HELICOPTER ROTOR BLADE DYNAMICS

INTRODUCTION

The dynamic behavior of a helicopter rotor blade can be simulated using a PACE® TR-48 Desk Top Analog Computer as the model. The computer with electronic switching, solid-state components and high-speed repetitive operation solves the integrodifferential and other equations describing the system. It then provides high-speed read-out of the results. These Notes provide a brief analysis of the system dynamics involved and a description of the computer model performing the simulation.

SYSTEM ANALYSIS

The primary result of the helicopter's main rotor action is a vertical lifting force. However, the rotor's motion also develops forces required for horizontal propulsion, aircraft stabilization and control. All of these forces result from the tilting of the rotor head or the entire aircraft, and from the "flapping" of the rotor blades. The blades are attached to the rotor drive shaft by hinges that permit them to flap in the direction normal to the plane of rotation.

When the blades are stationary, they droop down against stops. When in motion they turn upward, and are kept at a level close to the plane of rotation by a large centrifugal force. The forces acting on the rotor blades are indicated in figure 1.

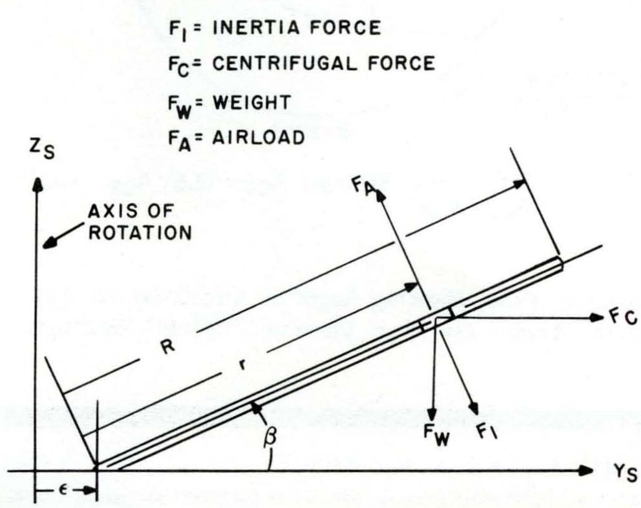

Figure 1: Side View Of Helicopter Rotor Blade

The analytic procedure used provides a set of equations that describe the dynamic behavior of a flapping rotor blade element. These equations define parameters for the system force balance equation. The latter, obtained by summing moments about the flapping axis, is the integrodifferential equation,

$$I\left(\sin\beta\cos\beta\,\omega^2 + \frac{d^2\beta}{dt^2}\right) = 1/2\,\rho\,C_E\int_0^K C_L U^2 r\,dr \quad (1)$$

in which,

- C_L = lift coefficient, a non-analytic function of the angle of attack
- U = velocity of the blade element (in ft./sec.)
- C_E = mean cord in circle of rotation (in ft.)
- ρ = air density (in slugs/cu. ft.)
- I = blade moment of inertia (in slug-sq. ft.)
- ω = rotor angular velocity (in radians/sec.)
- β = blade flap angle (in radians)
- r = radius of blade element (in ft.)

The angle of attack (α) is equal to the sum of the rotor pitch angle and the angle by which the horizontal (tangential) velocity is displaced from the true air speed. The rotor pitch angle is a function of the "stick" position described by:

- A_{CS} = the basic rotor pitch controlled by "control stick"
- A_{LS} = the pitch generated primarily by lateral movement of the "cyclic stick"
- B_{LS} = the pitch generated primarily by longitudinal movement of the "cyclic stick".

COMPUTER SIMULATION

The details of blade motion are important in analyzing hinge-transmitted, shear stresses and other causes of aircraft vibration. In addition, a knowledge of the blade dynamics is required in investigating stall as a function of "stick" position and angle of attack. The computer simulation of blade dynamics produces contour plots showing the angle of attack for various "stick" positions.

A two-speed computation technique is used to solve the system equations. Continuous real-time computation provides solutions to equations that are dependent upon azimuth angle (ωt). These solutions in turn provide the inputs for computer circuits that operate with rotor blade length (X) as the independent variable. High-speed repetitive operation of these circuits provides the integral input to the force balance equation.

The TR-48 Computer model uses 46 amplifiers in addition to high-speed electronic-switches, comparators and multipliers. A variable diode function generator provides the lift coefficient vs. angle of attack function.

RESULTS

The simulation produced a set of contour plots shown in figures 2, 3 and 4. They show angle of attack (α) for the various "stick" settings described by A_{CS}, A_{LS} and B_{LS}. The plots indicate that the helicopter would stall for control stick settings (A_{CS}) of 10° and 12.5°. For these settings,

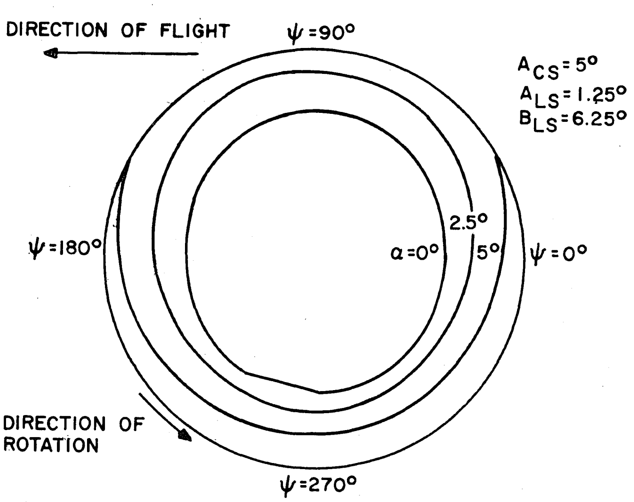

Figure 2: Non-Stall "Stick" Settings; A_{CS} = 5°, A_{LS} = 1.25°, B_{LS} = 6.25°

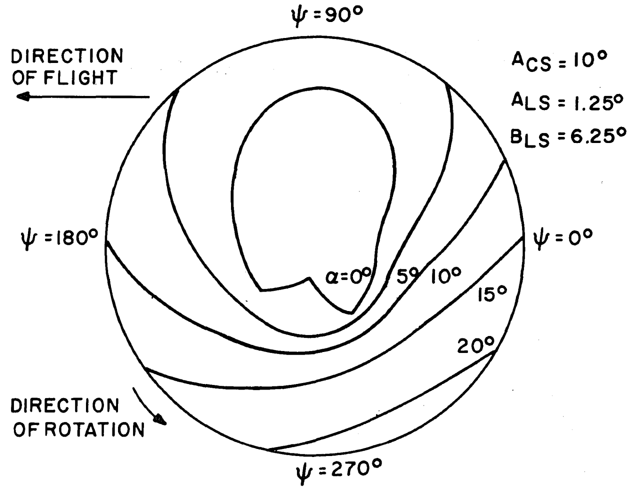

Figure 3: Stall "Stick" Settings; A_{CS} = 10°, A_{LS} = 1.25°, B_{LS} = 6.25°

the desired initial angle of attack (α_o) exceeds 12°, a critical value representing the start of the stall region in the C_L vs. α function.

This application demonstrates a practical technique for solving integrodifferential equations with the desk-top analog computer and for effectively reading-out the high-speed results obtained.

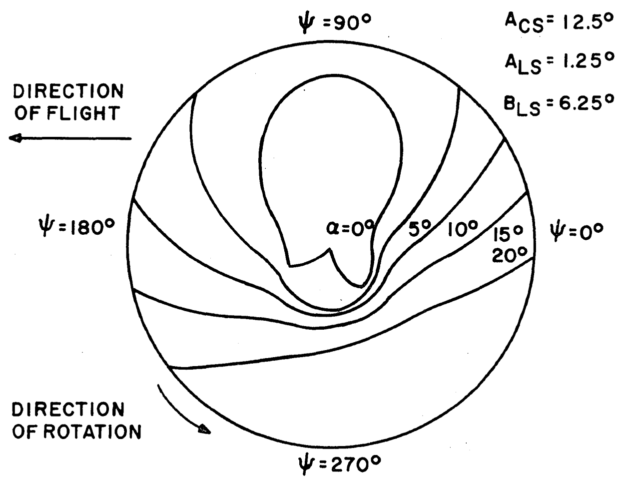

Figure 4: Stall "Stick" Settings; A_{CS} = 12.5°, A_{LS} = 1.25°, B_{LS} = 6.25°

Contour Plots Showing Angle of Attack (α) vs. Azimuth Angle (ψ) For Various "Stick" Settings.

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