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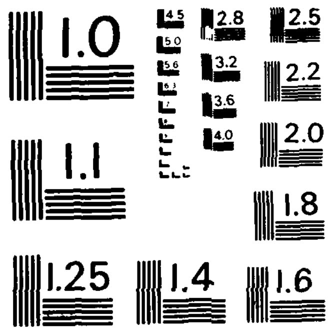

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AEROELASTICITY IN TURBOMACHINE-CASCADES

Final Scientific Report under Grant AFOSR-83-0163

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Report EPFL/LTA-TM-3-84

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AEROELASTICITY IN TURBOMACHINE-CASCADES

Final Scientific Report under Grant AFOSR-83-0063

A. Bölcs *, *T. Fransson*, *P. Suter* **

Report EPFL/LTA-TM-3-84

February 1, 1984

**) Principal Investigator Dec. 15, 1982 - Sept. 30, 1983

*) Principal Investigator Oct. 1, 1983 - Dec. 14, 1983

(See Chapter 6)

EPF-LAUSANNE ***LABORATOIRE DE THERMIQUE APPLIQUÉE***

PROJECT No: AFOSR-83-0063

"AEROELASTICITY IN TURBOMACHINE-CASCADES"

T. Fransson, P. Suter
Laboratoire de Thermique Appliquée
Swiss Federal Institute of Technology - (EPF-Lausanne)
CH - 1015 LAUSANNE
Switzerland

Final Scientific Report under Grant AFOSR-83-0063:
December 15, 1982 - December 15, 1983

(This report constitutes thus the forth semi-annual progress report on the project "Aeroelasticity in Turbomachine-Cascades" under Grants AFOSR-81-0251 and AFOSR-83-0063).

Report Date: February 1st, 1984

Submitted by

Prof. A. Bölcs * Prof. P. Suter **

Principal Investigators

Prepared for:
United States Air Force
Air Force Office of Scientific Research
Building 410, Bolling AFB, Washington D.C. 20332
and:
European Office of Aerospace Research and Development
223-231 Old Marylebone Road
London NW1 5TH
G.B.

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SUMMARY

The aeroelastician needs reliable efficient methods for calculation of unsteady blade forces in turbomachines. The validity of such theoretical (or empirical) prediction models can only be established if researchers apply their flutter and forced vibration predictions to a number of well documented experimental test cases.

Under the present project, a report with nine selected standard configurations for the mutual validity of experimental and theoretical results has been prepared and distributed. Together with the standard configurations, unified nomenclature and reporting formats, to be used in the present work, have been defined.

Presently, "blind tests" predictions are performed at several research institutes, whereafter the experimental and theoretical aeroelastic results will be compiled and analyzed during the third (final) year of the project.

The potential for a very positive result from the joint research work has become increasingly larger, as many more institutions than originally previewed are interested in the establishment of the validity of existing and future theoretical models for flutter.

As part of the project, two experimental research programs have been initiated in fields where no data could be found in the open literature.

CONTENTS Page

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Appendix:

1. INTRODUCTION

In axial-flow turbomachines considerable dynamic blade loads may occur as a result of unsteadiness of the flow. The trend towards ever greater mass flows or smaller diameters in the turbomachines leads to higher flow velocities and to more slender blades. It is therefore likely that aeroelastic phenomena, which concerns the motion of a deformable structure in a fluid stream, will increase ever more in future turboreactors (fan stage) and industrial turbines (last stage) /1/.
The large complications, and high costs, of unsteady flow measurements in actual turbomachines makes it necessary for the aeroelastician to rely on cascade experiments and theoretical prediction methods for minimizing blade failures due to aeroealstic phenomena. It is therefore of great importance to validate the accuracy of flutter and forced vibration predictions as well as experimental cascade data and to compare theoretical results with cascade tests and trends in actual turbomachines.
Several well documented unsteady experimental cascade data exist throughout the world, as well as many different promising calculation methods for solving the problem of unsteady flow in two-dimensional and quasi three-dimensional cascades. However, due to different basic assumptions in these prediction methods, as well as many different ways of representing the obtained results, no real effort has been made to compare theoretical methods to each other. Furthermore, the validity of these theoretical prediction analysis can only, since hardly any exact solutions are known, be verified by comparison with experiments. This is very seldom done, partly because of the reasons mentioned above, partly as well documented experimental data normally are of proprietary nature.

2. OBJECTIVE OF THE RESEARCH PROJECT

It is the purpose of the present work to partly remedy the above mentioned situation by selecting a certain number of standard configurations for aeroelastic investigations in turbomachine-cascades and to define an unified reporting format to facilitate the comparison between different theoretical results and experimental standard configurations.
Several flutter prediction models shall be used to determine the aeroelastic behaviour of the selected standard configurations. The theoretical results will be compared to and evaluated together with the experimental data. It is intended to propose a detailed project for future aeroelastic basic research investigations in order to understand some of the physical reasons for different types of flutter.
The final objective of a comparative work of the present kind is of course to advance the physical understanding of a phenomena as well as to validate theoretical prediction models with experiments performed under actual conditions in the turbomachine, i.e. under consideration of unsteady rotor-stator interaction, flow separation, viscosity, shock-boundary layer interaction, three dimensionality etc. Such a far-reaching objective does however not correspond with the present state-of-art of aeroelastic knowledge, neither for prediction models nor as regards well documental experimental data to be used as standard configurations.
The scope of the present work will therefore be limited to fully aeroelastic phenomena under idealized flow conditions in two-dimensional or quasi three-dimensional cascades. Such interesting phenomena as rotor-stator interactions, stalled flutter and fully three-dimensional effects will thus be excluded, unless as an extension from the idealized two-dimensional cascade flow.

3. STATE OF THE PROJECT

The first two years of the three year project * has permitted the

- o initialization of the work
- o selection of the standard configurations to be used as reference cases for validation of theoretical models
- o definition of nomenclature and precise reporting format to be used by all researchers participating in the project
- o establishment and distribution of a report containing the standard configurations, nomenclature and reporting formats /2/.

In the established report "Two-Dimensional and Quasi Three-Dimensional Experimental Standard Configurations for Aeroelastic Investigations in Turbomachine-Cascades" /2/, nine standard configurations, ranging from flat plates to highly cambered turbine bladings and from incompressible to supersonic flow conditions, have been selected and a total of 203 aeroelastic cases, based upon existing experimental data, have been defined for analysis by existing prediction models for flutter and forced vibrations.

The aeroelastic behaviour of the selected standard configurations (see Table 1) are presently predicted as "blind test" calculations by the researchers participating in the theoretical part of the project (Table 2). As a second phase, the experimental data will be distributed to all researchers having performed the recommended analysis, in order to prepare a base for detailed discussions of the different experimental and theoretical results during the Third Symposium on Aeroelasticity in Turbomachines (1984, /3/, /4/, /5/).

In this second phase of the theoretical part of the project it will also be possible for the participants to eventually refine some aspects of their experimental and theoretical procedure as to explain eventual differences between their results and the results by other workers.

*) Sept. 1, 1981 to Aug. 31, 1982 under Grant AFOSR-81-0251 and
Dec. 15, 1982 to Dec. 14, 1983 under Grant AFOSR-83-0063

Experimental Configuration No	Institution	Geometry: Cascade		Geometry: Flow			Profile			Flow Field: Mach Regime					Flow Field: Separation			Kinematics: Exci-tation		Kinematics: Motion				Kinematics: Mode			Results						Parameters varied in the standard configuration
		Linear Cascade	Annular Cascade	2-Dimensional	Quasi 3-Dimensional	3-Dimensional	Flat plat	Thickness	Camber	Incompressible	Subsonic	Sub-Supersonic	Supersonic	Super-Subsonic	No stall	Partial stall	Fully stalled	Forced	Self-excited	Harmonic	Non-harmonic	Inter blade phase = 0	Inter blade phase ≠ 0	Bending	Torsion	Coupled	Steady blade pressures (C_p)	Unsteady blade pressures ($\tilde{C}_p$)	Lift coefficient (C_L)	Moment coefficient (C_M)	Aerodynamic work coefficient (C_W) and/or Aerodynamic damping (Ξ)	Flow visualization	
1	United Technologies Research Center	X		X				X	X	X					X			X		X		X	X		X		X	X		X	X		$\tilde{\zeta}, \bar{\tau}, ...$
2	University of Tokyo	X		X				X	X	X					X	X	X	X		X		X	X		X		X		X	X			τ, γ, x_α, ...
3	Tokyo National Aerospace Laboratory		X		X			X	X			X			X	X	X	X		X		X	X		X		X	X		X			$\tilde{M}_1, \tilde{M}_2$, ...
4	Lausanne Institute of Technology		X		X			X	X		X				X	X		X		X		X	X	X	X		X	X					$\tilde{M}_1, \bar{\beta}_1, \tilde{M}_2$, vibration mode, ...
5	Office National d'Etudes et de Recherches Aérospatiales	X		X				X			X				X	X	X	X		X		X	X		X		X	X		X	X	X	$\tilde{M}_1$, ..., $\tilde{P}_{t1}$, x, ...
6	Lausanne Institute of Technology		X		X			X	X			X			X	X		X	X	X		X	X	X	X		X	X				X	$\tilde{M}_1, \bar{\beta}_1, \tilde{M}_2$, vibration mode, ...
7	NASA Lewis Research Center	X		X				X	X				X	X	X			X		X		X	X		X		X	X		X	X	X	$\tilde{M}_1$
Theoretical Flat Plate Configuration 8				X			X			X	X		X	X	X			X		X		X	X		X			X	X	X	X		
Theoretical Circular Arc Configuration 9				X				X		X	X		X	X	X			X		X		X	X		X		X	X	X	X	X		

Table 1a: Summary of the nine standard configurations

Institution	Name	Classification number	Cascade				Profile				Configuration			Flow: Fluid		Flow: Mach regime					Flutter flow field			Kinematics: Excitation		Kinematics: Motion				Mode				Magnitude		Results			
			Isolated airfoil	Linear cascade	Annular cascade	Real machine	Flat plate	Thickness	Camber	Twist	2 - Dimensional	Quasi 3-Dimensional	3 - Dimensional	Inviscid	Viscous	Incompressible	Subsonic	Supersonic	Sub - Supersonic	Super - Subsonic	No stall	Partially stalled	Fully stalled	Forced	Selfexcited	Harmonic	Non-harmonic	Interblade phase = 0	Interblade phase ≠ 0	None (gust)	Bending	Torsion	Coupled	Small disturbance	Fully unsteady	Force/Moment	Damping/Stability limits	Unsteady blade press	Unsteady isobars
Physical Sciences Inc. University of Tokyo	Kemp Shoji	1		x			x				x			x		x					x			x		x		x		x	x	x		x		x		x	
Cambridge University	Whitehead/Smith	2		x			x				x			x		x	x				x			x		x		x	x	x	x	x		x		x		x	
Cambridge University	Whitehead	3		x			x				x			x				x			x			x		x		x	x	x	x	x		x		x		x	
Cambridge University	Whitehead	4		x			x	x	x		x			x		x	x				x			x		x		x	x		x	x		x		x		x	
Cambridge University	Whitehead	5		x			x	x	x					x		x	x	x	x	x	x			x		x		x	x		x	x		x		x		x	
United Technologies	Verdon/Caspar	6		x			x	x	x		x			x		x	x		x		x			x		x		x	x		x	x		x		x		x	
United Technologies	Verdon	7		x			x				x			x				x			x			x		x		x	x		x	x		x		x		x	
University of Tokyo	Kaji	8		x			x		x		x			x			x			x	x	x		x		x		x	x		x			x		x			
ONERA	Salaün	9			x		x			x			x	x			x				x			x		x		x	x		x	x		x		x			
ONERA	Salaün	10			x		x			x			x	x				x			x			x		x		x	x		x	x		x		x			
ONERA	Salaün	11		x			x			x	x			x				x			x			x		x		x	x		x	x		x		x			
NASA LeRC	Braun/Molls/Goldstein	12		x			x				x			x						x	x			x		x		x	x		x	x		x		x		x	
NASA LeRC	"	13		x				x	x		x			x						x	x			x		x		x	x		x	x		x		x		x	
Kyushu University	Namba	14		x			x	x	x		x			x				x			x			x		x		x	x		x	x		x		x	x	x	
Florence University	Martelli	15		x				x	x		x			x					x		x			x		x								x					
Florence University	Martelli	16		x				x	x		x			x			x				x			x		x				x				x		x		x	
Technische Hochschule Aachen	Gallus/Vogeler	17		x			x	x			x			x				x			x			x		x		x	x		x	x		x		x		x	
Nielsen Engineering and Research, Inc.	Nixon	18		x				x	x		x			x			x		x		x			x		x		x	x		x	x		x		x	x	x	
University of Tennessee	Caruthers	19		x				x	x		x			x			x				x			x		x	x	x	x	x	x	x	x	x				x	
University of California	Friedmann	20		x			x				x	x		x		x				x	x			x					x				x	x	x				
Lausanne Inst. of Technology	Fransson	21		x			x	x	x		x			x		x	x				x			x		x		x			x				x	x		x	x

Table 2: Theoretical participation

Standard Conf. No	Courtesy of	Velocity domain(s)	Compressor/ Turbine Configur.	Profile % thickness • camber	Linear/ Annular Configur.	Instrument on reference blade	Mode Torsion/ Bending	Representation
1	UTRC (F.O. Carta)	Incompress.	C	6% 10^{o}	Linear (Air)	• 20 transducers • Strain gages	T	$C_p(x)$, $\Delta C_p(x)$ for [illegible] C_M, Ξ = f(σ) C_M, Ξ = f(k)
2	Tokyo Univ. (H. Tanaka)	Incompress.	C + T	5% 16^{o}	Linear (Water)	• Strain gages	T	C_M, Ξ = f(σ) C_M, Ξ = f(k) C_M, Ξ = f(γ) C_M, Ξ = f(i)
3	NAL-Tokyo (H. Kobayashi)	Transonic (Sub+Super)	T	12.7 60^{o}	Annular (Freon)	• 10 transducers • Strain gages	T	$C_p(x)$ C_M, Ξ = f(M_2) C_M, Ξ = f(k) C_M, Ξ = f(σ)
4	EPF-Lausanne (M. Degen)	Subsonic	T	17% 45^{o}	Annular (Air)	• 12 transducers • Strain gages	B,T	C_M, Ξ = f(σ) C_M, Ξ = f(β_1) C_M, Ξ = f(p_2/p_{t1})
5	ONERA (E. Szechenyi)	Subsonic	C	3% 0^{o}	Linear (Air)	• 26 transducers • Strain gages	T	$C_p(x)$, $\Delta C_p(x)$ C_M, Ξ = f(M_1) C_M, = f(i) C_M, = f(k)
6	EPF-Lausanne (D. Schläfli)	Transonic (Sub+Super)	T	5% 14^{o}	Annular (Air)	• 5 transducers each on two blades • Strain gages	B,T	$C_p(x)$ C_M, = f(β_1) C_M, = f(M_2) C_M, = f([illegible]) C_M, = f(k)
7	NASA LeRC (D.R. Boldman)	Supersonic Transonic (Super+Sub)	C	3% -1.3^{o}	Linear (Air) Strain gages	• 12 transducers • Strain gages	[illegible]	$C_p(x)$, $\Delta C_p(x)$ C_M, = f([illegible]) C_M, = f(p_2/p_{t1})

Table 1b: Seven experimental standard configurations

The final comparison of the experimental and theoretical results will be distributed at the 1984 Symposium on Aeroelasticity /5/. Attention will then also be focused upon still unresolved aeroelastic problems and a coordination of future experimental and theoretical investigations may be initiated.

As part of the objectives to initiate basic experimental research on flutter phenomena in flow domains where a lack of data is present, one project on highly loaded subsonic turbine bladings has been initiated and one project as regards aeroelasticity in transonic compressors has been proposed (see chapter 4.4 for further details). Presently, the project progresses as planned in the "Unsolicited Research Proposal: Aeroelasticity in Turbomachine-Cascades" /6/ and the continuation proposals for the second and third years /7,8/, although there was a delay of about eight months in submitting the report on the standard configurations /2/, to the participants. This delay was due to the fact that all the standard configurations treat some material of proprietary nature, so that the choice of the form of presentation of the data needed extended discussion in some cases. However, the project will still be concluded towards the end of 1984 as originally planned.

4. PROGRESS IN THE PERIOD DECEMBER 1, 1982 - DECEMBER 14, 1983

4.1 Compilation of standard configurations

A large interest for the present project has been manifested by the fact that most of the major organizations in the field of aeroelasticity in turbomachines are participating in the work (Tables 2 and 3). Out of the 36 experimental data put at our disposal by different organizations (Table 3), seven have been retained as test cases. Two further configurations are based upon existing theoretical investigations, giving a total of nine standard configurations (Tables 1).

Institution	Name	Classification Number	Geometry	Flow	Flutter Flow Field	Kinematics	Mode	Results	Y/N	Remarks
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Yes, Y, Y, N, Y	• 2-dimensional isolated airfoils. The problem is treated in an AGARD Workshop [illegible].
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	No, Y, Y, Y, Y, N, Y, Y, Y, Y, N, N	• 2-dimensional or quasi 2-dimensional aeroelastic investigations in linear cascades.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Y, Y, Y, N, Y, Y, N	• Quasi 2-dimensional aeroelastic investigations in annular cascades.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Y, Y, N, N, Y	• Fully 3-dimensional aeroelastic investigations in real machines. • No fully 3-D calculation methods exist presently, we refer at hope to treat this at a later time.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Y, Y, Y, Y, Y	• [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Not appropriate	• Exact solutions. • Small perturbations, inviscid.

Remarks: ▨ = Not appropriate

Fig. 2

Classification of the 34 sets of experimental data and some exact solutions, from which the test cases will be chosen.

The scope of the present work is limited to two-dimensional or quasi two-dimensional configurations (parts B, C and E above).

In the choice of the standard configurations it was of interest to cover all velocity domaines in present and future turbines and compressors. The selected experimental standard configurations cover thus incompressible (2 configurations), subsonic (2), sub-to-supersonic (2) and super-to-subsonic (1) flow conditions (Table 1b). The geometries cover both compressor (4) and turbine (3) configurations.
A final report /2/ comprising the compiled standard configurations, including the steady aerodynamic data necessary for calculations, was distributed to all participants in the end of 1983.

4.2 Definition of nomenclature and precise reporting formats for the experimental and theoretical results

A minimum number of prescriptions should of course be used in a joint work of the present type. However, the main nomenclature must be standarized in order to avoid misinterpretations of the results and to facilitate the comparison of relevant information.
The present effort for standardization of nomenclature and reporting formats has been highly appreciated by the different participants. This is a point of great importance, especially for industrial organizations where the person working on an aeroelastic problem mostly not has the time to work out the differences in non-identical nomenclatures*.
In the present work, the recommendations for nomenclature and reporting formats are based upon the one normally used by the researchers participating in the project (Table 1a).
In the report on the compiled standard configurations /2/, the first chapters treat the standardization of nomenclature, both as regards the

- o steady cascade nomenclature (see /2/, chapter 2.1)
- o unsteady cascade nomenclature (see /2/, chapter 2.2)
- o precise reporting formats (see /2/, chapter 2.3)

*) Due to the large importance they attack to the standardization of nomenclature and reporting formats in the field of aeroelasticity in turbomachines, General Electric, Evendale, Ohio, has also decided to participate in the theoretical part of the project.

4.3 Theoretical "predictions" of the aeroelastic behaviour of the standard configurations

It is obvious that for a detailed evaluation of the state-of-art of prediction models for aeroelasticity, several codes should be compared. Presently, more than 30 methods have been announced for participation in the theoretical part of the project.
As mentioned in chapter 3, the project has been delayed as regards to the original time schedule set by the Scientific Committee to the Symposium on "Aeroelasticity in Turbomachines" in 1980 /4/, when it was proposed that the theoretical "predictions" should be performed by January 1, 1984. However, the report on the standard configurations was distributed towards the end of 1983, and the theoretical computions are currently performed and will be presented, as originally planned, at the 1984 Symposium on Aeroelasticity /5/.

4.4 Initiation of additional experiments in existing test facilities

The main objective of the present project is to establish the state-of-art of flutter prediction models and thereafter to initiate and follow up both new experiments in existing test facilities and new theoretical developments. This will be discussed in detail at the 1984 Symposium on Aeroelasticity.
As regards the experiments it has been found that no well documented aeroelastic data on

- o highly loaded turbine bladings
- o strip theory assumptions in transonic flows

can be found in the open literature.

Highly loaded turbine bladings

As mentioned in previous progress reports /9/, the observations during the present project have shown that experimental aeroelastic investigations on highly loaded subsonic turbine bladings are difficult to find in the open literature. To remedy this, such an experiment has been initiated at the EPF-Lausanne. The results of this investigation will be included as the fourth standard configuration on aeroelasticity /2 , chapter 3.4/.

Strip theory in the transonic flow regime

Another lack of well documented experimental data has been found in the transonic flow regime. It is well known that the linearized supersonic flat plate theories give very good agreements with two-dimensional compressor cascade experiments (thin airfoils). However, the validity of the strip theory, i.e. the use of the two-dimensional prediction methods in a quasi three-dimensional or three-dimensional upstream flow has never been established in the transonic flow regime. Theoretical investigations by Namba and Ishikawa /10/ indicate that three-dimensional effects in completely supersonic cascades are generally small and the strip theory predicts local as well as global aerodynamic forces with good accuracy. In the transonic flow regime, i.e. in the normal operating range of modern jet engines, however, the investigation by Namba and Ishikawa indicates that the strip theory assumption breaks down near the sonic span station and that three-dimensional effects are of primary importance. An experimental investigation in a quasi three-dimensional test facility would thus be of large interest of the development of fan stages in future jet engines. As an annular cascade test facility exists and as aeroelastic research is being performed in the transonic flow regime at EPF-Lausanne since several years, an Unsolicited Research Proposal for quasi three-dimensional aeroelastic investigations in a transonic compressor cascade has been submitted by EPF-Lausanne to the AFOSR /11/ on cost sharing basis. This project is proposed for three years and is specially devoted to shock oscillations in transonic flow and their eventual excitation mechanismus.

4.5 Travel

In connection with the ASME Gas Turbine Conference and Exhibit in Phoenix, Arizona, on March 28-31, 1983, and as part of the present project Prof. A. Bölcs and Mr. T. Fransson visited several institutions in the United States:

- United Technologies Research Center, East Hartford, Connecticut
- Massachussett Institute of Technology, Cambridge, Mass.
- Detroit Diesel Allison, Cincinatti
- General Electric Company, Indianapolis, Indiana
- NASA Lewis Research Center, Cleveland
- AFOSR , Washington

At these visits the project on "Aeroelasticity in Turbomachine-Cascades" was discussed in detail, as was other research projects performed at EPF-Lausanne:

- o Steady Supersonic flow calculations
- o Unsteady Subsonic flow calculations
- o Flutter investigations in a transonic annular turbine cascade

The discussions during these visits proved to be very fruitful, both as regards scientific exchange and as a mean for information about the long term objectives of the project on "Aeroelasticity in Turbomachine-Cascades" and its potential outcome for manufacturers of turbomachines and jet engines.

4.6 Reports

The report EPFL/LTA-TM-83-2

T. Fransson P. Suter	"Two-Dimensional and Quasi Three-Dimensional Experimental Standard Configurations for Aeroelastic Investigations in Turbomachine-Cascades"

was distributed to all participants as a direct result of the present project.

Three other reports on Aeroelasticity in Turbomachines were published at the EPF-Lausanne during the research period covered in the present report

A. Bölcs	"A Test Facility for the Investigation of Steady and Unsteady Transonic Flows in Annular Cascades" ASME-Paper 83-GT-34
D. Schläfli	"HTX-VB2917: Flatterversuche Teil 5 - Schlussbericht Aerodynamische Messungen" Report EPFL/LTA-TM-8-83
O. Sari	"Versuche zur Stosstabilisation an einem Turbinengitter" Report EPFL/LTA-TM-12-83

5. RESEARCH PLANNED FOR THE PERIOD DECEMBER 15, 1983 - DECEMBER 14, 1984

During the next few months the unsteady experimental data will be received from the researchers responsible for the seven experimental standard configurations/2/. These data will thereafter be compiled and prepared for comparison with the computations.
Simultaneously, the theoretical "predictions" will be performed by other researchers, whereafter these results will be treated in the same way as the experimental data.
The theoretical and experimental results will then be analyzed and the state-of-art of flutter prediction models will be defined.
The results will be presented and discussed at the 1984 Symposium on Aeroelasticity /5/.
Apart from the computation and evaluation of the results from the project "Aeroelasticity in Turbomachine-Cascades", the EPF-Lausanne will continue the aeroelastic research in turbomachines on the following projects:

- o flutter in annular transonic turbine cascade
- o flutter in annular high subsonic turbine cascade
- o self-excited blade vibrations in linear high subsonic turbine cascade
- o (eventually flutter in annular transonic compressor cascade)

Intermediate results from the first three projects will be presented at the 1984 Symposium on Aeroelasticity /5/, and the fourth project has been initiated as an unsolicited research proposal to AFOSR with cost sharing by EPF-Lausanne.

6. CHANGE OF PRINCIPAL INVESTIGATOR

As Prof. Suter has, from October 1, 1983 left the Federal Institute of Technology , Lausanne, for the Zurich Institute, a change of Principal Investigator will be performed with this report. The new Head of the Laboratoire de Thermique Appliquée (LTA) is Prof. A. Bölcs, who has been the Head of Turbomachinery Section at the LTA for the last ten years.

This change of Principal Investigator was discussed with the Program Manager, Dr. Anthony AMOS, during the visit of Prof. Bölcs and Mr. Fransson to Bolling Air Force Base last April.

7. CONCLUSIONS

During the first two years of the project "Aeroelasticity in Turbomachine-Cascades", nine standard configurations for aeroelastic investigations in turbomachine-cascades have been selected and compiled. A standarized nomenclature and reporting format, to be used by all researchers in the present project, has been defined. A report with the steady aerodynamic data necessary for "predicting" the aeroelastic behaviour of the standard configurations has been prepared and distributed.
An absence of well documented experimental data has been found in the domain of high turning subsonic turbine blades and transonic/ supersonic quasi two-dimensional thin airfoil investigations. To remedy this, the EPF-lausanne has initiated two research programs for basic flutter investigations. It is intended that the results from both projects could serve as test cases for future prediction models.

8. REFERENCES

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Journal of Aircraft, Vol. 16, No 5, 1979

/2/ T. H. Fransson, P. Suter (Coordinators) — "Two-Dimensional and Quasi Three-Dimensional Experimental Standard Configurations for Aeroelastic Investigations in Turbomachine-Cascades"
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/3/ "Aéroélasticité dans les turbomachines"
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/4/ P. Suter (Editor) — "Aeroelasticity in Turbomachines"
Proceedings of the Symposium held in Lausanne, Switzerland, 1980

"Unsteady Aerodynamics of Turbomachines and Propellers"
Symposium to be held in Cambridge, U.K. on Sept. 24 - 27, 1984

/5/ T.H. Fransson, P. Suter — "Unsolicited Research Proposal for Grant AFOSR-81-0251: Aeroelasticity in Turbomachine-Cascades"
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