MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963-A

①

FTD-ID(RS)T-1587-84

FOREIGN TECHNOLOGY DIVISION

EFFECT OF A SHEAR LAYER ON THE STABILITY OF AN
AXISYMMETRIC EXTERNAL COMPRESSION AIR INTAKE

by

Z. Kunyuan, Y. Shaozhi, P. Chenyi

AD-A190 622

88 3 09 010

EDITED TRANSLATION

FTD-ID(RS)T-1587-84   21 October 1985

MICROFICHE NR: FTD-85-C-000928
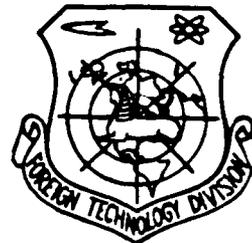
EFFECT OF A SHEAR LAYER ON THE STABILITY OF AN
AXISYMMETRIC EXTERNAL COMPRESSION AIR INTAKE

By: Z. Kunyuan, Y. Shaozhi, P. Chenyi

English pages: 10

Source: Hangkong Xuebao, Vol. 4, Nr. 3, 1983, pp. 56-62

Country of origin: China
Requester: Scitran
          F33657-84-D-0165
Requester: FTD/TQTA
Approved for public release;
distribution unlimited.

FTD-ID(RS)T-1587-84   Date 21 Oct 19 85

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this
translation were extracted from the best quality copy available.

i

EFFECT OF A SHEAR LAYER ON THE STABILITY OF AN AXISYMMETRIC EXTERNAL COMPRESSION AIR INTAKE

Zhang Kunyuan, Yu Shaozhi, Peng Chenyi
(Nanjing Aeronautical Institute)

ABSTRACT

This paper presents the effect of six shear layers with strength ranging from 5-11% entering the lip in various positions on the stability of a variable center cone external compression air intake under the condition of a M 1.72 incident stream.

It was experimentally proven that a shear layer below 10% in strength entering the axisymmetric intake near the lip did not cause boundary layer separation inside the intake cowl. A shear layer up to 11% in strength could enter the intake duct in any position at its entrance without causing buzz. The literature shows a shear layer with 6-7% strength can lead to a buzz in a two-dimensional air intake. Thereby, it was demonstrated that an axisymmetric intake duct has a higher resistance to buzz caused by the shear layer.

I. Introduction

The stable operating range is an important characteristic for a supersonic air intake under subcritical conditions. In the past decades, many scholars had conducted research on this subject and different theories were introduced. This paper studies the effect of a shear layer on the stability of an axisymmetric external compression air intake.

Ferri's shear layer theory which is well recognized has been verified by many investigators [1]. His theory states: When a shear layer which is formed by the intersecting of shock waves enters the air intake near the cowl lip, it causes a boundary layer, separation from the inside cowl surface and induces a buzz in the intake. This is the well known Ferri criterion.

In the late 1960's in the UK, Fisher and others successfully applied Ferri's criterion to the design of the two-dimensional air intake for the supersonic transport "Concorde"[2]. They pointed out that a buzz could occur when the shear layer with a strength of not less than 6~7% entered the lip of the air intake. The strength is defined as the ratio of the total pressure of the upstream before the interception of the shock waves. Their report also pointed out that the tendency of the separation of the boundary layer on the inside cowl surface increased with increasing shear layer strength and decreased with increasing distance between the shear layer and the cowl.

The Fisher's result is very valuable for a two-dimensional air intake. However, it cannot directly solve similar problems of axisymmetric air intakes. There are differences between these two types of air intakes, because their reactions to a shear layer and other details are quite different. This paper presents the effect of a shear layer on the subcritical stability of the axisymmetrical air intake.

II. Shear layer of a typical biconic intake   /57

Let us first study the behavior of a biconical air intake with a maximum incident flow of M = 2.2. The half angles of first and second cone of the intake duct center cone are 17.5° and 25°, respectively. At an incident flow of M = 2.2, the first oblique wave will seal the intake. At M < 2.2, the second shock will cover the intake. When M is between 1.8 and 2.2, theoretically there are three different situations in this critical and subcritical operating condition: (1) critical, (2) slightly sub-critical and (3),
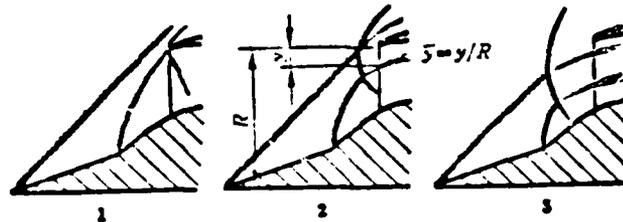
2

comparatively large sub-critical (Figure 1).

Figure 1. Shock systems of a biconic intake

Now, based on the structures of the above wave systems, let us calculate the shear layer strength. The definition of a shear strength can be expressed as follows:

$$S = \frac{\text{total pressure difference of the two sides of shear flow}}{\text{total pressure of incoming stream}} \times 100\%$$

Figure 2 shows the calculated results. In addition, the distance "y" (or the relative distance "$\bar{y}$") between the second shock shear layer and the cowl lip is one of the important factors affecting the magnitude of the shear layer. "y" or "$\bar{y}$" is a *function of the Mach number and the coefficient of flow ϕ (see* Figure 3).
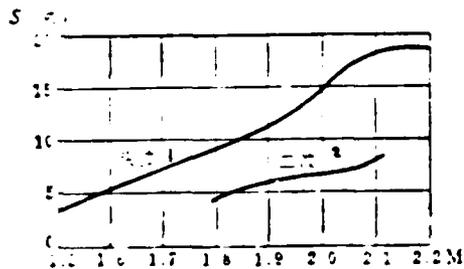

Figure 2. Variation of strength S_v with M
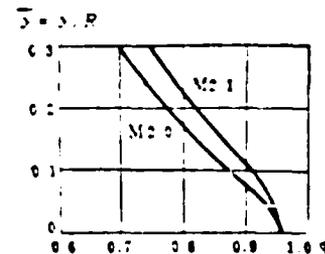1--first shock; 2--second shock

Figure 3. Variation of $\bar{y}$ with ϕ

From the calculated results, we can see when M = 1.8-2.1, the shear layers of the biconic air intake have the following two basic characteristics:

(1) The shear layer of the first shock wave is stronger.
Its strength ranges between 8.8-17.8%. Nevertheless, in the
vicinity of critical conditions, this stronger shear layer will
not enter the cowl lip. It will enter the cowl lip only under
comparatively large subcritical conditions.

(2) The strength of the shear layer of the second shock wave
is between 4.8~8.0%. It enters the cowl lip at the beginning of
subcritical conditions. The maximum value occurs when the flow
coefficient $\phi < 0.9$ and distance $\bar{y} > 0.09$.

Based on experimental data published abroad, we noticed that
the weakest shear layer to cause the buzz of an axisymmetric air   /58
intake had a strength of 14.2% [3]. Based on this fact, it is
believed that any shear layer with strength greater than 14.2%
should not be allowed to enter the cowl lip in our analysis. This
paper focuses on the study of the correlation between the shear
layer and the axisymmetric air intake while the shear layer strength
is below 14.2%, yet much higher than the Fisher's 6~7%.

III. Test model and equipment

The experiment model used was the single cone external com-
pression air intake type with an adjustable apex angle. The posi-
tion of the cone axis could be adjusted. This model could generate
shear layers with strengths of 5.2, 6.1, 7.9, 9.1, 10.2 and 11%,
respectively. The shear layer could also be allowed to enter the
cowl lip from a different distance "y". The inlet diameter of the
model $\phi = 106$ mm; wind tunnel test section, 300x300 mm; and R $\stackrel{\sim}{\sim}$
2×10^6 as calculated from the intake diameter of the model. Along
the model flow range, four dynamic pressure transducers and ports
for measuring static pressure and total pressure were installed
in order to measure the static and the dynamic parameters under
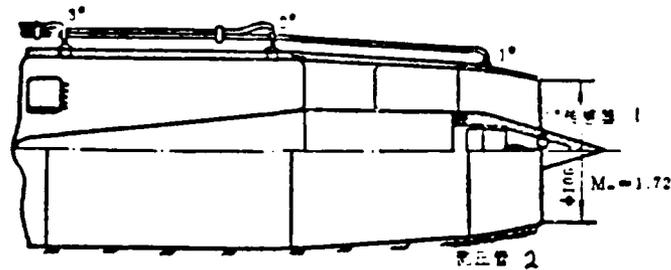different conditions. Figure 4 shows the sketch of the model.

4

Figure 4. Model of intake

1--transducer; 2--pressure measuring tube

IV. Test results

(1) Before and after the shear layer with a strength of 11%
entered the cowl lip, the cross section of the air intake exit
end did not show any static pressure fluctuation.

Six cones with different apex angles were, respectively, posi-
tioned according to design so that each shock wave would cover the
intake. During experimentation, each shear layer of the six
different strengths at the cowl lip were either allowed or not
allowed to enter the intake duct. At the same time, we closely
observed if there is any apparent change in the working condition
of the air intake, especially any change in the static pressure
fluctuation on the exit cross section. It was found when a shear
flow with any one of these six strengths entered the air intake at
the cowl lip, the air intake did not show any sign of buzzing. Only
when the shock wave was pushed a distance from the cowl lip, the
intake began to buzz, i.e., the positive shock wave started flutter-
ing, and the static pressure at the exit increased significantly.
In other words, there existed a maximum stable subcritical operating
condition. See Table 1.

Figure 5 shows the plot of the existing static pressure at the
exit of the air intake duct with 24° apex angle when $1 > \phi > 0.93$.
Although the shear layer with a strength of 10.7% already entered
the cowl lip, there was no apparent change of the pressure fluctua-
tion in the supercritical condition.

5

TABLE 1. Parameters at the limit of stable subcritical operation

1. 名 称	2. 锥 角 ↑	2··	24°	20°	18°	··
3 试验中剪变层强度 S_7 %		···	···	9.4	7.8	6.1
4 正激波最大稳定距离（距唇口）(mm)		11	11	13	5	4
5 此时工下流量系数 ¢		0.94	···	0.91	0.95	0.95
6 此时剪下平变层距离 (mm)		·	6.3	8.2	3.6	3.0
7 剪变层进入前出口压力脉动 $\frac{\Delta P_M}{P}$		···	···~2	1~2	1~2	1~2
8 剪变层进入后出口压力脉动 $\frac{\Delta P_M}{P}$ %		1~2	1~2	1~2	1~2	1~2

1--description; 2--apex angle; 3--shear layer strength during testing; 4--maximum positive shock wave stable distance (from cowl lip); 5--ditto, coefficient of flow; 6--ditto, shear layer distance; 7--pressure fluctuation at exit before shear layer entering the intake; 8--pressure fluctuation at exit after shear layer entering the intake

Figure 5. Pressure fluctuation at exit of 24° cone model.

1--supercritical condition before shear layer entering the intake ¢ = 1; 2--stable subcritical condition after the shear layer entering the intake ¢ = 0.98-0.92; 3--buzz ¢ = 0.64

In short, when a detectable unsteady flow begins to appear in the air intake, the shear layer has already departed from the cowl lip for a considerable distance. Therefore, it is reasonable to conclude that the unsteady stream is not caused by the shear layer, but is possibly caused by the separation of the boundary layer of the central body.

(2) The strongest shear layer, when entering the cross section of the intake duct from different distances, does not induce buzzing.

6

TABLE 2. Results obtained with the strongest shear layer entering
the cowl at different distances from lip

1. 试 验 方 法	2. 逐步后退中心锥维持临界工况								3. 中心锥固定逐步推出正激波
4. 剪切层距离 y	0	2	3	4	5	7	7.5		10~2
5. 出口压力脉动	1~2	1~2	1~2	1~2	1~2	1~2	1~2	1~2	1~2
6. 进气道工况		7		无 任 何 喘 振 迹 象					

1--test method; 2--gradually retracting the center cone to
maintain the critical condition; 3--center cone fixed, pushin·
out the positive shock wave step by step; 4--shear layer distance,
y (mm); 5--pressure fluctuation at the exit; 6--intake duct working
condition; 7--no detectable buzz

We used two different methods to control the entrance distance
"y" of the shear layer. First, we gradually retracted the center
cone to maintain the critical condition. Secondly, at a fixed
cone position, we pushed the positive shock wave toward the cone
apex step by step. Thus, the distance "y" between the shear
layer and the cowl lip gradually increased to approach the center
cone. Table 2 shows the results obtained with the strongest shear
layer entering the cowl at different distances from the lip.

No buzz was induced when the shear layer entered at any posi-
tion of the lip cross section of our experimental air intake assembly.

We conducted similar experiments for the other five shear
layers of different strengths. The results were practically the
same as above. Therefore, the six shear layers of different
strengths in this investigation did not induce the air intake
buzzing regardless of the distance of entrance from the lip.

(3) Characteristics of the flow separation on the inside
cowl surface.

It is generally believed that the buzz induced by the shear
layer is caused by the separation of the boundary layer on the inside
cowl surface. Therefore, the presence of the separation zone is a
necessary condition to cause this type of unsteady flow. In our

7

experiment, we noticed that the shear layer did not have the capa-
bility to initiate a buzz in the air intake. Therefore, it was
important to investigate whether or not the shear layer initiated
the boundary layer separation on the inside cowl surface. We studied
the characteristics of boundary layer separation on the inside cowl   /60
surface with the shear layer of different strengths entering the
lip at various distances. Figure 6 shows the test results. In this
diagram, there are 16 test locations. When the strength was less
than 10%, no separation of the boundary layers inside the cowl lip
was observed at seven locations. The corresponding static pressure
fluctuations also did not reveal any abnormalities. The amplitudes
of the pressure fluctuations ranged only between $1 \sim 2\%$ of the
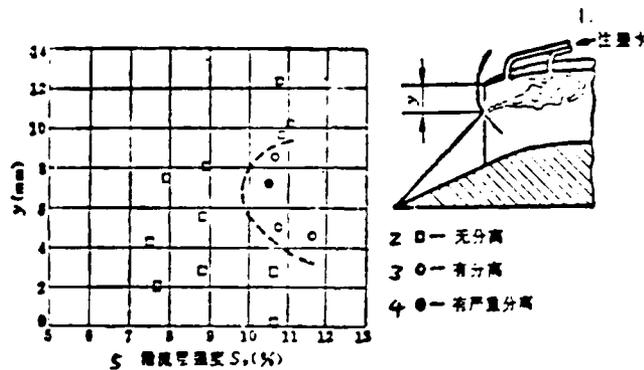total pressure of the incoming stream.

Figure 6. Effect of strength S_v and distance v on cowl
          lip separation.

1--ink injection; 2--□ - no separation; o - separation;
● - serious separation; 5--strength of shear layer S_v(0/0)
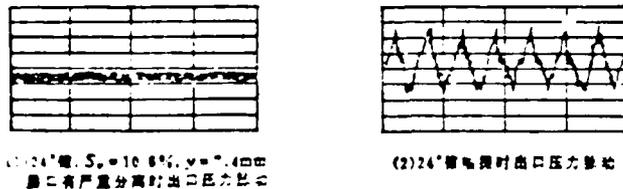

Figure 7. Pressure fluctuations at exit of 24° cone
          model.
     (1) without end (2) with buzz
1--24° cone, pressure fluctuations at exit when serious separation
   occurs at the cowl lip;
2--24° cone pressure fluctuations at exit during buzzing

8

When the shear layer strength was greater than 10%, four out of nine test locations showed separations on the cowl lip. One of them, S_v = 10.6% and y $\overset{\sim}{\sim}$ 7.4 mm, was quite serious. However, even when a boundary layer separation zone exists, the static pressure fluctuations at the model's exit remains still very small (Figure 7). This observation indicates that buzz will not be induced when the boundary layer separation does not seriously block the intake.

Moreover, we observed that there was a certain distance at which the shear layer would cause the most significant effect. Outside the range of y = 5 to 9 mm, the shear layer with a strength of 11% could not cause the separation of the boundary layer. In this investigation, the most significant effective distance is $\bar{y}$ = y/R = 10~18.

This investigation has proven that the shear layer with a strength (S_v) of 11% will not damage an axisymmetric intake duct. Based on this observation, we can predict that in an axisymmetric air intake, the shear layer strength shall be higher than 11% before it can induce a Ferri type unsteady flow.

As it should be, for the air intake of a full size engine, it is not a simple problem to determine the maximum tolerable shear layer. Other factors must also be considered. Hence, the results of this investigation should not be considered as a unique criterion. However, based on our investigation and other published results of two-dimensional air intakes, we can conclude that the axisymmetric air intake can stand higher strength shear flow than the two-dimensional air intakes.

V. Conclusions

(1) In order to cause a separation of the boundary layer on the inside cowl surface of an axisymmetrical air intake, the shear layer strength has to exceed 10%. However, no buzz can be induced if the separation does not seriously block the stream.

9

(2) A significant separation of the boundary layer occurs only
when the shear layer enters the cowl at a certain distance from the
lip. In this investigation, we find that the distance is between
10 ~ 18% of the cowl radius, i.e., 5~9 mm.

(3) A shear layer with a strength of 11% will not cause the —
air intake to buzz. The axisymmetric air intake can stand a
higher shear layer strength than the two-dimensional air intake.

REFERENCES

[1] A. Ferri and L. M. Nucci, The Origin of Aerodynamic
     Instability of Supersonic Inlets at Subcritical
     Conditions, NACA RM L50 K30, Jan. 1951.

[2] S. A. Fisher, M. C. Neale, A. J. Brooks. On the Subcritical
     Stability of Variable Ramp Intakes at Mach Number around 2,
     ARC R8M3711, 1970.

[3] D. G. Stewart, Supersonic Diffuser Instability--the Effect
     of Design Geometry on Intakes of 25° Cone Semi-angle at
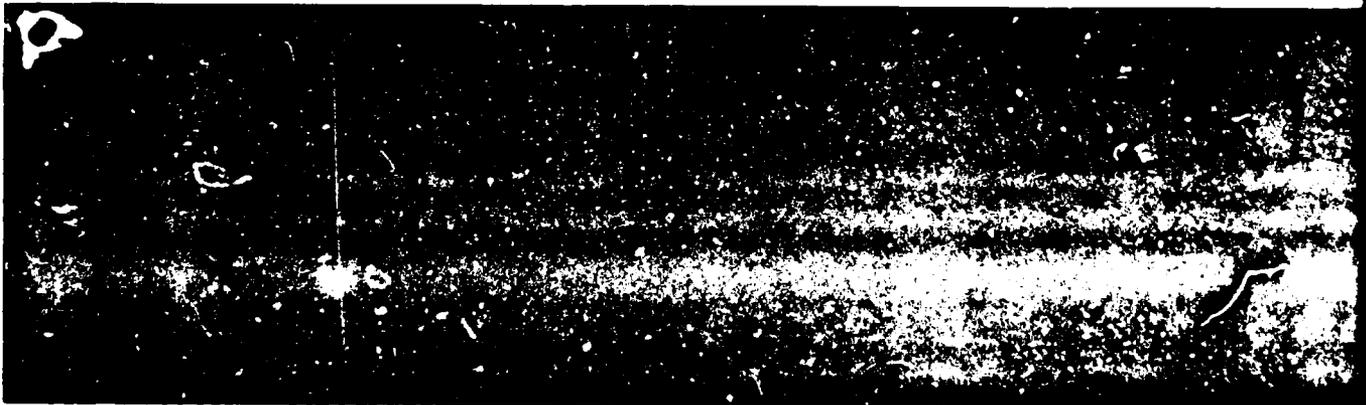   M1.83, ARL Report ME104, 1962.

END

FILMED

1 NOV 85

FTD

Doc II

SP

END

DATE

FILMED

4—88

DTIC