NASA TECHNICAL MEMORANDUM

NASA TM-77826

FOR REFERENCE

NASA-TM-77826 19850015926

GENERATION AND DEVELOPMENT OF SMALL-AMPLITUDE DISTURBANCES IN A LAMINAR BOUNDARY LAYER IN THE PRESENCE OF AN ACOUSTIC FIELD

Yu. S. Kachanov, V. V. Kozlov, V. Ya. Levchenko

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546   APRIL 1985

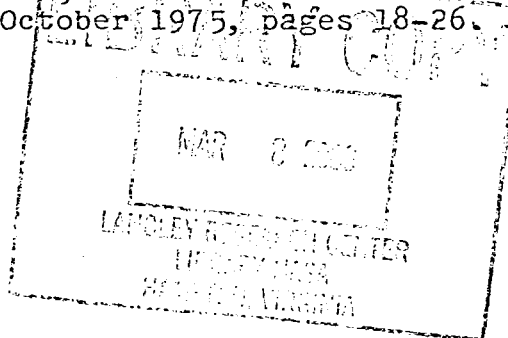| 1. Report No. NASA TM-77826	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle GENERATION AND DEVELOPMENT OF SMALL-AMPLITUDE DISTURBANCES IN A LAMINAR BOUNDARY LAYER IN THE PRESENCE OF AN ACOUSTIC FIELD		5. Report Date APRIL 1985
		6. Performing Organization Code
7. Author(s) Yu. S. Kachanov, V.V. Kozlov, V.Ya. Levchenko		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw 4004
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The effect of acoustic perturbations on the initial stage of the transition of a laminar flow into a turbulent one in a boundary layer is studied. The stage of development of small sinusoidal oscillations of the so-called Tollmin-Schlichting waves is also examined. The results of this study reveal one of the possible mechanisms for the influence of the acoustic field on the transition.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	Unclassified and Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	19	

GENERATION AND DEVELOPMENT OF SMALL-AMPLITUDE DISTURBANCES IN A LAMINAR BOUNDARY LAYER IN THE PRESENCE OF AN ACOUSTIC FIELD

Yu. S. Kachanov, V. V. Kozlov, V. Ya. Levchenko*

Researchers [1-6] have been considerably interested in the   /18**
effect of oscillations in an external flow on the transition of
a laminar flow into a turbulent one in a boundary layer. Interesting
experimental data were obtained as a result of the research; they
allowed the features of the process to be judged. In particular,
the important dependence of the transition characteristics on the
intensity and spectral composition of the applied acoustic field
was shown . However, the mechanism for the effect of acoustic per-
turbations on the transition process still remains unknown; the
available experimental material only allows us to advance definite
hypotheses (see, for example [5]). Their confirmation requires
further research.

. This publication studied the effect of acoustic perturbations
on the initial stage of the transition, the stage of development
of small sinusoidal oscillations of the so-called Tollmin-Shlichting
waves. Inasmuch as in the boundary layer type flows, this initial
stage greatly determines the entire transition process, the
results of this study reveal one of the possible mechanisms for
the influence of the acoustic field on the transition.

Experiments were conducted in a subsonic low-turbulent closed
type T-324 wind tunnel [7] with cross-section of the working
section 1 m x 1 m and flow rates 3.5 m/sec < u_o < 10 m/sec. The
degree of turbulence of the incident flow in this range of velocities
did not exceed 0.04%. Studies were made of perturbations in the
boundary layer of a flat plate made of organic glass, 1300 mm long,
1000 mm wide, 10 mm thick with ellipse-shaped nose with semiaxes

---

1

2:132 mm from the working side, and 8:132 mm from the opposite. The plate was set at zero angle of attack . An essentially gradient-free flow was thus realized above its surface, in the same way as in publication [8].

Longitudinal sound waves that propagate upwards in the flow were created with the help of 6GD.8.80 dynamic loudspeakers arranged inside the deflector at a distance about 4 m from the plate downwards on the flow. A sinusoidal signal of assigned frequency was fed to the dynamic loudspeaker through the amplifier from a GZ-18 sound signal generator. The intensity of the acoustic field in the free flow above the plate was recorded by a microphone attached to the coordinate spacer in a special deflector. The signal was fed from the microphone to the PSI-202 noise gage outlet.

In the frequency range studied in the experiments, nonuniformity of the sound field within the measurement section was no more than ±1 db.

1. In flows of the boundary layer type, the transition to turbulence occurs because of the development of small perturbations, and a large part of the zone for perturbation development is described by the linear theory of hydrodynamic stability. It was natural /19 to assume that the destabilizing effect of the external flow oscillations on the transition process observed in experiments [1-6] is explained by the intensive growth of small perturbations in the oscillating boundary layer. The first stage of the experiments therefore studied the effect of sound perturbations of varying frequency f_{so} and amplitude A_{so} on the stability characteristics of the laminar boundary layer on a flat plate.

Theoretical calculations unexpectedly showed that in the region of frequencies of external flow oscillations that are comparable to the frequencies of eigen oscillations in the stationary boundary layer, the nonstationariness of the flow does not influence the stability characteristics of the boundary layer with low amplitudes of the applied oscillations [9]. This conclusion also

2

' required experimental verification.

The experiments were conducted according to a technique that was similar to that employed in publication [8]. The vortex sinusoidal perturbations in the boundary layer (Tollmin-Shlichting waves) were created by a vibrating belt. The development of the perturbations was recorded using a wire sensor of a thermoanemometer type DISA 55D00 which moves freely along and transverse to the boundary layer. The difference in the technique was the use of a frequency analyzer FAT-1 (with transmission width of the band 4 Hz) to measure the intensity of the harmonic perturbation and increase the signal/noise ratio, and ChZ-22 frequency meter to monitor the frequencies of the signals fed to the belt and the dynamic loudspeaker.

When the frequency of the Tollmin-Shlichting wave (written further as the T-S wave for brevity) did not coincide with the sound frequency f_{so}, its intensity was measured directly at the outlet of the frequency analyzer as in the absence of a sound field.

When the frequencies of the sound wave and the T-S wave ($f = f_{so}$) coincide, changes are difficult because it is necessary to separate the sinusoidal-time signals which vary in nature, but are similar in frequency. In this case, the common signal fed to the outlet of the thermoanemometer is formed, first, of a signal linked to the vortex perturbation in the boundary layer (T-S wave) which must be measured, second, of a signal induced directly by sound perturbations for which the thermoanemomenter is also sensitive, and third, of a signal caused by vibration in the coordinate spacer which rests on the vibrating plate.

In order to separate these signals which are roughly equal in the magnitudes, a special technique was used which used the "fast" dependence of the phase of the first of these perturbations on the longitudinal coordinate x. Under experimental conditions, the T-S wavelength was $\lambda \sim 20$ mm. At a distance $\lambda/2$, its phase

3

changed by 180°, while the phase and the amplitude of the signal associated with vibration of the coordinate spacer and the plate remained approximately constant under experimental conditions. The same could be said of the phase and amplitude of the signal directly associated with sound perturbations (sound wavelength was no less than 2 m). As a result, the superposition of the two sinusoidal signals of the second and third type yielded a sinusoidal signal b = $B\cos(2\pi f_{so}t+\phi)$ (t--time), whose amplitude B and phase $(2\pi f_{so}t+\phi)$ could also be considered to be independent of x at distances $\_\lambda/2$. The coherence of all types of signals was guaranteed by feeding voltage to the belt and the dynamic loudspeaker from one generator.

Under these conditions, for the root-mean-square quantity e_Σ of the total signal taken from the outlet of the thermoanemometer and compiled of all three components, it is easy to obtain the expression

$$e_\Sigma^2 = \frac{B^2}{2} + \frac{A^2(x)}{2} + B \cdot A(x) \cos(\varphi - 2\pi x/\lambda),$$

(1)

where $a = A(x)\cos(2\pi f_{so}t - 2\pi x/\lambda)$--signal of the first type, i.e., T-S wave (we examine the case of $f=f_{so}$). The dependence of A on x reflects the increase or damping in the perturbation with movement in the boundary layer on the longitudinal coordinate.

At point $x = x_0$, where $\cos(\phi - 2\pi x/\lambda) = 1$, we have

$$e_{max}^2 = \left(\frac{B}{\sqrt{2}} + \frac{A(x_0)}{\sqrt{2}}\right)^2 \text{ i.e. } e_{max} = e_f + e_{TS}(x_0),$$

(2)

and at point $x = x_1 = x_0 + \lambda/2$

$$e_{min}^2 = \left(\frac{B}{\sqrt{2}} - \frac{A(x_1)}{\sqrt{2}}\right)^2, \text{ i.e. } e_{min} = e_f - e_{TS}(x_1),$$

(3)

where the designations e_f and $e_{TS}(x)$ have been introduced for the root-mean-square magnitudes of perturbations b and a respectively, and designations e_{max} and e_{min} for the maximum and minimum values

4

$e_\Sigma(x)$. Subtracting (3) from (2), we obtain

$$\frac{e_{TS}(x_0) + e_{TS}(x_1)}{2} = \frac{e_{max} - e_{min}}{2}$$

or

$$e_{TS}(x_2) = \frac{e_{max} - e_{min}}{2}, \quad \text{where} \quad x_0 < x_2 < x_1. \tag{4}$$

The right side of equation (4) gives us the root-mean-square value of T - S wave intensity at a certain point x_2 betwen points x_0 and x_1. In the experiments, the middle of interval (x_0, x_1) was taken as this point; it corresponds to linear interpolation for the function $e_{TS}(x)$ at the given interval. Under experimental conditions, this interpolation is justified by the slowness of the change in $e_{TS}(x)$.

When the thermoanemometer sensor moves downwards over the flow, curves $e_\Sigma(x)$ were obtained which are approximately described by equation (1). A typical experimental curve $e_\Sigma(x)$ is presented in figure 1. The values e_{max} and e_{min} that were found with the help of interpolation in each period were substituted into (4). Values were thus obtained for intensity of the T-S wave $e_{TS}(x)$ at each period.

Movement of the sensor on the longitudinal x coordinate during each cycle of change was made with constant value of voltage E in the diagonal of the thermoanemometer bridge, i.e., along the line which equals the average flow velocity, which under experimental conditions corresponded to motion with constant dimensionless transverse coordinate $\eta = y/\sqrt{vx/u_\infty}$, where y--distance to surface of the plate, while v--kinematic viscosity of air.

Using these measurements with fixed values of T-S wave frequencies and sound, curves were constructed for increment in the T-S waves on the longitudinal x coordinate. The relationship
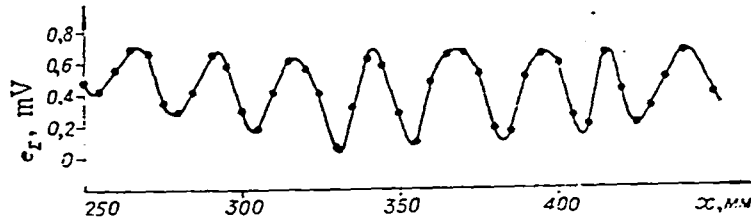
Figure 1. Typical Curves for Change in
Root-Mean-Square Magnitude of
Summary Signal from Thermoanemometer
on Longitudinal Coordinate with
$F=F_{so}=156 \times 10^{-6}$, $u_\infty=8.7$ m/sec.

$\ln(u'/u'_n)=f(x)$, where u'--root-mean-square magnitude of the vortex
mode of perturbation for the longitudinal velocity component,
while u'_n -- its value at a random initial point determined the
points on the neutral curve which were then plotted on a graph in
coordinates (F , $Re_{\delta \cdot}$), where $Re_{\delta \cdot}=\frac{\delta^\cdot u_\infty}{\nu}$ --Reynolds number computed

from the thickness of displacement δ^*. As in publication [8], the
measurements were made in the region of maximum perturbation $u'=u'(\eta)$.

The experiments were conducted in a range of change in sound
signal frequency f_{so} from 32 to 150 Hz. The frequency parameter
for the sound $F_{so} = 2\pi\nu f_{so}/n^2_\infty$ changed in limits from 100×10^{-6}
to 600×10^{-6}, and for the T-S wave, $F = 2\pi\nu f/u^2_\infty$ changed in limits
from 100 to 10^{-6} to 400×10^{-6}.

It is customary to characterize the condition of the oscillating
boundary layer by the parameter $\zeta = 2\pi f_{so}x/u_\infty = F_{so}Re_x$ (values $\zeta < 1$
correspond to the quasistationary mode, $1 < \zeta < 10$--to the inter-
mediate, and $\zeta > 10$--to the high-frequency mode [6]). In these
experiments, the parameter ζ changed in limits from 7 to 200 with
$F \neq F_{so}$ and from 11 to 40 for the case of $F = F_{so}$.

The sound amplitude A_{so} changed in experiments in limits
from 82 to 110 db. This range of change in intensity of the sound
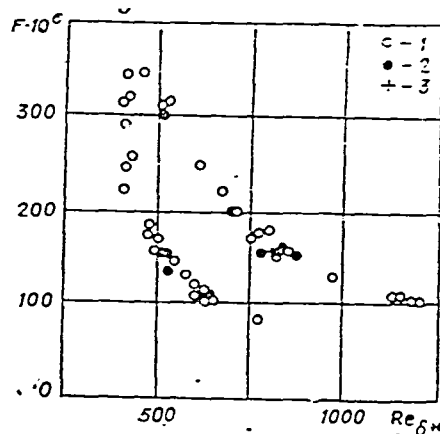waves with flow rates from 3.5 to 10 m/sec corresponds to the range

6

Figure 2. Stability Diagram
Key:
1. Stationary flow [8]
2. Flow with applied sound
    field ($F = F_{so}$)
3. Stationary flow, wave is
    generated by plate vibration

of change in acoustic component for the degree of turbulence ε_{so}
from 0.006 to 0.3%. (Level A_{so} = 82 db or ε_{so} = 0.006 - 0.017%
corresponds to the background noise in the unit which is integrated
for all frequencies).

When the sound signal frequency differed from the wave frequency
T-S ($F \neq F_{so}$), the effect of sound on the development of the T-S
wave could be observed directly when the sound was turned on and
off. It was found that the T-S wave amplitude did not change in
this case, i.e., the sound field does not have an influence on the
development of these waves.

The neutral points that were obtained when the sound field
frequencies and T-S waves were equal ($F = F_{so}$) for different
values of sound intensity A_{so} are presented in fig. 2. Figure 3
presents the curve for T-S wave increase with $F = F_{so} = 120 \times 10^{-6}$.
Comparison with the results obtained when there is no sound, as
well as those illustrated in figures 2 and 3 show that even in
this case the effect of the sound field on the development of the
T-S wave is not observed.

7

The results of the conducted experiments thus showed that in the ranges of change in the parameters indicated above, the presence of longitudinal sound waves (and plate vibrations associated with them) does not have a noticeable effect on the characteristics of laminar boundary layer stability. This corresponds to the conclusions of the stability theory of an oscillating boundary layer [9]. The strong influence of sound perturbations on the transition observed experimentally [1-5], consequently, cannot be explained by the change in the laws governing the development of small perturbations.

2. The effect of the sound field on the transition to turbulence could occur either through its influence on the laws governing the process of perturbation development and destruction of the laminar boundary layer, or through the effect on the level of perturbation of the laminar boundary layer on its initial section. The large role of the initial magnitude of eddy perturbations (T -S waves) is shown in publication [10] and was noted by the authors of this work. Because there is no effect of sound waves on the laws governing the development of perturbations at the initial (linear) stage, the authors focused further attention on the second aspect of the question.

Experimental data [1, 3-5] indicate that destabilization of the boundary layer under the influence of sound perturbations occurs when the frequencies of the applied acoustic field are in the range of unstable eigen frequencies of the stationary boundary layer. Publication [3] has noted for this case the visual observation of the waves in the boundary layer with frequencies that equal the frequencies of the applied acoustic field. The presence of induced waves in the boundary layer under the influence of the acoustic field, in addition to this work (see below), was observed in studying the structure of flow near the transition made on the same device as in this work, but using another technique [11]. However, the mechanism for excitation of eddy waves because of the significant difference in the applied (sound) and induced (eddy)
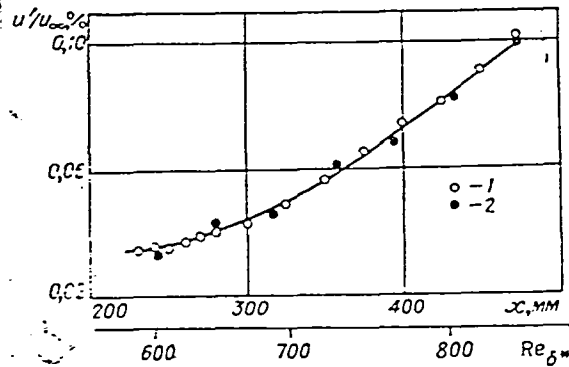
8

Figure 3.   Curves for Increment in Eddy Perturbations with $F = 120 \times 10^{-6}$

Key:
1.   Stationary flow
2.   Flow with applied sound field, $F_{so} = F$, $A_{so} = 95$ db, $\varepsilon_{so} = 0.038\%$

vibrations remained obscure. The appearance of these waves before the transition could be explained, for example, by the stronger increment in the natural T-S wave of the sound frequency under the influence of the acoustic field on the linear and later stages of development. However, if we do not speak of the nonlinear and subsequent stages of development in the perturbations, one can assume that excitation of vibrations by the acoustic field occurs through an increase in their initial amplitude.

When a transverse sound field is applied in the region of the front edge of the plate, generation of eddy perturbations was found [4]. It was found that when a longitudinal sound field was applied, there was also generation of perturbations because of vibration in the model in a transverse direction.

The measurements made with the help of a standard VIP-2 vibration meter confirmed the presence of significant time-sinusoidal transverse vibrations in the plate and generation of coherent eddies on its nose even with low intensities of sound (about 85 db). The frequency of the vibrations and the eddies always coincided with the sound wave frequency. This observation prompted the authors to study the mechanism for generation of perturbations and their

9

development in the boundary layer.

Measurements of the magnitudes of plate vibrations noted that the vibration meter sensor was sensitive to sound vibrations of air, and it became necessary to separate the signal associated with vibration of the surface, and the signal caused directly by the sound. For this purpose, the magnitude of the latter signal was measured separately by a sensor, isolated from the vibrating surfaces. The effectiveness of the vibration insulation was especially verified and was close to 100%.

The vibration amplitude essentially did not differ from the velocity of the incident flow in the range from $0 \leq u_\infty \leq 10$ m/sec, but depended significantly on the position of the vibration sensor on the plate. Only the relative amplitudes of vibration with different values of intensity A_{so} and frequency f_{so} of sound and unaltered position of the sensor, referred to the amplitude of vibrations with certain fixed f_{so} and A_{so}, figure in the further results of changes. The absolute value of the vibration amplitude reached several microns.

The eddy waves that can be generated on the front edge of the plate were studied according to the technique that is stated above for the case of $F = F_{so}$ (but without a vibrating belt, whose role was played by the front edge). The wavelengths of these perturbations and the rates of their propagation corresponded to waves T - S. With weak vibrations of the plate, the amplitude of these waves was low, and they were successfully observed only in the region of the II branch of the curve of neutral stability for the Blasius profile (after increment inside of the curve), but with strong vibrations, they could be easily recorded in the entire studied range of change in the Reynolds numbers and the frequency parameters, including in the region of branch I.

For a more reliable identification of the induced vibrations with waves T-S, profiles of perturbations were measured on the
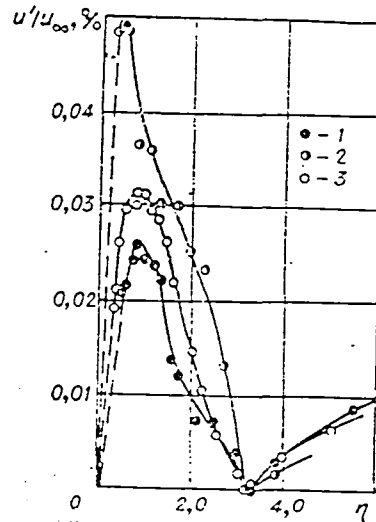
Figure 4. Profiles of Vortex Per-
turbations Induced in a
Boundary Layer

Key:
1. by sound waves ($F = F_{so}$ = 200
x 10^{-6}, $Re_{\delta} \sim 620$. $A_{so} \cong 104.3$ db,
ε_{so} = 0.115%)

2. by plate vibration ($F = F_{vib}$ =
200 x 10^{-6}, $Re_{\delta} \sim 645$):

3. by vibrating belt (F = 200 x 10^{-6},
Re_{δ} = 600.

transverse coordinate η. With frequency parameter $F = F_{so}$ = 200
x 10^{-6} and Reynolds number $Re_{\delta} \approx 620$, this profile is presented in
fig. 4. Its comparison with the corresponding profile obtained
for the T - S wave generated with the help of a normal vibrating
belt in the absence of sound with $Re_{\delta *}$ = 600 indicates the
identity of the waves.

In order to separate the influence on generation of T - S
waves of sound and vibrations, and to exclude the possibility of
generation of an intensive T - S wave from the eddy mode of
turbulence of the incident flow (which could increase when sound
is turned on [5]), the role of vibration of the plate in generating
these waves was studied separately. For this purpose, a vibrator
was attached to the plate. It is an electric motor with out-of-

11

balance shaft. In the absence of sound, this vibrator made it
possible to produce sinusoidal vibration of the plate of roughly
the same amplitude as under the influence of a sound field.

It was found that even in this case, a normal T - S wave
develops in the boundary layer. The corresponding profile for
perturbation u' = u'(η) is presented in figure 4 for the case
where the amplitude of plate vibration assigned by the vibrator
was roughly 2-fold greater than its vibration in the sound field.
With the same amplitude of plate vibration and other conditions
equal, when there is sound (without a vibrator) and there is no
sound (with vibrator), the intensities of these waves were
essentially the same. This important fact indicates that the
T - S wave in the boundary layer does not develop under the
influence of sound perturbations directly, nor because of increase
in the eddy mode of turbulence of the incident flow, but exclusively   /24
because of plate vibration.

In order to reveal the role of the front edge in generating
perturbations, a study was made of the process of development of
induced perturbations, when plate vibration was induced by sound.
The neutral points that were obtained in this case essentially
coincide with the corresponding points that were obtained by the
method of vibrating belt both when there is a sound field (see
part 1) and when it is missing [8]. A measurement was also made
of the development of perturbation induced only by plate vibration
without a sound field, for the frequency parameter of vibration
$F_{vib} = F = 156 \times 10^{-6}$. The resulting neutral point is illustrated
in figure 2 by a cross. The waves that are thus generated by the
vibrating front edge of the plate develop according to the same
laws as the T - S waves in a stationary boundary layer. The
findings also indicate the absence of distributed generation of
perturbations over the entire extent of the boundary layer, which
would inevitably result in a change in the nature of development
of perturbations and a displacement of the neutral points. Con-

sequently, the only element which is responsible for excitation of the T - S waves in the oscillating boundary layer is the front edge of the plate which vibrates under the influence of sound waves.
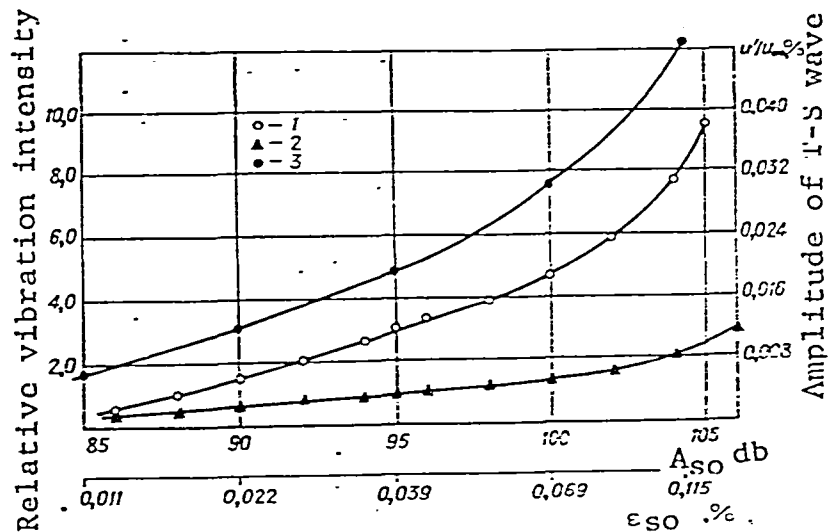

Figure 5.   Amplitudes of Vibrations and Waves
            Generated by Them Depending on Intensity
            of Sound with t_{so} = 111.8 Hz
Key:
    1.   Plate vibration
    2.   Vibration of working part
    3.   Amplitude of generated Tollmin-Shlichting
         wave with $F = F_{so} = 200 \times 10^{-6}$, $Re_{\delta} = 620$.

With this nature of T - S wave development, the question of the reasons for vibrations in the plate and the conditions for their development became very important.   It was found that under the influence of sound waves, not only the plate and the coordinate spacer vibrate, but also the working part of the wind tunnel, as well as its other parts.   The vibration intensity of the working part was roughly 2-3-fold lower than the vibration intensity of the plate.   With fixed frequency of sound f_{so}, the dependence of the vibration amplitude of the working part and the plate on the sound intensity is presented in fig. 5.   It also illustrates the corresponding change in the T - S wave intensity u'/u_{∞} generated on the vibrating nose of the plate.

13

It was noted during the experiments that the plate vibration amplitude with fixed sound intensity has a strong dependence on the frequency of the sound vibrations (see fig. 6), and this dependence abounds with a large number of resonance peaks. Some
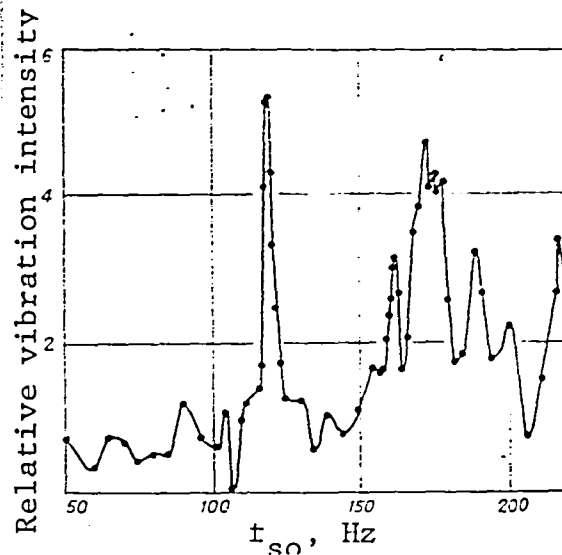

Figure 6.   Amplitude of Plate Vibration
            Depending on Dimensional Frequency
            of Sound with A_{so} = 95 db.

of these peaks were observed on a similar graph for vibration of the working part, and some (for example, the peak at f_{so} = 118 Hz) were even observed for other parts of the tunnel that were insulated for vibration from the working part. The vibrations were sharply intensified, probably when the sound frequency approached one of the natural plate frequencies, or the working part, whose vibrations were transferred to the plate. A possible reason for the appearance of some of the "resonances" could be the development of standing sound waves (in addition to traveling) in the channel of the wind tunnel.

The effect of dimensional sound frequency on the intensity of the T - S generated wave with fixed dimensionless frequency parameters $F = F_{so} = 200 \times 10^{-6}$, Reynolds number $Re \approx 620$

14

and sound pressure A_{so} = 95 db is presented in fig. 7 (the corresponding values of the acoustic component of the degree of turbulence ε_{so} are presented at the bottom of the same figure). For comparison, curves are illustrated here for the intensities of plate vibrations and the working part of the tunnel. A distinct
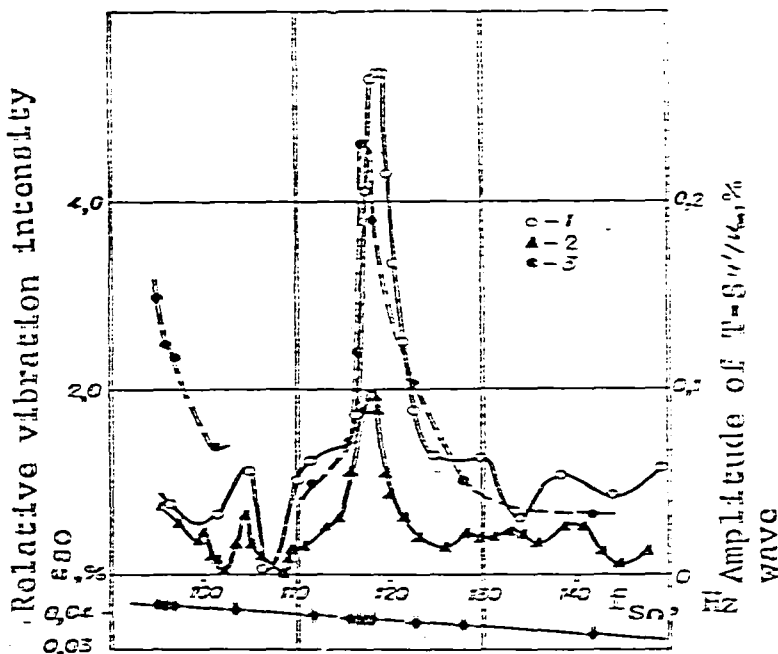

Figure 7. Amplitudes of Vibrations and Waves Generated by Them Depending on the Dimensional Frequency of the Sound with A_{so} = 95 db.

Key:
1. plate vibration
2. vibration of working part
3. amplitude of generated Tollmin-Shlichting wave with $F = F_{so} = 200 \times 10^{-6}$ $Re_{\delta*}$ ==.

correlation is visible between the vibration in the working part of the tunnel, vibration of the plate and intensity of the induced T - S wave, which again indicates that the vibrations are the reason for generation of the T - S wave.

These results can apparently explain the resonance nature of the influence of sound perturbations on the position of the

15

transition obtained in publications [2,5]. Strong increase in the vibration amplitude of the streamlined surface probably occurred in these experiments with certain dimensional sound frequencies.

For the frequencies that yield especially strong vibrations, experiments to study the stability of the laminar boundary layer in relation to the generated T - S waves were repeated. No features were found in this case, while the neutral points, as before, fell into the spread of points on the curve of neutral stability of the stationary boundary layer.

The results that were obtained in this work indicate one of the possible mechanisms for the effect of the acoustic mode of turbulence of the incident flow (with small magnitude of the eddy mode) created by outside sources of sound and the influence of the vibrations on the transition of the laminar boundary layer into turbulent (see, for example, [12, 13]).

CONCLUSION

Sound waves emitted along the flow in the direction opposite to the flow result in vibrations in the streamlined model. Neither the plate vibrations nor the sound field itself have a noticeable influence on the characteristics of stability of the laminar boundary layer. All the influence of the sound field on the magnitude of the eddy perturbations in the laminar boundary layer (in the studied range of parameters) is reduced to generation of Tollmin-Shlichting waves by the front edge of the plate. The stability of the laminar boundary layer in relation to these waves does not differ from its stability in relationship to the Tollmin-Shlichting waves generated by a normal belt.

The amplitude of plate vibrations rises with an increase in sound intensity and has a strong dependence on its frequency which has a resonance nature in the region of certain frequencies. Together with the vibration amplitude, there is a strong change in the intensity of the generated Tollmin-Shlichting waves which

16

is clearly correlated with it.

The authors are grateful to A. S. Ginevskiy and N. F. Polyakov for discussing this problem.

BIBLIOGRAPHY

1. Bacon, J.; Pfenninger, W.; Moore, C. Summary of Laminar Boundary Layer Control Research (ASD TDR-63-554), 1964, Vol. 1.

2. Spangler, I. G.; Walls, C. S. AIAA J., 1968, Vol. 6, No. 3.

3. Knapp; C. F.; Roache, P. J. AIAA J., 1968, Vol. 6, No. 1.

4. Mechel, F.; Schilz, W. Acustica, 1964, Vol. 14, p. 325.

5. Vlasov, Ye. V.; Ginevskiy, A. S. Uch. Zap. TsAGI, 1971, Vol. II, No. 2, p. 1.

6. Obremski, H. J.; Fejer, A. A. J. Fluid. Mech., 1967, Vol. 29, 1,p. 93.

7. Bagayev, G. I.; Golov, V. K.; Medvedev, G. V.; Polyakov, N. F.; in Aerofizicheskiye issledovaniya ["Aerophysical Studies"], Novosibirsk, 1972.

8. Kachanov, Yu. S.; Kozlov, V. V.; Levchenko, V. Ya. Izv. Sib. otd. AN SSSR, seriya tekhn. nauk, 1974,Iss. 2, No. 8.

9. Levchenko, V. Ya.; Solov'yev, A. S. Izv. Sib. otd. AN SSSR., seriya tekhn. nauk., 1975, No. 13, Issue 3.

10. Klebanoff, P. S.; Tidstrom, K. D. NASA Techn. Note, No. D-195.

11. Domaratskiy, A. N.; Polyakov, A. I.; Skurlatov, A. I. Izv. Sib. otd. AN SSSR, seriya tekhn. nauk. (at press).

12. Schubauer, G. B.; Skramsted, H. K. NASA Techn. Rep., 1948, No. 909.

13. Barnes, F. H. Doct. diss., University of Edinburgh, Faculty of Pure Science, October, 1966.