Dec. 23, 1958 A. W. BLACKMAN, JR., ET AL 2,865,174

SCREECH REDUCTION IN COMBUSTION CHAMBERS

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FIG. 1

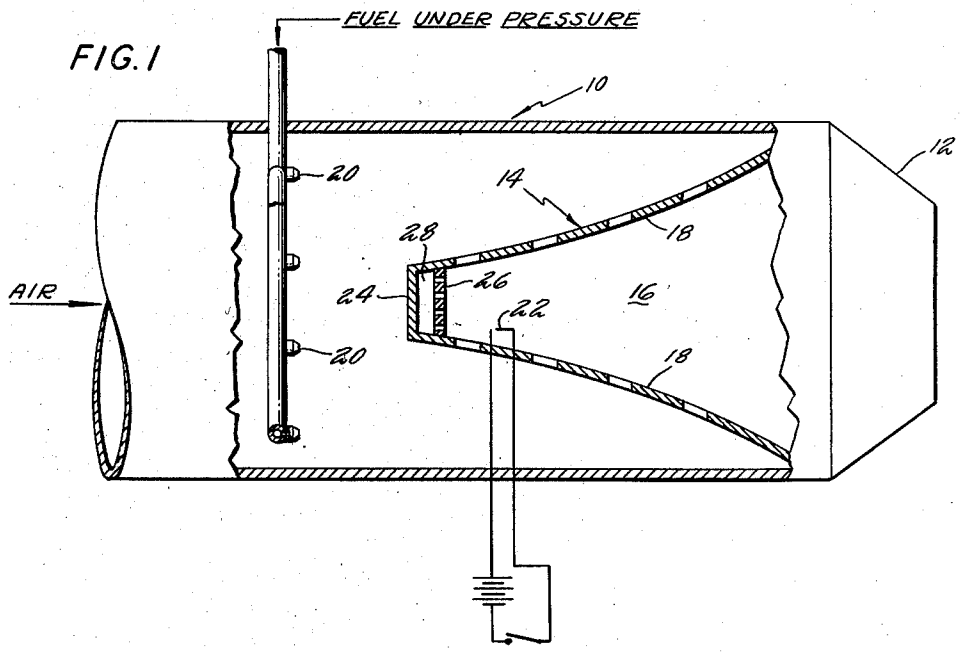


FIG. 2

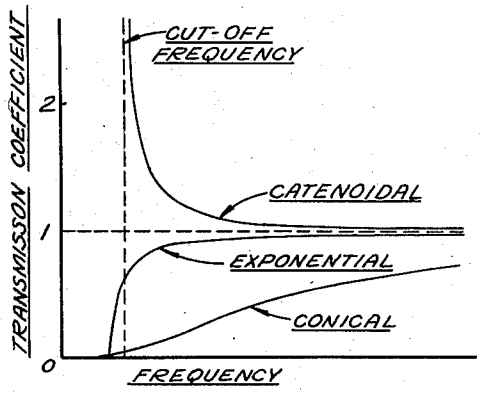
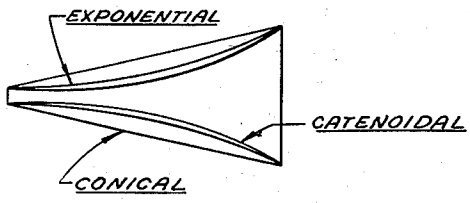


FIG. 3



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SCREECH REDUCTION IN COMBUSTION CHAMBERS

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This invention relates to screech reduction in combustion chambers and more particularly to the problem of screech reduction of high output combustion chambers.

In combustion chambers screeching combustion is characterized by high amplitude flamefront and pressure oscillations occurring at a resonant frequency of the combustion chamber cavity. This type of combustion usually occurs in high output combustion chambers such as those used with rockets, ramjets, and turbojet afterburners. These high amplitude pressure fluctuations usually destroy the combustion chamber in a matter of seconds. It is therefore an object of this invention to provide a combustion chamber configuration in order to control the foregoing instabilities of combustion.

These and other objects will become readily apparent from the following detailed description of the drawing in which:

Fig. 1 is a schematic illustration in partial cross section of a typical burner configuration according to this invention.

Fig. 2 is a graphic illustration of the properties of three shapes of combustion chambers, and

Fig. 3 graphically illustrates the comparative shapes of the combustion chambers whose properties are analytically displayed in Fig. 2.

According to this invention a means for reducing or eliminating screech instabilities is provided through the use of exponentially or catenoid shaped combustion chambers. Thus it has been found that straight sided or conically shaped combustion chambers must be avoided in order to improve the screech operation of combustion chambers. Thus for example as shown in Fig. 1, an outer casing is generally indicated at **10** which terminates in aft exhaust nozzle **12**. The nozzle **12** receives gases from a combustion section generally indicated at **14** which has a combustion chamber **16** defined by perforated walls **18** which are curved and diverge in a downstream direction. The shape of the walls **18** according to this invention are preferably catenoidal or exponential rather than of conical shape.

Fuel is introduced through a plurality of nozzles **20** which are located sufficiently upstream of the combustion chamber to provide a thorough mixing with the incoming air. The mixture of fuel and air is ignited by any suitable means **22** within the combustion chamber at an upstream location therein. The upstream end of the combustion chamber is defined by an imperforate wall **24** which runs transversely of the perforated wall **18**. Another transverse perforated wall **26** is located upstream and substantially parallel to the wall **24** thereby forming a tuned chamber **28** therebetween. The wall **26** is in the form of an absorption liner tuned to the resonant frequency of the combustion chamber so as to eliminate longitudinal oscillations therein.

The advantage of the exponential or catenoid combustion chamber shape for eliminating resonant oscillations becomes apparent by comparing the curves or plots of transmission coefficient vs. frequency presented in Fig.

2. The transmission coefficient is a measure of the radiating efficiency of a horn combustion chamber and is defined as the ratio of the power radiated out of a given horn to a power radiated by the same excitation source moving with the same velocity into a cylindrical tube of infinite length having the same cross-sectional area as the small end of the horn. It can be seen from Fig. 2 that for frequencies above the cut-off frequency practically all the energy is radiated outwardly of the horn so that substantially no resonance can occur within the combustion chamber. In other words, below the cut-off frequency any energy or waves will tend to remain within the combustion chamber horn and resonate therein. On the other hand, any waves above the cut-off frequency will tend to radiate aft and outwardly so that they have substantially little or no effect on the combustion chamber proper. Oscillations in the transverse modes will be eliminated because of the scattering effects produced by the diverging combustion chamber walls. Longitudinal resonance below the cut-off frequency can readily be absorbed by the absorption liner **26**. It should be added that Fig. 3 in the drawing is intended to show the configuration of the various combustion chambers whose properties are defined by the graphic analysis in Fig. 2.

In further consideration of the problem solved by this invention reference should be made to the following:

Theoretical considerations

A general equation for a horn-shaped combustion chamber can be written as:

$$y=y_0\left[\cosh\left(\frac{x}{h}\right)+T\sinh\left(\frac{x}{h}\right)\right] \qquad (1)$$

The symbols are defined in the nomenclature section. When $T=h/x_0$ and h is allowed to go to infinity the horn is conically shaped with a half angle equal to

$$\tan^{-1}\left(\frac{y_0}{x_0}\right)$$

When $T=1$,

$$y=y_0e^{\frac{x}{h}} \qquad (2)$$

and the horn is exponentially shaped, and when $T=0$,

$$y=y_0\cosh\left(\frac{x}{h}\right) \qquad (3)$$

and the horn is catenoidal.

In general, there are two basic ways by which a horn-shaped combustor can reduce combustion instabilities; (1) by eliminating resonance through radiation of pressure pulsations, or (2) by eliminating resonance through dispersal of pressure oscillations. The effectiveness of the various horn shapes for the elimination of instabilities by radiation can be determined by comparing the "transmission coefficients" for the various shapes. The transmission coefficient is defined as the ratio of the power radiated out of a given horn to the power radiated by the same excitation source moving with the same velocity into a cylindrical tube of infinite length having the same cross-sectional area as the small end of the horn. It can be seen from Fig. 2 that above a certain frequency (defined as the cut-off frequency) the catenoidal and exponential shapes are superior to the conical shape as radiators. Above the cut-off frequency they radiate practically all their energy input and, hence, no resonance should occur in the horn. For the exponential and catenoidal shapes the cut-off frequency can be written as

$$\nu_0=\frac{c}{2\pi h} \text{ providing } y_0\ll h \qquad (4)$$

Below the cut-off frequency there is no true wave motion in the horn and pressure waves originating at the small end of the horn decay exponentially as they travel toward the large end. There appears then to be two possibilities for eliminating resonance within the horn, (1) when the cut-off frequency is high with respect to the frequency or frequencies to be eliminated, and (2) when the cut-off frequency is low with respect to the frequency to be eliminated. In general, the first method is considered to be more effective, but the method to be used will depend on the frequencies to be eliminated and the space available for the combustion chamber.

Nomenclature

y—Coordinate in y direction
x—Coordinate in x direction
y_0—Radius of the small end of a horn
x_0—Distances from the throat of a conical horn to where the apex of the cone would be if the cone extended back to its apex
T—A coefficient having a value between zero (0) and one (1)
h—Distance in which the diameter of a horn cross section increases by a factor e=2.718
c—Velocity of sound
ν_0—Cut-off frequency
d—Diameter of horn
d_0—Diameter of horn at the throat

It therefore has been shown that the shape of a combustion chamber should be either catenoid or exponential or shall take a shape which will be somewhat in a range between these two configurations. This is best explained by stating that the combustion chamber horn shape is best defined as in Equation 1 above where the value of T is between zero and one. In addition, it should be added that the length of the horn should be slightly less than or equal to the combustion chamber length and that the diameter of the small end of the horn should be smaller than the value 2_h.

As a result of this invention, it will be apparent that a highly efficient and safe combustion chamber configuration has been provided whereby destructive screech burning of high output combustion chambers is eliminated.

Although several embodiments of this invention have been illustrated and described herein, it will be apparent that various changes and modifications may be made in the construction and arrangement of the various parts without departing from the scope of this novel concept.

What is desired by Letters Patent is:

1. In a jet type power plant having an elongated combustion section, an outer casing defining said combustion section, said section having a longitudinal axis, a burner located in said casing and having a flow of gases therethrough along its longitudinal axis, said burner having side walls perforated throughout their length and which are continuously curved and diverge in a downstream direction and terminate at their downstream end adjacent said outer casing, an imperforate wall portion running transversely of said perforate walls and located adjacent the upstream end of said burner, a perforated wall member

spanning said burner transversely of said axis and running parallel to said imperforate wall portion and located downstream thereof, said transverse wall and member forming a tuned chamber, means for injecting fuel upstream of said imperforate wall portion, and ignition means adjacent said imperforate portion.

2. In a power plant according to claim 1 wherein said curved walls define an exponential curve.

3. In a power plant according to claim 2 wherein said curved walls define a catenoidal curve.

4. In an axial flow burner construction, a duct having a combustion supporting gas flowing therethrough along a substantially longitudinal axis, a combustion section in said duct including walls diverging from the axis of said duct in a downstream direction forming a horn, a tuned chamber at the upstream end of said combustion section, said walls being continuously curved in said downstream direction and being perforated over a major portion of its axial length, the curvature of said wall being defined by the equation,

$$y=y_0\left[\cosh\left(\frac{x}{h}\right)+T\sinh\left(\frac{x}{h}\right)\right]$$

with T having a value substantially between zero and one, and where

y=coordinate in y direction
y_0=radius of the small end of a horn
h=distance in which the diameter of a horn cross section increases by a factor e=2.718
x=coordinate in x direction
T=A coefficient having a value between zero (0) and one (1)

5. In an axial flow jet propulsion type power plant having an elongated combustion section, a casing defining said combustion section and having a longitudinal axis, an elongated burner located in said casing and being coaxially disposed therewith whereby the combustion fluids flow substantially along said axis, said burner having continuously perforated side wall portions which are substantially continuously curved and diverging in a downstream direction, said wall portions terminating at their downstream end adjacent said casing, an imperforate burner wall portion forming a closed upstream end of said burner, a perforated wall portion in said burner downstream of said imperforate burner and forming a tuned chamber in cooperation with said burner side wall portions, means for introducing fuel upstream of said burner whereby the fuel and air mixture pass from outside to the inside of said burner through the perforations of said side wall portions, and means in said burner for igniting the combustion fluids.

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