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Investigation and Experiment on a Short Dump-Diffuser of the Combustor

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ABSTRACT

This paper is intended to introduce optimal geometrical parameter matching obtained by using water flow simulation on the box-type specimen and blasting tests on the sector-type specimen for the short dump-diffuser of an annular combustion chamber, and some special problems occurring in practice, such as, the effects of the factors -- the head of flame tube,inlet cap, inlet support strut, splitting flow cone, air drawn from the wall surface and inlet velocity profiles on diffuser performance and its flow status, the obtained results provide the foundation for its practical application.

INTRODUCTION

As advanced engines are developed, operation conditions of the combustor get more and more severe,and the performance requirements get more and more rigorous. Therefore, the annular combustor has been greatly developed and widely used. For this kind of combustor is required an inlet diffuser with short length, low pressure loss, and insensitivity to distortion of the inlet velocity profile. The short dump-diffuser can meet these requirements, it has been used in annular combustors for a great many advanced engines, such as: Viper 632, M45H, RB199, Lazac-04, F100, etc, but the data published before was limited in to research of a few variable factors [1-3]. Only a few valuable publications could be found on this subject.

Experimental research into the problems which may occur in practical applications was conducted. For structure parameter matching of the diffuser, the head of flame tube, inlet cap, inlet support strut, splitting flow cone, air drawn from wall surface, splitflow ratio, inlet velocity profile, etc. a perspex box-type model was tested through water flow simulation. Its construction factors can be varied in a wide range, and its inner flow status clearly observed. A suitable construction matching can be selected on the basis of comparisons. A design method of the orthogonal test was used for select-testing. For some essential factors, the single-factor tests were conducted in order to search out suitable parameter matching between prediffuser and dump region. The results were obtained within a general range of construction parameters of short dump-diffusers used in several advanced combustors [4].

Then, the verification-test and the necessary supplemental tests were carried out on the 90° sector all-metal model by means of cold-blowing so as to make the results more accurate and practical.

The comparison test was used for determining the effects of several particular construction factors occuring in the practical applications and their scope and degree. Some regular results obtained from tests have guide significance [6].

This paper summarizes experimental and research results presented in references [4-6], and provides the practical useful ground for the arrangement of con-

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struction and performance prediction in the product design.

NOMENCLATURE

A	cross-sectional area
B	bleed air ratio (be possessed of inlet total flow percent)
C_p	static pressure recovery coefficient
h	annular height
L	axial length
M	Mach number
P_t	total pressure
P_s	static pressure
V	velocity
α	coefficient of kinetic energy flux, $\alpha=\int_0^A (V_i/V_{cp})^3 \frac{dA}{A}$
β	wall surface angle of outer diffuser
η	diffuser effectiveness
γ	angle of splitting flow cone
λ	loss coefficient, $\lambda=(P_{t1}-P_{t3(or.4)})/\frac{\alpha_1}{2}\rho V_{cp1}^2$
2θ	wall angle of pre-diffuser

Subscripts

1	pre-diffuser inlet
2	pre-diffuser outlet
3	diffuser outlet
4	combustor outlet
0	outer annular
i	inner annular
in	into
p	pre-deffuser
d	dump-region
c	cone

TEST MODEL AND TEST FACILITY

1. Test Model and Test Program

A cross section sketch of box-type and section-type model are shown in Fig. 1. The main variable parameters are shown in table 1.

For the dump-diffuser with straight-walled pre-diffuser, according to orthogonal systems's item L_{27}, the first tests were carried out by varying the following six factors: 2θ, L_p, L_d, β_o, β_i (inclvding one cross factor) and three levels. Then, according to orthogonal system's item L_8, the test was conducted by varying L_p, L_d, β_o, β_i and L_{in}, while 2θ was kept constant. As a result, the optimun matching was selected. For the trumpet pre-diffuser, the head, inlet cap and inlet support, etc, with the different constructions, single-factor tests are carried out.

Table 1. System Geometry

parameter	W. T.(1)	B. T.(2)	complex number
2θ	7°, 11°, 15°, 18°	10.5°, 12°, 15°	12(W.T.).
L_p/h_1	1.5, 2.0, 2.36, 2.5, 4.0	1.67	4(B.T)
β_o	30°, 40°, 55°, 70°	40°, 66°48'	12(W.T)
β_i	30°, 40°, 50°, 70°	40°, 70°	2(B.T)
L_d/h_1	0.5-2.0	1.7	
L_{in}/L_p	0-0.75		
γ	35°, 55°, 70°		
L_c	0, 14		
cap	No.1		
strut	No.1, No.2		
head	blust, semicircular, flame-tube		

(1) W.T.--water flow simulation test,
(2) B.T.--blown test.

2. Test Facility and Instrumentation

The models were tested respectively in the water flow simulator and the cold-blowing rig.

In the above two tests, the flow-inhibiting bar (box-type model) with different diameters and the plate (sector-type model) with orifices of different size were used respectively to form different inlet velocity profile. The $\alpha_1 = 1.005 - 1.145$, and $\alpha_1 = 1.01 - 1.22$ were likely reached respectively.

The measured sections are shown in Fig. 1. The inlet parameters and the velocity distribution were measured respactively by means of several five-orifice rakes for total pressure and orifice on the wall surface for static pressure in section 1. Total pressure and static pressure may be measured in section II and III at a number of points. The flow field in the dump region was measured by moving a five-orifice probe.

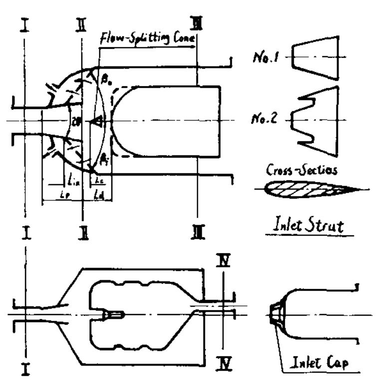

Fig. 1 Cross Section Sketch of Test Model

The total and static pressures also may be measured in section IV. All pressures are measured by the manometer or the water column manometer.

In the definition of loss coefficient, P_S is the mass mean total pressure, V_{cp} is the mass-derived mean velocity. The loss coefficient $_3$ determined according to the energ equation for the system.

The flow drawn from the inner and outer wall surfaces are controlled by the valves respectively, measured by the turbo-flow meter and the frequency meter.

The flow patterns are recorded with the tracing method, hand drawing or photography in the water flow simulation test.

MAIN TEST RESULTS AND ANALYSES

I. The Parameter Matching of the Pre-diffuser and the Dump Region:

According to the requirements of small pressure losses and stable flow, etc, the results obtained from water flow simulation are as follows:

1. Pre-diffuser
   (1) straight wall pre-diffuser is better
   (2) $2\theta = 7°–12°$
   (3) $L_p/h_1 = 2.0 - 2.5$
2. Dump region
   (1) $L_d/h_1 = 1.0 - 1.5$
   (2) β_o and β_i : Its better to take 30°–40°
   (3) L_{in}/L_p: Its suitable to take 0.5
   (4) The outlet shape of pre-diffuser should be in favour of the formation of stationary vortex.

The above conclusions have been further confirmed and modified through a series of water flow simulations and single-factor cold-blowing tests.

The tests for a number of the trumpet pre-diffusers indicated that when the smaller value of L_d was taken, the stable state could be achieved, but it was sensitive to inlet flow field distortion. An increase of L_d makes separation easily occur in the pre-diffuser. Extra-high area ratios for straight wall pre-diffusers also produces separation.

The dump distance L_d is the key parameter affecting dump diffuser performance.

Both the water flow simulation and the cold-blowing test achieved a unanimous conclusion (see Fig. 2): in generaly it is better to let $L_d/h_1 = 1 - 1.5$. From Fig. 2 it can be seen that the pre-diffuser loss coefficient is about 10–20 percent of the total diffuser loss coefficient. Therfore, the pressure loss in the dump region is a big portion of diffuser pressure loss, so it is necessary to design its construction with a great care.

There is some difference between the loss coefficients measured in the two tests. It may be attributed to the difference in flow state caused by the different test model and working substance.

From Fig. 2 and Fig. 3 it follows that the extra large wall surface angle in the outer diffuser may be unsuitable.

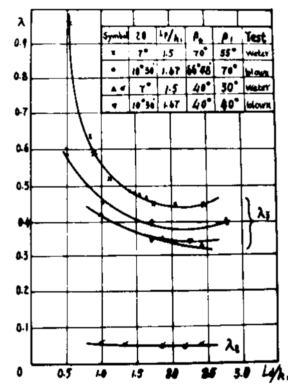

Fig. 2 Effect of Dump Distance on Loss Coefficient

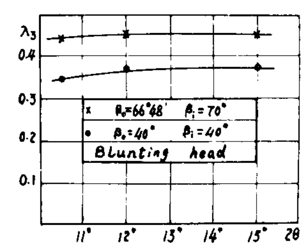

Fig. 3 Effect of β and 2θ on Loss Coefficient (λ_3)

The outlet shape of the pre-diffuser will affect the good formation of the stationary vortex. Comparison of different-shaped flow patterns in two pre-diffuser outlets is shown in Fig. 4. That explained the desisn of the pre-diffuser outlet with curled edges that was used on Pegasus MK104 engine combustor.

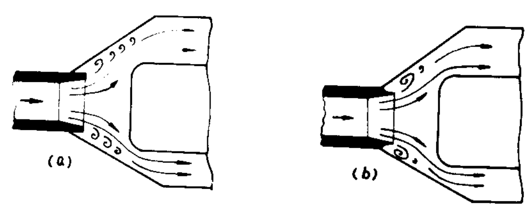

Fig. 4 Comparison of Different-Shaped Flow Patterns in Two Pre-Diffusers outlets

In order to examine the above montioned parameter matching, a model including estimated geometric parameters from six advanced combustor dump-diffusers was tested, which shows that parameter matching and performance are in accord with their scopes.

The water flow simulation [4] also indicated that the flow state in the listed six diffusers was stable.

II. Results of Practical Experimental Research

1. Effect of Flame Tube Head

Turbulent flow occurs at the outlet of the dump diffuser without the head, there can't be a symmetric stationary vortex, and it is sensitive to inlet flow field distortion [6]. After the dump diffuser was fixed with the head without the orifice, generally, a stable stationary vortex can be formed there.

As shown in Fig. 5, the flow patterns drawn for the water flow simulation basically agree with the flow moving direction and velocity distribution measured by means of the five-orifice probe. Because of the stationary vortex formed, this diffuser is characterized by its insensitivity to the inlet radial flow field. The test results shown in Fig. 6 indicated that as a_1 increases, the flow rate distribution between inner and outer annular path almost remains unchanged. The loss coefficient only varies a little as well.

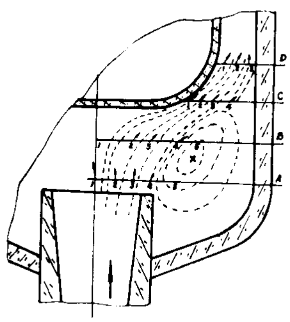

Fig. 5 Result of Observe and Measure for Dump Region

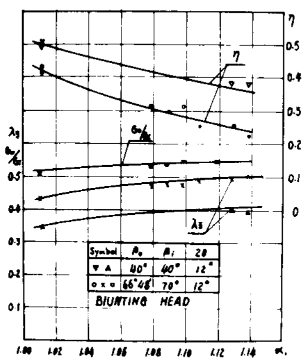

Fig. 6 Effect of Inlet Velocity Profile on Diffuser Preformance

For the head with orifices (i.e. the true flame tube), if the dump distance is smaller its performance deterioration falls down as compared with the head without orifices (see Fig. 7), this may be associated with the reduction of impact loss in the head inlet.

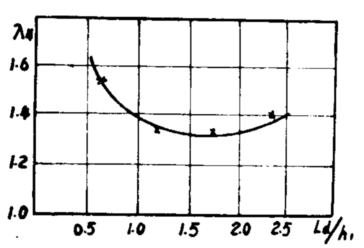

Fig. 7 Effect of Dump Distance on Loss Coefficient (λ_4)

2. Effect of Inlet Cap

The inlet cap is widely used in combustors. Its fanction is to improve combustion the stability and the uniformity of the exit temperature field. Recently, it's also used on combustors with short dump diffusers, such as, the combustor of Olympus 593- MK602, M45H etc.

Observing exit flow fields in tests of other types of diffusers (as bleed type diffuser), it was found that the inlet cap installed could obviously improve flow moving stability, and in the dump diffuser, as there is no unstable exit flow field, the installed inlet cap does not play any role in this respect.

The cap, installed on whichever diffusers, can slightly reduces the pressure loss. This can be explained through the water flow simulation by smoothing the flow line, diminishing impact and turning loss.

Since it probably does not have a significant effect, a lot of combustors with short dump diffuser were not designed with on inlet cap, but because of other problems exposed during its evolution or in the combustor tests, it can also be comsidered to install the inlet cap, which will not produce any unfavourable effect.

3. Effect of a Flow-splitting Cone

When the opening angle of external diffuser is smaller and, in particular, when the length L_{in} is smaller, such as the dump diffuser used in F100 engine combustor, it was found in the water flow simulation that the stationary vortex could be hardly formed in the dump region, and crushed vortexes were formed along the inner wall surface of the diffuser, which extended to the inlet of inner and outer passage. Later on, this problem was solved by installing a flow-splitting cone on the dump diffuser.

The conducted test was composed of six programs which come from the combination of 3 flow splitting cones, respectively, with cone angles of 35°, 50° and 70°, and two installing positions, L = 0, and 14mm. From the above tests, the following conclusions were drawn:

(1) After installing the flow-splitting cone the stable stationary vortex can be surely formed (see Fig. 8). When the value γ is in a certain range, its pressure loss with flow-splitting cone almost remains unchanged, or can even drop down a bit.

(2) When L_c is too small, the horseshoe-shaped vortex in fourmed behind the flow-splitting cone, so that the pressure loss goes up.

(3) After installation of the flow-splitting cone, it is sensitive to distortion of the inlet velocity profile. However, the inlet velocity profile must match with requirements in practical applications.

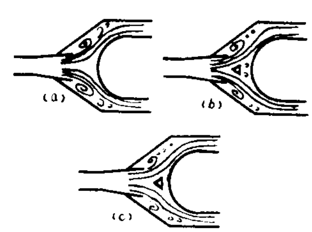

Fig. 8 Effect of Flow-Splitting Cone on Diffusers Flow Stutus

4. Effect of Inlet Strut

It is sometimes unavoidable to install struts in the passages of the combustor diffuser, so this is also a practical problem. Tests were conducted for two different installations of struts (see Fig. 1). The results are shown in table 2.

Table 2. Effect of Inlet Strut

strut	no	No.1	No.2
λ_3	0.33--0.36	0.50--0.52	0.57--0.58

(1) The installation of struts makes the pressure loss increase. This is due to: (a) the flow velocity

increases because of blockages caused by struts, therefore, the pressure loss increases; (b) Flow separation occured at the trailing edge of the struts, and fluctuated near both sides of the support struts.

(2) It is unfavourable to install struts (i.e No.2) between the pre-diffuser and the dump region. This was analysed in ref. [6]. The strut in the Viper 632 combustor was installed in the pre-diffuser passage, in the Olympus 593 - MK602, etc., it is installed in the dump region, this arrangement is reasonable.

5. Effect of Air-Bleeding from the Diffuser wall Surface

Air used for both the aeroplane and the engine, generally is bled from the wall surface of the combustor diffuser. Tests of air bleeding were conducted in two bleeding positions to determine its effect on loss coefficient of the diffuser (see Fig. 1). The results are given in Fig. 9, from which it can be seen that air-bleeding downstream of the diffuser can give a little improvement in the performance of the diffuser, while unsymmetrical air-bleeding from the inner and outer sides has no significant effect on the flow distribution among the inner and outer annular passages.

Similar conclusions were also reached in ref. [8]. This was determined by the characteristics of the dump diffuser.

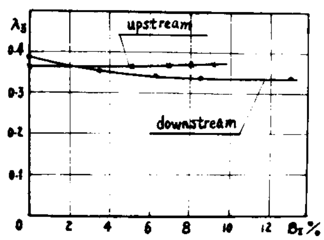

Fig. 9 Effect of Bleeding Position on Loss Coefficient (λ_3)

6. Effect of the Inlet Velocity Profile

Both the water flow simulation and cold-blasting test indicated that the variation of the radial flow velocity distribution at the inlet had no significant effect on the flow distribution among the inner and outer annuluses, but had a certain effect on the loss coefficient. The cold-blasting test was conducted for the diffuser installed with the head and without orifices. Results are given in Fig. 6. It is essentially in accordance with the results obtained from the water flow simulating test [6]. The effect of the inlet flow field distortion on the performance of the dump diffuser is much less than the results obtained in the tests on the vortex-controlled diffuser [9].

For the diffuser installed with the head with orifices, the effect of the inlet flow field distortion on the total loss coefficient of the combustor is a bit greater (Fig. 10). This may be associated with the increase of mixing losses in the flame tube due to the distortion of the inlet flow field.

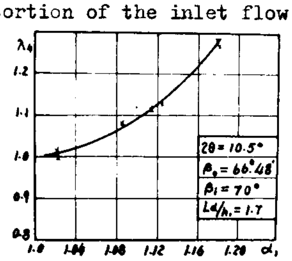

Fig. 10 Effect of Inlet Velocity Profice on Los Coefficient (λ_4)

7. Effect of the Flow-splitting Ratio

The diffuser performance is obtained by varying the flow-splitting ratio in the cold-blasting test (Fig. 11). The results show that, when S = 1 or so, the diffuser performance is the best, which is well in accordance with optimal flow-splitting ratio presented in ref. [10]. i.e. when the flow ratio of the inner-outer annuluses is equal to their geometric area ratio, its performance is the best. As reported in ref. [1-2], the effect of the above factor on the performance had been tested as well, and the similar results were also obtained. Our tests were only intended to verify those results mentioned in [1-2].

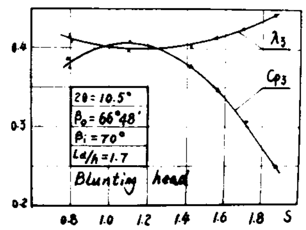

Fig. 11 Effect of Flow-Splitting Ratio on Diffuser Performance

CONCLUSIONS

1. The short dump diffuser with simple construction is insensitive to the distortion of the inlet velocity profile. Therefore, it is very suitable for use in short annular combustors.

2. In order to secure its good performance and stable flow, the construction parameters of the pre-diffuser and the dump region must be arranged reasonably. The parameter matching given in this paper can be used as reference to designs.

3. The installed head with orifices can reduce its sensitivity to the dump distance (gap). For M_1 = 0.3, total pressure recovery coefficients can be reached above 0.94 by reasonable matching of parameters.

4. It is not necessary to install the inlet cap on a flame tube. The flow splitting cone can improve the guality of the stationary vortex. A air bleeding from the wall surface had no significant effect on diffuser performance, in the tested configurations.

5. Installed struts will cause the pressure loss to increase. The case must be taken to prevent flow from separating at the trailing edges of the struts. Meanwhile, the struts should not be installed between the pre-diffuser and the dump region.

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