General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)
COMPARATIVE EVALUATION OF GAS-TURBINE ENGINE COMBUSTION CHAMBER STARTING AND STALLING CHARACTERISTICS FOR MECHANICAL AND AIR-INJECTION

I. N. Dyatlov

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

I. N. Dyatlov

SCITRAN
Box 3456
Santa Barbara, CA 93108

National Aeronautics and Space Administration
Washington, D.C. 20546

Translation of "Sranvitel'nyaya otsenka puskovykh
i sryvnychkh kharakteristik kamery sgoraniya GTD pri mekhaniches-
kom i vozdukhno-mekhanicheskom raspylivani topliva", IN:
(Gorenie v potoke) Combustion in a Flow, Edited by A.V. Talantov
Kazan, Kazanskiy Aviacionny Institute (KAI, Trudy, Seriia

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.

UNCLASSIFIED - UNLIMITED
Comparative Evaluation of Gas-Turbine Engine Combustion Chamber Starting and Stalling Characteristics for Mechanical and Air-Injection Mechanical Fuel Atomization

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:

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

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].

1. Results of Tests to Determine Chamber Stalling Characteristics

Figure 1

- • -  \( \psi_2 = 40 \, \text{m/s} \);
- o -  \( \psi_2 = 70 \, \text{m/s} \);
- x -  \( \psi_2 = 100 \, \text{m/s} \);
- △ -  \( \psi_2 = 130 \, \text{m/s} \)
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.

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 $\omega_2$ 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.
A change in $\Lambda_{f_0} = f(w_2)$ for mechanical and air-injection mechanical fuel atomization is depicted in Figure 2.

A rather sharp decrease in $\Lambda_{f_0}$ (especially where $w_2 \leq 90-130$ m/s) is 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 $\Lambda_{f_0}$ 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 \( \omega_2 < 100 \text{ m/s} \) in stalling modes, fuel pressure ahead of the investigated injector was reduced to \( \approx 0.3 \pm 3 \text{ n/cm}^2 \).

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.

The author of [3] comes to the same conclusions. He points out that, when fuel pressure drops below \( p_t \text{ min} \), 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 \( \alpha_f \) change with respect to velocity and for air-injection mechanical fuel atomization for different \( \Delta G_a \) values.

Where \( \Delta G_a \times 10^2 = 0.2 \pm 0.3 \) in the entire range of velocities \( (\omega_2 = 40 \pm 130 \text{ m/s}) \), \( \alpha_f \) will fall significantly higher than during mechanical atomization. Suffice it to say that, where \( \omega_2 = 70 \text{ m/s} \), \( \alpha_f \) 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 \( \alpha_f \) increase during air-injection mechanical atomization does not require high \( \Delta G_a \) values, the optimum magnitude of which (depending on \( \omega_2 \)) will range from \( \Delta G_a \times 10^2 = 0.18 \pm 0.4 \). The optimum \( \Delta G_a \) magnitude drops when \( \omega_2 \) increases.
In stalling modes, atomized air overpressure corresponding to $\alpha_{fo\ max}$ ranged from $0.981 \div 1.962 \text{ n/cm}^2$, $\frac{p_a}{p_s} \approx 1.1 \div 1.2$.

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

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 $w_2 = 40 \text{ m/s}$, $\alpha_{fo}$ 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 $w_2 = 130 \text{ m/s}$.

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 $40 \div 130 \text{ m/s}$ velocity range, air-injection mechanical fuel atomization provides (where $\Delta G_a x 10^2 < 0.8$) 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, $\alpha_{st\ max}$ 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.
Dependence $\alpha_{st} = f(w_2)$ 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 $\geq 5.9$ 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.
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 to 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 observed when $w_2 = 80 \div 120$ m/s. $\alpha_{st}$ changes very slightly when $w_2 > 130$ m/s.

$\alpha_{st} = f(w_2)$ curves fell considerably higher when atomized air was supplied to the TVF and $\Delta G_a \times 10^2 \geq 0.4$ 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 $\Delta_a \times 10^2$ magnitude in all modes
with respect to $w_2$ will range from 0.2 - 0.4. A further $\Delta_a$ increase reduces
air-injection mechanical atomization effectiveness. In particular, where $\Delta_a
\times 10^2 = 0.5$, the range of advisable 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 - 2.943 n/cm², while $\frac{p}{p_x} \approx 1.1 - 1.24$, 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


Received by the Editorial Board
29 November 1969