Propulsion and Power Research 2012;1(1):12–28

http://ppr.buaa.edu.cn/

Propulsion and Power Research

www.sciencedirect.com

ORIGINAL ARTICLE

Unsteady cooperative flow in compression system

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Received 14 February 2012; accepted 5 November 2012
Available online 20 December 2012

KEYWORDS

Unsteady cooperative flow;
Unsteady natural flow;
Time-space structure of the flow field;
Compression system;
Aero-engine;
Flow over multi-bodies;
Asymmetric flow;
Axial compressor transonic flow

Abstract When there are several bodies with relative motion in a flow field, such as the flow in the compression system of modern aero-engine, the flow field will have certain special features, one of which is that the time-space structure of such multi-bodies unsteady vorticity flow field would be either of unsteady natural flow (UNF) pattern or of unsteady cooperative flow (UCF) pattern. If we further examine the aerodynamic design system of aero-engine, there is no mechanism for the unsteady cooperative flow to occur, in other words the flow field must be of the unsteady natural flow type. If certain technical measures can be adopted to transform UNF into UCF, the aerodynamic performances will surely be improved. This is the main task the author and their colleague have been devoted to and the results are reviewed in the present paper with emphases laid on basic ideas, technical approaches and experimental verifications.

1. Introduction

Around the beginning of new centuries, the group of "Aerodynamic Design of Compression System Layout" of the National Key Laboratory of Science and Technology on Aero-Engine Aero-Thermodynamics began to undertake series of key projects of basic research, focusing on a question: Is there any new mechanism and new approach for the aerodynamic performances of aero-engine compression system to be further improved? After analyzing the basic simplification assumption underlying the modern

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Peer review under responsibility of National Laboratory for Aeronautics and Astronautics, China.

Production and hosting by Elsevier

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http://dx.doi.org/10.1016/j.jppr.2012.11.001

Nomenclature

f_e	excitation frequency
f_{shed}	vortex shedding frequency
$\overline{f}_e$	relative excitation frequency, $\overline{f}_e = f_e/f_{shed}$
i	angle of attack
$\dot{m}$	mass flow
n	rotate speed
$\overline{n}$	correct rotate speed
P^*	total pressure
Q	volume flux
SM	stall margin
τ_{RF}	reverse flow time ratio
π	pressure ratio
η	efficiency
σ	total pressure recovery coefficient
δ	coefficient of the relative increment
Δ	coefficient of the absolute increment

Superscript and subscript

D	parameters under design condition
S	parameters under stall condition
cor	correct parameters
max	parameters under maximum loading condition

Abbreviations

CS	compression system
CT	casing treatment
UNF	unsteady national flow
UCF	unsteady cooperative flow
TE	turbine engine
WIE	wake impact effects
WS	turbofan engine

aerodynamic design system, we propose a new concept, i.e. "the Unsteady Cooperative Flow in Compression System" (shortened to UCF in CS) [1]. Up to now 14 doctor dissertations have been completed focused on this new idea, in which 2 were awarded the first prize of science and technology by French SAFRAN Group, one evaluated as the 2008 national outstanding doctor dissertation. Since there are numerous projects, equipment, staff members and software related to UCF in CS, these projects lasted dozen years and many graduate students were graduated, it is thought necessary to arrange and publish a review paper to highlight the related academic ideas to guide subsequent graduate students and to solicit valuable opinions from specialists in the same occupation.

For concise and clear presentation, the present paper attempt to lay emphases on physical essence of the new idea, rather than enumerate symbols and formula. Experimental facilities, testing system and computational fluid dynamics (shortened to CFD) software related will not be expounded. Although our experiments and CFD simulations have experienced success and setbacks, only part of them is included to illustrate status quo, and thus the paper consists of five parts:

(1) Introduction.
(2) Idea of UCF in CS.
(3) Technical exploration and arrangements to improve the time–space structure of unsteady vortex flow and the corresponding aerodynamic parameters.
(4) Part of our experiment results to illustrate in Section 4.
(5) Summary in Section 5.

2. Unsteady cooperative flow in compressor

When there are several bodies with relative motion in a flow field, such as the flow in the compression system of modern aero-engine, the flow field has certain special features, one of which is that the time–space structure of such multi-bodies unsteady vortex flow field would be either the unsteady natural flow (shortened to UNF) or the unsteady cooperative flow (shortened to UCF). If certain technical measures can be adopted to transform UNF into UCF, the random time–space structures would be transformed into an orderly one. However this character has not been considered in the current aerodynamic design system of aero-engine, and thus there exists a possibility to improve the time-averaged aerodynamic performances by means of transforming the random time–space structure into an orderly one, which will be expounded in the present part.

2.1. The compression system's function and the unsteady vorticity flow

It is well-known that the basic function of the compression system is to boost the incoming flow by doing work on it. The classic Euler formula describes the two elements in the process the rotor blade row does work on the incoming flow, i.e. the circumferential velocity of the rotor blade and the change in the circumferential velocity component of the incoming flow. Unsteady effects in the above-mentioned process was analyzed in the classic literature [2], however, the mechanism of work-doing was not connected to the time–space structure of the unsteady flow field, and thus questions would be asked as follows. (1) What is the role the unsteady flow field plays in the work-doing process? (2) What is the relationship between the unavoidable dynamic energy losses of the flow occurring in the process with the time–space structure of the unsteady flow field? (3) What is the effect the stagger arrangement of the stator blades and the rotor blades has on the time–space structure of the unsteady flow