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ABOUT APPROACHES TO RESEARCH OF FLAT LPT CASCADES AT LOW RE NUMBERS

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Annotation

A flat LPT cascade has been studied on the CIAM exhauster rig at lower Re numbers and slightly raised turbulence. Special attention is paid to measurements of total pressure field behind the throttle unit (in front of the cascade), as well as flow traversing behind the cascade.

1 Study features

The LPT test cascade is made of six "aft-loaded" profiles and has the following geometry parameters:

β_1^0	β_{2eff}^0	c_m	t	δ^0	d_1	$\bar{d}_2$	γ^0	L, mm
53.6	27.7	0.159	0.718	17.9	0.024	0.038	59.2	59.51

The tests are carried out on the У-300C CIAM exhauster rig. For cascade testing at lower Reynolds numbers the inlet lemniscates flaps are equipped with the throttle unit (TU) reducing cascade pressure p_1^* much lower the barometric one. The У-300C rig diagram with the throttle unit is shown in Fig. 1.

Special attention is paid for measurements of total pressure field along the cascade front both w/o throttle unit (exhauster mode at inlet pressure p_1^* = 1 bar) and with throttle unit at rig inlet (inlet pressure p_1^* = 0.9 and 0.5 bar). The pressure is recorded in averaged blade height-wise plane from bottom inlet flap to upper inlet flap, i.e. within several steps.

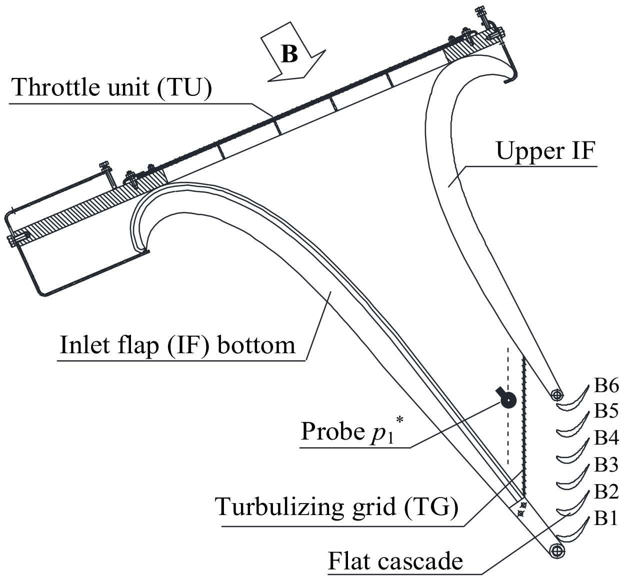

Fig. 1. У-300C rig inlet diagram with throttle unit (TU) and turbulizing grid (TG).

The tests are carried out w/o turbulence grids at mode λ_{2is} = 0.61 typical for LPT last stages cruise regime.

2 Cascade testing without throttle unit

Fig. 2 shows profile losses vs λ_{2is} without throttle unit at inlet flaps and at cascade pressure p_1^* = 1.0 bar.

It is seen that the profile losses level at exhauster modes near λ_{2is} = 0.85 is not high and makes up $\zeta_{pr.}$ = 0.02 – 0.025. It is evident of practically zero cascade turbulence level due to smooth (lemniscates) shape of feeding duct.

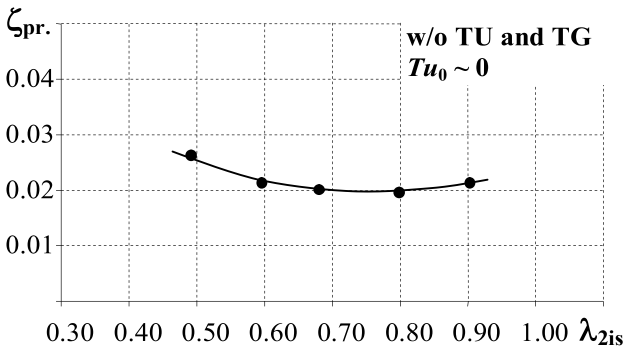

Fig.2. Profile losses $\zeta_{pr.}$ vs cascade λ_{2is} (w/o TU and TG, $p_1^* = 1$ bar).

Fig. 3 shows pressure p_1^* via cascade front from bottom inlet flap to upper inlet flap. The distribution is of uniform nature and well agrees with total pressure measurements by Pitot tubes at the 3rd and 5th blade leading edges.

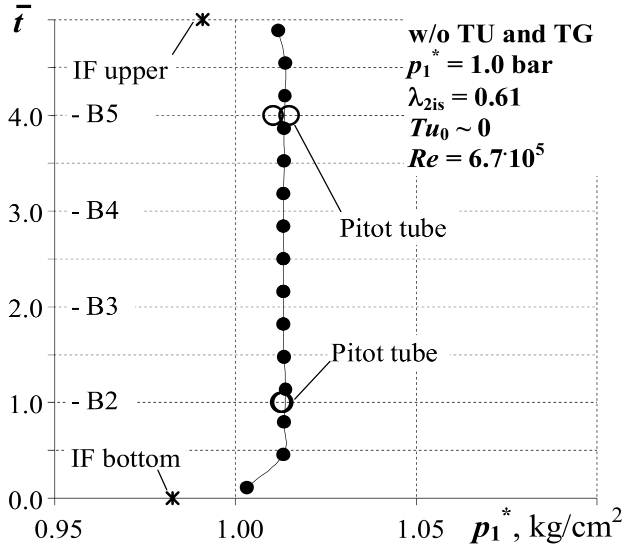

Fig.3. Total pressure p_1^* vs cascade front (w/o TU and TG, $p_1^* = 1$ bar, $\lambda_{2is} = 0.61$).

Flow traversing (Fig. 4) has shown that near interblade duct end wall there occur significant secondary flows and losses. However, there is no influence of secondary flows in averaged height-wise blade duct part.

Flow exit angle β_2 via blade height (Fig. 5) is of ordinary nature with some increase in secondary flows zone. Flow angle lag from effective angle β_{2eff} does not exceed 2.5 – 3.0 degrees.

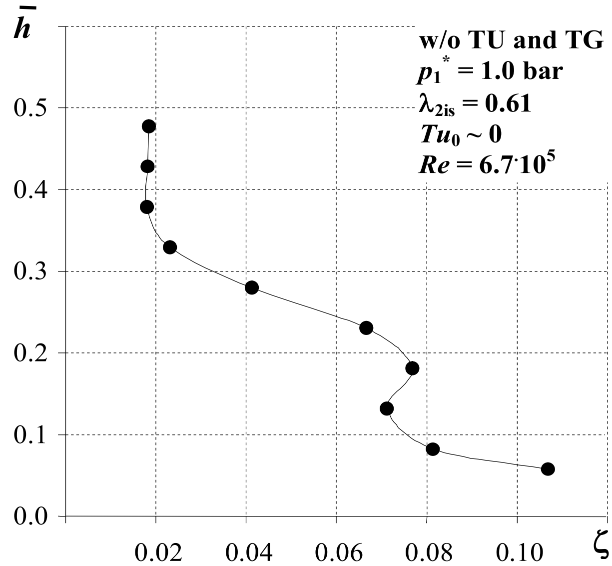

Fig.4. Losses ratio ζ vs cascade blade height (w/o TU and TG, $p_1^* = 1$ bar, $\lambda_{2is} = 0.61$).

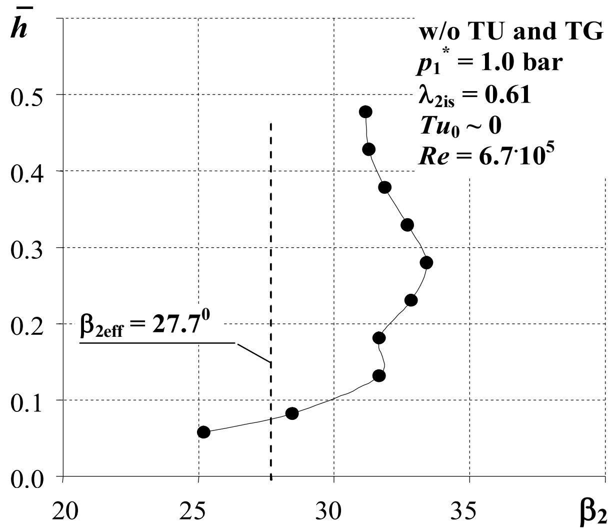

Fig. 5. Flow exit angle β_2 vs cascade blade height (w/o TU and TG, $p_1^* = 1$ bar, $\lambda_{2is} = 0.61$).

3 Cascade testing with throttle unit and inlet total pressure $p_1^* = 0.9$ bar

Total pressure p_1^* via cascade front with existing throttle unit and inlet cascade pressure $p_1^* = 0.9$ bar at the same mode $\lambda_{2is} = 0.61$ as before has a uniform nature (Fig. 6).

Flow traversing with existing throttle unit at the same mode (Fig. 7) shows that the zone and intensity of secondary flows and secondary losses are significantly greater. It might be explained by some decrease of Re number. However, profile losses level (blade height average part of interblade duct) as before makes up about $\zeta_{pr.}$ = 0.02 – 0.025.

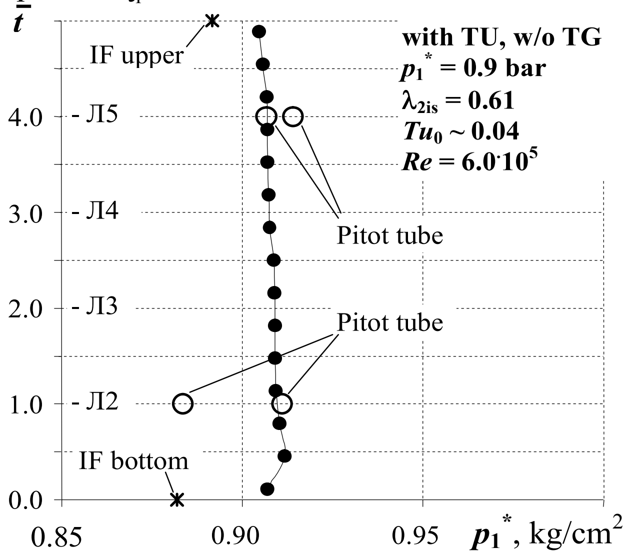

Fig.6. Total pressure p_1^* vs cascade front (with TU, w/o TG, p_1^* = 0.9 bar, λ_{2is} = 0.61).

When operation mode increasing up to λ_{2is} = 0.85 (i.e. some greater Re number) zone length and secondary flows and losses intensity significant decrease. Some flow turbulence impact by throttle unit probably is unessential.

Flow angle β_2 via blade height at existing throttle unit (Fig. 8) is practically of the same nature as without throttle unit. When increasing operation mode up to λ_{2is} = 0.85 flow angle lag from effective angle β_{2eff} essentially decreases.

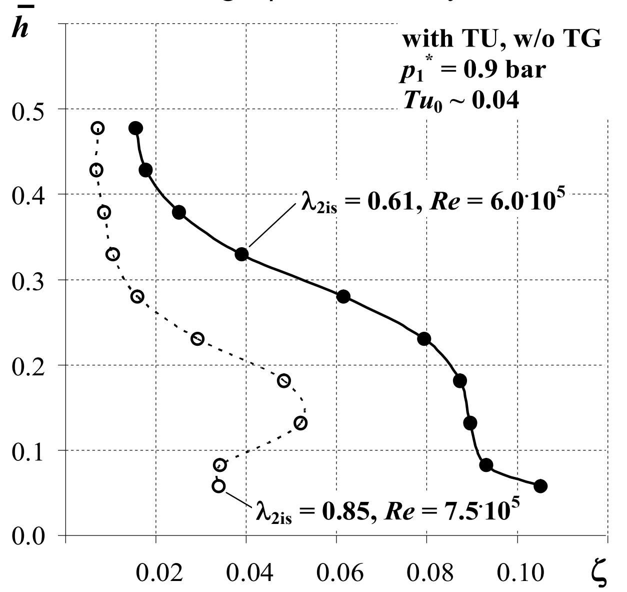

Fig.7. Losses ratio ζ vs cascade blade height (with TU, w/o TG, p_1^* = 0.9 bar).

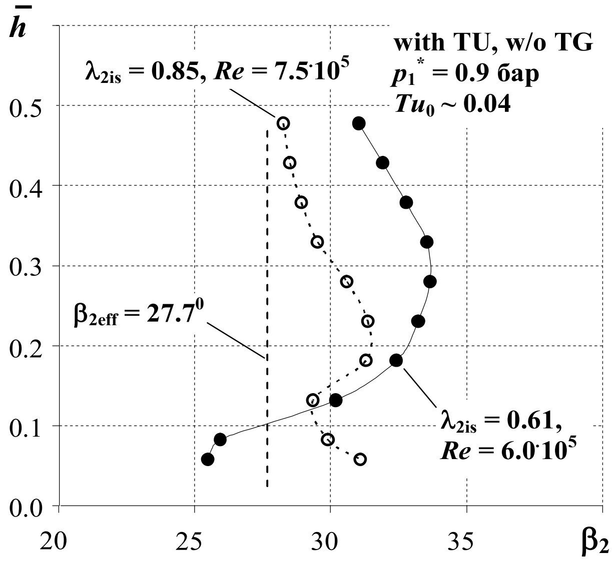

Fig. 8. Flow exit angle β_2 vs cascade blade height (with TU, w/o TG, p_1^* = 0.9 bar).

4 Cascade testing with throttle unit and inlet total pressure p_1^* = 0.5 bar

Fig.9 displays total pressure p_1^* vs cascade front at exiting throttle unit and cascade total pressure p_1^* = 0.5 bar. It is seen that at lower Re number value the pressure via cascade front is as before of uniform nature.

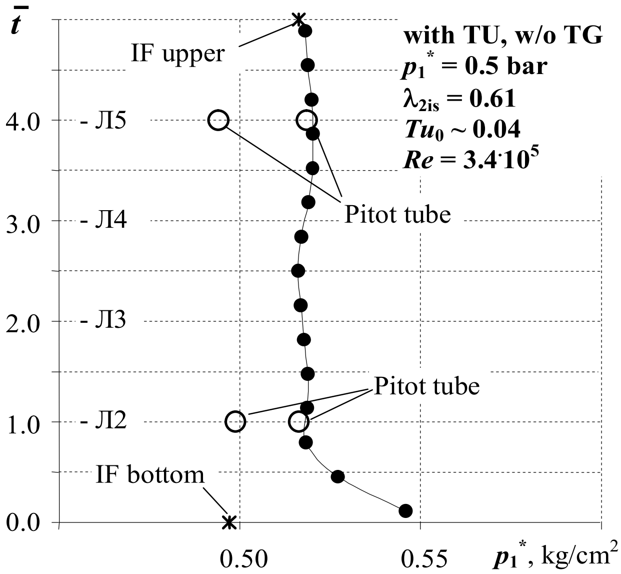

Fig. 9. Total pressure p_1^* vs cascade front (with TU, w/o TN, p_1^* = 0.5 bar, λ_{2is} = 0.61).

Flow traversing at throttle unit existence and cascade inlet total pressure p_1^* = 0.5 bar at the same mode λ_{2is} = 0.61 (Fig. 10) shows that secondary flow zones close in blade height average sections and it results in intensive flow separation at blade suction side and sharp losses increase. The value of total (profile + secondary) losses in this zone 4 – 5 times greater than actual cascade profile losses.

Flow separation (either intensive boundary layer thickening) at blade suction side is confirmed by significant flow angle β_2 rise in blade height average of duct part (Fig. 11).

When operation mode increase up to $\lambda_{2is} = 0.85$ value (i.e. greater Re number) flow separation and also flow exit angle essentially decrease.

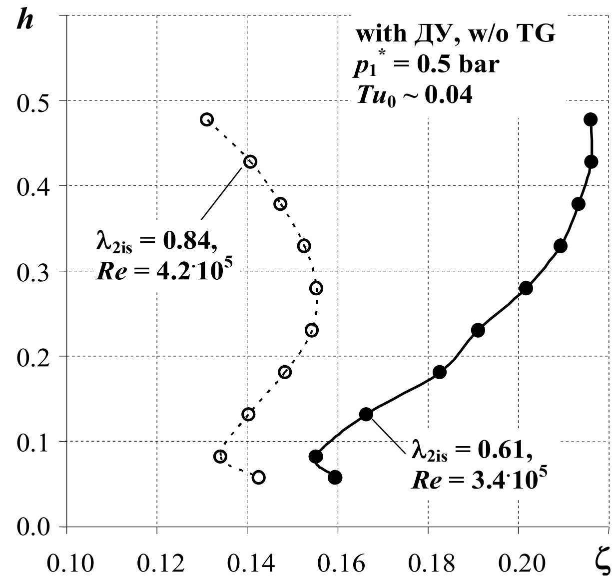

Fig. 10. Losses ratio ζ vs cascade blade height (with TU, w/o TG, $p_1^* = 0.5$ bar).

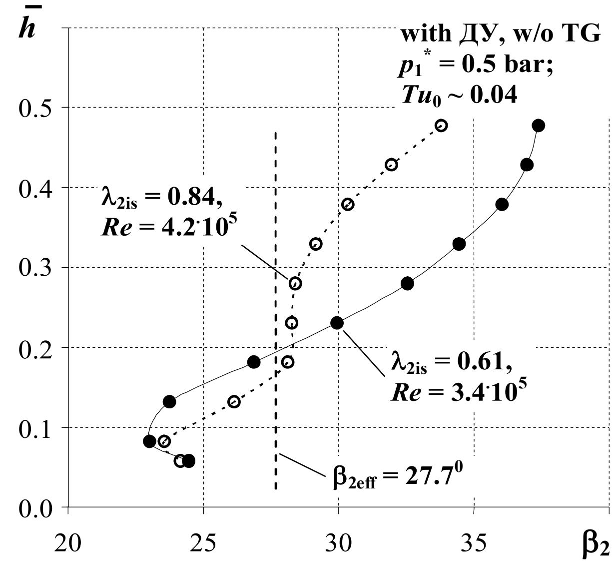

Fig. 11. Flow exit angle vs cascade blades height (with TU, w/o TG, $p_1^* = 0.5$ bar).

5 To comparison cascade testing results with throttle unit and without throttle unit

Measurements have shown that at typical mode for multistage LPT last stages ($\lambda_{2is} = 0.61$) both without throttle unit and its existence and various Re number level the total pressure p_1^* distributions via cascade front have uniform nature.

Fig. 12 shows blade height losses for all the compared cases. It is seen that without throttle unit blade height secondary losses distribution has common nature and modest length. The interblade duct part of blade height average has profile losses of about $\zeta_{pr.} = 0.02 – 0.025$.

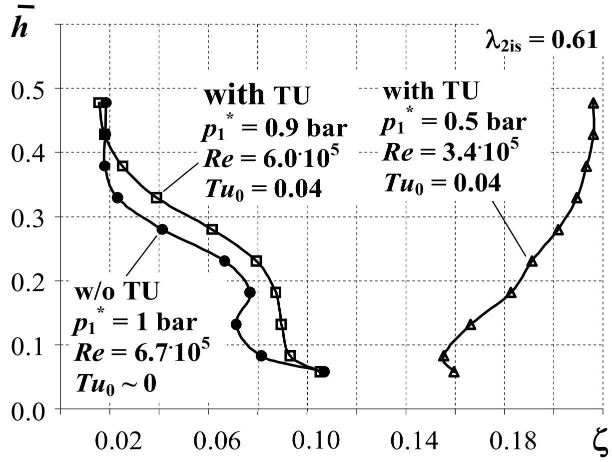

Fig.12. Losses ratio ζ vs cascade blades height (with and w/o TU, Re = (6.0 and 3.4)·10^5.

With throttle unit ($p_1^* = 0.9$ bar and $Re = 6\cdot10^5$) the zone and secondary flow intensity and losses due to slightly lower Re numbers have significantly increased. Turbulence flow influence by throttle unit on cascade flow and losses is probably unessential.

Further cascade pressure decrease ($p_1^* = 0.5$ bar; $Re = 3.4\cdot10^5$) results in closing suction side secondary flows at interblade duct part of blade height average where flow separation occurs (either intensive boundary layer thickening) and total losses sharply rise.

6 Conclusion

- The research conducted has shown that at lower Reynolds numbers due to boundary layers thickening in flat cascades secondary flows and secondary losses greatly increase.
- In the cascade tested due to rather short blades (blade length ratio $h/l = 1$) at cascade inlet pressure reduction $p_1^* < 0.6 \ldots 0.7$ bar secondary flows close in the duct part of blade height average and total (profile + secondary) losses measured in this zone 4 – 5 times greater than actual cascade profile losses.
- At typical mode for last stages of multistage LPT ($\lambda_{2is} = 0.61$) both without throttle unit and its presence and various Re number level $Re = (6 - 3) \cdot 10^5$ total pressure p_1^* distribution versus cascade front has a uniform nature.
- Experimental study of profile losses in flat cascades at lower Reynolds number values field should be carried out without influence of secondary flows, in particular, at blade relative length $h/b > 2$.
- Detailed study of secondary (end) losses in the field of lower Re number values is up-to-date task for further research.

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