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Aero Elastic Analysis of a Transonic Fan Blade with Different Mach Numbers

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ABSTRACT

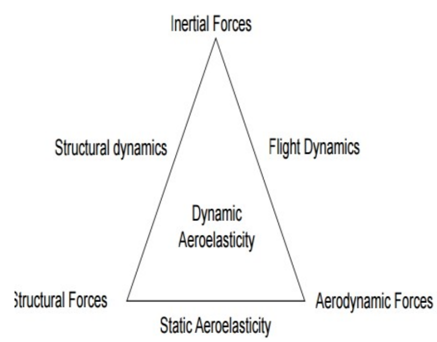
In aircraft engine design (and in other applications), small improvements in turbine efficiency may be significant. Since analytical tools for predicting transonic turbine losses are still being developed, experimental efforts are required to evaluate various designs, calibrate design methods, and validate CFD analysis tools. However, these experimental efforts must be very accurate to measure the performance differences to the levels required by the highly competitive aircraft engine market. Due to the sensitivity of transonic and supersonic flow fields, it is often difficult to obtain the desired level of accuracy.

In this thesis, the development of high-performance turbine airfoils is investigated under the supersonic condition. Transonic turbine airfoil is designed and modeled in 3D modeling software Catia. CFD analysis is done by considering k-ε turbulence model at different velocities of air to verify the aerodynamic performance of turbine airfoil. The velocities of air are varied by changing the Mach number 0.8, 0.9, 1, 1.1 and 1.2. Analysis is done in Ansys.

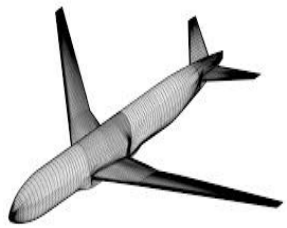
INTRODUCTION

AEROELASTICITY

Aero elasticity is the study of the interaction of inertial, structural and aerodynamic forces on aircraft, buildings, surface vehicles etc.



is the branch of physics and engineering that studies the interactions between the inertial, elastic, and aerodynamic forces that occur when an elastic body is exposed to a fluid flow. Although historical studies have been focused on aeronautical applications, recent research has found applications in fields such as energy harvesting and understanding snoring. The study of aero elasticity may be broadly classified into two fields: static aero elasticity, which deals with the static or steady response of an elastic body to a fluid flow; and dynamic aero elasticity, which deals with the body's dynamic (typically vibrational) response. Aero elasticity draws on the study of fluid mechanics, solid mechanics, structural dynamics and dynamical systems. The synthesis of aero elasticity with thermodynamics is known as aerothermoelasticity, and its synthesis with control theory is known as aeroservoelasticity.



History

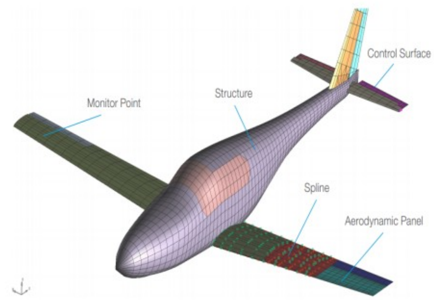
The 2nd failure of Samuel Langley's prototype plane on the Potomac has been attributed to aeroelastic effects (specifically, torsional divergence). Problems with torsional divergence plagued aircraft in the First World War and were solved largely by trial-and-error and ad-hoc stiffening of the wing. In 1926, Hans Reisner published a theory of wing divergence, leading to much further theoretical research on the subject.

In the development of aeronautical engineering at Caltech, Theodore von Kármán started a course "Elasticity applied to Aeronautics". After teaching for one term he passed it over to Ernest Edwin Scheler, who went on to develop aero elasticity in that course and in publication of textbooks on the subject.

In 1947, Arthur Roderick Collar defined aero elasticity as "the study of the mutual interaction that takes place within the triangle of the inertial, elastic, and aerodynamic forces acting on structural members exposed to an airstream, and the influence of this study on design.

Static aero elasticity

In an aero plane, two significant static aero elastic effects may occur. Divergence is a phenomenon in which the elastic twist of the wing suddenly becomes theoretically infinite, typically causing the wing to fail spectacularly. Control reversal is a phenomenon occurring only in wings with ailerons or other control surfaces, in which these control surfaces reverse their usual functionality (e.g., the rolling direction associated with a given aileron moment is reversed)



Control reversal

Control surface reversal is the loss (or reversal) of the expected response of a control surface, due to deformation of the main lifting surface. For simple models (e.g. single aileron on an Euler-Bernoulli beam), control reversal speeds can be derived analytically as for torsional divergence. Control reversal can be used to an aerodynamic advantage, and forms part of the Kaman servo-flap rotor design.

LITERATURE SURVEY

The following works are done by some authors onaero elastic of a transonic fan Blade:

The work done by Zhizhong Fu, Yanrong Wang [1], This paper presents a comprehensive investigation of aero elastic stability for a high aft-swept transonic fan blade with low hub-to-tip ratio. The evolution of the blade's aeroelastic stability in the first bending modes is studied. A 3D flutter computation representing today's industry standard is performed. Steady state flow field and motion-induced unsteady

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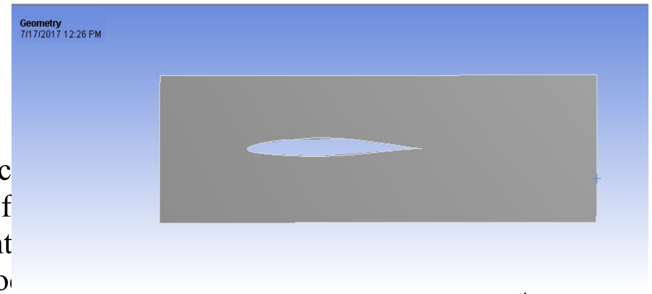
pressures acting on the blade have been determined by a 3D Reynolds-Averaged Navies-Stokes (RANS) equations with a standard k-ε turbulence model.

The work done by William J [2],

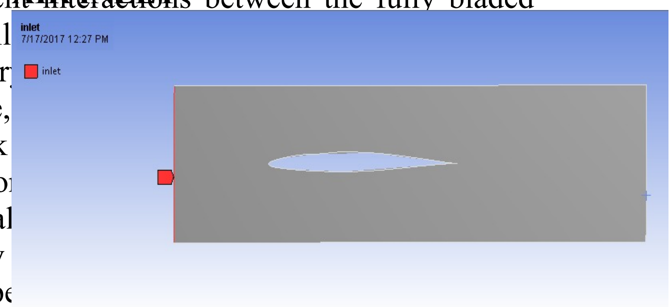
This report describes the development of a generic
that could be used to assess modeling approaches f
blade and simulate the initial and post-containment
revolutions following blade release. Though the mo
to evaluate continued rotation and post-containment interactions between the fully bladed
disk and fan case, it does not represent a fully install
all the system dynamics characteristics necessar
containment event includes the initial blade release,
release blade impact with the trail blade. The work
method for predicting forced vibratory blade respo
developed using modal and harmonic analysis. Total
engines when the incoming airflow is partially
conditions can have varying effects on engine pe
effects are often in the form of performance degradation where the distorted airflow causes a
loss in pressure rise, and a reduction in mass flow a
result of vibratory blade response that can ultimately
in turn can quickly cause partial damage to a sing
entire compressor blade row, leading to catastrophi
work done byJohannes Schweiger[4],Active aeroe
several years now. Their common incentive are im
stability by the intentional use of aeroelastic effec
characteristics of a new aircraft project must be i
process, and the structural and flight control syste
The work done by Robert M. Wallace [5], A new method for predicting forced vibratory blade response to total pressure distortion has been developed using modal and harmonic analysis. Total pressure distortions occur in gas turbi
partially blocked or disturbed. Distorted inlet condit
performance and engine life. Short-term effects
degradation where the distorted airflow causes a l
mass flow and stall margin. Long-term effects are
can ultimately lead to high cycle fatigue (HCF), w
damage to a single blade or complete destruction of
to catastrophic failure of the gas turbine engine.

ANALYSIS OF AERO ELASTIC OF A TRANSONIC FAN BLADE

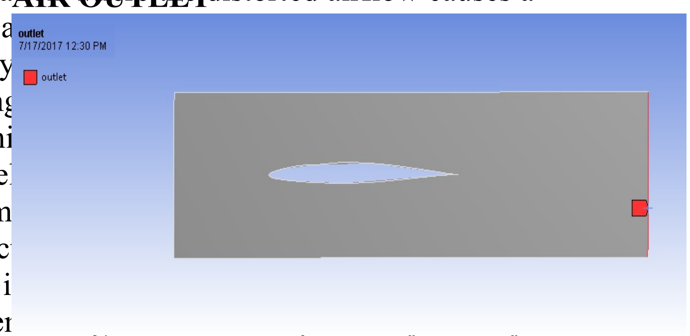
IMPORTED MODEL



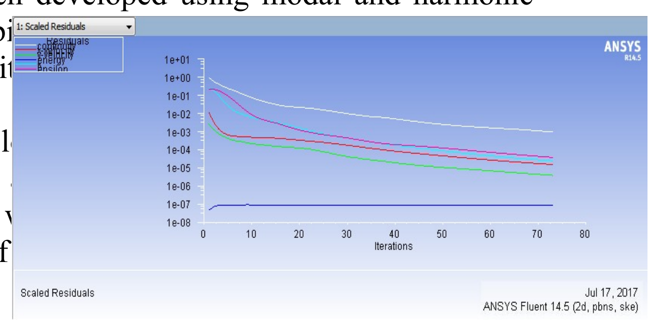
AIR INLET



AIR OUTLET



ITERATIONS



STRUCTURAL ANALYSIS OF AERO ELASTIC OF A TRANSONIC FANBLADE

IMPORTED MODEL

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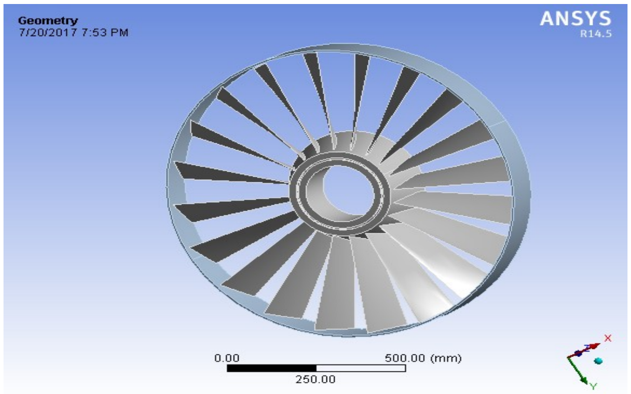
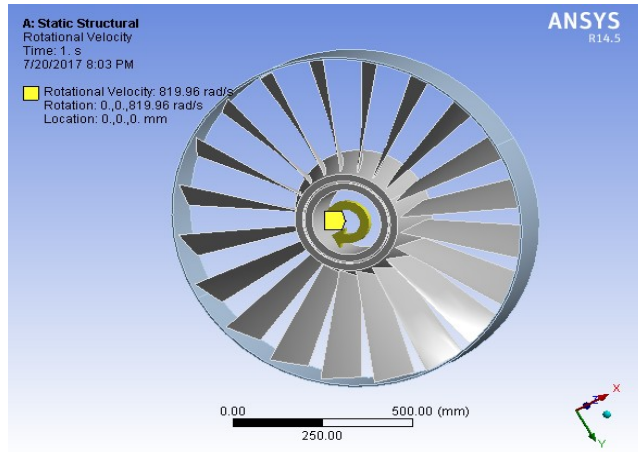
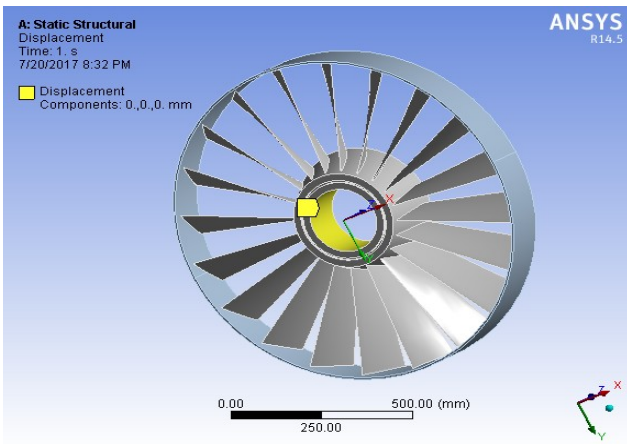
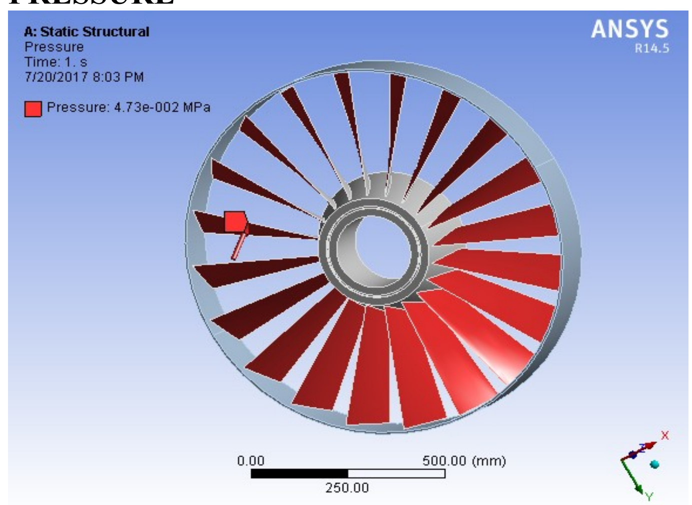




DISPLACEMENT



PRESSURE



ROTATIONAL VELOCITY

RESULT & DISCUSSIONS

CFD ANALYSIS

Mach numbers	Pressure (Pa)	Velocity (m/s)	Turbulent kinetic energy(k)(m^2/s^2)	Mass flow rate (kg/s)
0.8	4.73e+04	3.40e+02	6.42e+02	-8.1062317e-06
0.9	5.97e+04	3.83e+02	7.93e+02	-1.001358e-05
1	7.36e+04	4.26e+02	9.59e+02	5.722e-6
1.1	8.89e+04	4.69e+02	1.14e+03	3.8146973e-06
1.2	1.06e+05	5.11e+02	1.33e+03	2.8610229e-06

GRAPHS

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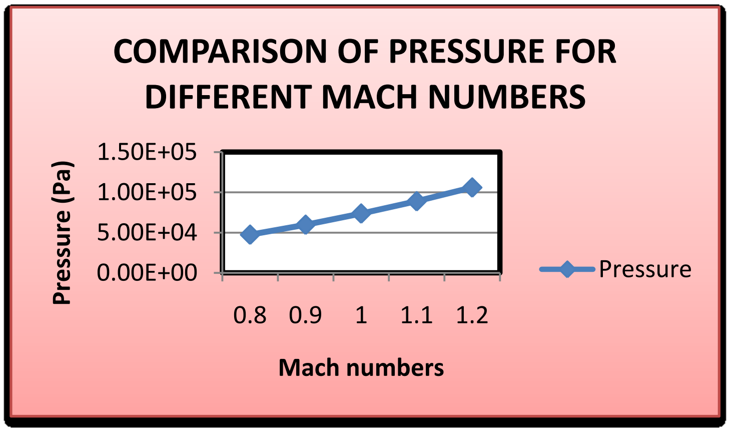
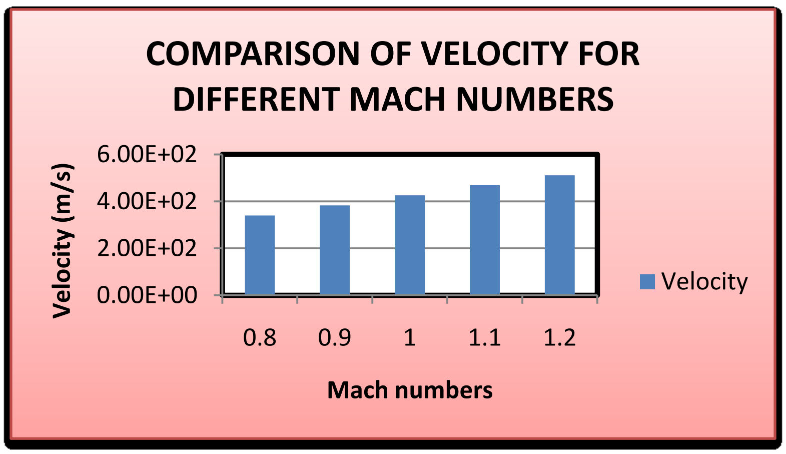
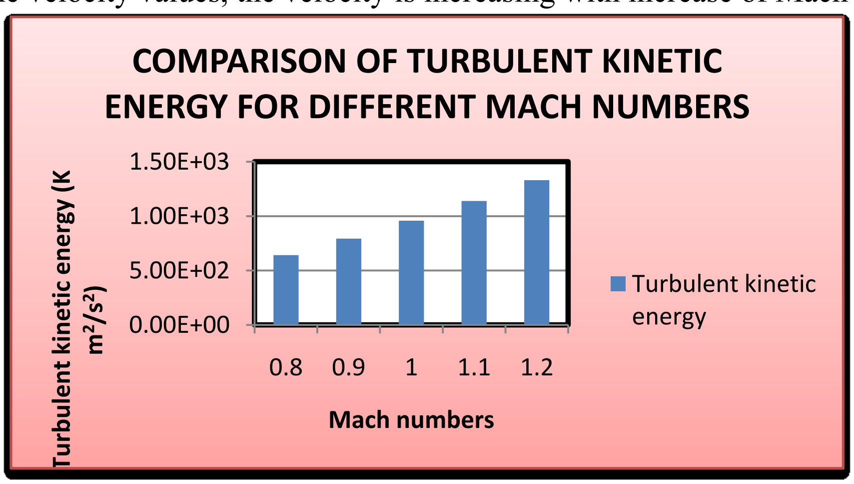


By observing the pressure values, the pressure is increasing with increase of Mach Number.



By observing the velocity values, the velocity is increasing with increase of Mach number



By observing the turbulent kinetic energy values, the value is increasing with increase of Mach number

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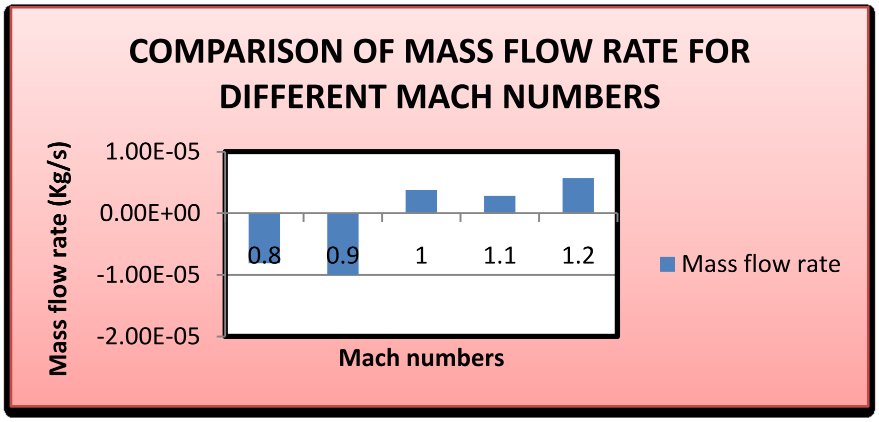
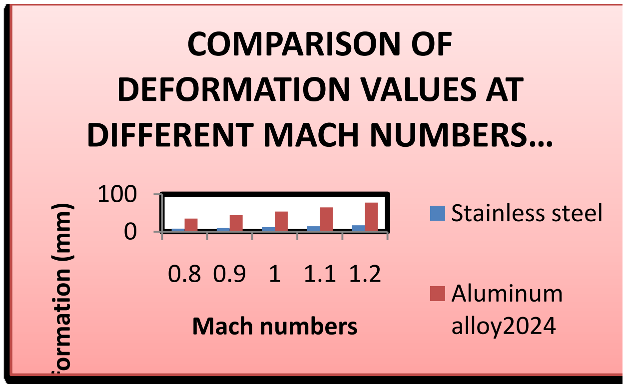
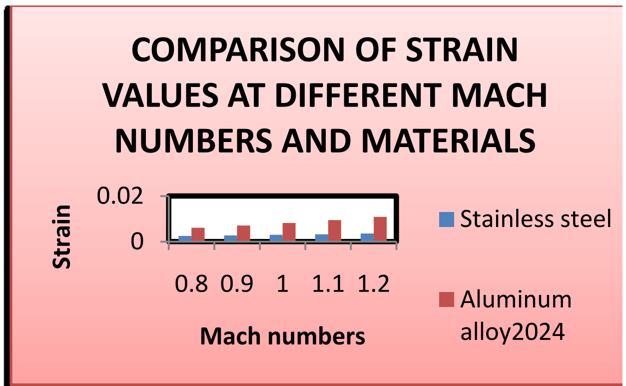


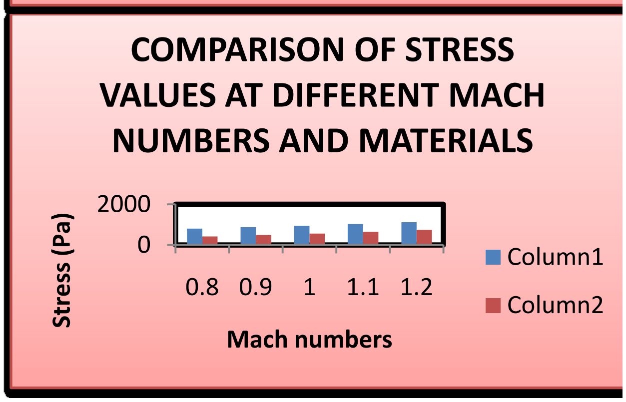
STRUCTURAL ANALYSIS

Mach number	Materials	Deformation (mm)	Strain	Stress (Pa)
0.8	**Stainless steel**	7.9249	0.0025478	805.56
	Aluminum alloy 6061	34.845	0.0061197	418.94
0.9	**Stainless steel**	9.8496	0.0027552	870.84
	Aluminum alloy 6061	43.857	0.0071154	486.63
1	**Stainless steel**	12.008	0.0029924	945.12
	Aluminum alloy 6061	54.053	0.0082349	562.72
1.1	**Stainless steel**	14.388	0.0032564	1028
	Aluminum alloy 2024	65.056	0.0094457	645
1.2	**Stainless steel**	17.05	0.003553	1120.9
	Aluminum alloy 2024	77.821	0.010852	740.57

GRAPHS







CONCLUSION

In this report, the development of high-performance turbine airfoils is investigated under the supersonic condition. Transonic turbine airfoil is designed and modeled in 3D modeling software Catia. CFD analysis is done by considering k-ε turbulence model at different velocities of air to verify the aerodynamic performance of turbine airfoil. The velocities of air are varied by changing the Mach number 0.8, 0.9, 1, 1.1 and 1.2. Analysis is done in Ansys.

By observing CFD analysis results, the pressure, velocity and turbulent kinetic energy is increasing by increase of Mach number. By increase of these values, the efficiency of the fan increase due to high output values.

By observing the structural analysis results, the deformation and strain values are increasing for higher Mach number due to high pressures. By comparing between the materials, the stress values are less than the yield stress values for both materials and they more for Aluminum alloy than Steel. But Aluminum alloy can be preferred due to its high strength to weight ratio.

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