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STALL FLUTTER ANALYSIS OF PROPFANS

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ABSTRACT

Stall flutter is a self-excited limit cycle oscillation triggered by separation of flow during part of every cycle of oscillation. Under takeoff conditions, the propfan blades may operate at high angles of attack and have the potential to stall flutter. The aerodynamic phenomenon associated with an airfoil oscillating into and out of stall is called dynamic stall. The forces generated in dynamic stall are an order of magnitude greater than the forces in separated flow with no vibration.

The present research is aimed at developing methods for the analysis of stall flutter of propfans and the computer implementation of these methods in the general purpose computer program, ASTROP - Aeroelastic STability and Response Of Propulsion systems.

Prediction of forces during dynamic stall has been a continuing research effort. The methods vary from solving the basic equations of fluid mechanics (purely theoretical) to fitting the analysis to direct measurement (empirical). The empirical methods take less time to implement and are able to quantitatively produce the dynamic stall effects. However, they require extensive experimentation and data before a model is developed. In addition, they do not provide any information about the physics of the flow. On the other hand, the purely theoretical methods are computationally expensive and not preferred for preliminary design work.

This report briefly reviews the dynamic stall analysis methods, and presents the application of two empirical models to the stall flutter analysis and correlation with experimental data of a propfan.

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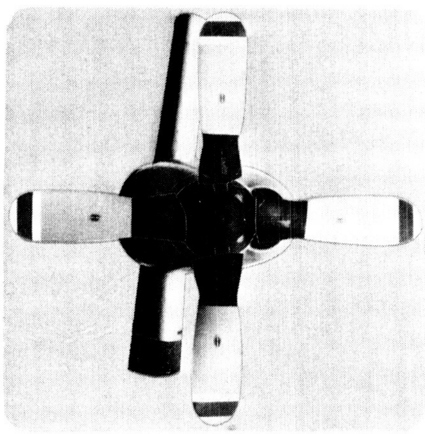
PURPOSE

To obtain maximum aerodynamic and acoustic performance, the trend in high speed propeller design has been toward thin, swept blades. These new designs are called propfans. A research program to establish the required technology for successful design of propfans is in progress at the NASA Lewis Research Center. Analysis of stall flutter, that may occur at takeoff conditions, is part of this research program. This involves the evaluation of the stall flutter analysis methods for propfans and the development of new analysis methods.

PURPOSE

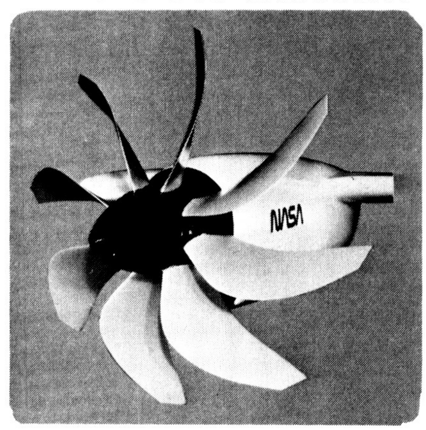


- ***THICK AIRFOILS***
- ***4 STRAIGHT BLADES***
- ***LIGHT DISK LOADING (10-15 SHP/D^2)***
- ***2-D, SUBSONIC, ISOLATED AERO***
- ***HIGH AR BLADES-BEAM BEHAVIOR***
- ***EMPIRICAL MODELS***

MACH 0.6 DESIGN

ATP TECHNOLOGY

MACH 0.8 DESIGN



- ***8-10 SWEPT, VERY THIN BLADES***
- ***HIGH DISK LOADING (30-40 SHP/D^2)***
- ***3-D, TRANSONIC, CASCADE AERO, AREA-RULED SPINNER & CONTOURED NACELLE***
- ***LOW AR BLADES-PLATE DYNAMICS***
- ***EMPIRICAL TO CFD MODELS***

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OBJECTIVES

The objectives of the research are to (1) develop stall flutter analysis methods for propfans, (2) verify the analyses with experimental data, and (3) implement the analyses in the general purpose aeroelastic analysis program ASTROP - Aeroelastic STability and Response of Propulsion systems.

- **DEVELOP STALL FLUTTER ANALYSIS METHODS FOR PROPFANS**
- **CORRELATE WITH EXPERIMENTAL DATA**
- **IMPLEMENT IN ASTROP CODE**

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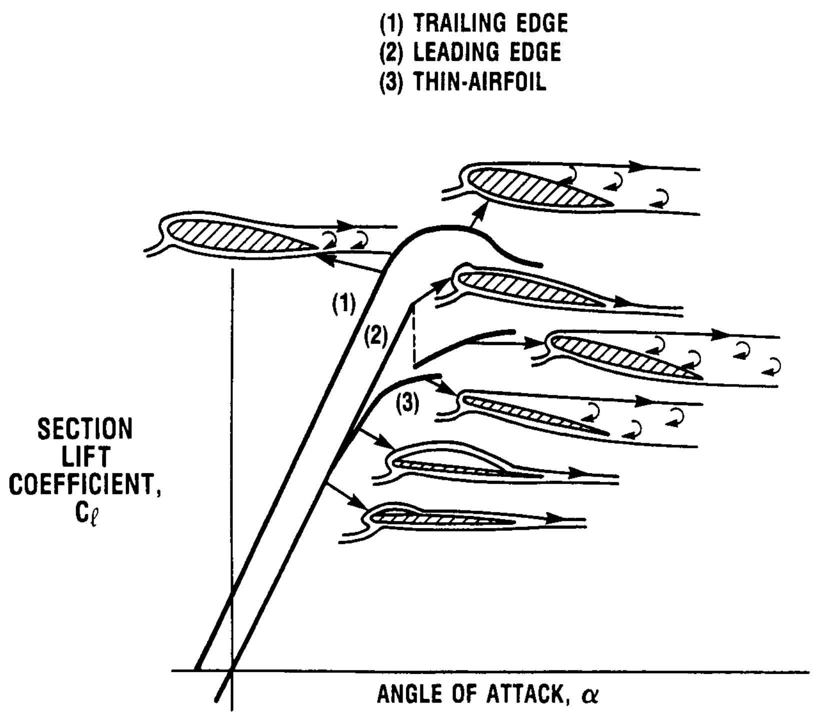
TYPES OF STATIC STALL

Three types of static stall or separation under static conditions have been identified (McCullough and Gault, 1951). They are (1) the trailing edge stall, (2) leading edge stall, and (3) thin airfoil stall. In trailing edge stall the boundary layer separation progresses gradually forward from the trailing edge and there is a gradual loss of lift. Leading edge stall is identified by the burst of the leading edge separation bubble when the stall angle is reached and is associated with sudden loss of lift. In the thin-airfoil stall, a separation bubble originates near the leading edge and elongates as the angle of attack is increased. This type of stall is associated with gradual loss of lift. These three types of stall occur for airfoils with thickness-to-chord ratios (t/c) greater than 0.15, 0.09 to 0.15, and less than 0.09 respectively. Propfans have airfoils in the t/c range of 0.02 to 0.04, and hence are assumed to exhibit thin airfoil stall.



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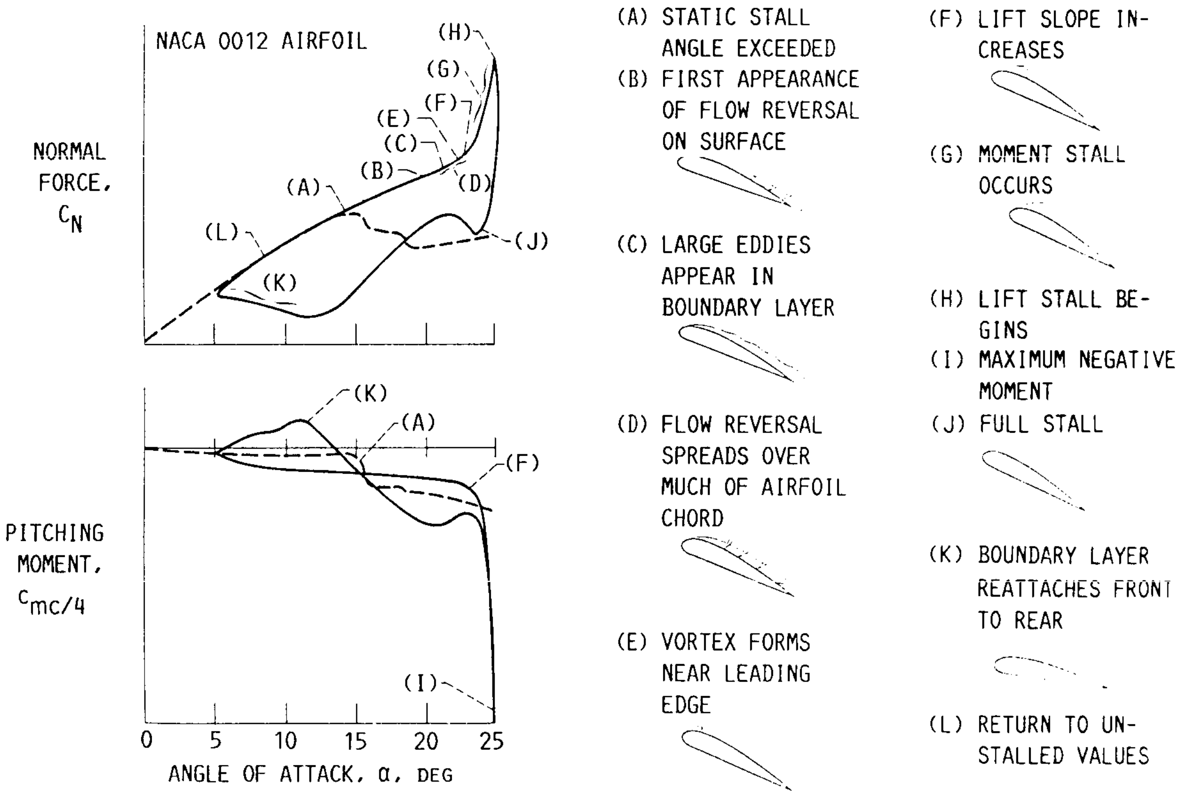
DYNAMIC STALL EVENTS ON AN OSCILLATING AIRFOIL

Dynamic stall refers to the aerodynamic phenomena of an airfoil oscillating into and out of stall. The predominant feature (McCroskey, 1981) is the shedding of a vortex-like disturbance from the leading edge, which alters the chordwise pressure distribution. This vortex moves downstream at about 35 to 40 percent of free stream velocity. The unsteady forces due to the passage of this vortex are much greater than the corresponding static values.



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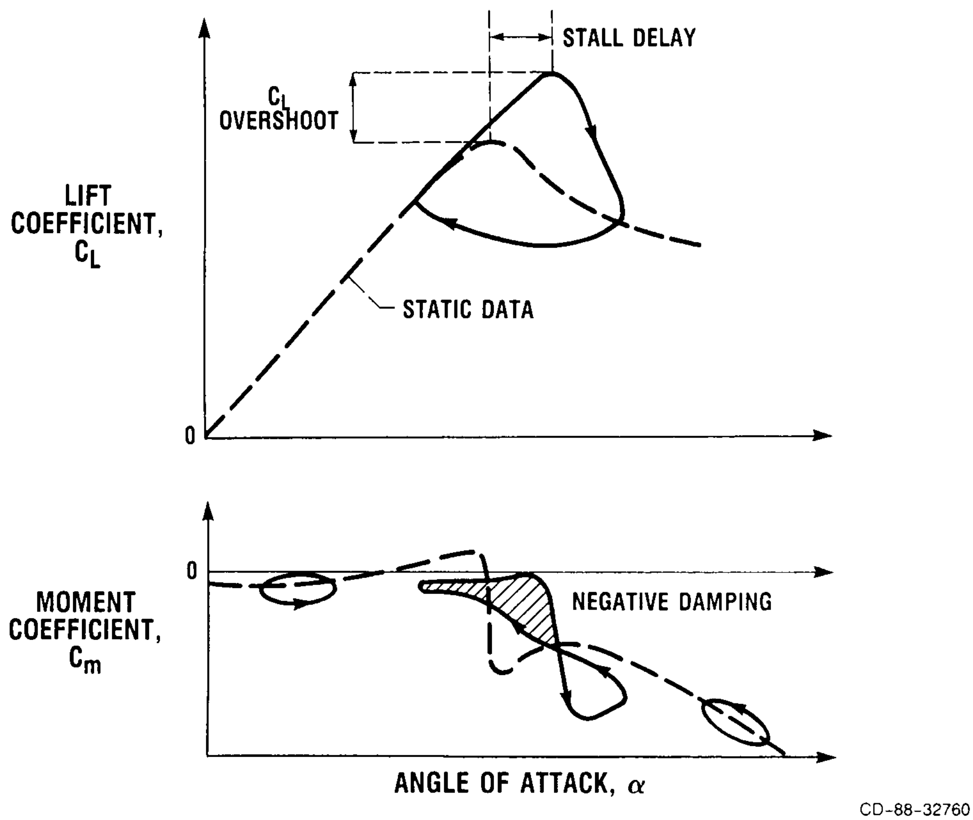
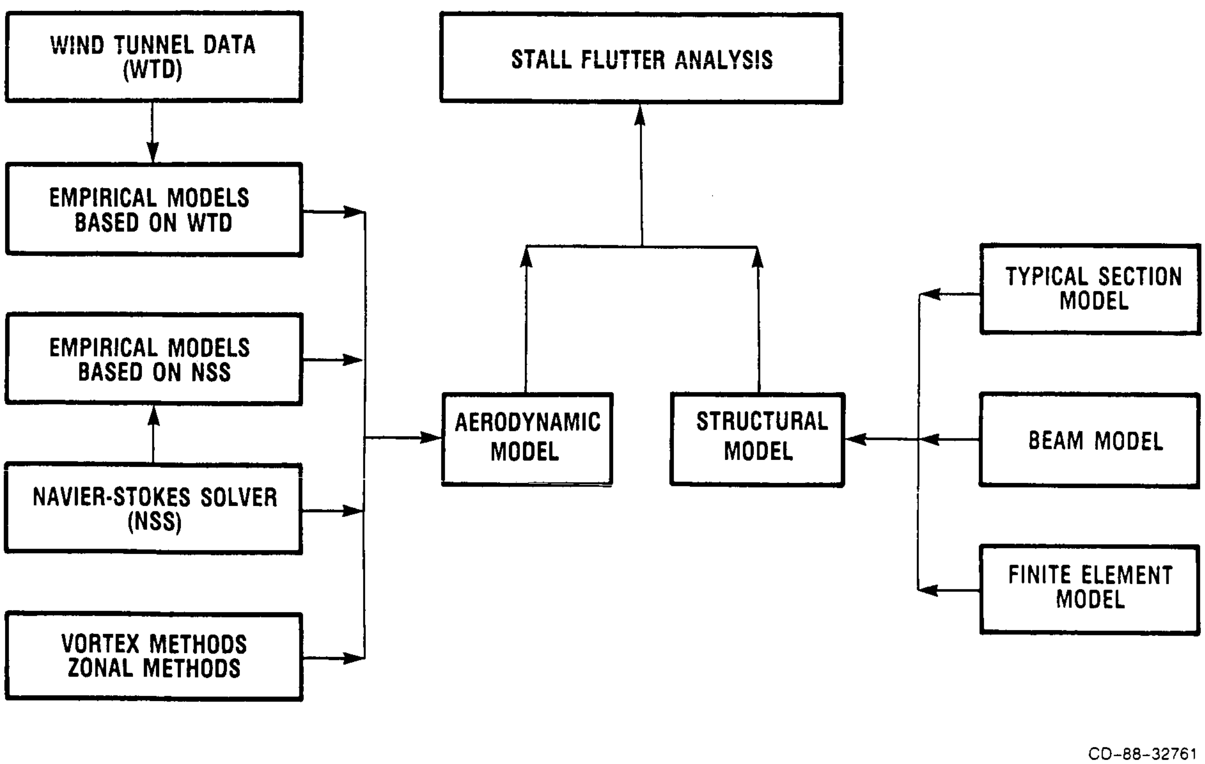
IMPORTANT EFFECTS OF DYNAMIC STALL

Three important effects resulting from dynamic stall are (1) flow separation is delayed to an angle beyond the static stall angle (stall delay); (2) the forces and moments are an order of magnitude larger than the static values (overshoot); (3) the variation of the forces versus angle of attack shows hysteresis. Stall flutter, a self-excited limit cycle oscillation can occur if hysteresis leads to negative damping. The magnitude of these effects depend on the airfoil shape, Mach number, and Reynold's number of the flow over the airfoil and on amplitude and frequency of oscillation.



STALL FLUTTER ANALYSIS METHODS

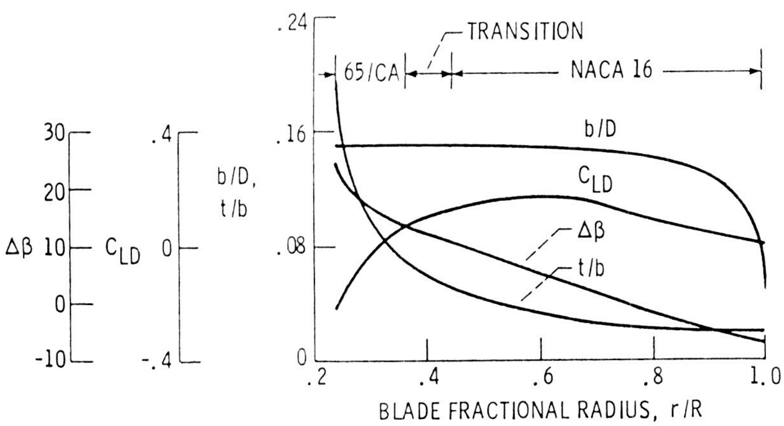
Two components are needed to analyze stall flutter--an aerodynamic stall model and a structural model. The aerodynamic models available to analyze dynamic stall vary from solving the basic fluid mechanics equations to fitting analysis to experimental data (Reddy and Kaza, 1987). The Navier-Stokes Solvers (NSS), vortex methods, and zonal methods attempt to solve the fluid mechanics equations in their fundamental form by numerical techniques with varying degrees of simplifications and assumptions. These models require a significant amount of computer time. In the empirical models an analytical fit is attempted to approximately reproduce wind tunnel data. The empirical models take less computer time and can be used in a routine aeroelastic analysis though they are not able to give the complete picture of the flow. The structural models vary from a two-degree-of-freedom typical section model to a finite element model with a large number of degrees of freedom.



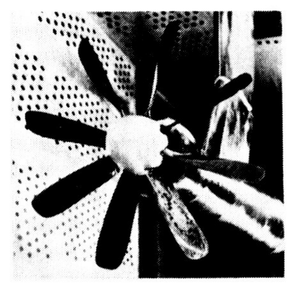
SR2 PROPFAN MODEL

A propfan model SR2 exhibited stall flutter type behavior at static thrust condition in wind tunnel testing (Smith, 1985). This propfan has 8 unswept metallic blades with NACA 16 series airfoils for 45 percent of the span and NACA 65 series airfoils for 37 percent of the span. The thickness ratio (t/b), twist ($\Delta\beta$), design lift coefficient (C_{LD}), and planform (b/D) distribution are established to provide for high efficiency.

VARIATION OF PROPELLER DESIGN PARAMETERS WITH BLADE RADIUS FOR THE UNSWEPT SR-2 PROPELLER



SR-2 PROPFAN, 8 BLADES, 0° SWEEP



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APPROACH

Two empirical aerodynamic stall models, model A and B, and a finite element structural model were selected to analyze the SR2 propfan stall flutter. Model A uses fewer parameters in modeling the dynamic stall than does model B. A single blade is considered for the analysis. Normal mode analysis is used in formulating the governing equations of motion. The aerodynamic forces are calculated at a selected number of stations (strips) and integrated to obtain the total generalized forces on the blade. Combined momentum-blade element theory is used to calculate the induced velocity.

AERO-DYNAMIC MODEL: STRIP THEORY WITH EMPIRICAL DYNAMIC STALL MODELS

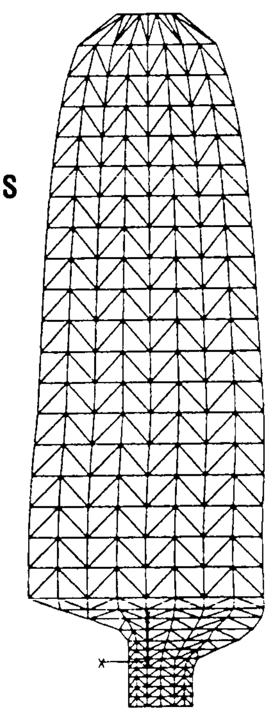
- MODEL A (GORMONT, 1973): TWO PARAMETERS GIVEN AS FUNCTION OF MACH NUMBER AND AIRFOIL THICKNESS TO CHORD RATIO.
- MODEL B (GANGWANI, 1983): ANALYTICAL FIT WITH 24 PARAMETERS

STRUCTURAL MODEL

- FINITE ELEMENT STRUCTURAL MODEL

SOLUTION METHOD

- INTEGRATION IN TIME



FINITE ELEMENT STRUCTURAL MODEL

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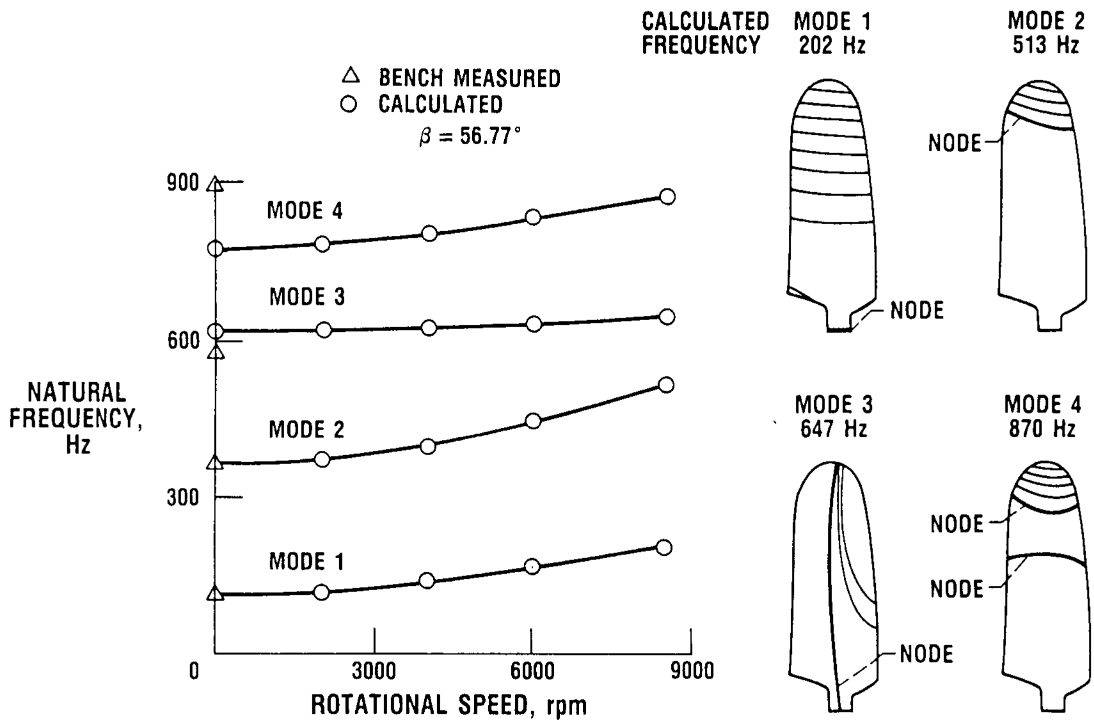
CALCULATED NATURAL FREQUENCIES AND MODE SHAPES

The variation of the calculated first four natural frequencies with rotational speed is shown in the diagram below. The COSMIC NASTRAN program with triangular elements (CTRIA2) was used for the analysis. The first two calculated natural frequencies agreed well with the measured bench values whereas the third and fourth showed about 8 to 13 percent error. The frequencies show the effect of centrifugal force, the effect being higher for first, second, and forth modes than for third mode. The first four mode shapes calculated with blade setting angle, ß, equal to 56.77°, using COSMIC- NASTRAN, showed that the first mode is 1st bending, the second mode is second bending, the third mode is 1st torsion mode and the fourth mode is third bending.



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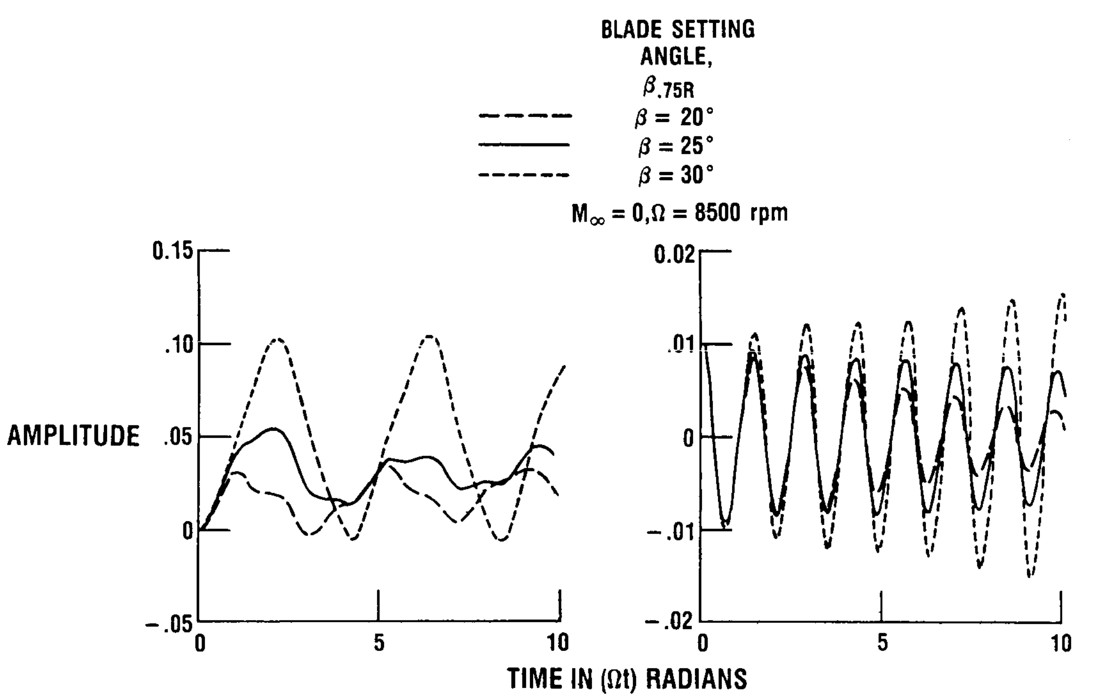
STALL FLUTTER RESPONSE WITH DYNAMIC STALL MODEL A

The operating condition considered for the analysis is 8500 rpm at zero free stream velocity, that is static thrust condition. Four modes are used in the analysis.

The figure on the right shows the variation of the first normal coordinate with time. The response shows that the first normal coordinate, which is predominantly bending, is converging to a steady value for the three setting angles considered (20, 25, and 30), thereby indicating stable oscillations. The response of the second and fourth normal coordinates showed stable oscillations.

The response of the third normal coordinate, (shown on the left) which is predominantly torsion, shows a converging trend for $\beta = 20°$. A limit cycle oscillation is predicted at $\beta = 25°$, and a diverging oscillation at $\beta = 30°$. The calculated frequency of the limit cycle oscillation is 617 Hz. This is qualitatively in agreement with the experimental data which showed a very high response at $\beta = 31.8°$ at a frequency of 600 Hz.

The analysis indicated that the stall flutter response for this propfan is essentially a single degree of freedom response, since the modes are uncoupled.



RESPONSE OF THE FIRST NORMAL MODE RESPONSE OF THE THIRD NORMAL MODE

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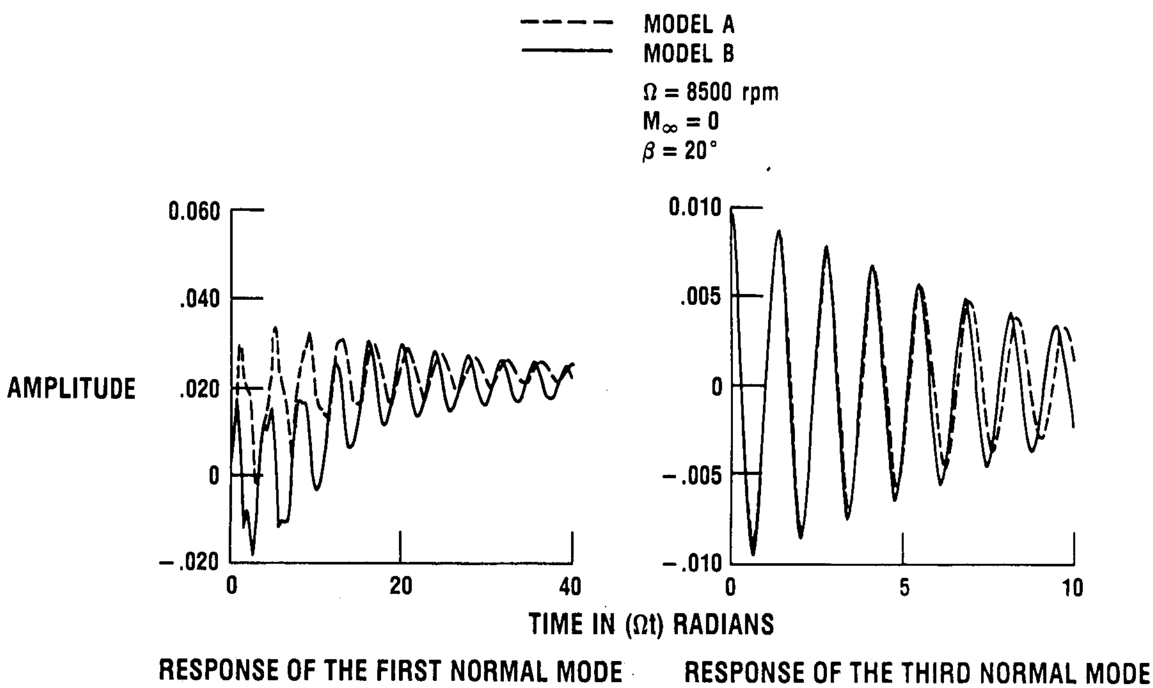
COMPARISON OF THE RESPONSE OF DYNAMIC STALL MODELS A AND B

The response calculated from the dynamic stall models, model A and model B, is compared next. The rotational speed is 8500 and the setting angle is 20°. Free stream velocity is zero. Both the models predicted the same type of response.



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STALL FLUTTER RESPONSE WITH DYNAMIC STALL MODEL A

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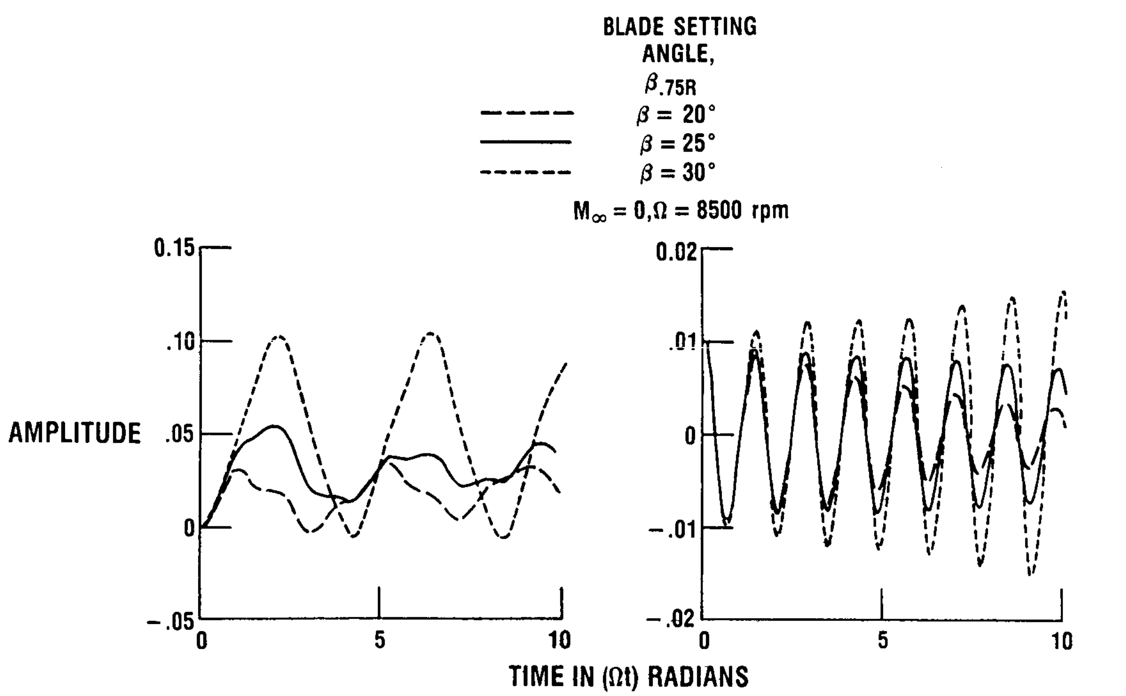

RESPONSE OF THE FIRST NORMAL MODE RESPONSE OF THE THIRD NORMAL MODE

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COMPARISON OF THE RESPONSE OF DYNAMIC STALL MODELS A AND B

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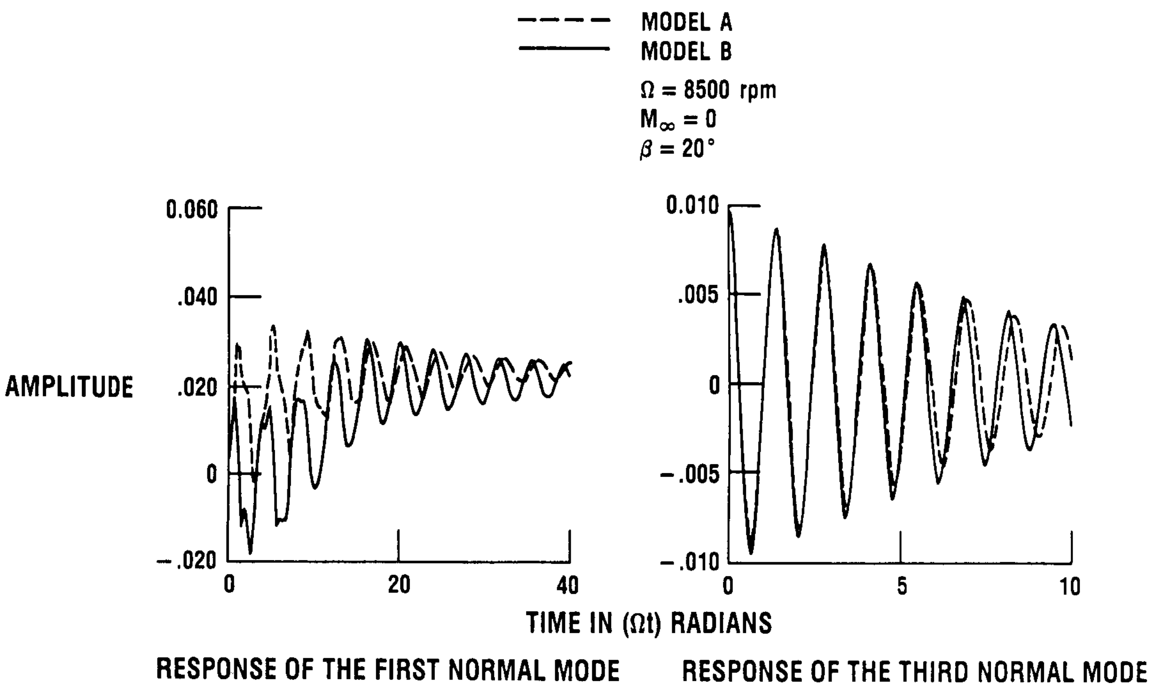

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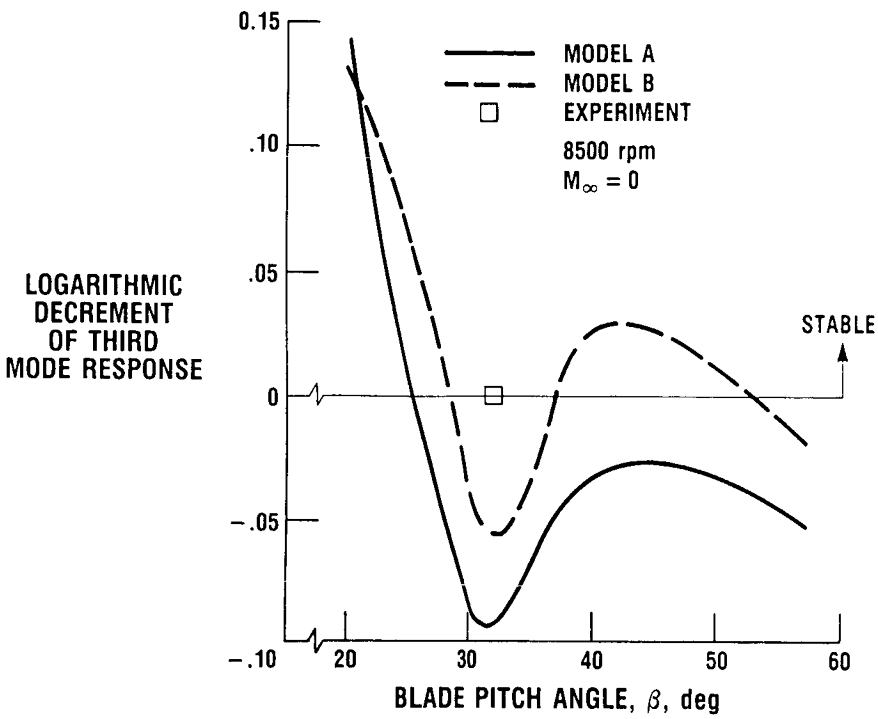
LOGARITHMIC DECREMENT COMPARISON

A study of the variation of logarithmic decrement with the blade pitch angle as predicted by both the dynamic stall models showed that both models predict the same type of behavior. However, it is seen that model B predicts the stall angle at a higher value than that predicted by model A.



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SUMMARY

The two empirical dynamic stall models employed in the stall flutter analysis of the SR2 propfan predicted the setting angle, mode, and the frequency as that observed in the experiment. However, they failed to give any detail of the flow at the dynamic stall condtions. A comparison of the response obtained with three empirical models, not presented here, showed that the response depends on the empirical model used. A computational fluid dynamics approach is planned to better understand the physics of the flow and the dynamic stall phenomenon of propfan airfoils.

- **ONLY QUALITATIVE PREDICTION POSSIBLE WITH EMPIRICAL MODELS.**
- **PREDICTED RESPONSE SENSITIVE TO EMPIRICAL MODEL**
- **RANGE OF VALIDITY OF EMPIRICAL MODELS RESTRICTED BY THE EXPERIMENTAL DATA USED TO DEVELOP THE MODEL**
- **COMPUTATIONAL FLUID DYNAMICS (CFD) APPROACHES ARE REQUIRED TO PREDICT PHYSICS OF FLOW AND DYNAMIC STALL PHENOMENON OF PROPFAN AIRFOILS**

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