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Helicopter Flapping Under Dynamic Stall

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Abstract: *A helicopter is an aircraft that is lifted and propelled by one or more horizontal rotors, each consisting of two or more rotor blades. The main objective of this seminar topic is to study the basic concepts of helicopter aerodynamics. The forces acting on helicopter i.e. lift, drag, thrust and weight are considered for developing analytic equations. The main topics that are discussed include blade motions like blade flapping, feathering and lead-lag. The effect of stall on helicopter blade flapping is studied and it was noticed that there is a sudden lift drop at this stall condition. It was also found that dynamic stall occurs due to rapidly changing angle of attack, which inturn affect the air flow over the airfoil. Blade flapping angle and induced angle of attack are the main parameters concerned with stall. The theory behind blade element analysis has been inferred in detail. The importance of all these in the present scenario are also taken into consideration.*
Keywords: *Flapping, Dynamic stall, angle of attack, airfoil, lift, drag.*

I. Introduction

The science of aerodynamics is the fundament of all flight. Ignor Sikorsky's vision of rotating wing aircraft that could safely hover and perform other desurable flight maneuvers under full control of the pilot took thirty years to be achieved. This rotating aircraft we know it today as helicopter. The great Leonardo da Vinci years back in his drawing showed a basic human carrying helicopterlike machine an obvious elaboration of Archimedes water-screw. The origin of sucessful helicopters can be traced from the achievements of Lilienthal, Langly then to the first pilot controlled aircraft by the Wright Brothers in 1903 to the present date.

1.1 Background and scope

A helicopter is an aircraft that is lifted and propelled by one or more horizontal rotors, each rotor consisting of two or more rotor blades. A helicopter works by having its wings move through air while the body stays still. The helicopter blades are called main rotor blades. During flight there are four forces on the helicopter and those forces are

- lift
- drag
- thrust
- weight

Helicopters are in wide usage in present era. Due to its rapid action and novelty it has created a great impact in the upper class. Rapid flight action inturn results in a special type of stalling process called dynamic stall. A helicopter flies because aerodynamic forces necessary to keep it aloft are produced when air passes about the rotor blades. The rortor blade is an aerdodynamic structure that makes flight possible. Its shape produces necessary lift when it passes through the air. Heliocopter blades have airfoil sections designed for a specific set of flight charactericties. In this report we are going to study in detail helicopter flapping and the effect of dynamic stall on it.

The topic involves the basic understanding of helicopter blade characteristics i.e. structure, nomenclature and its action under fluid flow and stall. This literature survey deals with the basic study related with helicopter aerdynamics.These factors are the main criteria on which the design and development of helicopters depend. For a helicopter in motion, there are different types of blade movements that occur. In order to study and understand the topics related, various jornals and books have been referred, as illustrated in'REFRENCES' chapter -6.

1.2 Dynamic stall and its effect

The main journal *Helicopter blade flapping with and without small angle assumption in the presence of dynamic stall* by Jyoti Ranjan Majhi, Ranjan Ganguli(1) deals with the general flapping equation without taking into account the small angle assumptions. The validity of the small induced inflow angle of attack assumption is investigated in various flight regimes. Moreover it's better to assume that the flap angle and inflow angle are large angles in helicopter dynamics.

In the journal *Dynamic stall on a fully equipped helicopter model* by K.Mulleners, K.Kindler, M.Raffel (2) tells about three dimensinal stall observed on the rotor of a fully equipped helicopter model. It's said that dynamic stall on an airfoil comprises a series of complex aerodynamic phenomena into an unsteady change of the angle of attack. Finite wing and rotational effects as well as blade lag motion should be considered for aComprehensive understanding of dynamic stall on retreating helicopter rotor blades.

In *Shallow and deep dynamic stall for flapping low Reynolds number airfoils* by Michael V, Luis Bernal, Chang-Kwon Kang (3) its described about various experiments based on flow visualisaton and direct force measurement Comparison of classical unsteady aerodynamic theory, for an airfoil spanning the test section seek to elucidate the impact of flow separation on the validity of the various approaches and on prediction of lift coefficient time history.

1.3 Air foil

An airfoil is the shape of a wing or blade of propeller, rotor, turbine or sail as seen in cross section.

An airfoil-shaped body moved through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the direction of motion is called drag. The lift on an airfoil is primarily the result of its angle of attack and shape. When oriented at a suitable angle, the airfoil deflects the oncoming air, resulting in a force on the airfoil in the direction opposite to the deflection. Most foil shapes require a positive angle of attack to generate lift, but cambered airfoils can generate lift at zero angle of attack. This turning of the air in the vicinity of the airfoil creates curved streamlines which results in lower pressure on one side and higher pressure on the other. The thicker boundary layer also causes a large increase in pressure drag, so that the overall drag increases sharply near and past the stall point.

As a wing moves through air, the air is split and passes above and below the wing. The wing's upper surface is shaped so the air rushing over the top speeds up and stretches out. This decreases the air pressure above the wing. The airs flowing below the wing moves in a straighter line, so its speed and air pressure remains the same. Since high air pressure always moves toward low air pressure, the air below the wing pushes upward toward the air above the wing. The wing is in the middle, and the whole wing is "lifted." The faster an airplane moves, the more lift there is. And when the force of lift is greater than the force of gravity, the airplane is able to fly.

Airfoil design is a major facet of aerodynamics. Various airfoils serve different flight regimes. Asymmetric airfoils can generate lift at zero angle of attack, while a symmetric airfoil may better suit frequent inverted flight as in an aeobic airplane. Modern aircraft wings may have different airfoil sections along the wing span, each one optimized for the conditions in each section of the wing. Movable high-lift devices, flaps and sometimes slats, are fitted to airfoils on almost every aircraft.

1.4 Airfoil Terminology

The various terms associalted with airfoil are:

- The *suction surface* is generally associated with higher velocity and lower static pressure.
- The *pressure surface* has a comparatively higher static pressure than the suction surface. The pressure gradient between these two surfaces contributes to the lift force generated for a given airfoil.
- The leading edge is the point at the front of the airfoil that has maximum curvature.
- The *trailing edge* is defined similarly as the point of maximum curvature at the rear of the airfoil.
- The *chord line* is a straight line connecting the leading and trailing edges of the airfoil.
- The *chord length* is the length of the chord line.
- The *mean camber line* is the locus of points midway between the upper and lower surfaces.
- *Pitch angle: The* mechanical angle between the chord line of the airfoil and the plane of rotation of the rotor.
- *Angle of attack:*The acute angle formed between the chord line of an airfoil and the resultant relative wind

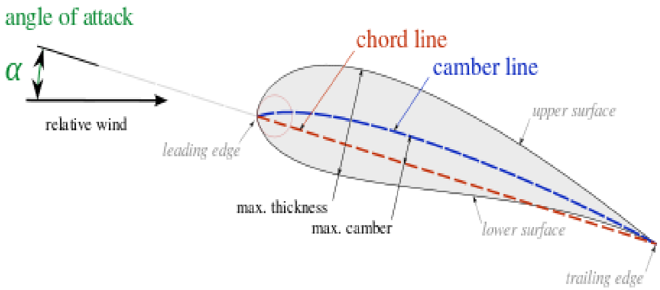

Fig .1: Airfoil nomenclature

II. Theoretical Study

2.1 Helicopter Rotor

A helicopter main rotor is the combination of a rotary wing and a control system that generates the aerodynamic lift force that supports the weight of the helicopter, and the thrust that counteracts aerodynamic drag in forward flight. Each main rotor is mounted on a vertical mast over the top of the helicopter, as opposed to a helicopter tail, which connects through a combination of drive shaft and gearboxes along the tail boom. A helicopter's rotor is generally made of two or more rotor blades. The blade pitch is typically controlled by a swashplate connected to the helicopter fllight controls. Helicopters are one of the major examples of rotary-wing aircraft.

The helicopter rotor is powered by the engine, through the transmission, to the rotating mast. The mast is a cylindrical metal shaft that extends upward and is driven by the transmission. At the top of the mast is the attachment point for the rotor blades called the hub. The rotor blades are then attached to the hub.

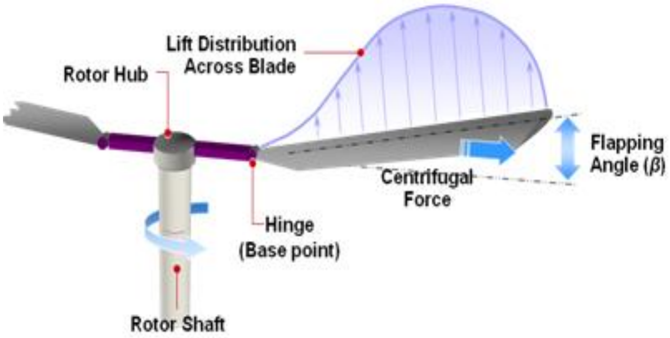

Fig 2.1: Helicopter rotor

Limiting conditions

1. Helicopters with teetering rotors must not be subjected to low-g condition because such rotor systems do not control the fuselage attitude.
2. When operating in sandy environments, sand hitting the moving rotor blades erodes their surface. This can damage the rotors and presents serious and costly maintenance problems.

2.2 Blade motions

A rotating blade can have the following three types of motions:

- Flapping
- Feathering
- Lead and lag

2.2.1 Helicopter Flapping

In order to get a clear idea of blade flapping we must be clearly know the concept of *dissymetry of lift.*Dissymmetry of lift is the difference in lift that exists between the advancing half of the rotor disk and the retreating half. It is caused by the fact that in directional flight the aircraft relative wind is added to the rotational relative wind on the advancing blade, and subtracted on the retreating blade. All rotor systems are subject to Dissymmetry of Lift in forward flight. At a hover, the lift is equal across the entire rotor disk. As the helicopter gain air speed, the advancing blade develops greater lift because of the increased airspeed and the retreating blade will produce less lift, this will cause the helicopter to roll.

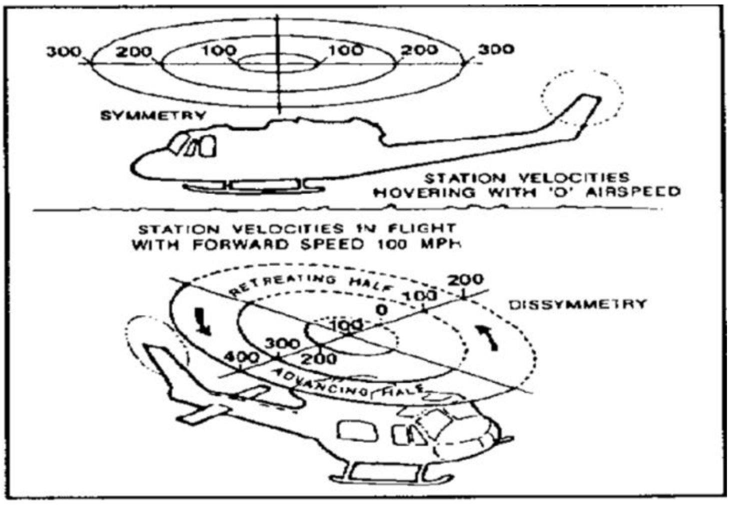

Fig 2.2: Symmetry and Dissymmetry of "LIFT"

Dissymmetry of lift in helicopter aerodynamics refers to an uneven amount of lift on opposite sides of the rotor disc.The dissymmetry is caused by differences in relative airspeed between the advancing blade and the retreating blade.

Dissymmetry of lift is compensated by *blade flapping*, because of the increased airspeed and lift on the advancing blade will cause the blade to flap up and decreasing the angle of attack. The decreased lift on the retreating blade will cause the blade to flap down and increasing the angle of attack. The combination of decreased angle of attack on the advancing blade and increased angle of attack on the retreating blade through blade flapping action tends to equalize the lift over the two halves of the rotor disc. Thus Flapping is the up and down movement of the rotor blades about a flapping hinge (or flexible hub). Blades flap in response to changes in lift caused by changes in velocity of the relative wind across the airfoil, or by cyclic feathering. No flapping occurs when the tip path plane is perpendicular to the mast.

2.2.2 Helicopter feathering

Blade feathering is the term for changing blade angle. It influences the blade's angle of attack. A blade feathers along its longitudinal axis, and a bearing is usually used to support this. The blade angle is set by the control rod, which is connected to the swashplate. Changing the blade pitch will result in a change in blade flapping behaviour. The place where the control rods connect to the blade, and the position of the flapping axis both influence feathering and, therefore, blade angle. Feathering is the rotation of the blade about its span-wise axis. Feathering can be uniform throughout the rotor through collective inputs. Feathering can be adjusted differentially through cyclic manipulation.

2.2.3 Lead Lag

Coriolis force tends to make a rotor blade want to speed up and slow down it's rotation around the mast. If the blade is rigidly attached to the mast but isn't strong enough, it could develop stresses large enough to break the blade.A lead lag hinge simply is a hinge which allows the blade to pivot slightly forward and backward.

2.3 Stall

A stall is a condition in aerodynamics wherein the angle of attack increases beyond a certain point such that the lift begins to decrease. The angle at which this occurs is called the critical angle of attack. This critical angle is dependent upon the profile of the wing, its planform, its aspect ratio, and other factors, but is typically in the range of 8 to 20 degrees relative to the incoming wind for most subsonic airfoils. The critical angle of attack is the angle of attack on the lift coefficient versus angle-of-attack curve at which the maximum lift coefficient occurs. Flow separation begins to occur at small angles of attack while *attached* flow over the wing is still dominant. As angle of attack increases, the separated regions on the top of the wing increase in size and hinder the wing's ability to create lift. At the critical angle of attack, separated flow is so dominant that further increases in angle of attack produce less lift and vastly more drag.

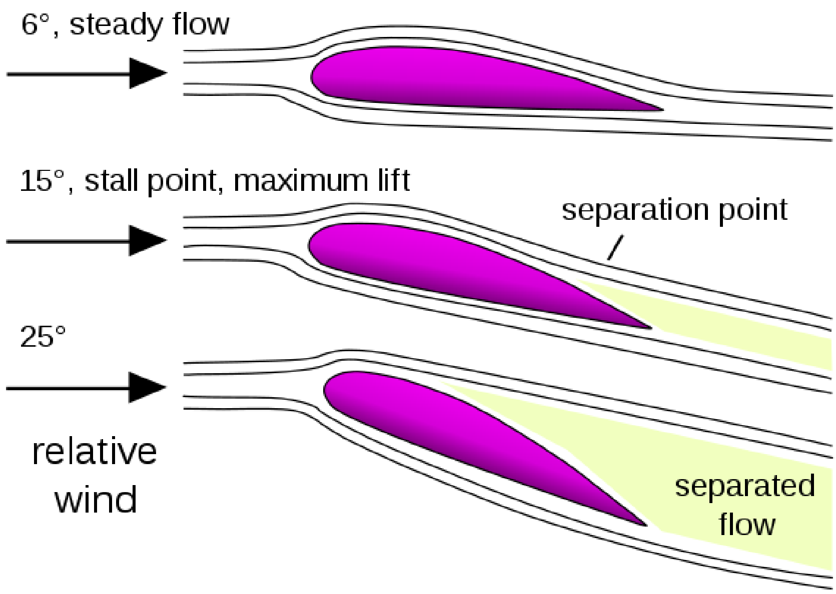

Fig 2.3: Stall formation

One symptom of an approaching stall is slow and sloppy controls. As the speed of the aircraft decreases approaching the stall, there is less air moving over the wing, and, therefore, less air will be deflected by the control surfaces at this slower speed. Some buffeting may also be felt from the turbulent flow above the wings as the stall is reached.

2.4 Dynamic Stall

Dynamic stall is a non-linear unsteady aerodynamic effect that occurs when airfoils rapidly change the angle of attack. The rapid change can cause a strong vortex to be shed from the leading edge of the airofoil, and travel backwards above the wing. The vortex, containing high-velocity airflows, briefly increases the lift produced by the wing. As soon as it passes behind the trailing edge, however, the lift reduces dramatically, and the wing is in normal stall.

A dynamic stall is a stalled condition different from a statically stalled condition. It is a transient, non-permanent condition. Airfoil stalls at a given angle of attack. This critical angle of attack is the angle of attack that gives the highest coefficient of lift, ie, beyond this angle of attack, the CL decreases due to increased airflow separation on the upper side of the airfoil. This is measured in a static, steady-state, constant system.However, the airflow separation on top of the wing is in reality dynamic and always changing, and during these changes we may see conditions, beyond the nominated critical angle of attack, where the airflow is less separated than in the above steady-state scenario.

Dynamic stall is mostly associated with helicopters and flapping wings. During forward flight, some regions of a helicopter blade may incur flow that reverses, and thus includes rapidly changing angles of attack. Stall delay can occur on airfoils subject to a high angle of attack and a three-dimensional flow. When the angle of attack on an airfoil is increasing rapidly, the flow will remain substantially attached to the airfoil to a significantly higher angle of attack than can be achieved in steady-state conditions. As a result, the stall is delayed momentarily and a lift corfficient significantly higher than the steady-state maximum is achieved. Helicopter, flapping wings, oscillating wings of insects, propellers are all associated with dynamic stall.

III. Case Study

3.1 Blade element analysis

The blade element theory is used to obtain the loads acting on a blade section. Blade element theory involves breaking a blade down into several small parts then determining the forces on each of these small blade elements. These forces are then integrated along the entire blade and over one rotor revolution in order to obtain the forces and moments produced by the rotor. If the blade element method is applied to helicopter rotors in forward flight it is necessary to consider the flapping motion of the blades as well as the longitudinal and lateral distribution of the induced velocity on the rotor disk.
The blade cross section consists of an airofoil section:

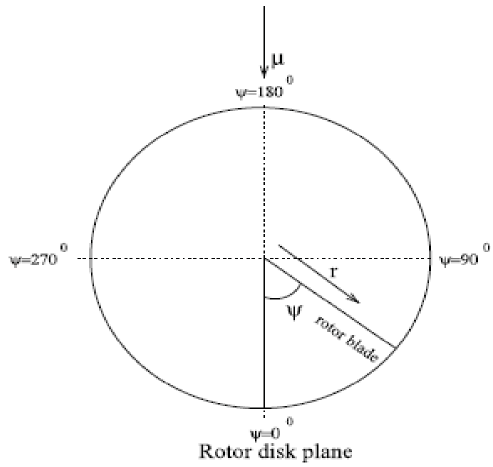

Fig 3.1: Rotor disc plane

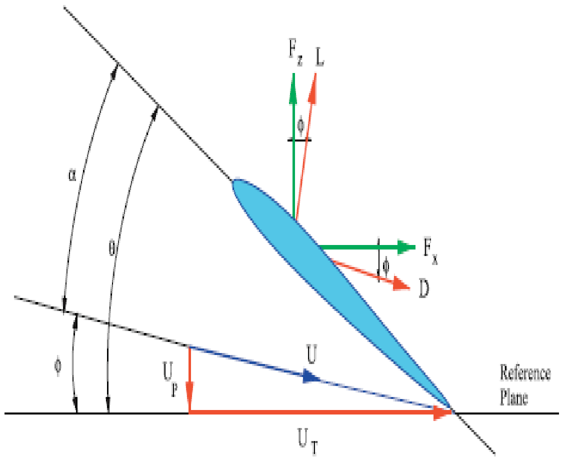

Fig 3.2: Blade element velocity and forces

3.1.1 Blade element velocity components

There are three dimensional components of velocity, an in plane component of velocity $U_{T,}$ an out of plane component,U_P and a radial component $U_R U_R$=(ΩR)μcosΨ

U_P= (ΩR)(λcosβ+rβ+μsinβcosΨ)

U_T=(ΩR)(rcosβ+μsinΨ) where $\mu = \frac{v_\infty cos\alpha}{\Omega R}$

4.1.2 Blade element forces

Lift and drag forces per unit blade span are:

$L=\frac{1}{2}\rho U^2 CC_L$

$D=\frac{1}{2}\rho U^2 CC_D$

where, U=resultant velocity

$C_L = C_L(\alpha)$

$C_D = C_D(\alpha)$

The lift and drag forces act perpendicular and parallel,respectively, to the dorection of the resultant flow velocity.

3.2 Graphical study

The main objective of this paper is to address two issues:

- The validity of small β assumption
- The validity of the small φ assumption.

These assumptions are inestigated in the foregoing sections.

3.2.1 Flapping response

In the following case study, a uniform inflow model is used. We see that θ0 increases from 1 degree to 16 degree. For low θ0 the effect is primarily on the phasing of the flap response but at higher θ0, its affects both magnitude and phasing. The small β assumption over pedicts the effective angle of attack which results in appropriate lift prediction which in turn brings out an erroneous flap response.

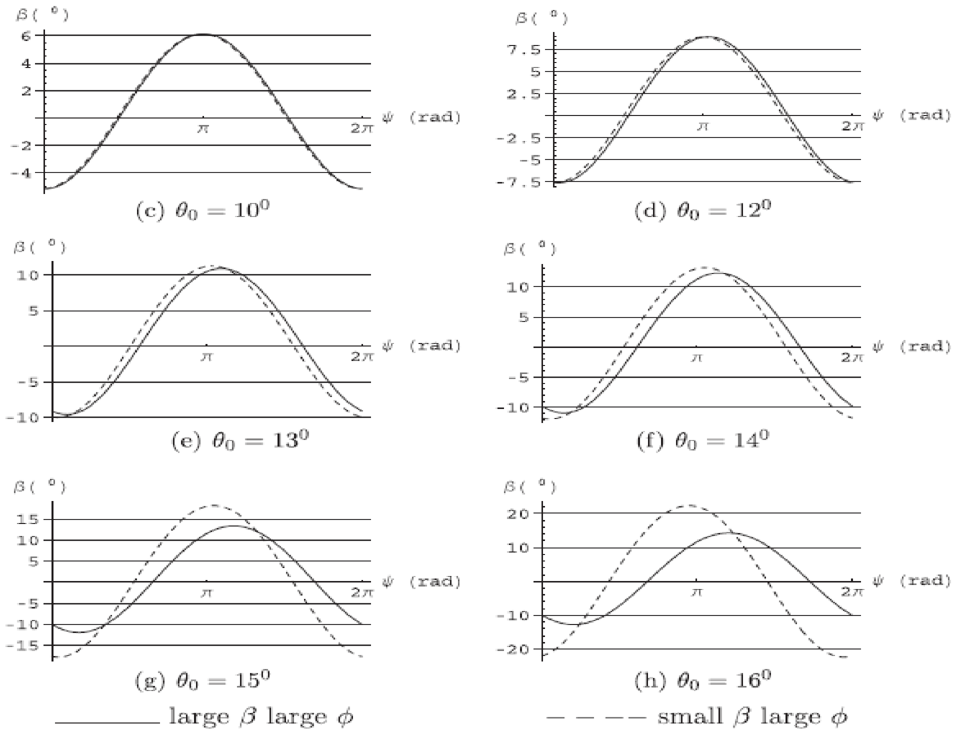

Fig 3.3: Variation of φwith azimuth for collective pitch.

3.2.2 Induced inflow angle

In this the small flap angle approximation formulation is not always valid. Φ is assumed to be large. The nature of the induced inflow angle that is wether it is really large or a small angle approximation can be made which reduces the mathematical compliations inolved in this study.

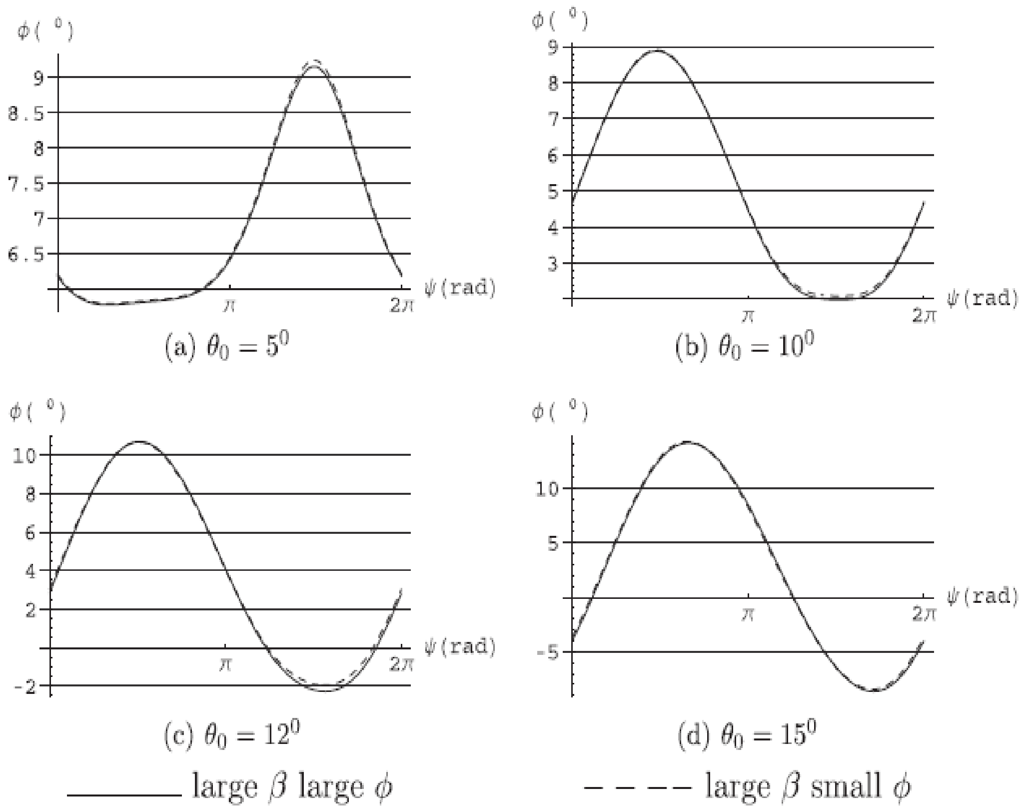

Fig 3.4: Variation of φ with azimuth for $\frac{c}{\sigma}$=0.15

IV. Conclusion

In this report, the basic concepts related to helicopter aerodynamics is described and studied. Details regarding airofoil, helicopter rotor, blade motions are known. A complete justification to the seminar topic "*helicopter flapping under dynamic stall*" is done. Flapping of helicopter blades and the effect of stall on the helicopter motion is discussed in detail. Dynamic stall is given the prime emphasis.

The conclusions assessed from the above Chapters are given below:

- There are three components of velocities:
  1. Radial component U_R
  2. Tangential component U_T
  3. Perpendicularar component U_P

- There are mainly three forces acting on an element:
  1. Inertia force (opposing the flapping motion)
  2. Centifugal force (acting radially outwards)
  3. Aerodynamic force (normal to the blade)

- Blade element forces
  1. Lift (act perpendicular to direction of the flow velocity)
  2. Drag (act parallel to direction of the flow velocity)

- Rotating blades of helicopter mainly has three types of motions
  1. Blade flapping
  2. Blade feathering
  3. Lead and lag

Dissymetry of lift in helicopter is compensated by the flappindg of blades.It is better to assume that the flap angle β and inflow angle φ are larger angles in helicopter dynamics.No flapping occurs when the tip path plane is perpendicular to the mast. A stall occurs at the critical angle of attack. At this point lift force suddenly reduces and the drag force increases. Dynamic stall occurs when airfoil rapidly changes the angle of attack.When dynamic stall occurs, the vortex containing high velocity airflows increase the lift, which futher decrease after passing the trailing edge.

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REFRENCES

Journal Papers:

[1] Jyothi Ranjan Majhi, Rajan Ganguli, Helicopter blade flapping with and without small angle assumption in the presence of dynamic stall, *Applied Mathematical Modelling*, 2010, *3726*-3740.

[2] K.Mulleners, K.Kindler, M. Raffel J, *Dynamic stall on fully equipped helicopter model*, Aerospace science and technology2009, 72-76.

[3] Michael V, Luis Bernal, Chang-Kwon Kang, *Shallow and deep dynamic stall for flapping low Reynolds number airfoils* 2009, 833-901.