A 71-23906

NASA TECHNICAL MEMORANDUM

NASA TM-77024

# COMPARATIVE EVALUATION OF GAS-TURBINE ENGINE COMBUSTION CHAMBER STARTING AND STALLING CHARACTERISTICS FOR MECHANICAL AND AIR-INJECTION

I. N. Dyatlov

(NASA-TM-77024) COMPARATIVE EVALUATION OF GAS-TURBINE ENGINE COMBUSTION CHAMBER STARTING AND STALLING CHARACTERISTICS FOR MECHANICAL AND AIR-INJECTION (National Aeronautics and Space Administration) 12 p G3/07

N83-32805

Unclas 13577

Translation of "Sravnitel'naya otsenka puskovykh i sryvnykh kharakteristik kamery sgoraniya GTD pri mekhanicheskom i vozdushno-mekhanicheskom raspylivanii topliva", IN: (Gorenie v potoke) Combustion in a Flow, Edited by A.V. Talantov. Kazan, Kazanskiy Aviationny Institute (KAI, Trudy, Seriia Aviatsionnye Dvigateli, No. 124), 1970, pp. 160-169.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, DC 20546
FEBRUARY 1983

STANDARD TITLE PAGE

| | |
|---|---|
| 1. Report No. NASA TM-77024 | 2. Government Accession No. |
| 3. Recipient's Catalog No. | |
| 4. Title and Subtitle COMPARATIVE EVALUATION OF GAS-TURBINE ENGINE COMBUSTION CHAMBER STARTING AND STALLING CHARACTERISTICS FOR MECHANICAL AND AIR-INJECTION | 5. Report Date February 1983 |
| | 6. Performing Organization Code |
| 7. Author(s) I. N. Dyatlov | 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 3542 |
| | 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 Translation of "Sravnitel'naya otsenka puskovykh i sryvnykh kharakteristik kamery sgoraniya GTD pri mekhanicheskom i vozdushno-mekhanicheskom raspylivanii topliva", IN: (Gorenie v potoke) Combustion in a Flow, Edited by A.V. Talantov Kazan, Kazanskiy Aviationny Institute (KAI, Trudy, Seriia Aviatsionnye Dvigateli, No. 124), 1970, pp. 160-169. (A71-28954)

16. Abstract Theoretical and experimental study of the effectiveness of propellant atomization with and without air injection in the combustion chamber nozzle of a gas turbine engine. Tests show that the startup and burning performance of these combustion chambers can be improved by using an injection during the mechanical propellant atomization process. It is shown that the operational range of combustion chambers can be extended to poorer propellant mixtures by combined air injection mechanical atomization of the propellant.



| | |
|---|---|
| 17. Key Words (Selected by Author(s)) | 18. Distribution Statement UNCLASSIFIED - UNLIMITED |

| | | | |
|---|---|---|---|
| 19. Security Classif. (of this report) Unclassified | 20. Security Classif. (of this page) Unclassified | 21. No. of Pages 12 | 22. Price |

UDC 536.46:621.454

# COMPARATIVE EVALUATION OF GAS-TURBINE ENGINE COMBUSTION CHAMBER STARTING AND STALLING CHARACTERISTICS FOR MECHANICAL AND AIR-INJECTION MECHANICAL FUEL ATOMIZATION /160 *

I. N. Dyatlov

Presents results of experimental research into the starting and stalling characteristics of combustion chambers with mechanical and air-injection mechanical fuel atomization.

Establishes that air-injection mechanical atomization makes it possible to improve chamber starting and stalling characteristics and to expand chamber operating range to lean mixture compositions.

Stalling and starting characteristics were tested in a chamber section, depending on the overall value of excess-air coefficient $\alpha$.

Absolute magnitude $\alpha$ for a constant air stream velocity was changed by changing fuel consumption.

Fuel consumption was recorded at the moment of stalling or starting. The range of the air parameters at chamber inlet was:

$$t_2 = 120 \div 175^\circ \text{ C}, \; P_2 = 1.05 \div 1.1 \text{ ata}, \; w_2 = 40 \div 140 \text{ m/s}.$$

Characteristics were recorded for a fuel-air injector (TVF) operating with

*Numbers in margin indicate pagination in foreign text.

and without a supply of atomized air and for a series-produced engine dual-orifice injector, which in future we will call the series-produced injector.

The series-produced injector operated only in the idle passage as starting and stalling characteristics were recorded.

The TVF without atomized air supplied to it appears to be a conventional single-orifice swirl injector [1, 2]. /161

1. Results of Tests to Determine Chamber Stalling Characteristics

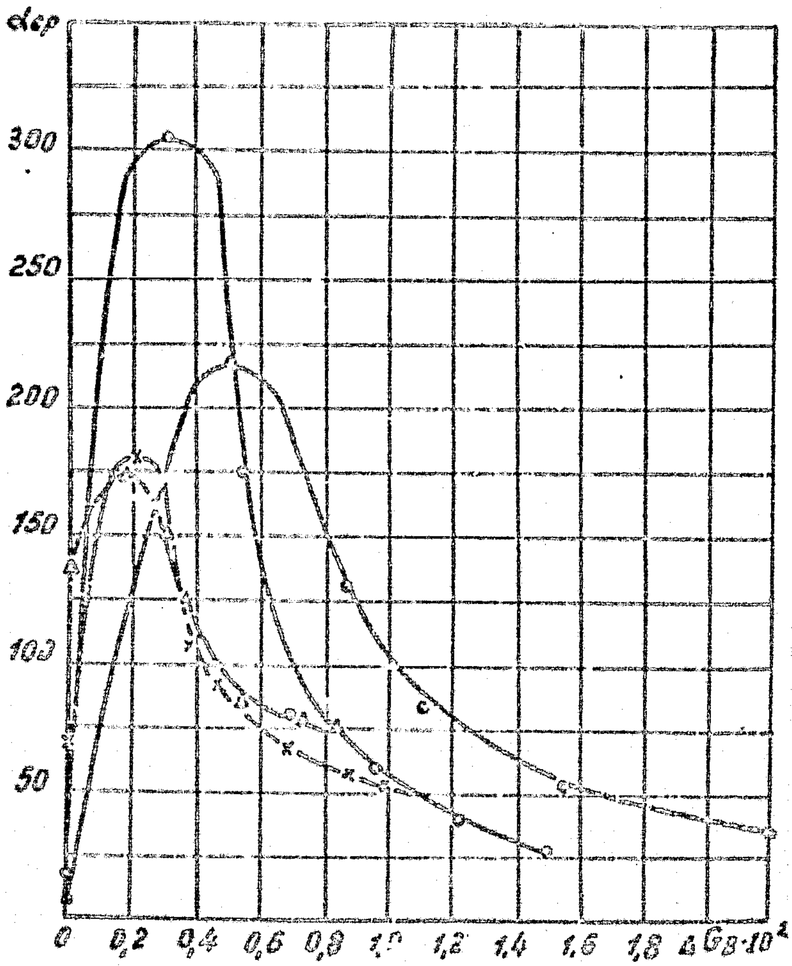


Figure 1

● -- $w_2$ = 40 m/s; o -- $w_2$ = 70 m/s;
x -- $w_2$ = 100 m/s; Δ -- $w_2$ = 130 m/s

Results of tests to determine the stalling characteristics of a chamber operating with a fuel-air injector are depicted in Figure 1. Values of the overall excess-air coefficient at which flameout begins $\alpha_{fo}$, are plotted on the Y-axis, while the relative flow of atomized air, which is the ratio of the air flow through the TVF to the overall air flow through the chamber in a given mode ($\Delta G_a = \frac{G_a}{G_c}$), is plotted on the X-axis.

Where $\Delta G_a = 0$, i. e., when no atomized air is supplied to the TVF and it operates like a conventional mechanical injector, value $\alpha_{fo}$ points will fall on the Y-axis. /162

It is evident from this figure that there initially will be a radical rise in $\alpha_{fo}$ (up to specific $\Delta G_a$ values) for all investigated air velocities at chamber inlet when atomized air is supplied to the TVF, i. e., the range of stable chamber operation with lean mixture compositions, and , when $\alpha_{fo\ max}$ is reached, a further $\Delta G_a$ increase will lead to a reduction in $\alpha_{fo}$. Optimal magnitude $\Delta G_a$ at which $\alpha_{fo}$ achieves maximum value corresponds to each $w_2$ value.

One may explain the nature of the flow of the $\alpha_{fo} = f(\Delta G_a)$ curves in the following manner.

In the region close to optimum magnitude $\Delta G_a$, inlet injector air insures (compared with mechanical) better fuel atomization and significantly improves the mixing process, while the velocity of the fuel-air mixture is relatively slight here, i. e., it is less than or equal to (for a given $\alpha$) flame velocity. As $\Delta G_a$ increases, the velocity of the fuel-air mixture rises and atomization and mixing improve, the result being reduction in the time a drop of fuel in the chamber takes to vaporize and stable combustion shifts towards a richer mixture composition, i. e., $\alpha_{fo}$ decreases.

An expansion in the range of stable chamber operation on a leaner mixture composition with air-injection mechanical atomization is explained not only by the improved fuel atomization. Research demonstrated that the twisted air stream leaving the TVF creates conditions favorable for flame stabilization, even in the absence of additional chamber profile devices. Consequently, in maximum mixture leanness modes, air-injection mechanical fuel atomization compensates for shortcomings in chamber profile device operation.

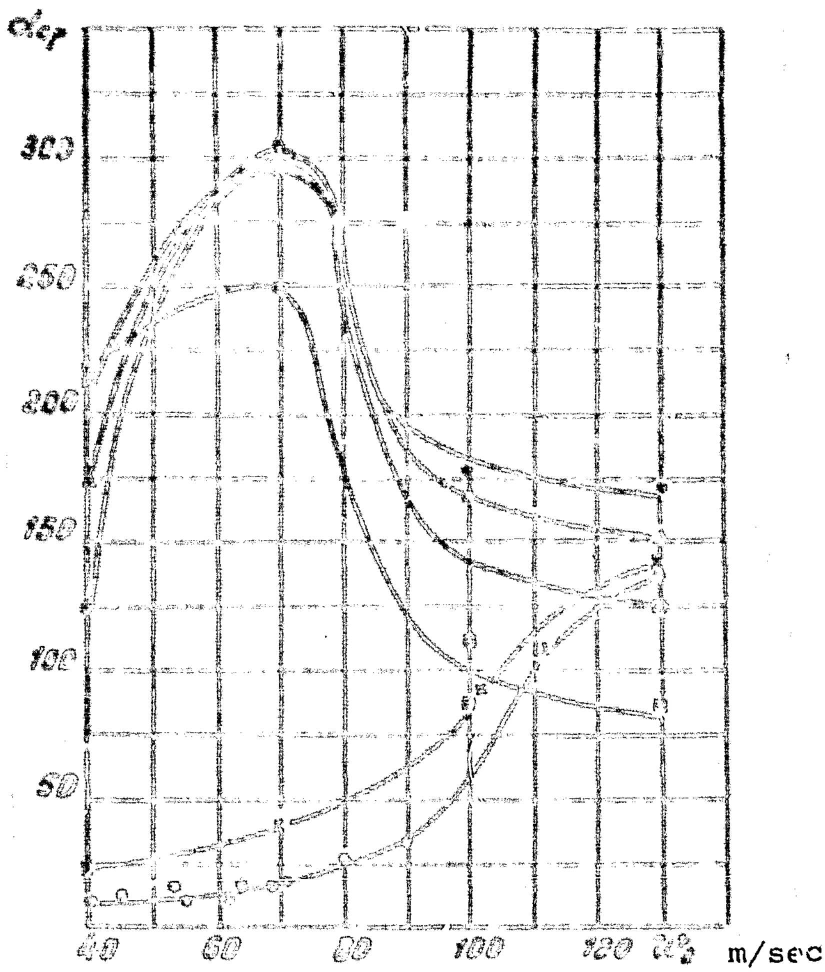




Figure 2. TVF With Air Supply: ● -- $\Delta G_a \times 10^2 = 0.2$; ▲ -- $\Delta G_a \times 10^2 = 0.3$; □ -- $\Delta G_a = 10^2 = 0.4$; ■ -- $\Delta G_a \times 10^2 = 0.5$; o -- TVF without air supply; x -- Series-produced injector (idle passage operating)

A change in $\alpha_{fo} = f(w_2)$ for mechanical and air-injection mechanical fuel atomization is depicted in Figure 2.

A rather sharp decrease in $\alpha_{fo}$ (especially where $w_2 \angle$ 90—130 m/s) is /163
observed during mechanical fuel atomization when $w_2$ decreases, both for the TVF and for the series-produced injector.

This curve course is not a specific special feature of the chamber investigated. As analysis demonstrated, an analogous picture is observed with other combustion chambers as well. The most-probable cause of the $\alpha_{fo}$ decrease at low $w_2$ values is deterioration of the mixing process due to the sharp drop in fuel pressure. Tests run show that, where $w_2 \angle 100$ m/s in stalling modes, fuel pressure ahead of the investigated injector was reduced to $\approx 0.3 \div 3$ n/cm$^2$.

Given the aforementioned pressures, instead of an atomized fuel cone, streams of fuel caught up by the initial stream of air and partially atomized are expelled from the injector. If the velocity of the air stream in the primary zone is slight, it does not insure proper atomization and mixing and, consequently, stable fuel combustion. /164

The author of [3] comes to the same conclusions. He points out that, when fuel pressure drops below $p_{t\ min}$, the atomized fuel cone turns into a jet and, not burning, is expelled from the chamber. Flameout begins the moment the atomized fuel cone turns into a jet.

Presence of liquid fuel residues from the chamber in preflameout modes also was observed in our tests.

Atomizing air supplied to the TVF creates conditions more favorable for the operating process to flow, regardless of fuel pressure.

The curves plotted in Figure 2 make it possible to trace the nature of the $\alpha_{fo}$ change with respect to velocity and for air-injection mechanical fuel atomization for different $\Delta G_a$ values.

Where $\Delta G_a \times 10^2 = 0.2 \div 0.3$ in the entire range of velocities ($w_2 = 40 \div 130$ m/s), $\alpha_{fo}$ will fall significantly higher than during mechanical atomization. Suffice it to say that, where $w_2 = 70$ m/s, $\alpha_{fo}$ during air-injection mechanical atomization is higher by a factor of approximately 8-18 than during mechanical atomization. By virtue of a $\Delta G_a$ increase, the advantage of air-injection mechanical atomization shifts to the zone of lower air stream velocities at chamber inlet.

Research conducted showed that a $\alpha_{fo}$ increase during air-injection mechanical atomization does not require high $\Delta G_a$ values, the optimum magnitude of which (depending on $w_2$) will range from $\Delta G_a \times 10^2 = 0.18 \div 0.4$. The optimum $\Delta G_a$ magnitude drops when $w_2$ increases.

In stalling modes, atomized air overpressure corresponding to $\alpha_{fo\ max}$ ranged from 0.981 ÷ 1.962 n/cm$^2$, $\frac{P_a}{P_s} \approx 1.1 \div 1.2$.

The following conclusion may be drawn from analysis of the Figure 2 mechanical atomization curves. /165

The series-produced injector operating only in the idle passage and providing better atomization here facilitates an increase in $\alpha_{fo}$ compared with the TVF operating without a supply of atomized air. This advantage of the series-produced injector makes a greater impact at low $w_2$ values.

For example, when $w_2$ = 40 m/s, $\alpha_{fo}$ for the series-produced injector is higher by a factor of approximately 2 than for the TVF, but is only a total of 15% higher when $w_2$ = 130 m/s.

Evidently, with a $w_2$ increase, the air stream in the chamber's primary zone improves atomization quality and the mixing process to such an extent that the spray created directly by the injector itself already loses its primary significance.

2. Results of Testing Combustion Chamber Lighting (Starting)

Tests run demonstrated that, in the 40 ÷ 130 m/s velocity range, air-injection mechanical fuel atomization provides (where $\Delta G_a \times 10^2 \angle 0.8$) stable chamber starting with a leaner mixture composition than is the case for mechanical atomization (Figure 3). Consequently, as the chamber is lit, as was the case when stalling characteristics were recorded, air-injection mechanical fuel atomization (due to a more-improved mixing process) expands starting quality ranges.

When atomized air is supplied to the TVF, $\alpha_{st}$ initially rises (up to specific $G_a$ values) and, upon achieving $\alpha_{st\ max}$, a further $\Delta G_a$ increase will lead to a reduction in $\alpha_{st}$. An optimum magnitude at which $\alpha_{st}$ achieves maximum value corresponds to each $w_2$ value. The course of the $\alpha_{st} = f(\Delta G_a)$ curves is analogous to that of the $\alpha_{fo} = f(\Delta G_a)$ curves.

ORIGINAL PAGE IS
OF POOR QUALITY

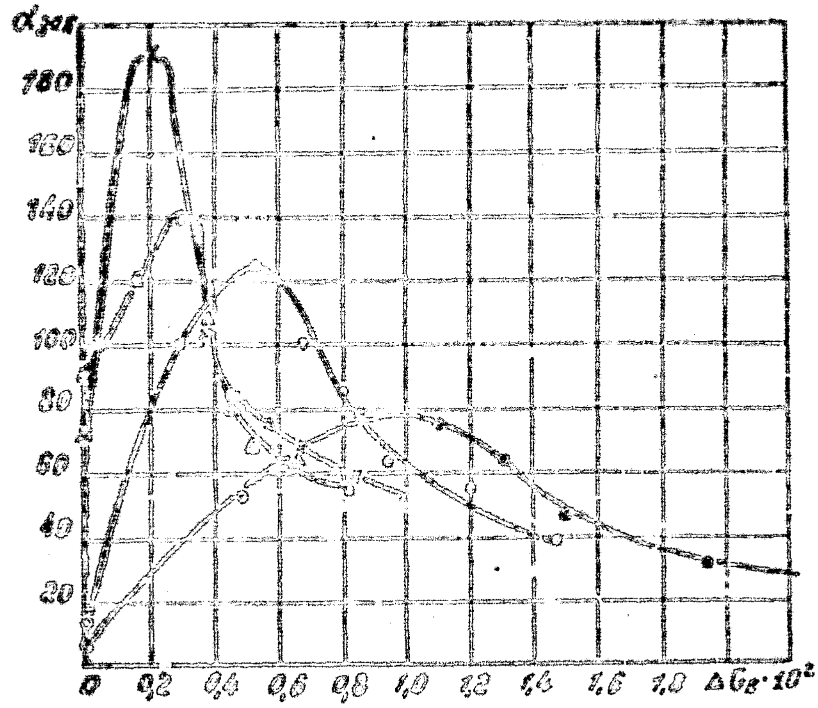


Figure 3
● -- $w_2$ = 43 m/s; o -- $w_2$ = 72 m/s;
x -- $w_2$ = 104 m/s; Δ -- $w_2$ = 131 m/s

Dependence $\alpha_{st} = f(w_a)$ for mechanical and for air-injection mechanical fuel atomization is depicted in Figure 4.

It follows from comparison of the $\alpha_{st} = f(w_2)$ (Figure 4) and $\alpha_{fo} = f(w_2)$ /166 (Figure 2) curves that $\alpha_{fo} \geq \alpha_{st}$ for the same $w_2$ value, i. e., a richer mixture composition means a stable start. This objective law occurs both during mechanical and during air-injection mechanical fuel atomization. Fuel pressure in starting modes is somewhat higher than in flameout modes and is $\leq 5.9$ n/cm$^2$. At this pressure, fuel jet decay begins at some distance from the injector nozzle and, in direct proximity to the nozzle, the fuel cone is the solid arched sheet characteristic of swirl injectors at low fuel pressures. Therefore, the basic factor impacting upon atomization quality and the mixing process at low fuel pressure is air stream velocity at the inlet to the chamber's initial zone. A noticeable improvement in starting conditions is observed when this velocity /167 is increased. However, this improvement occurs up to specific velocity above which $\alpha_{st}$ either remains constant or changes very slightly.

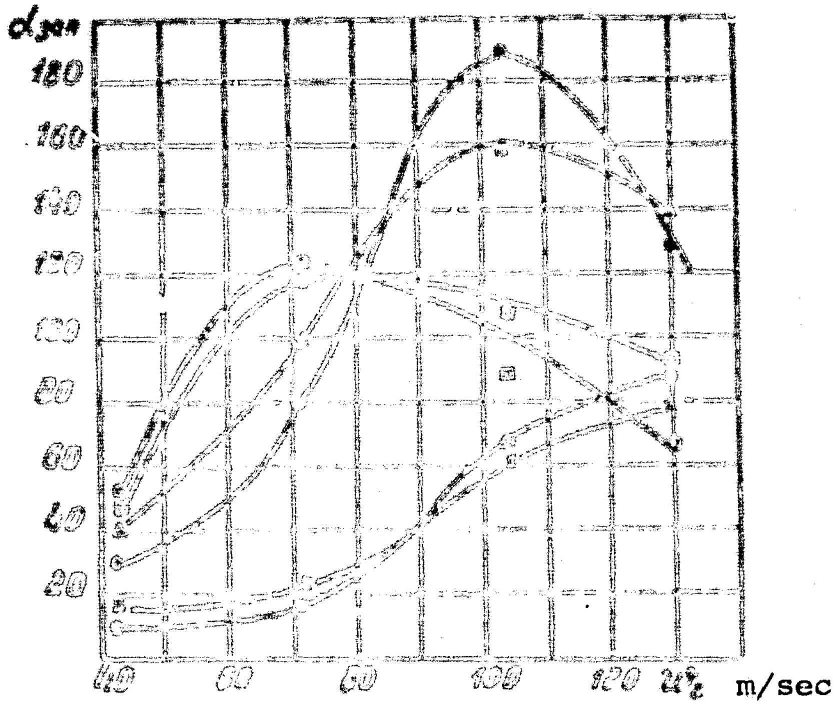


Figure 4. TVF With Air Supply: ● -- $\Delta G_a \times 10^2 = 0.2$; ▲ -- $\Delta G_a \times 10^2 = 0.3$; □ -- $\Delta G_a \times 10^2 = 0.4$; ■ -- $\Delta G_a \times 10^2 = 0.5$; o -- TVF without air supply; x -- series-produced injector (idle passage operating)

During mechanical atomization (Figure 4), a relatively steep rise of $\alpha_{st}$ for the series-produced nozzle will be found in the $w_2 = 80 \div 120$ m/s range and, given a further $w_2$ increase, $\alpha_{st}$ changes slightly. Chamber startability was tested with this injector up to $w_2 = 182$ m/s. The tests showed that, when $w_2$ changes from 120 to 150 m/s, $\alpha_{st}$ increases only 6%, remaining unchanged in the $150 \div 182$ m/s velocity range.

The $\alpha_{st} = f(w_2)$ curve for a TVF operating without a supply of atomized air where $w_2 = 40 \div 90$ m/s will fall somewhat below the series-produced injector curve, but is above the latter's curve when $w_2 = 90 \div 130$ m/s. The strongest $\alpha_{st}$ rise for the TVF, as was true for the series-produced injector, is ob- /168
served when $w_2 = 80 \div 120$ m/s. $\alpha_{st}$ changes very slightly when $w_2 \geq 130$ m/s.

$\alpha_{st} = f(w_2)$ curves fell considerably higher when atomized air was supplied to the TVF and $\Delta G_a \times 10^2 \leq 0.4$ than was the case with mechanical atomization in the entire range of velocities tested. However, the greatest $\alpha_{st}$ rise for air-injection mechanical atomization is observed at low $w_2$ values. For example, where $w_2 = 70$ m/s, $\alpha_{st}$ during air-injection mechanical atomization was higher by a factor of approximately 6-8 than was the case during mechanical atomization. By virtue of the $w_2$ rise and because of the more-intense $\alpha_{st}$ rise, the curves will converge during mechanical atomization. It is higher only by a factor of 2 during air-injection mechanical atomization where $w_2 = 120$ m/s than it is during mechanical atomization.

As follows from Figure 4, the optimum $\Delta G_a \times 10^2$ magnitude in all modes with respect to $w_2$ will range from $0.2 \div 0.4$. A further $\Delta G_a$ increase reduces air-injection mechanical atomization effectiveness. In particular, where $\Delta G_a \times 10^2 = 0.5$, the range of advisible air-injection mechanical atomization use is limited to $w_2 \leq 120$ m/s.

Atomizing air overpressure, which reaches (where $\alpha_{st\ max}$) magnitudes on the order of $0.981 \div 2.943$ n/cm$^2$, while $\frac{P_a}{P_x} \approx 1.1 \div 1.24$, rises somewhat in starting modes (as compared with stalling modes).

## Conclusions

Use of air-injection mechanical fuel atomization makes it possible to:

1. Improve chamber starting and stalling characteristics in the lean mixture composition range.

2. Expand the range of stable chamber operation.

## Bibliography


1. Dyatlov, I. N. Air-Injection Mechanical Fuel Atomization in Gas-Turbine Engines. Trudy KAI, Edition 55, 1960.

2. Ibid. On Air-Injection Mechanical Fuel Atomization. Ibid, Edition 86, 1964. /169

3. Shakhurin, S. I. Investigation of Gas-Turbine Engine Combustion Chamber Characteristics in Threshold Leanness Modes at Altitude. Trudy MAI, Edition 157. Moscow, Mashinostroyeniye, 1964.

Received by the Editorial Board
29 November 1969