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EXPERIMENTAL INVESTIGATION OF ACOUSTIC LINERS TO SUPPRESS SCREECH IN HYDROGEN-OXYGEN ENGINES

by John P. Wanhainen, Harry E. Bloomer, and David W. Vincent
Lewis Research Center
Cleveland, Ohio

TECHNICAL PAPER proposed for presentation at
Third Combustion Conference sponsored by the
Interagency Chemical Rocket Propulsion Group
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INTRODUCTION

As a part of an extensive investigation being conducted at the Lewis Research Center to explore the combustion dynamics of hydrogen-oxygen combustion systems, an experimental study of the use of acoustic liners to suppress screech was conducted in the Rocket Engine Test Facility. Liner design variables of open area ratio, liner thickness, liner backing distance, liner length and aperture shape were studied in a 10.78-inch diameter cylindrical combustor at a chamber pressure of 300 psia. The effects of changes in liner design parameters were evaluated by ramping the hydrogen injection temperature down into screech and determining the change in hydrogen temperature stable operating limits.

Author

APPARATUS

The heat-sink combustor (fig. 1) used in the investigation was comprised of a concentric tube injector, a cylindrical external pressure jacket, a perforated plate acoustic liner and a convergent-divergent exhaust nozzle with a contraction ratio of 1.89. The chamber internal diameter was 10.78 inches and the combustion chamber length from the injector to the throat was about 18 inches. The absorbing liners were 9 inches in length. The heat-sink acoustic liners tested included both circular (fig. 2) and noncircular aperture configurations (fig. 3). Circumferential partitions were used to minimize steady flow behind the liner and, thus, the flow through the apertures to simplify the calculation of liner absorption coefficients.

A 487 element, uniform pattern concentric-tube type injector (fig. 4) was used in this phase of the investigation. The fine pattern injector was selected because of its poor stability characteristics or high hydrogen screech transition temperature (fig. 5) to provide as severe a test as possible for the absorbing liners. The predominant mode of instability encountered was first tangential with a peak-to-peak amplitude of about 140 psi.

RESULTS AND DISCUSSION

The Pratt-Whitney acoustic liner program, based on Helmholtz resonator theory, was used to calculate the absorption coefficients for the various liner configurations tested (fig. 6). The coefficients were calculated

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for an arbitrary value of sound pressure level of 190 db, a wave frequency (3250 cps) corresponding to the first tangential mode for the engine and no flow past or through the apertures. In the 3/16-inch wall thickness, the liners tested had open areas of 5, 10, 15 and 20 percent. The 10 percent open area liner was the best configuration, stable in all tests at hydrogen injection temperatures about 60° R (fig. 7). With this liner, the screech amplitude which reached values of 140 psi peak-to-peak without a liner, was less than 10 psi (fig. 8).

The variation in stability with the various 3/16-inch wall liners is a combined effect of open area ratio and liner cavity gas temperature on absorption characteristics because the temperature varied between configurations (fig. 9). There was a considerable variation in temperature depending on the location behind the liner and an increase in the average value from 600° to 1000° R as the open area was varied from 5 to 20 percent. This variance in gas temperature undoubtedly results from different amounts of combustion gas recirculation behind the liner. In addition, one might also expect a variation in cavity gas temperature with injector element size, spacing and the propellant combination. Thus, unless a means of controlling cavity gas temperature is found, such as a gas bleed, the designer is faced with an experimental program to optimize the final acoustic liner design.

Analytical predictions based on acoustic theory were in agreement with experimental results only when flow past the apertures was included in the calculation of liner absorptivity. Without flow past the apertures included, an anomoly existed in the stability correlation. Two configurations with the same calculated absorption coefficients (0.15 and 0.2 open area ratios) of 0.099 provided different hydrogen temperature stable operating limits (fig. 10). To obtain a reasonable agreement between theory and experiment, it was necessary to use a flow velocity of 280 feet per second past the apertures in the calculation of absorption coefficient. The stability correlation indicated that a liner with a minimum coefficient of about 0.25 calculated including flow past the apertures was required to stabilize the combustor used at a hydrogen injection temperature of 60° R (fig. 11). A satisfactory agreement between the results of thick and thin wall liners was not obtained even when the effects of a 280 feet per second flow velocity past the apertures was used in the absorption coefficient calculations (fig. 12). Possibly, the effects of flow past change with liner thickness and aperture diameter.

The effect of liner length was evaluated with a 10 percent open area, 3/16-inch wall liner, the most successful full length configuration. The partial length liners were evaluated positioned at the injector end of the thrust chamber. The length of the liner was reduced to 17 percent of the full length configuration without affecting the stability characteristics of the combustor (fig. 13). It appears that the most effective placement of resonators is at the injector end of the thrust chamber.

The slotted and cross liners tested to determine the effect of aperture shape on absorption characteristics demonstrated results similar to circular aperture liners of the same wall thickness. The 10 percent open area liner again provided the best stable operating range (fig. 14). Both cross liners which were designed for an open area of 10 percent were stable so the effect of peripheral length on absorptivity was not evaluated. However, these results indicate that aperture shape does not have a first order effect on liner absorptivity.

SUMMARY

1. High frequency combustion instability in hydrogen-oxygen engines of the size investigated can be suppressed using a properly designed array of Helmholtz resonators.

2. Liner cavity gas temperature which varied with liner variables such as aperture size, open area ratio and axial position, has a strong effect on liner absorption characteristics. Thus, unless a means of predicting or controlling cavity temperature is found, no rational design procedure is possible.

3. Analytical predictions based on acoustic theory were in limited agreement with experimental results providing the effects of flow past the apertures of 280 feet per second was included in the calculation of absorption coefficient. Additional data evaluating the effect of flow past the apertures are required before liner absorption characteristics can be predicted.

4. Liners with absorption coefficients of 0.25 or higher, calculated including flow past the apertures, were required to eliminate screech in the combustor used in the tests at a hydrogen injection temperature of 60° R (minimum available).

5. Full combustor length liners were not required to suppress acoustic mode instability for the particular combustor used in the investigation. A 17 percent partial length liner positioned at the injector end of the thrust chamber provided stable combustion to a hydrogen injection temperature of 60° R.

6. Liner designs need not be limited to circular apertures; full length slots appeared to be just as effective as circular apertures.

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ENGINE ASSEMBLY

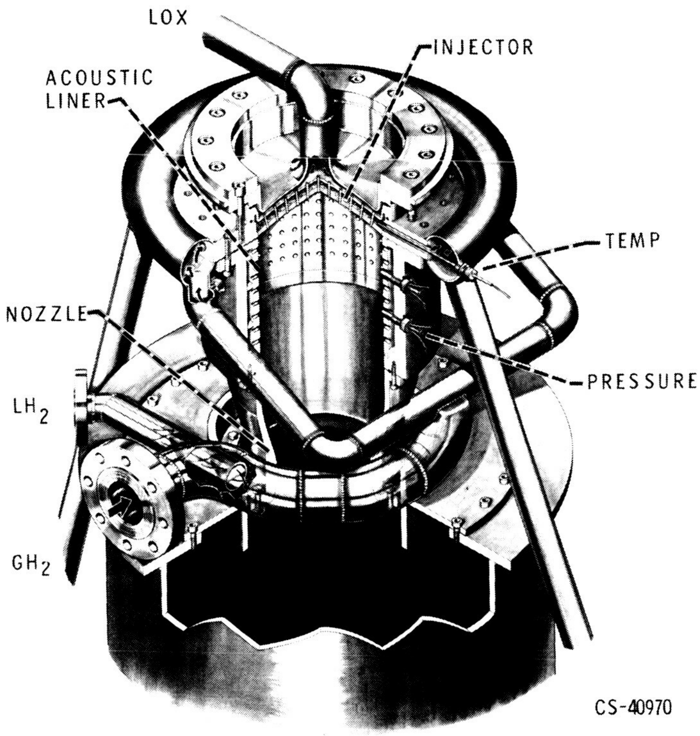
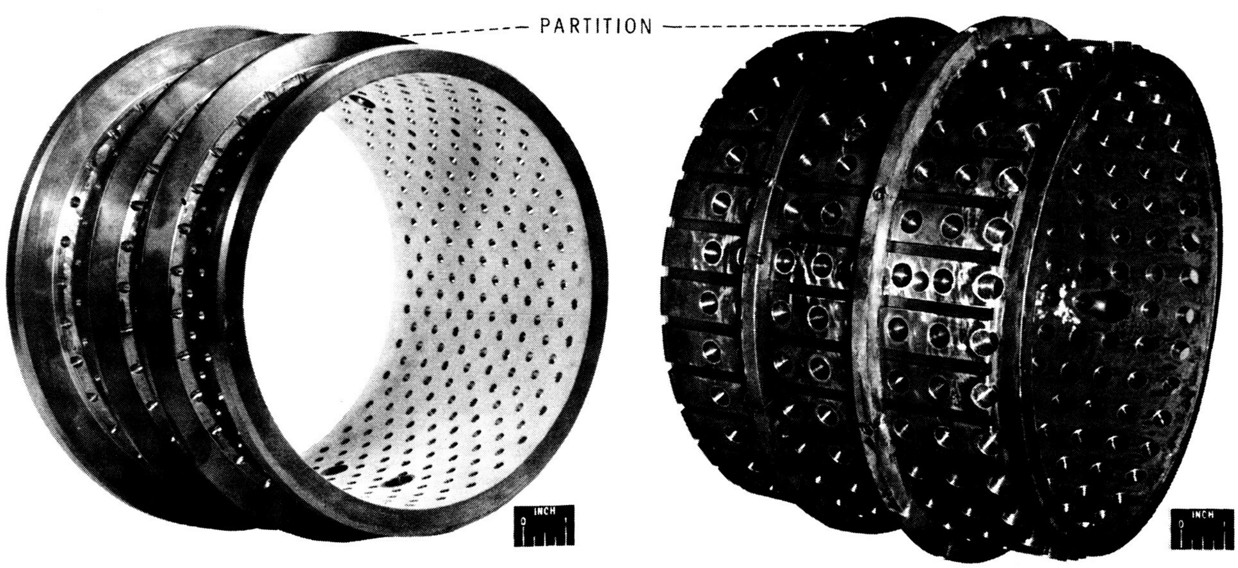


Figure 1

TYPES OF ACOUSTIC LINERS TESTED



(A) 3/16 IN.-THICKNESS

(B) 3/4 IN.-THICKNESS

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Figure 2

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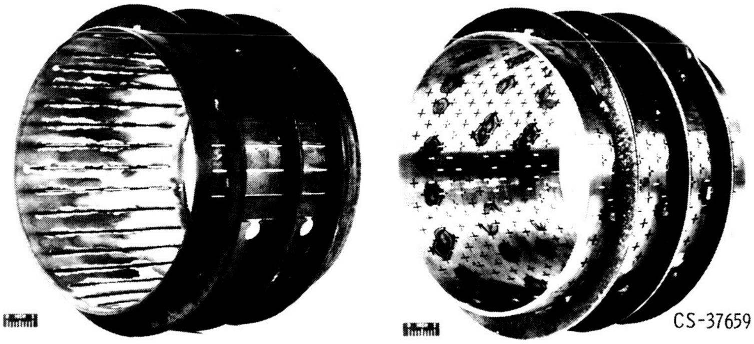
TYPES OF ACOUSTIC LINERS TESTED



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(A) SLOT LINER. (B) CROSS LINER.

Figure 3

FACEPLATE VIEW OF INJECTOR

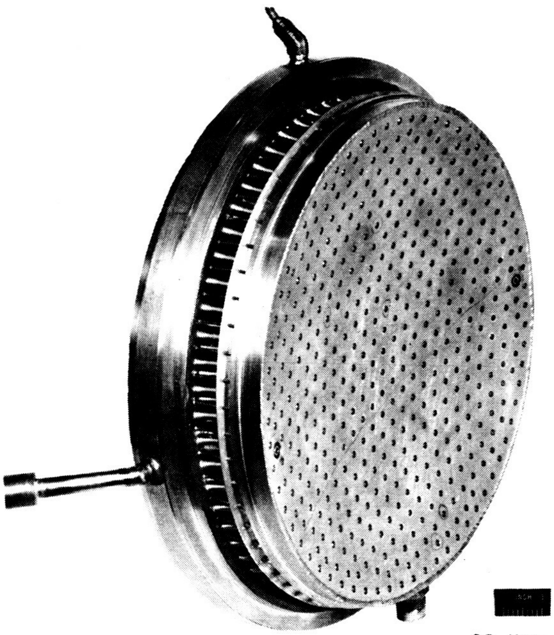

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Figure 4

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STABILITY CHARACTERISTICS WITHOUT LINER

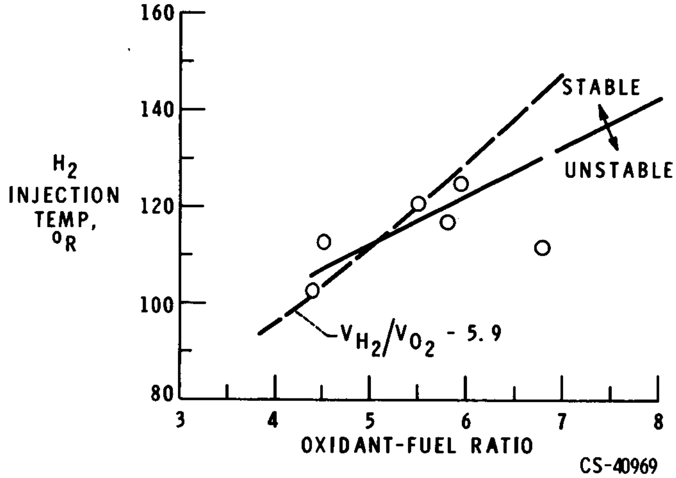

Figure 5

LINER ABSORBING CHARACTERISTICS

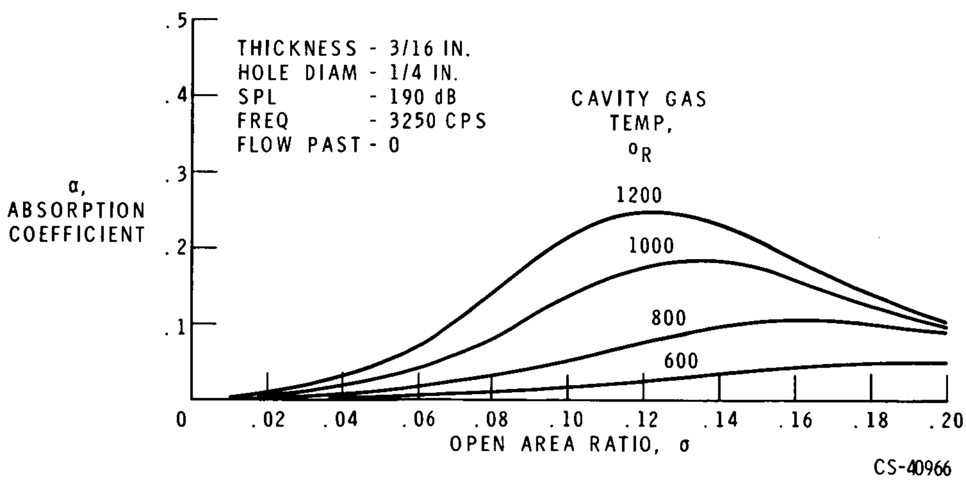

Figure 6

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COMBUSTION STABILITY LIMITS

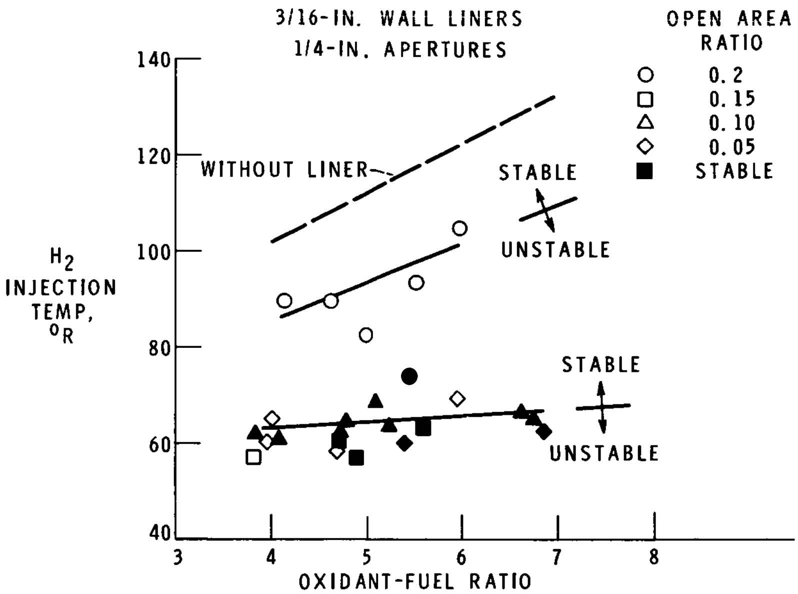

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Figure 7

ANALYSIS OF PRESSURE OSCILLATIONS

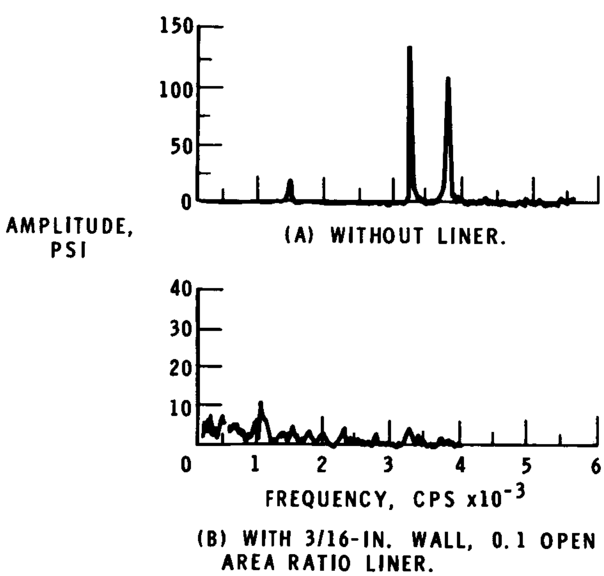

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Figure 8

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LINER CAVITY GAS TEMPERATURES

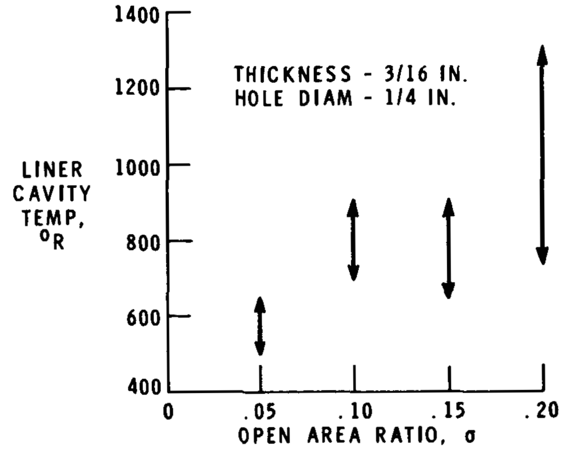

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Figure 9

COMBUSTION STABILITY CORRELATION

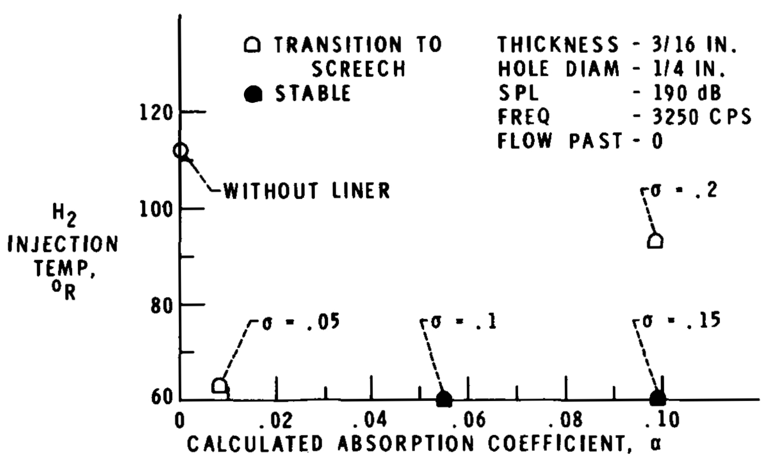

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Figure 10

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COMBUSTION STABILITY CORRELATION

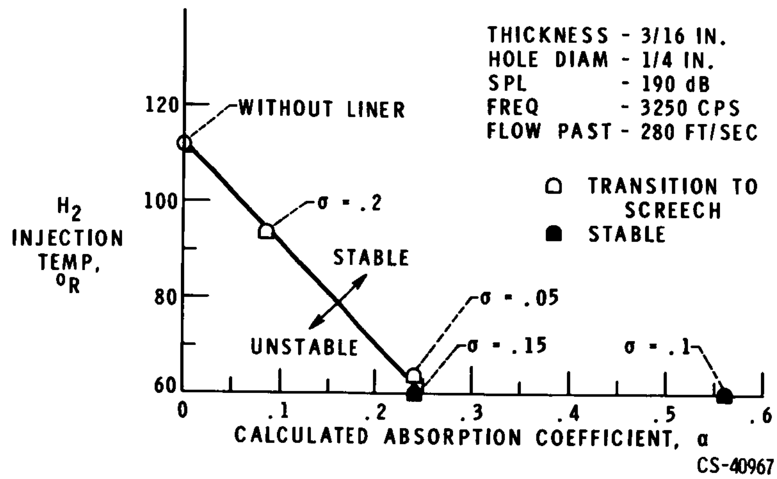

Figure 11

COMBUSTION STABILITY CORRELATION

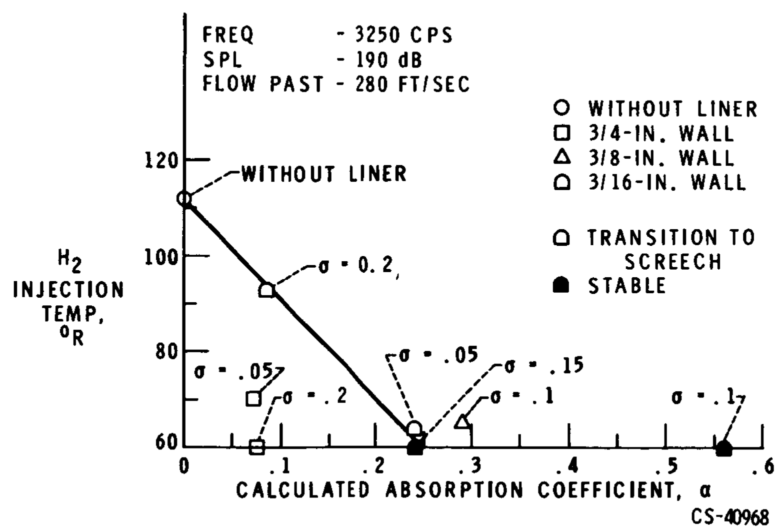

Figure 12

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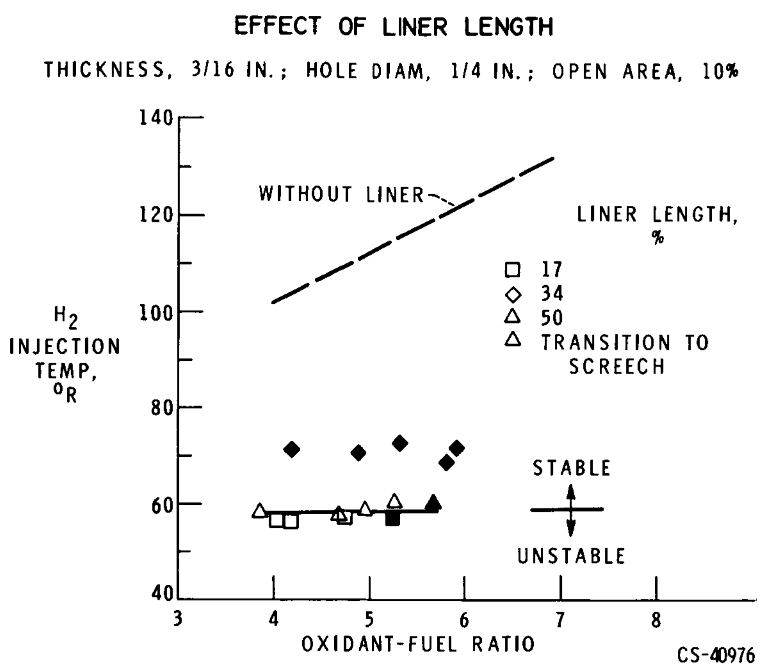

Figure 13

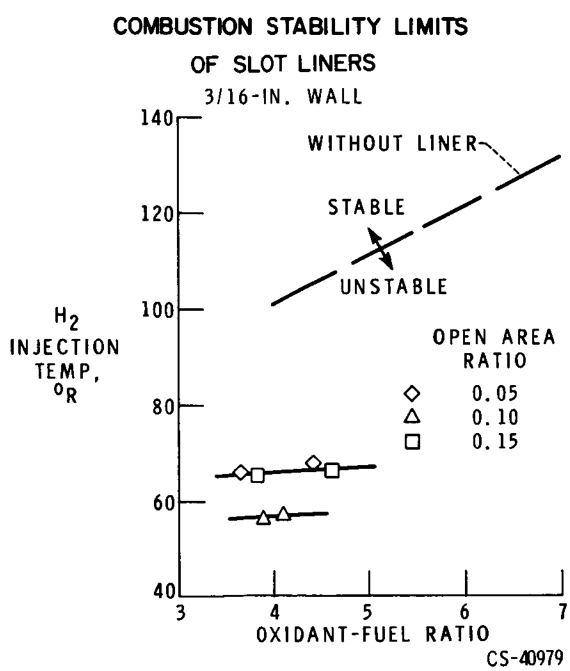

Figure 14