Excitation of an Acoustic Resonator by Turbulent Flow

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Excitation of an Acoustic Resonator by Turbulent Flow

Summary of the paper briefly:

1) Mechanism of strong excitation of s.p. at resonant frequency by spurious flows - specifically applied here to excitation of an annular resonator by turbulent pipe flow. It is believed that the results may be equally well applied to excitation of resonators by turbulent boundary layers such as occur on aircraft surfaces on along the walls of windtunnels.

2) It is suggested that shear layers which form across the resonator at its face interact with the downstream edge forming a jet edge system whose operation is enhanced by the presence of a resonator in the jet. The most extensively studied jet edge system has been that giving rise to the bedstone model. We will briefly justify the assertion that the edgetone and the excitation of a jet edge resonator system are similar phenomena.

3) Having established these similarities, it is possible to draw certain conclusions from bedstone behaviour and apply them to the jet edge resonator system, especially as regards the relation between shear layer disturbance wavelength and on-axis dimension. This relation in turn gives rise to a simple approximate formula which predicts the occurrence of peak resonator excitation.

4) Finally, experiments will be briefly described which demonstrate that the operation of the jet edge resonator system is consistent with the proposed jet edge model.
Edgetone Operation
- to refresh memories - a typical jet edge config shown in

Slide 1

1. If the thin jet exiting from left is unstable it will begin to oscillate
   - creating a fluctuating flow field
   - edge plate placed in the path of the jet - which gives rise to a dipole-like disturbance source. The edgetone source produces an acoustic frequency gradient which stabilizes the edgetone operation at a particular frequency.
   - this frequency is directly proportional to jet velocity and inversely prop to jet edge sep

2. - J - T - of edgetone by transition to higher freq regimes - velocity increased
   - transitions - maintain jet oscillation
   - x in region of max jet instability

4 min

2. Quantitatively the stable operation of the edgetone may be characterized by a gain criterion suggested by Powell

[shown at bottom of slide 1]

Here: \( \gamma \)'s are so-called effectiveness coefficients - the effectiveness with which these oscillations give rise to fluctuating flow near the edge
fluctuations give rise to a propagating disturbance. The effectiveness with the propagating disturbance in turn perturbs the flow.

- These 3 factors and the amplification of a flow perturbation by the jet instability describe the operation of the classical edge tone.

- If a resonator is present, two additional factors are required to determine the effectiveness with which the edge excite the acoustic resonances, and $\beta$, being the effectiveness with which the acoustic resonance distorts the flow.

- Existence of a feedback circuit operating on the flow may be considerably different if a resonator is present.

- From gain criterion, several limiting cases

1. **First**, if $\beta$ is large and the feedback terms are small, the development of the shear layer oscillation between the jet exit and the edge result simply from amplification of flow perturbation (typically at the natural instability point) by the natural amplification of the flow. Feedback is controlled.

2. **Secondly**, if $\beta$ is small and the feedback terms are large growth of the shear layer oscillations result from a forcing along the entire length of the shear layer between the jet exit.
and the edge by the acoustic feedback - this case may be called feedback controlled.

Free - generally V-edge tones operate somewhere between these extremes.

Jet-edge - resonator systems. Based on edgeline experiments.

Now - before we can make predictions about the behavior over the orifice of an acoustic resonator - such as that shown in

Slide 2

we must answer several questions. Since superficially the 2 configs appear similar.

1) First - can edge-tone phenomena occur in the flow in turbulent? It is a common misconception that edgeline operation is restricted to low-speed laminar operation, but from the fact that most of the well-known experimental investigations have treated this case - In fact turbulent edgelines have been investigated and have been observed to occur up to speeds of Mach 1.

2) a) To change the characteristic of flow disturbances by the introduction of edge-tones and b) to smaller values than corresponding laminar case since deceleration oscillations are limited by vortex formation.
and subsequent degeneration into 3-D turbulence.

so turbulent jet-edge system may exist.

2. Secondly, there is the question of geometry.

The edgewise configuration shown in the previous sketches and the system shown there appear considerably different but in fact there are important features:

First, a separation shear layer which forms downstream of a separation point, and

(ii) a downstream obstruction.

The shear layer forms the vibrating system, and the obstruction is the source of stabilizing feedback.

It has been observed that edgewise operation is not critically dependent on the nature of the edge. Virtually any type of obstacle will do. It can also be observed that it is not necessary that there be flow around both sides of the obstruction.

Finally, there is a third question:

What is the effect of a reattachment jet to a jet-edge system, in the presence of a reattachment hole?
Thus, neither the presence of turbulent flow - nor the differences in geometry between the edgetone and the scraft system - subs in here.

From the fact that the system shown here shares the same major components (the edgetone and turbulent edgetone) and that turbulent edgetones may exist, it is not possible to conclude that the phenomenon of resonance of an acoustic generator by turbulent growing flow is in essence similar to the edgetone immediately - several conclusions may be drawn.

1. **Effects of Resonators**

   The effects of resonators on jet-edgetone operation have been thoroughly investigated.

   Their primary effect is to limit the operation of the system to the frequencies of the resonator. The presence of a resonator dampens the free growth of the edgetone.

   The effect of a resonator also produces very strong feedback caused by the edgetone to become part of the feedback control loop, thus creating instability. The flow over the orifice is destabilized controlled by the resonator.
of the resonator response

Secondly

The system is feedback controlled. It is logical to expect peak excitations when there is the greatest coupling between the feeding oscillating river layer and the feedback mechanism, i.e., the cause for resonance. Thus, the system will tend towards the form shown in stick 3,

which shows that the maximum net displacement in any stage is between \( x \) and \( y \) is an

\[
\frac{y}{x} = (m - 0.5)
\]

In all stages, this implies that \( y \) is twice the streamwise orifice length. In stage 2

\( y = \frac{3}{2} x \) and so on.

The condition for peak excitation results almost automatically from this condition upon substitution into

the form in which I have
written the result is
\[ f_l = kU(e^{-0.5}) \]

where \( k \) is the ratio of the shear layer disturbance convection velocity to the freestream velocity.

It also follows from the wavelength criterion that when a resonator is present during operation in stage 1, it will be preferred. Since this condition produces near the maximum resonator excitation in the second and higher stages, there will be some cancellation over part of the orifice length. Thus the excitation will be smaller.

D. Experiments

Turning now to the experiments, the apparatus actually used is shown in [Slide 4].

and consisted of a length of 75 mm pipe cut completely off on a pipe to form a circular perforated surface. A short section of 150 mm pipe was used to form the outer wall of an annular resonator which was closed at both ends by flanges. Various holes allowed the acoustic field in the resonator to be explored.
For the experiments described here, the orifice was located centrally and varied in length from 6 to 125 mm, while the resonator length was varied from 50 to 100 mm. Pipe centre line velocities ranged from 10 to 160 m/sec.

Results

The resonator was observed to be excited very strongly at frequencies corresponding to the resonator-annulus modes—the excitation sequence being from low to high frequencies as the velocity was increased.

There was no attempt to produce very high levels in the resonator, but the maximum level registered at any time during the tests was 1170 dB.

The major results are shown in slide 75 which shows the existence of two stages—confirming the edge-tone-like behavior and also a definite preference for stage 1 operation
Stage 2 peaks were all of the order of 30 dB less than Stage 1 peaks.

The numbers plotted against the groups of points correspond to inferred ratio of convection to free stream velocity, assuming that the \( \frac{\lambda}{V} = (m - 0.5) \) wavelength criterion is correct.

These values are consistent with measured convection velocities measured elsewhere and are taken to mean that the assumed wavelength criterion is at least approximately correct.

Slide 6

Shows previously reported results for the correlation of skin friction layers by turbulent boundary layers. They can be seen to display a similar trend, although the results are somewhat scattered. Probably due to the large variability of geometry from one experiment to the next.
Conclusions

Thus, I think it is possible to conclude that the excitation of sidebranch acoustic resonators occur by a process analogous to that of the edgetone, that is due to the interaction of a shear layer with a downstream edge. Knowing this, it is possible to predict at least approximately when self-excitation will be a problem and to provide insight into the elimination of such problems.
POWELL'S GAIN CRITERION for
EDGETONE operation in the
presence of a RESONATOR

$$\eta_s (\eta_t \eta_d + \eta_r \eta_d') q = 1$$

fig. 1
WAVELENGTH CRITERION

Stage 1
\[ \frac{L}{\lambda_v} = 0.5 \]

Stage 2
\[ \frac{L}{\lambda_v} = 1.5 \]

In general: \[ \frac{L}{\lambda_v} = (m - 0.5) \quad m = 1, 2, 3 \ldots \]

and: \[ f_{\lambda_v} = u_v \]

hence: \[ fL = u_v(m - 0.5) \]
\[ = \kappa U(m - 0.5) \]

where: \[ \kappa = \frac{u_v}{U} \]

fig. 3
OTHER EXPERIMENTAL RESULTS

\[ f_L (m/sec) \]
\[ U (m/sec) \]

- TSUI
- PANTON and MILLER
- MEYER, MECHEL and KURTZE
- MACK

Stage 2
Stage 1

fig. 6