Research on Ultra-Highly Loaded Turbines

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Keywords: Turbine, Highly loaded, Large turning angle, Aerodynamic performance

1. Introduction
There is an increasing need for development of highly loaded turbines to decrease engine weight. However, aerodynamic efficiency of such highly loaded turbines tends to decrease as the turning angle of the blade rows becomes larger. In the development of ultra-highly loaded cascades, various tests have been made so far at NAL using newly constructed linear and annular cascades to make the internal flow/loss mechanisms clear. The following sections describe the merits of the highly loaded turbines and the purposes, topics, history and some latest results of the present study.

2. Merits of Ultra-Highly Loaded Turbines
1) The turbine component is one of the heaviest parts among many engine components and so, the engine weight could be reduced significantly when highly loaded blades are adopted: The blades can reduce the turbine stages and size, and can reduce their number required and therefore, the manufacturing and maintaining cost.
2) Currently, the rapid increase of cooling-air mass flow rate required for high temperature turbines becomes a big problem in engine developments from an aerodynamic performance point of view. The reduction of the blade number can solve this problem. Because of the large gas temperature drop after the highly loaded turbine stage, the cooling air required for the following turbine stages can be reduced or made not necessary.

3. Goal of the Present Study
Fig. 1 shows a geometry comparison between a conventional highly loaded cascade (CHLC) with 113 deg turning angle and the present ultra-highly loaded cascade (UHLC) with 160 deg. As the blade turning angle increases, the blade loading generally tends to increase. The aerodynamic efficiency, however, tends to decrease due mainly to increased secondary flows and flow separations occurring in the blade passages. The aim of the study, therefore, is at how to control such flow phenomena while keeping high efficiency (i.e., low pressure loss) and high loading at the acceptable levels.

4. Methods of Approach
1) To approach the final goal surely in such development of unconventional blades, it is essential to understand the complex internal flows and the associated loss generation mechanisms. We have conducted very detailed flow measurements and obtained new ideas for designing better blade geometry and better cascades based on the experimental data.
2) Not to be limited to the conservative design techniques with empirical data, it is also essential to use new design techniques such as the current advanced CFD tools.

5. History of the Present Study
2) We studied an ultra-highly loaded turbine in “A Basic Study of Contra-Rotating Turbines” which was one of the NAL Special Research Topics in 1993-1994.

6. Some Results
1) Fig. 2 (left) shows detailed experimental total pressure loss distributions obtained at five traverse measurement planes in a linear ultra-highly loaded cascade. We can see that the endwall boundary layer upstream of the cascade, i.e., low-energy (loss) fluids, is strongly driven onto the blade suction surface by a pair of passage vortices. The passage vortices are, in fact, very
strong due to very large pressure gradient inside the ultra-highly loaded cascades. Finally, all the endwall low energy fluids are accumulated into the single loss core at the cascade outlet. Fig.2 (right) shows how the loss value increases from the cascade inlet to the outlet.

2) Fig.3 shows distributions of flow velocity at ten traverse planes located upstream, inside and downstream of an annular cascade of ultra-highly loaded blades. Velocity acceleration and deceleration regions are seen clearly. The distributions are deformed significantly by the strong passage vortices. This figure shows the time-averaged velocity distributions.

3) To simulate the unsteady flows in rotors by using a stationary cascade and to know the effects of unsteadiness caused by upstream blade interaction on the downstream cascade performance, rotating cylindrical rods were installed in front of the test cascade as shown in Fig.4: The rods produce periodical wakes which enter the test ultra-highly loaded cascade. Fig.4 shows the instantaneous wake movements in the cascade. As seen here, the wakes are deformed significantly while they pass the cascade. With the help of the diagram (b) below, we can see that the cascade outlet loss decreases when the wakes collide with the cascade’s leading edge while the loss increases when the wakes pass through the cascade passage.

7. Summary and Future Plans
1) There are a lot of problems to be solved in the development of high efficiency ultra-highly loaded turbines.
2) We have seen very complex flows inside the passage of ultra-highly loaded turbine cascades. These should properly be controlled to reduce the losses by adopting three dimensional blade configurations. CFD work will be extensively used for this purpose.
3) New types of turbines, such as contra-rotating turbines with ultra-highly loaded blades, are to be studied to decrease engine weight further.

References