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Summary

Lean combustion limits were determined for a premixed-prevaporized propane-air mixture with flat plate flame stabilizers. Experiments were conducted in a constant area flame tube combustor utilizing flameholders of varying percentages of blockage and downstream counterbores. Combustor inlet air velocity at ambient conditions was varied from 4 to 9 meters per second. Flameholders with a center hole and four half holes surrounding it were tested with 63, 73, and 85 percent blockage and counterbore diameters of 112 and 125 percent of the thru hole diameter, in addition to the no counterbore configuration. Improved stability was obtained by using counterbored flameholders and higher percentages of blockage. Increases in mixture velocity caused the equivalence ratio at blowout to increase in all cases.

Introduction

This study was made to determine the effect of various flameholders with different downstream counterbore sizes and percentages of blockage on lean combustion blowout limits.

Several studies (refs. 1 to 5) about premixed prevaporized combustion have been made in an attempt to understand better this type of process and its application to future aircraft gas turbines. Some of the recognized advantages of premixed-prevaporized systems in relation to combustion efficiency are: superior performance, high durability and low levels of exhaust-gas pollutants. However, many aspects of the premixed-prevaporized combustion process are still not well understood. Some of these aspects that need to be examined (refs. 6 to 9) are the effect of flame and material temperature, flameholder geometry, equivalence ratio, and fuel types. In this study the effect of flameholder geometry, counterbore sizes and percentages of blockage, on flame stability for lean burning equivalence ratios are reported.

This test program is an extention of a similar investigation presented in reference 10. Reference 10 discusses blowout limits for different percentages of flameholder blockage, along with the effects of turbulence on stability. In this reported experimental research, flameholders incorporating counterbore geometries and a range of blockages were investigated in an effort to assess their influence on combustion stability. Both factors, percentage of blockage and counterbore size, were found to influence lean stability limits.

The experimental work was carried out in a flame tube combustor using a premixed-prevaporized mixture of propane and air. The fuel flow and airflow varied from 0.5 to 2 grams per second and from 16 to 26 grams per second, respectively. The combustor Reynolds number range was from 10 000 to 20 000, using temperature and pressure at ambient conditions. Nine flameholders were tested with three percentages of blockage (63, 73, and 85 percent) and two counterbore sizes.

Equipment and Procedure

A flow schematic of the experimental apparatus is shown in figure 1. Air from the main laboratory compressor and propane from a 455-gram cylinder are mixed to create the combustion mixture. Propane was used because its combustion characteristics are similar to those of jet aircraft fuels.

Figure 2 is a photograph of the system controls and monitoring equipment. The fuel was preheated in the cylinder to increase the pressure and overcome any line losses in the system. Air and propane flow were measured with two flowmeters having ranges of 40 and 3.5 m^3/hr. Two thermocouples were mounted upstream of the flowmeters to record the inlet temperature. Fuel and air pressure were also measured.

Fuel Injector

The fuel injector used in this study is illustrated in figure 3. Fuel was discharged into the premixing section through four tubes entering the combustor, downstream of the air entrance. These four stainless steel tubes were located radially, 90 degrees apart, and were 3.2 mm in diameter and 13 mm long. The tube size was chosen so the flow blockage would be minimal. Each of the four tubes were sealed at one end, and three equally spaced 1.45 mm diameter holes were drilled in each tube.

A fuel manifold 6.35 mm in diameter supplied fuel to each fuel injector tube. The main purpose of this fuel injector configuration was to provide a uniform fuel/air mixture throughout the duct cross section.

Flameholders

Nine flameholder plates were tested in this program to investigate the relationship between flameholder geometry and flame stability. Three different flameholder blockages were tested, 63, 73, and 85 percent, along with two percentages of counterbore size. All nine of the perforated plate configurations are derived from the same basic design (fig. 4). The flameholders, fabricated out of type 304 stainless steel, were 10.2 mm thick and 35 mm in diameter. The plates had one center hole and four half-holes. The distance between hole centers remained the same for each plate. The outer holes were located 15.7 mm radially from the center hole and the center-to-center dimension between the outer holes was 22.3 mm.

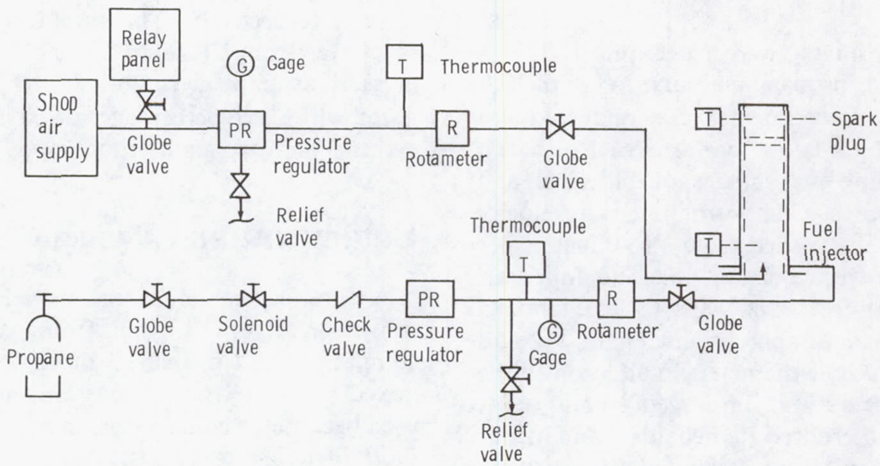


Figure 1. - Schematic of experimental apparatus.

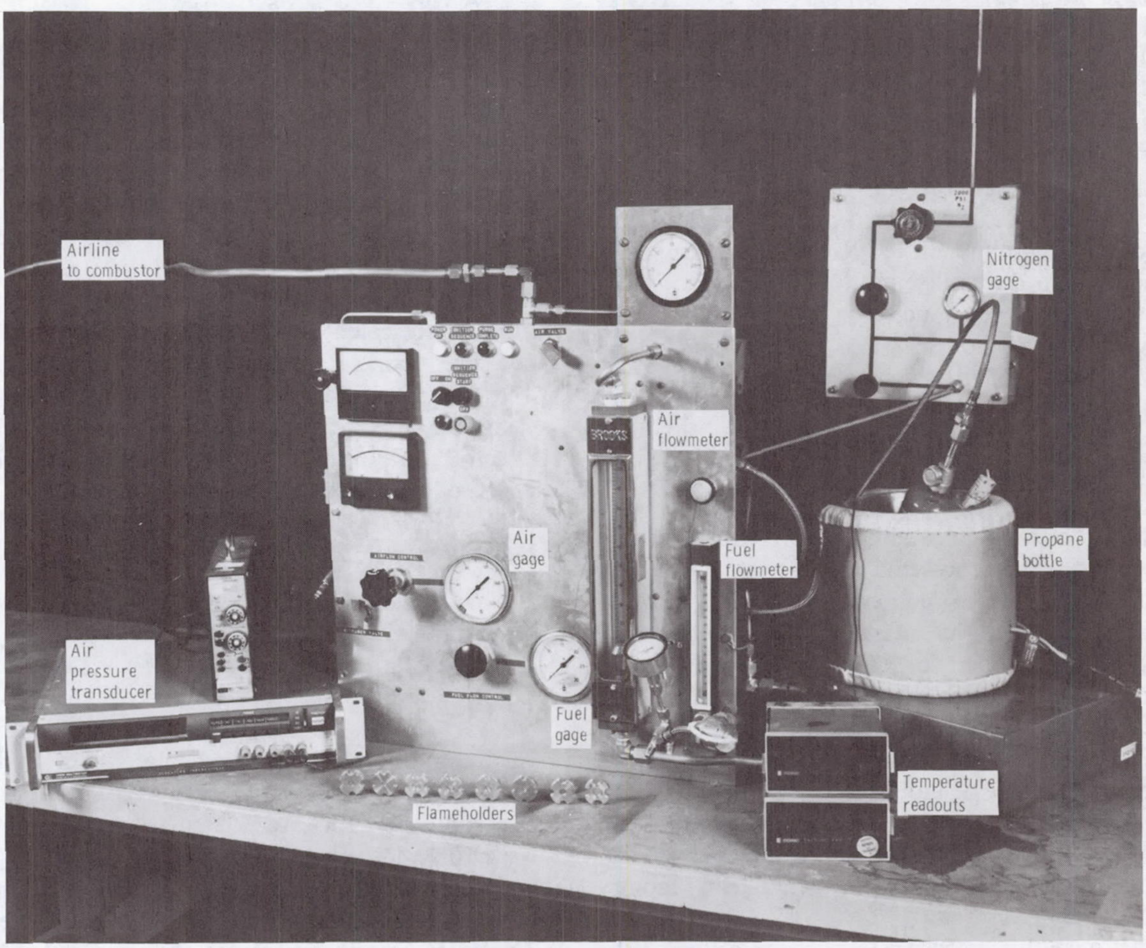


Figure 2. - Assembled controls on cart.

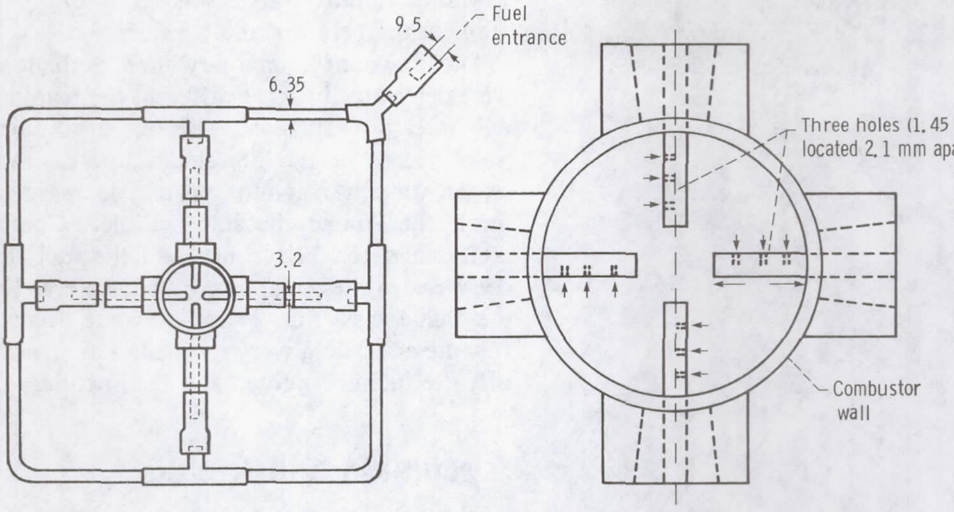


Figure 3. - Fuel injector (All dimensions in mm.)

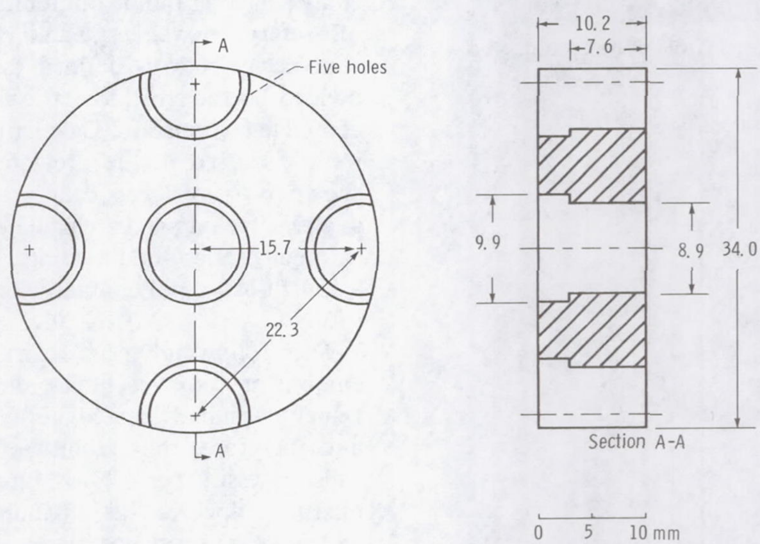


Figure 4. - Flameholder configuration for 73 percent blockage and 9.9-mm counterbore. (All dimensions in mm.)

The flameholders with counterboring were drilled to the depth of 2.6 mm on the downstream face. The 63 percent blockage flameholder had a 10.8 mm diameter thru hole and 12.0 mm or 13.4 mm counterbore corresponding to 112 or 125 percent of the thru hole diameter. The 112 or 125 percent counterbore was held constant for all flameholders with counterboring. The other flameholders with counterbore had 73 percent blockage with an 8.9 mm diameter thru hole and counterbore diameter of 9.9 mm or 11.1 mm, and 85 percent blockage, 6.4 mm diameter thru hole and counterbore diameter of 7.2 mm or 8.0 mm. Also flameholders without counterbore were tested for each percentage of blockage. The nine different flameholder configurations are listed in Table I and shown in a photograph in figure 5.

Combustor

Combustion occurred in a constant cross-sectional tubular combustor (see fig. 6). The flame tube combustor, 35 mm in diameter, was supplied with a premixed-prevaporized air-propane mixture. Fuel was discharged from the fuel injector into the premix section. The distance from the point of fuel injection to the flameholder was 150 mm. The flameholder, described in a previous section, defined the premixed and combustion zones. Fuel-air mixture temperature was measured upstream and downstream of the flameholder plate with Chromel-Alumel thermocouples inserted through the duct wall. Combustion was initiated by a spark plug placed 25 mm downstream of the flameholder. The combustion zone, 50 mm long, was opened to the atmosphere.

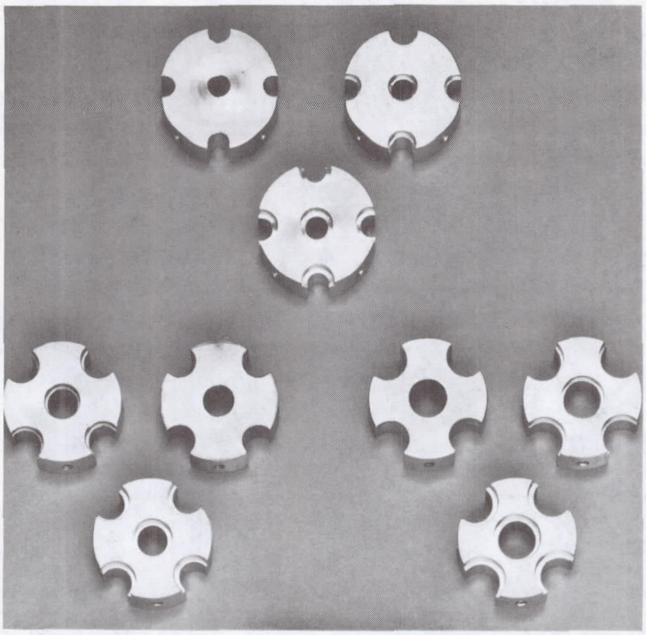


Figure 5. - Stainless-steel flameholder plates with different percentages of blockage and counterbore sizes.

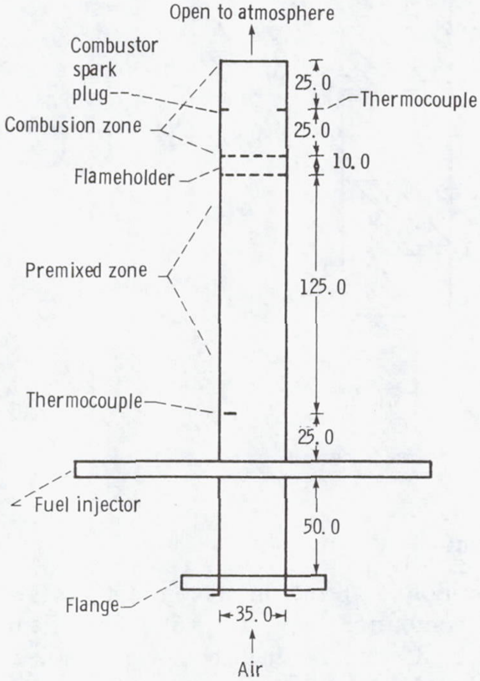


Figure 6. - Fuel-air mixing section layout. (All dimensions are in mm.)

Test Conditions and Procedure

The parameters varied in this study were: percent of blockage, counterbore diameter and air flow rate. The fuel flow and airflow were regulated from 0.5 to 2 grams per second and from 16 to 26 grams per second. Reference velocity, based on combustor cross-sectional area and airflow rate and density in the premix zone, was varied from 4 to 9 meters per second. The combustor Reynolds number range was from 10 000 to 20 000 at ambient temperature and pressure.

The blowout flammability limits of the fuel-air mixture were determined for the different flameholder geometries and inlet air velocities. The test procedure for a data point was to set the air velocity to a desired value, then switch the spark ignitor on and increase the fuel flow until the flame became visible. Combustion was maintained for 30 seconds and the fuel flow was then decreased while maintaining a constant airflow rate until the flame blew out. When blowout occurred, the fuel flowmeter reading was recorded. The fuel flow was shut off, the fuel line purged and the next data point set.

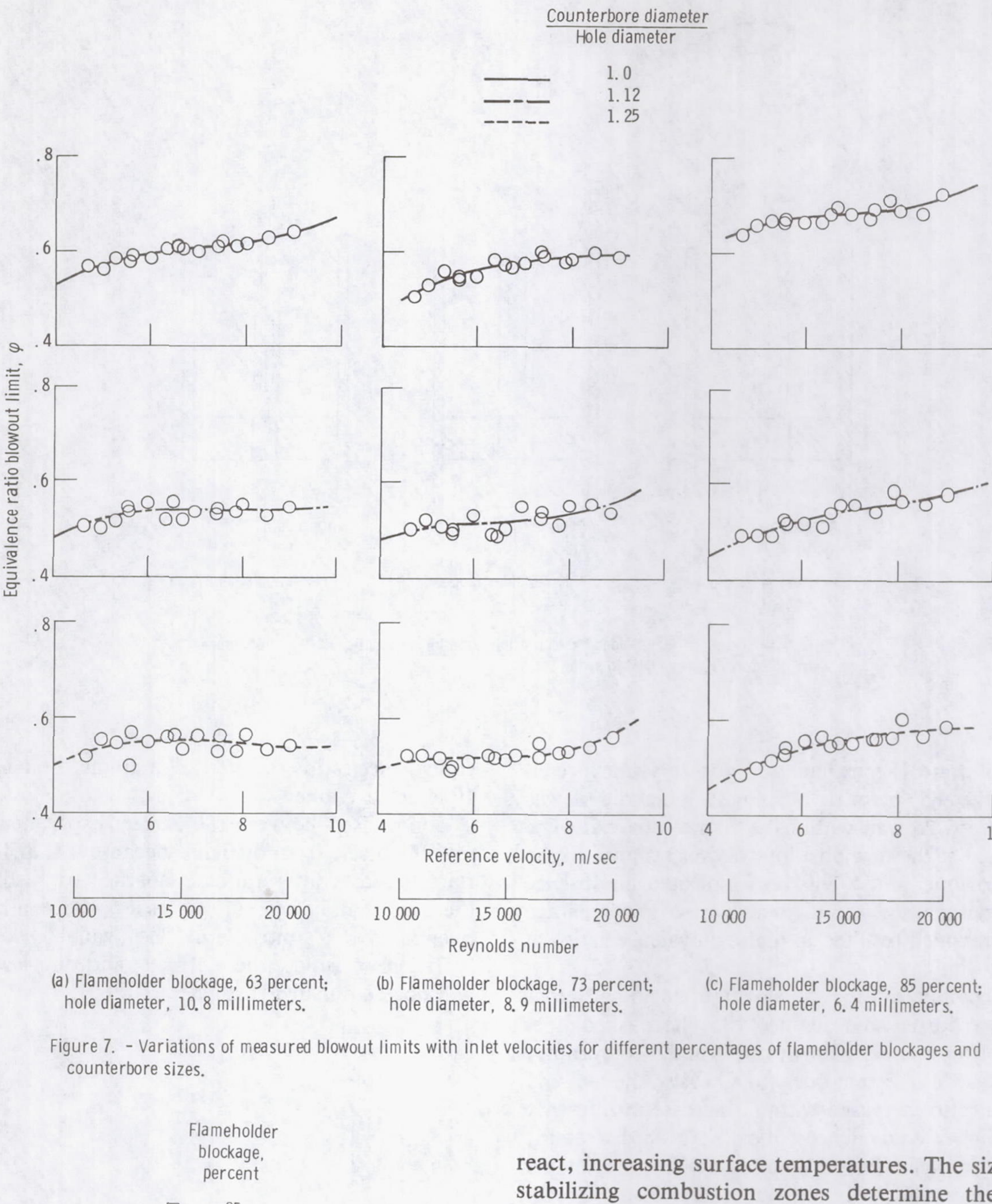
Discussion and Results

Figure 7 shows the lean stability limits for all nine flameholders tested. The lean stability limits or equivalence ratio blowout limits are plotted as a function of reference velocity and Reynolds number. The equivalence ratio is defined as the actual fuel/air ratio divided by the stoichiometric fuel/air ratio required for complete combustion. Calculations for reference velocity were discussed in the previous section. All the curves shown in figure 7 were drawn using a standard regression analysis technique to calculate the "best fitting line" through a series of data points. The calculated equation is a fourth-order polynomial with a correlation coefficient of 0.99.

The following trend can be recognized for the combustor blowout limits. In general, a higher inlet velocity resulted in a higher blowout equivalence ratio and therefore, the stability of the flame deteriorated. This necessity for higher equivalence ratios at higher mixture velocities was attributed to faster mixing rates and smaller residence times. As the jet velocity was increased, richer mixtures were necessary to compensate for all these factors (ref. 11).

Figure 8 compares the three different percentages of blockage without counterbore and shows their effect on blowout equivalence ratios. An increase in percentage of blockage from 63 to 73 percent decreased lean blowout limit, thereby improving stability. Opposite results were obtained with the 85 percent blockage flameholder. It can be observed in figure 8 that this flameholder produced high blowout limits, the worst case of stability in this experiment. This behavior was attributed to the test setup which affected the recirculation zone for this particular configuration as described below.

Recirculation zones begin to have first order importance when they are responsible for stabilizing the flame. When the rate of heat loss by thermal conduction is less than the rate of heat release by fuel reaction, combustion occurs. The flame is stabilized in these recirculation zones when premixed-prevaporized gases



(a) Flameholder blockage, 63 percent; hole diameter, 10.8 millimeters.

(b) Flameholder blockage, 73 percent; hole diameter, 8.9 millimeters.

(c) Flameholder blockage, 85 percent; hole diameter, 6.4 millimeters.

Figure 7. - Variations of measured blowout limits with inlet velocities for different percentages of flameholder blockages and counterbore sizes.

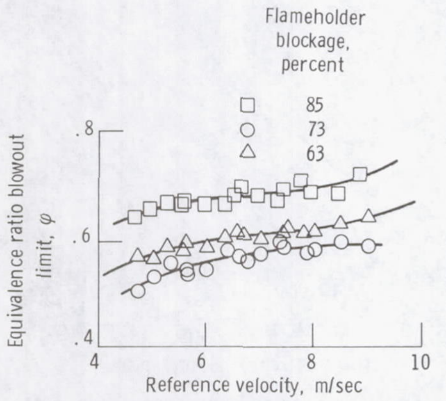


Figure 8. - Variations of measured blowout limits with inlet velocities for flameholder blockages of 63, 73, and 85 percent (no counterbores).

react, increasing surface temperatures. The size of these stabilizing combustion zones determine the blowout limits for a given reference velocity and flameholder configuration.

This effect is illustrated in figure 9. A cross-sectional view of the flameholders, based on preliminary visual observations, shows the recirculation zones created by the jet flame. The length of the recirculation zone is increased by increasing the percentage of blockage from 63 to 73 percent. In both cases, a more stable combustion zone is established and the lean blowout limit decreased (fig. 8). However, for the 85 percent blockage, figure 9 shows that the combustion zone was not long enough to create any closed recirculation zones, and moreover, outside air was allowed to mix with the inside gases.

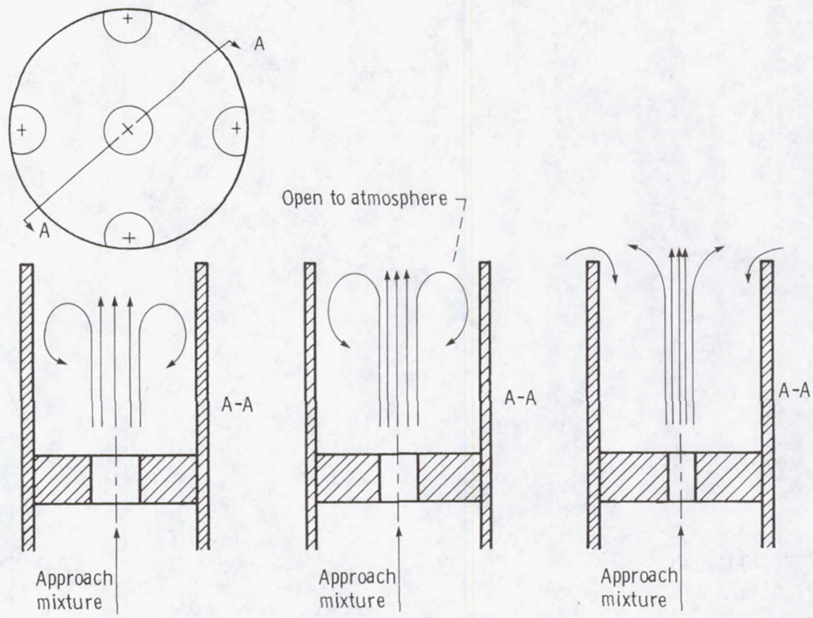


Figure 9. - Sketch of flameholder recirculation zone for perforated plate flameholders with no counterbores. (Not to scale.)

To corroborate the explanation for this unexpected behavior, the 85 percent blockage flameholder was moved forward 25 mm within the flame tube exit. The data obtained at the new position was very similar to the previous blowout limits. This also indicated an absence of closed recirculation zones for this specific percentage of blockage, which resulted in high equivalence ratios at the blowout limits.

Figure 10 compares the results of figure 8 and a similar experiment reported in reference 10. The dashed lines show data from that experiment for 75 and 94 percentage of blockage for a 12.7 mm liner. In all cases, the blowout equivalence ratio increased with an increase in reference velocity. Higher equivalence ratios were needed at the higher mixture velocities to compensate for the smaller residence times and faster mixing rates. This was the same trend followed by the 35 mm liner at 63, 73, and 85 percentage blockage from the present experiment. The increased recirculation zone due to an increase in liner diameter size was probably the reason for obtaining the lowest equivalence blowout ratios.

Comparing the 35 mm liner data of the present experiment with the 22.2 mm liner data from reference 10, a similar behavior effect of the percentage of blockage is observed. For both the 35 mm and 22.2 mm liners, the increase in percentage of blockage improved flame stability (the 85 percentage blockage is considered a special case, as was previously explained). The fact that the greater blockage produced larger blowout equivalence ratios for the 12.7 mm liner tests in reference 10 is not explained.

Comparison between the current experiment and that in reference 10 is difficult because of differences in flameholder configurations, absence of insulation and the fact that in one of the cases, the combustor was opened to the atmosphere. The available data are not sufficient to isolate these effects, and direct comparison will not be pursued further.

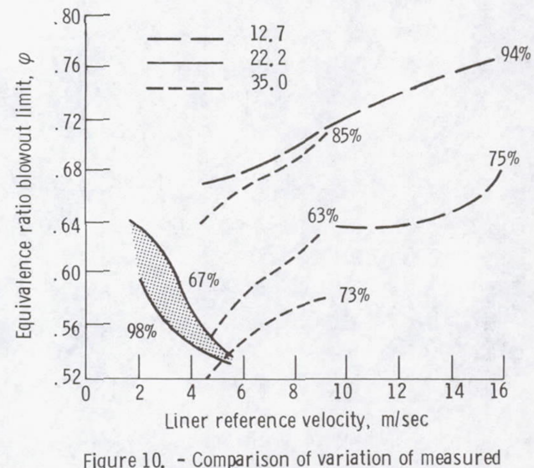


Figure 10. - Comparison of variation of measured blowout limits versus liner reference velocity with data presented in reference 1 for different percentages of flameholder blockage (no counterbores).

Figure 11 shows how counterbored flameholders affect lean blowout equivalence ratios for different percentages of blockage. The main purpose of the counterbores was to study their ability to stabilize the flame over a broad range of flow conditions. Figure 11(a) shows data for the 63 percent blockage plate and counterbores of 12.0 and 13.4 mm. The slope of the three lines with respect to the velocity are about the same. However, there is a considerable difference between the counterbored flameholders and the one without counterbore. The decrease in blowout limit was due to the fact that counterboring served to increase the flame diameter resulting in an increase in the surface area of the plate that was exposed to the flame. This, in turn, raised the surface temperature of the flameholder above that of the plate without counterboring at the same jet velocities. Counterboring also decreased the surface area of the plate that was exposed to the cool reactants (ref. 12).

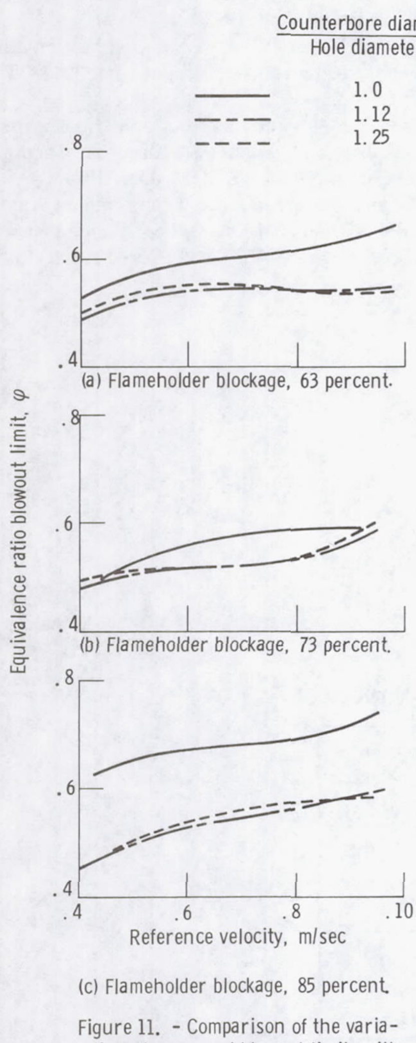


Figure 11. - Comparison of the variation of measured blowout limits with inlet velocities for different counterbores at a determined percentage of blockage.

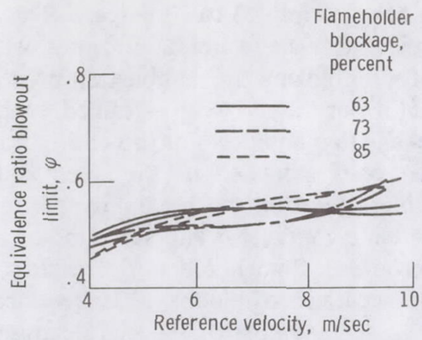


Figure 12. - Comparison of the variation of measured blowout limits with inlet velocities for different percentages of counterbored flameholders.

These factors helped to stabilize the flame and lower blowout equivalence ratios. The same results were obtained with flameholders that had 73 and 85 percent blockage (figs. 11(b) and (c)). Differences in counterbore size did not show any effect in blowout equivalence ratios in any case.

Figure 12 shows all of the stability curves for the counterbored flameholders with different percentages of blockage. Notice that all of the data are in the same region. Equivalence ratio limits remained almost constant despite counterbore sizes or percentages of blockage. This shows that counterbored flameholders are less sensitive to changes in percentage of blockage than those without counterboring. Therefore, counterbored flameholder plates were more effective for providing a better method of flame stabilization than percentage of blockage.

Conclusions

The effects of percentage of blockage and counterboring of flameholders on blowout limits were studied for a premixed-prevaporized propane-air mixture. With ambient air inlet pressures and temperatures at the flameholder plane, propane fuel, ignitor, and a fixed premixing length, the combustor blowout limit was recorded for different air velocities. Conclusions from this flame stability experiment are the following:

1. The data revealed that an increase in mixture velocity caused the equivalence ratio blowout limits to increase, despite flameholder geometry or percentage of blockage. This necessity for richer mixtures is attributed to faster mixing rates (more uniform mixtures) and smaller residence times.

2. Increases in percentage of blockage improved stability for those flameholders without counterbores. Lean blowout equivalence ratios decreased with

increasing blockage from 63 to 73 percent. This was due to the enlargement of the recirculation zones, which were responsible for stabilizing the combustion process.

3. High blowout limits were obtained with the 85 percent blockage flameholder. For this configuration, the recirculation zones extended to the open end of the combustor liner, creating the possibility of outside air entering the flame combustor and surrounding the jets.

4. Counterbored flameholders decreased blowout limits in all percentages of blockage. This was caused by the increase in surface area of the plate exposed to the flame and the decrease of that area in contact with cool reactants. The various counterbore sizes did not show any difference in how they affect stability.

5. It was found that counterbored flameholders are less sensitive to changes in percentage of blockage than those without counterboring. The blowout limits remained almost constant for all the cases.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, May 9, 1983

References

1. Marek, C. J.; Papathakos, L. C.; and Verbulecz, P. W: Preliminary Studies of Autoignition and Flashback in a Premixing-Prevaporizing Flame Tube Using Jet-A Fuel at Lean Equivalence Ratios. NASA TM X-3526, May 1977.
2. Cooper, L. P.: Analysis of Effect of Flameholder Characteristics on Lean, Premixed, Partially Vaporized Fuel-Air Mixture Quality and Nitrogen Oxides Emissions. NASA TP-1842, May 1981.
3. Radhakrishnan, K; Heywood, J. B. and Tabaczynski, R. J.: Premixed Turbulent Flame Blowoff Velocity Correlation Based on Coherent Structures in Turbulent Flows. Combust. Flame, vol. 42, July 1981, pp. 19-33.
4. Anderson, D.: Effects of Equivalence Ratio and Dwell Time on Exhaust Emissions from an Experimental Premixing Prevaporizing Burner. ASME Paper 75-GT-69, Mar. 1975.
5. Marek, C. J.; and Papathakos, L. C.: Exhaust Emissions from a Premixing, Prevaporizing Flame Tube Using Liquid Jet A Fuel. NASA TM X-3383, Apr. 1976.
6. Ryason, P. R.; and Hirsch, E.: Cool Flame Quench Distances. Combust. Flame, vol. 22, Feb. 1974, pp. 131-132.
7. Ballal, D. R.; and Lefebvre, A. H.: Ignition and Flame Quenching in Flowing Gaseous Mixtures. Proc. R. Soc. London Ser. A., vol. 357, no. 1689, Oct. 1977, pp. 163-181.
8. Maekawa, M.: Flame Quenching by Rectangular Channels as a Function of Channel Length for Methane—Air Mixture. Combust. Sci. Technol., vol. 11, no. 3-4, 1975, pp. 141-145.
9. Ishikawa, N.; and Branch, M. C: An Experimental Determination of the Quenching Distance of Methanol and Iso-Octane/Methane Blends. Presented at the Combustion Institute Spring Meeting, (Salt Lake City, Utah), Apr. 19-20, 1976.
10. Huck, K. L.; and Marek, C. J.: Lean Combustion Limits of a Confined Premixed-Prevaporized Propane Jet. NASA TM-78868, Apr. 1978.
11. Radhakrishnan, K.; Heywood, J. B.; and Tabaczynski, R. J.: Premixing Quality and Flame Stability: A Theoretical and Experimental Study. NASA CR-3216, Dec. 1979.
12. McVey, J. B.; and Kennedy, J. B.: Lean Stability Augmentation Study. (UTRC-R79-914104-18, United Technologies Research Center; NASA Contract NAS3-20804.) NASA CR-159536, Apr. 1979.

TABLE I. – FLAMEHOLDER CONFIGURATIONS

Combustor diameter, mm	Hole diameter, mm	Flameholder blockage, percent	Counterbore diameter, mm
35	10.8	63	10.8 12.0 13.4
	8.9	73	8.9 9.9 11.1
	6.4	85	6.4 7.2 8.0

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15. Supplementary Notes

16. Abstract

Lean combustion limits were determined for a premixed-prevaporized propane-air mixture with flat plate flame stabilizers. Experiments were conducted in a constant area flame tube combustor utilizing flameholders of varying percentages of blockage and downstream counterbores. Combustor inlet air velocity at ambient conditions was varied from 4 to 9 meters per second. Flameholders with a center hole and four half holes surrounding it were tested with 63, 73, and 85 percent blockage and counterbore diameters of 112 and 125 percent of the thru hole diameter, in addition to the no counterbore configuration. Improved stability was obtained by using counterbore flameholders and higher percentages of blockage. Increases in mixture velocity caused the equivalence ratio at blowout to increase in all cases.

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