1999

FLUID MECHANICS OF COMPRESSIBLE DYNAMIC STALL CONTROL USING DYNAMICALLY DEFORMING AIRFOILS

M.S.Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: Army Research Office

OBJECTIVE: To develop flow control schemes through management of the unsteady vorticity field by dynamically deforming an airfoil for prevention of flow separation.

SUMMARY: This year the research effort was focused on identification of the surface flow features during compressible dynamic stall. For this, a 6-inch chord NACA 0012 airfoil was instrumented with 148 surface hot-film gages to identify the surface shear stress behavior in this flow. A new power supply was designed and built to power 30 anemometer bridges (donated by the Air Force Frank J. Seiler Research Laboratory). Then, a high-speed data acquisition system was developed to acquire 32 analog and 32 digital channels of data @ 768 KHz rate, either simultaneously or individually or phase locked to airfoil oscillation. Additional versatility was incorporated into the package to accommodate a move to PC based DAQ methods from the older microVAX II systems. More DDLE airfoil studies were carried out at M = 0.4, with measurable success, that support the application of this stall control approach to practical systems.

Professor Chandrasekhara delivered two invited papers in international conferences and two seminars (at NASA Langley and Georgia Tech) based on this research.

AN EXPLORATORY INVESTIGATION OF PULSATILE BLOWING TO CONTROL COMPRESSIBLE DYNAMIC STALL OVER AN OSCILLATING NACA 0015 AIRFOIL

M.S.Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: Army Research Office

OBJECTIVE: To study the feasibility of using the oscillating blowing technique to control the compressible dynamic stall of an oscillating NACA 0015 airfoil.

SUMMARY: This short 6-month project was carried out as a supporting effort for an effort from the US Army Aero Flight Dynamics Directorate(AFDD) whose goal is to establish the usefulness of oscillatory blowing as a means to control dynamic stall. A 6-inch chord NACA 0015 airfoil, with a leading edge slot was designed and fabricated during 1999. The structural integrity of the model for use in the CDSF is now under review. Experiments will begin soon and would initially evaluate the steady flow characteristics and then, the unsteady flow behavior of the baseline airfoil, before control of dynamic stall is attempted.

USE OF OSCILLATORY BLOWING TO CONTROL COMPRESSIBLE DYNAMIC STALL BEHAVIOR OF AN OSCILLATING NACA 0015 AIRFOIL

M.S.Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: US Army (NASA) Aero Flight Dynamics Directorate

OBJECTIVE: To investigate compressible dynamic stall control using the oscillating blowing technique on a trailing edge stalling oscillating NACA 0015 airfoil.

SUMMARY: This effort runs concurrently with the ARO effort to establish the usefulness of oscillatory blowing as a means to control dynamic stall. A 6-inch chord NACA 0015 airfoil, with a leading edge slot was designed and fabricated during 1999. This airfoil contains a symmetric plenum inside it with a 0.02-inch blowing slot at 20 deg to the upper surface. The experiments will be carried out in three stages. In the first stage, the airfoil characteristics of a non-slot configuration in steady flow will be established using point diffraction interferometry, followed by oscillating airfoil tests. Subsequently, dynamic stall control using oscillatory blowing will be attempted.

1998

FLUID MECHANICS OF COMPRESSIBLE DYNAMIC STALL CONTROL USING DYNAMICALLY DEFORMING AIRFOILS

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: Army Research Office

OBJECTIVE: To develop flow control schemes through management of the unsteady vorticity field by dynamically deforming an airfoil for prevention of flow separation.

SUMMARY: During the reporting period, detailed studies were carried out to determine the best shape adaptation strategy for producing dynamic stall *vortex free* flow over an oscillating airfoil under compressible flow conditions. Further, the effect of the rate of shape adaptation was investigated which showed that the slowest rate of phase-locked deformation was the best. In addition, improper shape adaptation was found to be destructive since dynamic stall onset was triggered prematurely. These studies have now established that dynamic geometry adaptation is a powerful tool with which the airfoil vorticity field could be manipulated for successful flow control.

In order to identify the basic fluid mechanics of the problem of compressible dynamic stall, a 6-inch chord NACA 0012 airfoil has been instrumented with 120 surface heat flux gages. Presently, the integration of these gages with 30 anemometer bridge circuits and a high-speed data acquisition system is ongoing. These hot film gages provide the surface shear stress behavior of this flow.

1997

A FUNDAMENTAL STUDY OF COMPRESSIBILITY EFFECTS ON DYNAMIC STALL OF FIXED AND ADAPTIVE AIRFOILS

M.S. Chandrasekhara, Research Professor, M.F. Platzer, Professor
Department of Aeronautics and Astronautics
Sponsor: Army Research Office

OBJECTIVE: To understand the fundamental fluid flow physics of compressible unsteady flow separation and dynamic stall onset over fixed and variable geometry airfoils, leading to innovative flow control methods.

SUMMARY: The research resulted in the identification of some of the key mechanisms of compressible dynamic stall onset. These are laminar separation bubble bursting, shock-included flow flow separation and interaction of the bubble with the local supersonic flow. Primarily, all are attributable to the development of strong adverse pressure gradient over the airfoil, which needs to be mitigated for achieving flow control. This led to the concept of the Dynamically deforming Leading Edge (DDLE) airfoil, whose leading edge curvature can be changed by as much as 320% in real-time while the airfoil oscillates, providing an airfoil that can adapt to each flow condition instantaneously. Successful preliminary tests were conducted to establish the proof of concept.

FLUID MECHANICS OF COMPRESSIBLE DYNAMIC STALL CONTROL USING DYNAMICALLY DEFORMING AIRFOILS

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: Army Research Office

OBJECTIVE: To develop flow control shemes through management of the unsteady vorticity field by dynamically deforming an airfoil for prevention of flow separation.

SUMMARY: This research project initiated in April 1997 is aimed at establishing the fluid mechanics of the flow over a dynamically deforming leading edge(DDLE) airfoil under high loading conditions as it operates near stall. Preliminary studies have shown that it is possible to reattach even grossly separated flow by changing the DDLE airfoil leading edge curvature and to re-establish the vorticity field for producing lift at angles well above the maximum operating angles of attack of a fixed geometry airfoil. In view of its relevance to helicopter retreating blade stall alleviation, an oscillating airfoil will be dynamically deformed carefully as it pitches up.

1996

A FUNDAMENTAL STUDY OF THE COMPRESSIBILITY EFFECTS ON DYNAMIC STALL OF FIXED AND ADAPTIVE AIRFOILS

M.S. Chandrasekhara, Research Professor, Dept. of Aeronautics and Astronautics
M.F. Platzer, Professor, Dept. of aeronautics and Astronautics
Sponsor/Funding: U.S. Army Research Officer

OBJECTIVE: To study compressibility effects on an airfoil in unsteady motion while it adapts locally to overcome the forces causing unsteady flow separation. The research has applications in active control of helicopter "retreating blade stall". Initiated in April 1994, as a follow-on to the previous research efforts.

SUMMARY: During 1996, the study focused on conducting detailed experimental studies to identify the various mechanisms of dynamic stall onset. Three separate mechanisms were discovered and depending upon flow conditions, these interacted with each other as well. As a means to control these mechanisms, the dynamically deforming leading edge (DDLE) airfoil was designed and fabricated using composite materials after a finite element formulation of the material behavior was completed. Further, a PC based control system was devised to control the leading edge deformation of the airfoil and thus its leading edge curvature in a precise manner. The systems were fully integrated and evaluated. Preliminary experiments were conducted using a high speed imaging system that was developed in the previous years. **Several thousand** point diffraction interferograms have been acquired in this phase of the study. Quantitative analysis of these data is about to begin.

TESTING OF THREE SPECIAL ARMY AIRFOILS IN THE COMPRESSIBLE DYNAMIC STALL FACILITY

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor/Funding: U.S. Army Aeroflightdynamics Directorate

OBJECTIVE: To study three special airfoils designed by the U.S. Army laboratory for dynamic stall performance under compressible flow conditions.

SUMMARY: This project was initiated in Oct. 1995. The U.S. Army Aviation Research and Development Center, Aeroflightdynamics Directorate has developed three special helicopter blade sections that have shown dramatic performance characteristics under helicopter flight conditions. The Army laboratory is interested in building a helicopter rotor using this blade section profile and test fly the helicopter. However, the performance of the blade sections under dynamic stall conditions, especially at compressible Mach numbers is unknown at this time. The study focused on this aspect. Extensive testing of the airfoils was completed in the NASA Ames compressible dynamic stall facility using point diffraction interferometry. Several hundred interferograms of the flow over a basic RC-608 section, and with two different leading (6 deg. And 10 deg.) slats were obtained. The improved performance of the rotor blade section is obvious from a qualitative evaluation of the images. The 10 deg. slat showed an even superior performance when compared to the 6 deg. slat. Quantitative evaluation is ongoing using image processing software developed in-house.

1993

COMPRESSIBILITY EFFECTS ON AND CONTROL OF DYNAMIC STALL OF OSCILLATING AIRFOILS

M.S. Chandrasekhara, Research Associate Professor
Dept of aeronautics and Astronautics
M.F. Platzer, Professor, Department of Aeronautics and Astronautics
Sponsor: U.S. Army Research Office
Funding: ARO

OBJECTIVE: To study the effects of compressibility on dynamic stall of oscillating airfoils and control the process of dynamic stall. The research has application in helicopter "retreating blade stall". The knowledge will be useful in extending the flight envelope of future helicopter systems. On-going program since March 1990.

SUMMARY: The flow over a helicopter "retreating" blade is being simulated in a wind tunnel facility known as the *compressible Dynamic Stall Facility* (CDSF). The experimental flow conditions are such that the helicopter flight envelope is simulated. The reporting period saw two major accomplishments. One is the identification of a method of 'tripping' the blade boundary layer such that full scale flight Reynolds numbers effects are approached in the laboratory. Another is the development of a high speed camera system to obtain very high speed real-time point diffraction interferometry (PDI) flow images. The successful development of this challenging instrumentation system now enables documenting and studies of the rapid flow changes in a single oscillation cycle, which is critical to understanding the physics of the unsteady flow separation. Further, a fringe analysis program has been developed to map the global pressure field from the measured density field. With these, an unparalleled capability now exists that permits measurements of the flow changes when control efforts are implemented.

CONTROL OF DYNAMIC STALL OF AND COMPRESSIBILITY PITCHING AIRFOILS USING ADAPTIVE GEOMETRIES

M.S. Chandrasekhara, Research Associate Professor
Dept. of Aeronautics and Astronautics
M.F. Platzer, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force Office of Scientific Research
Funding: AFOSR

OBJECTIVE: To develop a deployable means of controlling the unsteady separated flows over a maneuvering wing by using wing geometries that adapt to the instantaneous flow over it. The research has applications in enhancing the maneuverability of fighter aircraft. Initiated in October 1992 as a follow-on effort to the basic studies carried out in the previous years.

SUMMARY: The flow over a transiently pitching aircraft wing (or airfoil) has been studied in the past to obtain a proper understanding of the compressibility effects that cause loss of lift and premature stall of pitching wings. It was identified that a reasonable means of controlling the

flow could be developed if the flow induced adverse pressure gradients over the wing could be favorably modified. Such a means would require instantaneous change of the wing shape. In other words, the wing should “adapt” to the local flow conditions on a continuous basis. However, this is a very challenging task. In an effort towards reaching this goal, a new electro-expulsive de-icing device on the wing leading edge was tested. Since the deformation produced by this was highly irregular, it was not acceptable. Currently, a new wing whose leading edge is fabricated from a composite material is being constructed. Additionally, the drive system that produces the necessary forces to deform the surface is being designed. Testing is expected to commence shortly.

1992

COMPRESSIBILITY EFFECTS ON AND CONTROL OF DYNAMIC STALL OF OSCILIATING AIRFOILS

M.S. Chandrasekhara, Research Associate Prof.
Department of Aeronautics and Astronautics
M.F. Platzer, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Research Office
Funding: ARO

OBJECTIVE: To study the effects of compressibility on dynamic stall of oscillating airfoils and control the process of dynamic stall. The research has application in helicopter 'retreating blade stall'. The knowledge will be useful in extending the flight envelope of future helicopter systems. On-going program since March 1990.

SUMMARY: The flow over a helicopter "retreating" blade is being simulated in the newly built Compressible Dynamic Stall Facility (CDSF) and studied with a view to understand the basic flow physics for possible improvements in the blade design. During the reporting period, the new flow field diagnostic technique known as Point Diffraction Interferometry, (PDI), was refined, developed further and used to measure the flow field. Also, a fringe analysis software package was developed to rapidly process the digitized interferogram images. A number of the images obtained from earlier experiments were processed. The unique feature of this package is its semi-automation and ability to produce graphical information of the flow variables. Also, the LDV data obtained in the previous year was analyzed, papers were prepared and presented.

COMPRESSIBILITY EFFECTS ON DYNAMIC STALL OF AIRFOILS UNDERGOING RAPID TRANSIENT PITCHING MOTION

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
M.F. Platzer, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force Office of Scientific Research
Funding: AFOSR

OBJECTIVE: To study the effects of compressibility on dynamic stall of an airfoil undergoing a rapid ramp type pitching motion with applications to supermaneuverability of fighter aircraft. On-going project since October 1989.

SUMMARY: In the reporting period, the technique of Point Diffraction Interferometry (PDI) developed in the Navy-NASA Joint institute of Aeronautics was used extensively to document the full flow field as well as the leading edge flow field over an airfoil executing rapid transient pitch maneuvers from 0-60 degrees angle of attack. The data was analyzed using an in-house developed fringe analysis software package. The results showed that compressibility unfavorably interacts with the outer inviscid flow to limit the airfoil performance. These studies also led to the concept that if the pressure distribution over the airfoil could some how be modified, then the airfoil could be made stall-free. Based on this, a new proposal to control dynamic stall using adaptive geometries was proposed, which was accepted and funded.