by stabilizing the flame and thereby producing high velocity jet at the exit. The size and shape of the afterburner may also affect the combustion performance and flame stabilization. So by changing the configuration of the afterburner thereby producing uniform combustion by utilizing maximum amount of available unburned oxygen from the primary combustor and achieving high performance in terms of exit velocity even more when compared to performance of actual afterburner.

KEYWORDS : Geometrical changes, unburned oxygen, flame stabilization, uniform combustion, exit velocity.

1. INTRODUCTION TO AFTERBURNER

on some jet engines, mostly military supersonic aircraft. Its purpose is to provide an increase in thrust, usually for supersonic flight, takeoff and or combat situations. Afterburning is achieved by injecting additional fuel into the jet pipe downstream of (i.e. after) the turbine. The advantage of afterburning is significantly increased thrust; the disadvantage is its very high fuel consumption and inefficiency, though this is often regarded as acceptable for the short periods during which it is usually used. Pilots can activate and deactivate afterburners in-flight and jet engines are referred to as operating wet when afterburning is being used and dry when not. An engine producing maximum thrust wet is at maximum power, while an engine producing maximum thrust dry is at military power.

2. CONFIGURATION CHANGES IN AFTERBURNER

The following are the list configurations analysed for exit velocity, exit temperature and o_2 mass fraction.

(a) Reference afterburner with liner,
(b) A reduced-diameter V-gutter flame holder,
(c) An inclined radial-gutter flame holder,
(d) An afterburner with a tapered shell, and
(e) The tapered shell Afterburner with liner.

2.1 Reference Afterburner Configuration

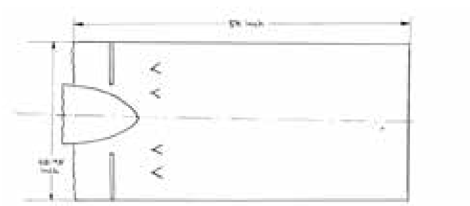

Fig.1 Cross section of reference afterburner

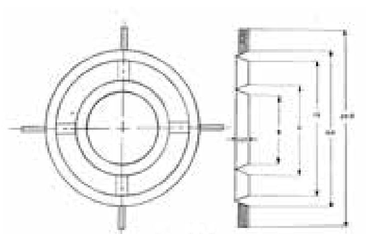

Fig.2 Reference V-gutter flame holder design

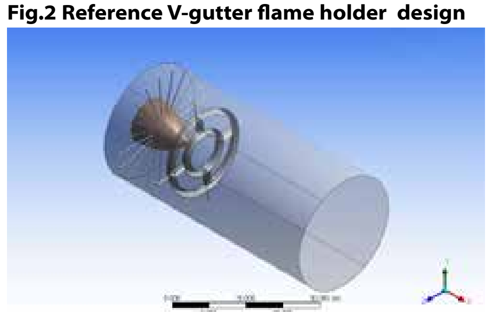

Fig.3 CAD model of reference configuration

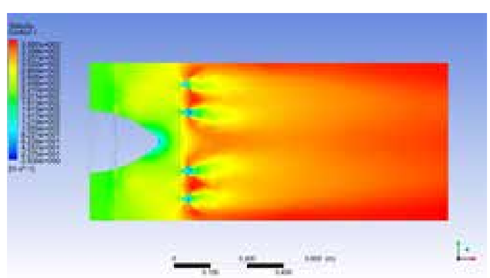

Fig.4 Velocity contour of reference configuration

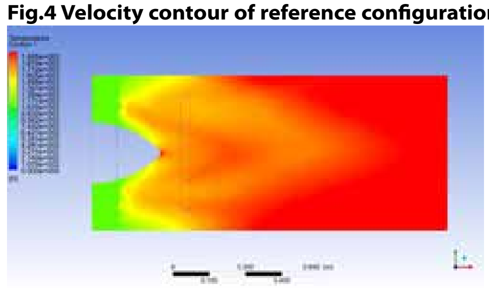

Fig.5 Temperature contour of reference configuration

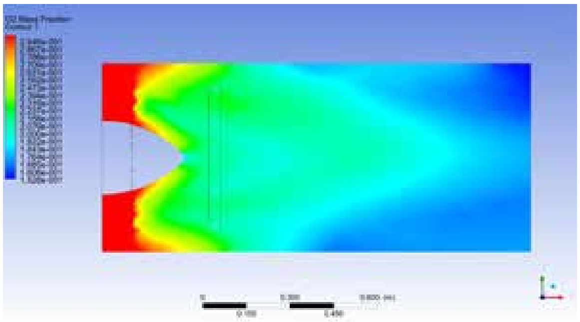

Fig.6 O2 mass fraction contour of reference configuration

2.2 Reference Afterburner With Liner

The reference afterburner with liner configuration is obtained by adding liner to the reference Afterburner configuration. The purpose of adding liner is to prevent the outer shell of the afterburner is protected from very high temperature by the liners. the gas which is coming from the turbine, a little bit of it goes into liners, those are also hot gases anyway, but the body of the jet pipe is indeed designed to withstand those kind of hot gases but not the very high temperature which is produced due to reheat. So the liners essentially contain inside them the hot gases that are coming from the turbine and creates a small safety zone for the outer shell of the jet pipe from the very high temperature which is produced inside the reheat zone. As a result of which liners are the integral part of the reheat or afterburning engine essentially for the protection of body of the jet pipe.

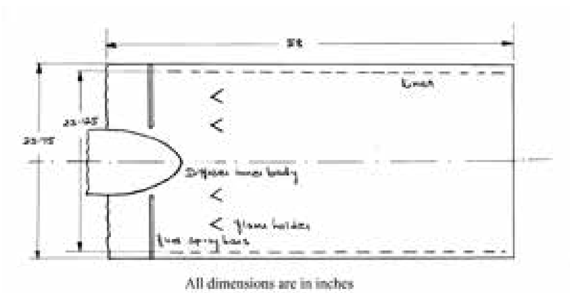

Fig.7 Cross section of reference Afterburner with liner

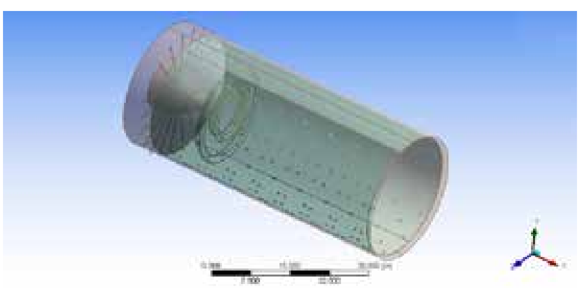

Fig.8 CAD model of reference configuration with liner

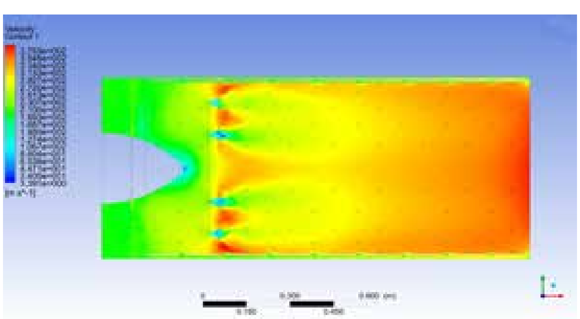

Fig.9 Velocity contour of reference configuration with liner

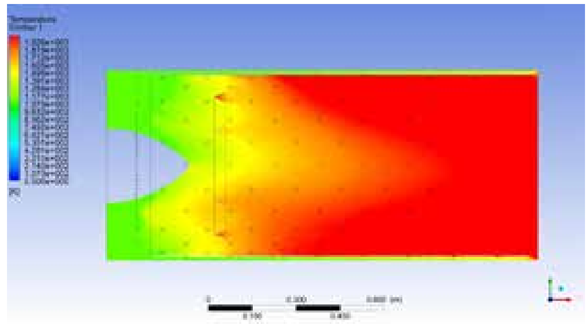

Fig.10 Temperature contour of reference configuration with liner

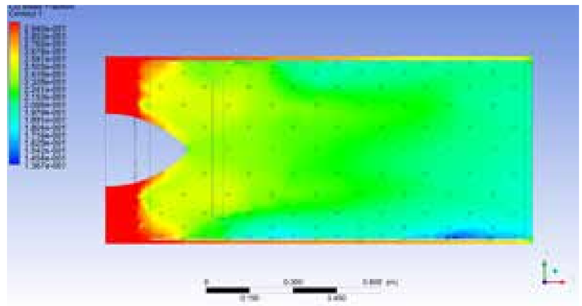

Fig.11 O_2 mass fraction contour of reference configuration with liner

2.3 Reduced diameter flame holder

The test with the reduced diameter flame holder were made in order to evaluate the changes in afterburner performance associated with a variation in flame holder gutter ring diameter while holding the projected blockage constant. In practical afterburner applications, reduction of the flame holder gutter diameter may be necessary to alleviate a serious afterburner shell- cooling problem. A schematic sketch of the reduced diameter flame holder is shown in fig.12. The maximum diameter of the outer gutter ring was 3 inches less than that of the reference configuration, thus increasing the distance between gutter edge and afterburner wall from 2.875 to 4.375 inches. The total projected blocked area, as well as the number of gutter rings and interconnecting gutters, was held constant. This resulted in gutter elements that were 0.5 inch wider than the reference elements. Constant diameter afterburner shells of 3.5 and 5.5 feet in length were used in the analysis.

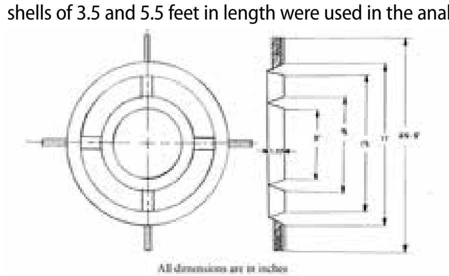

Fig.12 Reduced v-gutter flame holder diameter

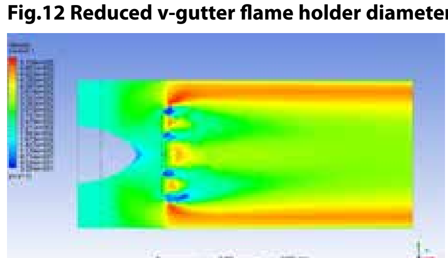

Fig.13 Velocity contour of reduced diameter flame holder

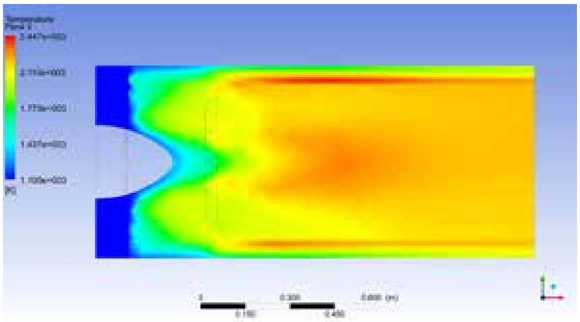

Fig.14 Temperature contour of reduced diameter flame holder

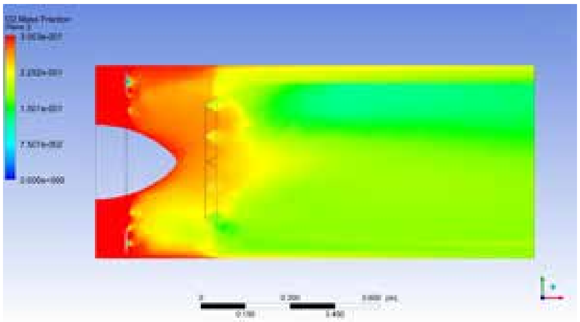

Fig.15 O_2 mass fraction contour of reduced flame holder diameter

2.4 Inclined radial gutter flame holder

The inclined radial gutter flame holder was designed to combine the simplicity and low-pressure loss characteristics of the annular gutter type flame holder with the inherent stability and high efficiency of the can type combustor. Such a flame holder , initially designed has been successfully used in a ram jet combustor. The present investigation sought to determine the applicability to and the performance of this type of flame holder in an afterburner. The side view of the inclined radial-gutter flame holder are shown in fig.16. The photograph of figure shows the view looking downstream in the direction of the gas flow. The central V-gutter ring and the outer half V-gutter ring (the straight side of which extends to form a cooling liner) are interconnected by radial gutters inclined in the direction of the flow. The long cooling liner configuration constructed by welding a hollow cylindrical shell to the original cooling liner is indicated by dotted lines. The afterburner length for both the short and long-liner configurations was 4.5 feet.

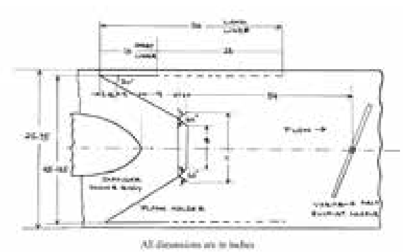

Fig.16 Cross section of Inclined radial gutter flame holder

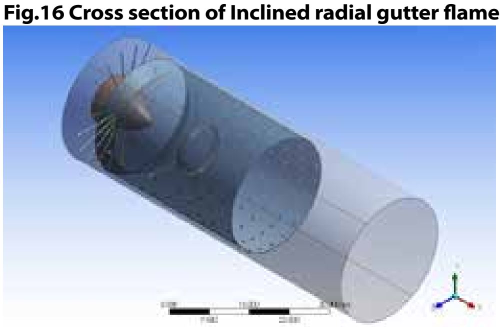

Fig.17 CAD model of Inclined radial gutter flame holder

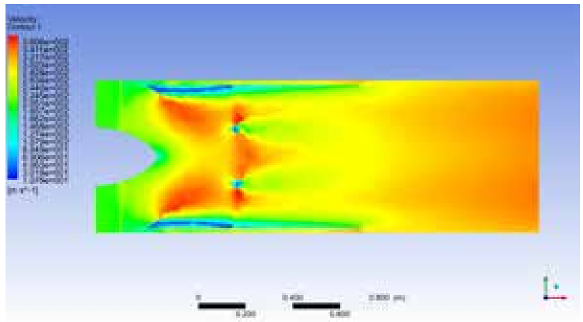

Fig.18 Velocity contour of Inclined radial gutter flame holder

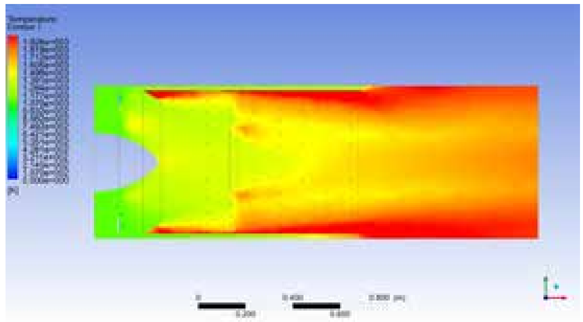

Fig.19 Temperature contour of Inclined radial gutter flame holder

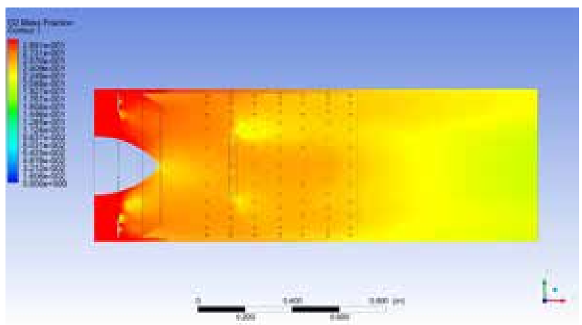

Fig.20 O_2 mass fraction of Inclined radial gutter flame holder

2.5 Tapered Shell Afterburner

The tapered shell afterburner is analysed in order to evaluate the penalties in performance caused by tapering the afterburner shell to conform to space or structural limitation. These limitations are particularly acute in pod-mounted installations and fuselages designed for minimum after-body drag. A schematic drawing of the tapered afterburner is shown in fig.21. The basic cylindrical afterburner diameter was maintained 6 inches downstream of the trailing edge of the flame holder, followed by a degree of taper selected on the basis of the most rigid space requirements expected of a typical aircraft installation. The particular afterburner used in the present investigation had a 5 degree wall taper and 14.3 percent less afterburner volume than a cylindrical afterburner of the same length. A series of fixed-area conical exit nozzles were used in place of the adjustable-area exhaust nozzle, which fits only the reference configuration afterburner duct. afterburner-inlet velocity was thus varied by changing the fixed-area nozzles.

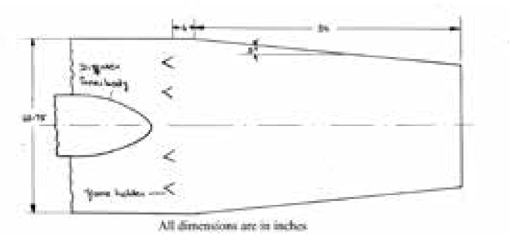

Fig.21 Cross section of Tapered shell afterburner

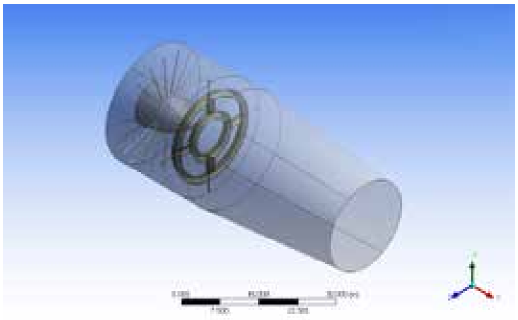

Fig.22 CAD model of tapered shell afterburner

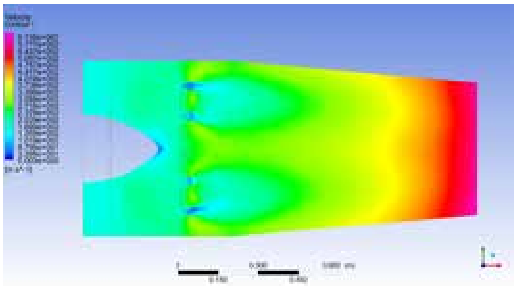

Fig.23 Velocity contour of tapered shell afterburner

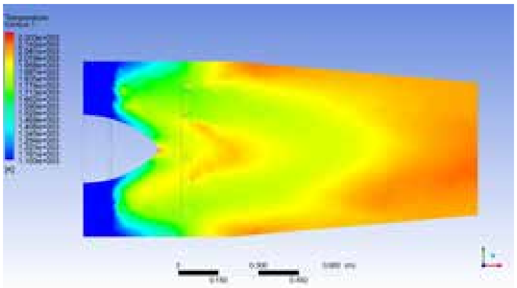

Fig.24 Temperature contour of tapered shell afterburner

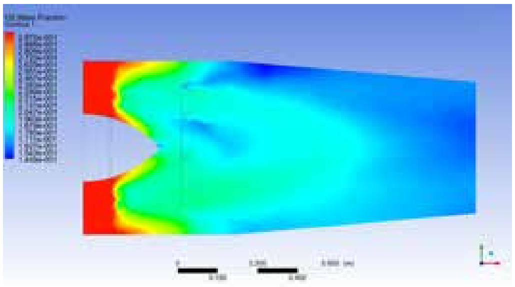

Fig.25 O_2 mass fraction of tapered shell afterburner

2.6 Tapered Shell Afterburner with Liner

Tapered shell afterburner with liner configuration is obtained by adding liner to the tapered shell afterburner. The purpose of adding liner is to prevent the outer shell of the afterburner is protected from very high temperature by the liners. The gas which is coming from the turbine, a little bit of it goes into liners, those are also hot gases anyway, but the body of the jet pipe is indeed designed to withstand those kind of hot gases but not the very high temperature which is produced due to reheat. So the liners essentially contain inside them the hot gases that are coming from the turbine and creates a small safety zone for the outer shell of the jet pipe from the very high temperature which is produced inside the reheat zone. As a result of which liners are the integral part of the reheat or afterburning engine essentially for the protection of body of the jet pipe.

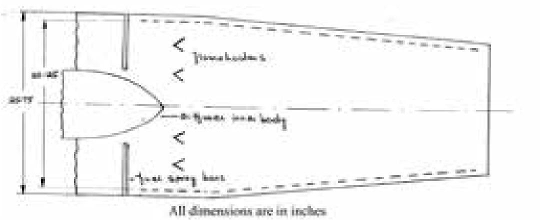

Fig.26 Cross section of tapered shell with liner

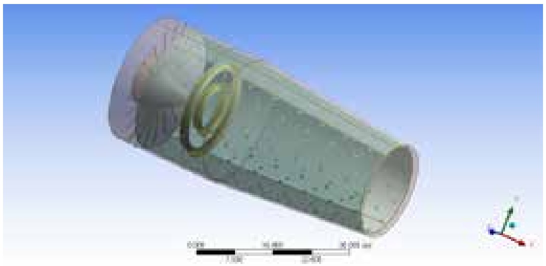

Fig.27 CAD model of tapered shell with liner

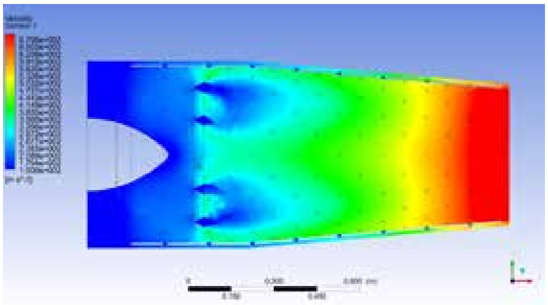

Fig.28 Velocity contour of tapered shell afterburner with liner

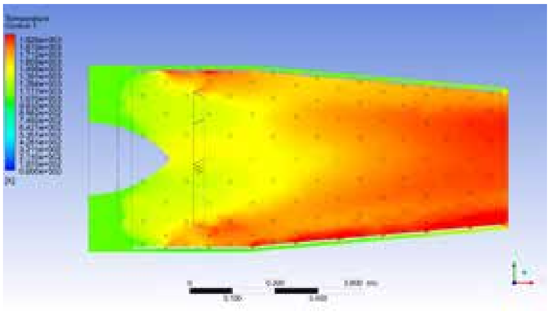

Fig.29 Temperature contour of tapered shell afterburner with liner

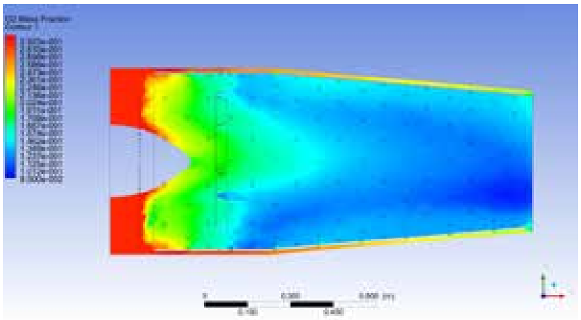

Fig.30 O2 mass fraction of tapered shell afterburner with liner

4.RESULTS AND DISCUSSIONS

Configurations	Velocity at the exit, (m/s)	O_2 mass fraction at the exit
Reference Afterburner	373	0.1527
Reference Afterburner With Liner	470	0.1490
Reduced Diameter Flame holder	326	0.1502
Inclined Radial Gutter Flame holder	391	0.2038
Tapered Shell Afterburner	611	0.1358
Tapered Shell Afterburner With Liner	678	0.0981

In this project the various configurations were investigated over a range of afterburner inlet pressure of 65 kilo Pascal, afterburner inlet gas temperature is 1100 k, inlet velocity for tapered shell afterburner with and without liner is 150 m/s, and inlet velocity for all other configurations is 200 m/s. Afterburner lengths from a minimum of 3.5 feet to a maximum of 5.5 feet. Jet-A (C12H23) fuel is injected from the fuel spray bars located just behind the turbine, into the hot gases from the turbine which comprises of carbon dioxide, vapour state of H2O, Nox, unburned oxygen, unburned nitrogen and lighted up. The turbulence model used is 'k-epsilon' , the combustion model used is 'Eddy- Dissipation' and the thermal radiation model used is 'P1'. The combustion takes place with very high temperature, the temperature raise to nearly 2000 k at the core of the jet pipe due to reheat. The product of the reheat combustion is carbon di oxide, vapour state of H2O and Nox. The mass fraction of oxygen,CO2,NO, H2O is 0.3, 0.3, 0.1, 0.3 respectively at the inlets. Since the actual flow inside the afterburner is transient in nature, the transient time step iteration is carried out for the combustion inside the afterburner and it is simulated for 20 seconds of reheat operation. The following are the results obtained from the reheat operation;

5.FUTURE ENHANCEMENT

Turbulence generators were mounted downstream of the V-gutter flame holder in order to evaluate the effects of mechanically introducing turbulence in the fuel-air mixture approaching the flame fronts. Some investigators have found a direct relation between turbulence and rate of flame spreading. we going to determine whether such a relation would manifest an improvement in afterburner performance.

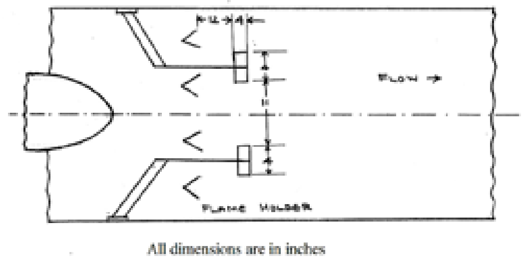

Fig.31 Vortex generator

The two types of turbulence generators added to the reference configuration flame holder are shown in fig.31 and fig.32. The turbulence generator of figure shows its origin to the tip vortex generators often used to improve subsonic-diffuser performance. The radial-vane mixer of figure consists of thin vanes twisted and mounted to impart flow deflection and rotation. Mixers of this type have been used in the diffuser passage of some turbojet compressors to promote a more uniform velocity profile.

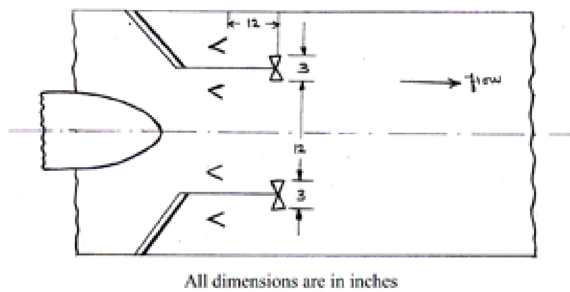

Fig.32 Radial vane mixer

Schematic diagrams of the turbulence generators in the installed position are presented in fig.31 and fig.32. Both types of generators were mounted between the two flame holder gutter rings 12 inches downstream of the gutter trailing edge. This particular position was the only one tried, although other positions were expected to give somewhat different degrees of performance. The cylindrical afterburner-shell length for both installations was 4.5 feet.

6.CONCLUSION

The tapered shell afterburner with liner used in this project had a 5 degree wall taper and 14.3 percent less afterburner volume than a cylindrical jet pipe with liner of the same length. Therefore, Tapered shell afterburner with liner configuration shows high velocity and low value of oxygen mass fraction at the exit when compared to all other configurations and also 14.3 percentage of volume is reduced by using this configuration, so by tapering the shell of the afterburner and adding liner, we can improve thrust as compared to reference afterburner configuration.

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