CRITERION ANALYSIS OF TRANSONIC AND SUPERSONIC FLOW AT NEAR- SURFACE ENERGY SUPPLY AND STATIONARY WAVE SHOCK

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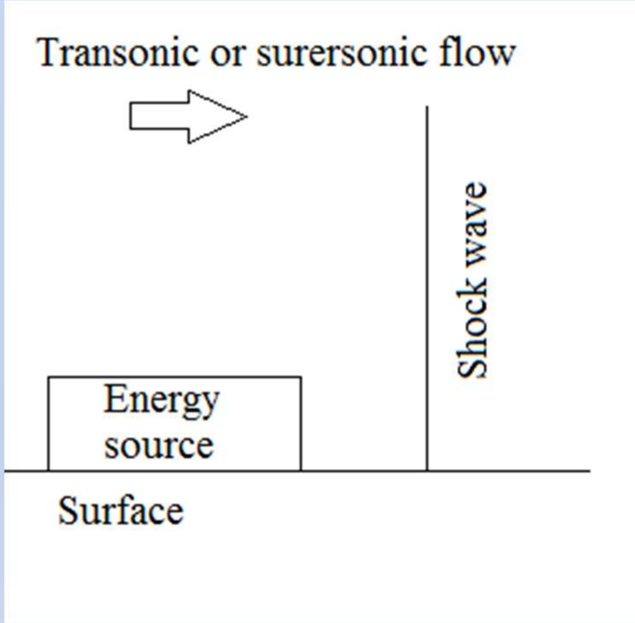
THE PROBLEM FOR STUDY

The simplified system



The shock wave is caused by

Example 1.
inflowing jet.

Example 2.
weak surface curvature.

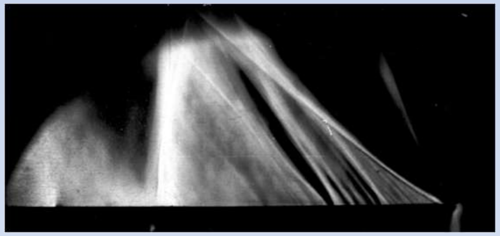
The examples

1. Energy deposition before gasdynamic stabilizer in combustion chamber

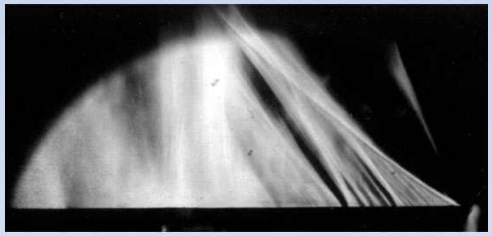
Example from abstract

1. P.K. Tretyakov, V.A. Zabaykin The ability to effect of pulsed-combustion mode to run high-speed ramjet// Models and Methods of aerodynamic Fifteenth International Workshop Yevpatoriya 4-11 June 2015 P. 145

2. The aerodynamic profile which is streamlined by the transonic flow in presence of some energy source ($M_\infty = 0.95$)



without discharge



with discharge

This photo from abstract:

2. Yuriev A.S., Korzh S.K., Pirogov S.Yu., et al. Transonic streamlining of profile at energy addition in local supersonic zone // The 3rd Workshop on Magneto-Plasma-Aerodynamics in Aerospace Applications: Proc. Moscow. 2001. P. 201-207.

THE AIM OF ENERGY SUPPLY IS TRANSFORMATION OF SHOCK WAVE STRUCTURE TO USEFUL TYPE.

SUBTASKS

1. The preliminary analytical prediction of the area of appropriate parameters.
2. The quick testing of the founded area of analytical parameters in terms of Euler equation. The result of this stage is reduction of the area of appropriate parameters.
3. The detail testing of the reduction area in terms of Navier-Stokes equations. The result of this stage is the further reduction of the area of appropriate parameters.

THE AIMS OF STUDY

- This study concerns improving methods for stage 1 with testing by the method of stage 2.
- All results for transonic streamline of profile were published [1].
- The result of this study is generalization of the criteria approach for prediction of the shock wave structure change caused by energy deposition during transonic streamline of aerodynamic thin profile at small angles of attack.
- The generalization performed for the case of supersonic flow in the channel for a model from stage 2. The last case is the simplified model of the combustion chamber of ramjet. The results for gasdynamic stabilizer are new.

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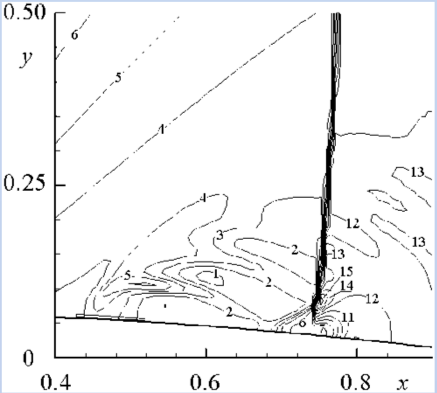
1. Aulchenko S. M., Zamuraev V. P., Kalinina A. P. // Thermal processes in the technique 2014. V. 6. № 11. P. 482-488.

THE USEFUL TYPES OF SHOCK WAVE CHANGE



1. It is useful to weak (or destroy) the closed shock wave for transonic streamline of profile [1] as presented in the fig. 1.

Fig. 1. The initial stage of disruption of the closed shock wave [1].

2. It is useful to create flow with the average Mach number which is approximately equal to 1 in the section with constant cross section [2] as presented in the fig. 2.

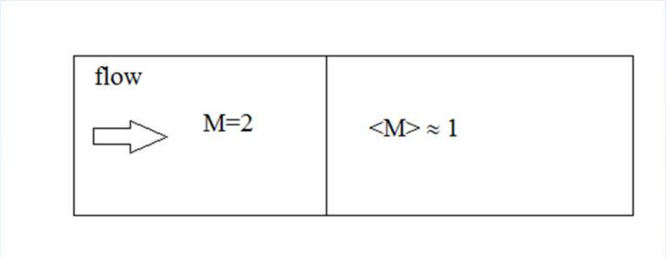


Fig. 2. The useful flow structure in the constant cross section in the combustion chamber [2].

1. Aulchenko S. M., Zamuraev V. P., Kalinina A. P. The criteria forecast of shock-wave structure at the transonic flow of the airfoil and the local supply of energy// Thermal processes in the technique 2014. V. 6. № 11. P. 482-488.).
2. P.K. Tretyakov, V.A. Zabaykin // Models and Methods of aerodynamic Fifteenth International Workshop Yevpatoriya 4-11 June 2015 P. 145

THE MODELS

1. The Euler equations for nonstationary regime and the plane geometry
2. The models for energy deposition
   1. Sometimes energy deposition process is instantaneous impulse energy supply [1] . For such case energy depositions is a periodical delta function.
   2. For other case energy deposition may be also characterized is similar to harmonic periodical process [2]. For this case it may be modeled by the harmonic function.
3. The solutions of the problem of a strong explosion which are derived by Sedov[3]
4. The mathematical manipulation to change the coordinate system, which moves relative to the system at a constant rate.
5. the criteria approach which was created for the case of transonic streamline of profile in terms of models which are presents in point 1-4 in this slide [4,5].

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1. I.A. Znamenskaya, I.A Koroteev, A.E. Lutsky Experimental realization of a two-dimensional problem of the collapse of the fracture plane during the ionization pulse flow with a shock wave // DAN. 2008. V. 420. №5. p. 619-622.
2. V.K. Baev A.V. Potapkin, V.V. Shumsky Manifestation of nonstationarity in the study of combustion processes // Novosibirsk, 1997. Preprint. SB RAS. №6-97. 43 p.
3. L.I. Sedov Methods of similarity and dimensionality in mechanics. M .: Gos. ed of technical and theoretical. L. 1957. 376 p.
4. Aulchenko S. M., Zamuraev V. P., Kalinina A. P. // Thermal processes in the technique 2014. V. 6. № 11. P. 482-488.
5. S.M. Aulchenko, V.P. Zamuraev, A.P. Kalinina Numerical and analytical studies of nonlinear effects transonic flow around airfoils with fluctuations of its surface element//Journal of Engineering Physics. 2014. V. 87. № 3. P. 616-627.

THE CRITERIA APPROACH FEATURES AND THE METHOD OF ITS GENERALIZATION FOR THE CHANNEL CASE

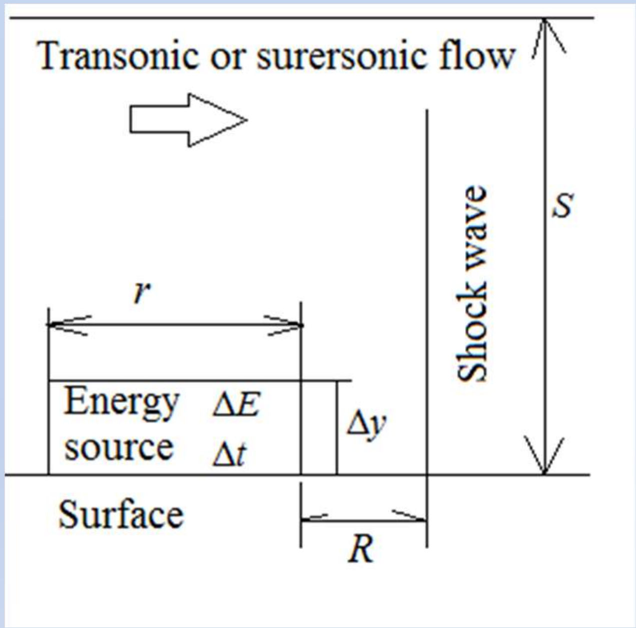
THE CRITERIA APPROACH HAS THE FOLLOWS FEATURES:

1. It is created for the problem characterized by the fixed parameters without energy supply stationary solution and for the different values of the energy supply parameters;
2. It can detect the quasi-stationary and pulsed mode
3. It has quantity of criteria is determined by the "Pi" - theorem;
4. It includes the sense criteria definition
5. It includes the approximate analytical expressions for the criteria values which are evaluated in terms of solution for the strong explosion for the case of profile.

GENERALIZATION OF THE CRITERIA APPROACH FOR THE CASE OF SUPERSONIC FLOW IN THE CHANNEL PERFORMS UNDER THE FOLLOWING CONDITIONS

1. The above properties which are described in the points 1 to 4 remain unchanged
2. The approximate analytical expressions should be evaluated for the corresponding Mach number
3. The new criteria should be added to the criteria system because the channel case is a restricted flow.

THE ENERGY DEPOSITION PARAMETERS AND THE SENSE DEFINITIONS OF MAIN CRITERIA



PARAMETERS

$S, R, r, \Delta y$ – (are the geometry parameters)

ΔE, Δt – impulse energy and the impulse period

THE MAIN CRITERIA

1. The homochronicity criterion Ho_r. along the length of the zone of energy supply.

$$Ho_r = \frac{\text{energy supply period}}{\text{time of gas migration throw the energy deposition zone}}$$

2. The criterion of intensity β

$$\beta = \left[\frac{\text{the energy } \Delta E \text{ which received by gas in the energy supply zone}}{\text{The same value } e \text{ in the gas flow}}\right]^{1/2}$$

THE MAIN CRITERIA (continuation of previous slide 1)

3. The criterion of transformation of flow H_λ

H_λ is equal to the Mach number of shock wave from the energy supply zone which received by the substitution of energy depositionparameters into strong wave problem solution.

H_λ = Mach number of shock wave from the energy supply zone which received by the substitution of energy depositions parameters into strong wave problem solution

4. The criterion of shift of closing shock *Ho*

$$Ho = \frac{\text{energy supply period}}{\text{The time of gas migration from energy deposition zone to the closed shock wave}}$$

5. The overlap criterion $H_{overlap}$

$$H_{overlap} = \frac{\text{size of essential influence of the energy deposition zone}}{\text{the size of cross section}}$$

This is evaluated by the substitution of energy depositions parameters into strong wave problem solution with approximation that the received energy is essentially more the energy of undisturbed flow.

THE MAIN CRITERIA (continuation of previous slide 2)

6. The sound criterion H_{sound}

$$H_{sound} = \frac{\text{energy supply period}}{\text{time at which gas moving from the zone to the expanding section}}$$

THE APPROXIMATE CONDITIONS OF UPWIND SHOCK MOVING

For the impulse regime ($Ho_r \geq 0.25$):

1. $\beta \geq 1$
2. $(Ho \leq 1,\ H_\lambda < 1)$ or $(Ho_{sound} \leq 1,\ H_\lambda \geq 1)$
3. $H_{overlap} > 0.5 \div 1$

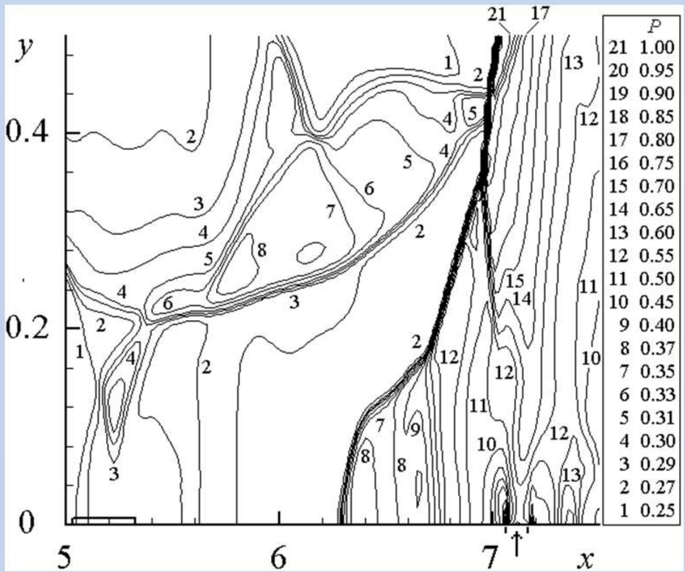
For the quasi-stationary regime ($Ho_r \leq 0.25$):

1. $\beta \geq 1$

Numerical values of the criteria are calculated according to the input parameters of the problem.

1. EXAMPLE OF THE ENERGY SUPPLY INTO THE CHANNEL (narrow zone)

M=2



These are details of shock-wave structure of the supersonic flow in a channel at the interaction energy source (rectangle near the bottom wall) with the shock wave from the transverse jet (arrow below the axis x). Parameters: $Ho_r = 0.76$, $\beta = 4.6$, $H_\lambda = 0.40$, $Ho = 0.27$.

<u>The criteria analysis allow to make some conclusions:</u>

1. $Ho_r = 0.76 > 0.25$ corresponds to the impulse regime
2. $\beta = 4.6 > 1$ corresponds to the strong shock wave cased by heat energy deposition
3. $H_\lambda = 0.40 < 1$ As a consequence, there is no interaction of strong shock wave with stationary shock caused by the jet. The precursor and a rarefaction wave propagating in the opposite direction arise. There is a triple configuration of shocks with hanging shock and others regimes are observed.
4. $Ho = 0.27 < 1$ corresponds to the upwind shift of average shock wave position

2. EXAMPLE OF THE ENERGY SUPPLY INTO THE CHANNEL (compact zone)

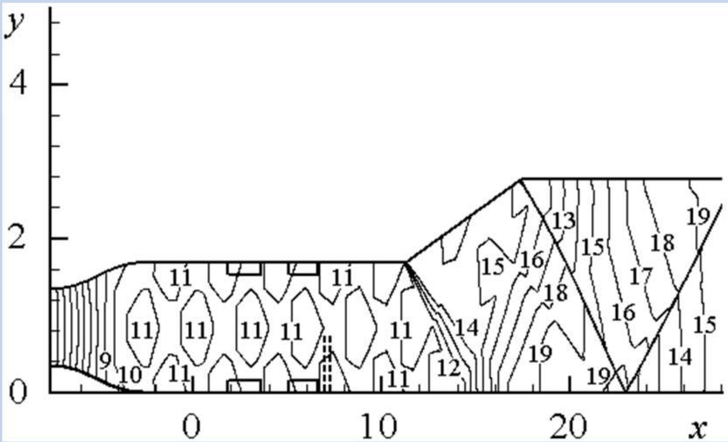


Fig. 1.The channel geometry and distribution of Mach number in steady supersonic flow in the absence of exposure to it. The values of the Mach number values of 1 to 2.8 in increments of 0.1 correspond to the line numbers 1 ÷ 19. Transverse line gives position of the jet; rectangles are the energy supply zones.

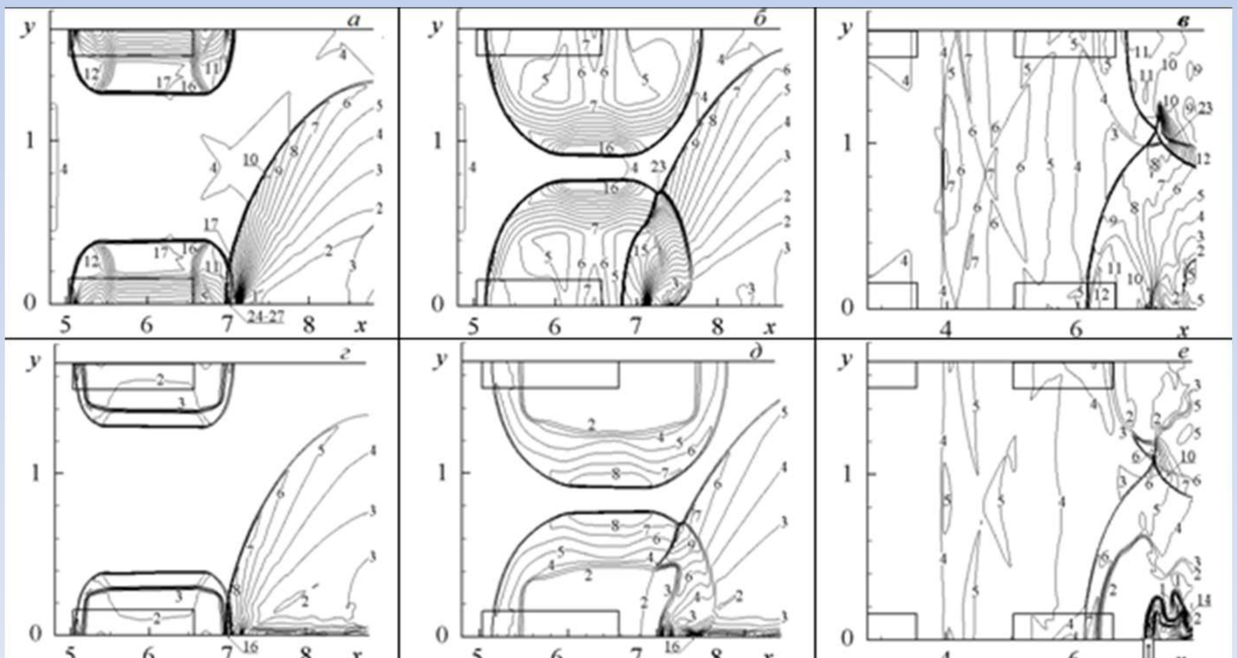


Fig. 2. The distributions of pressure (a, b, c) and density(d, e, f) at t = 0.15; 0.4; 4.83 (Δt=6). The pressure levels 1 ÷ 27 correspond to p from 0.10 to 1.20 in steps of 0.05, and then to 2.8 in increments of 0.4. The density levels 1 ÷ 16 correspond to ρ from 0.1 to 1.6 in increments of 0.1.

2. EXAMPLE OF THE ENERGY SUPPLY INTO THE CHANNEL (compact zone, continuation)

The criteria analysis allows make the conclusions:

1. $Ho_r = 4 > 0.25$ corresponds to the impulse regime

2. $\beta \approx \sqrt{\Delta E / \rho \Delta x \Delta y} / a = 3.3$ > 1 - corresponds to the strong shock wave cased by heat energy deposition

3. $\mathrm{H}_\lambda = D / a \approx \beta r / (2R / (M+1) + r) = 2.7$ > 1 As a consequence, there is interaction of strong shock wave with stationary shock caused by the jet.

4. $\mathrm{Ho} \approx \Delta t / (3\beta r / (4M^2 a) - r / (4\beta a) + (R + r/2)/(Ma)) = 3.3 \quad and \quad 1.6$ > 1

5. $\mathrm{Ho}_{\mathrm{sound}} = \Delta t / (3\beta r / (4M^2 a) - r / (4\beta a) + (R' + r/2)/(Ma)) =$ 1.3 *and* 0.93 <1

As a result the criteria approach predicts upwind shift of average shock wave position

ATTENTION!

Let's point to the fact that the criteria approach can predict only the upwind shock wave shift.

It impossible to predict the achievement of a shock wave up to narrowing of the channel, because this phenomena essentually depends significantly from the jet boundary condition.

CONCLUSIONS

- The importance of the criteria is determined by in that they allow to restrict the field of research, as well as a means of rough check of numerical calculations.

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Thank you for your attention !!!