11. Introduction to Helicopter Stability

2020

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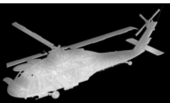

Overview

- I. Symbols
- II. Stability definitions
- III. Rotor characteristics
- IV. Control sensitivity
- V. Rotor static stability w/ speed and w/ AoA
- VI. Stability in hovering flight
- VII. Longitudinal stability in forward flight
- VIII. Dynamic stability in forward flight

Introduction

❖ To be designed w/ satisfactory flying qualities

- Flying/handling quality ··· stability and control characteristics

  on the safety of flight
  pilot’s impressions on the case of flying and maneuvering

- Certain primary stability and control requirements

  ··· depends on mechanical design (ex: control-friction limits)
  primarily aerodynamic nature
  (response of the rotor and fuselage to control or atmospheric disturbance)

- Subject

  - helicopter control and rotor damping caused by pitching or rolling → control sensitivity
  - static stability w/ speed
    w/ AoA ··· objectionably deficient
  - dynamic stability in hover / forward flight ··· determined by stability parameter above

I. Symbols, II. Stability definitions

❖ I. Symbols

- Nose up moment, angular displacement, velocities ··· (+)
- Lateral motion, which tends to raise the advancing side ··· (+)
- Changes in translation velocities to increase velocity, upward ··· (+)

❖ II. Stability definitions

- Trim ··· in steady flight, resultant force, moment = 0
- A/C stability ··· behavior of A/C after it is disturbed slightly from trim
- Static stability ··· statically stable, if there is initial tendency for it to return to the trim condition
- Dynamic stability ··· oscillation of A/C about its trim positions following a disturbance

I. Symbols, II. Stability definitions

- Fig. 11-1, if the envelope (dash line) decrease w/ time, dynamically stable

  increase w/ time, dynamically unstable

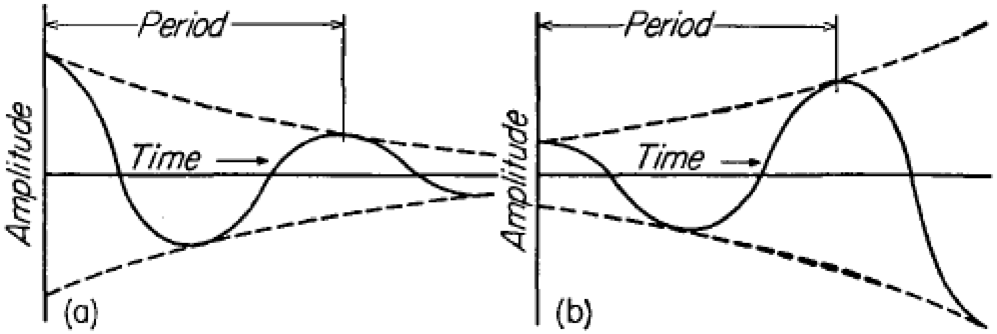

Fig. 11-1 Stable and unstable oscillations.
(a) Stable
(b) Unstable

- Time to double or half the amplitude ··· measure of the degree of stability / instability

  small time to half → highly stable

  small time to double → highly unstable

III. Rotor characteristics

① Rotor control

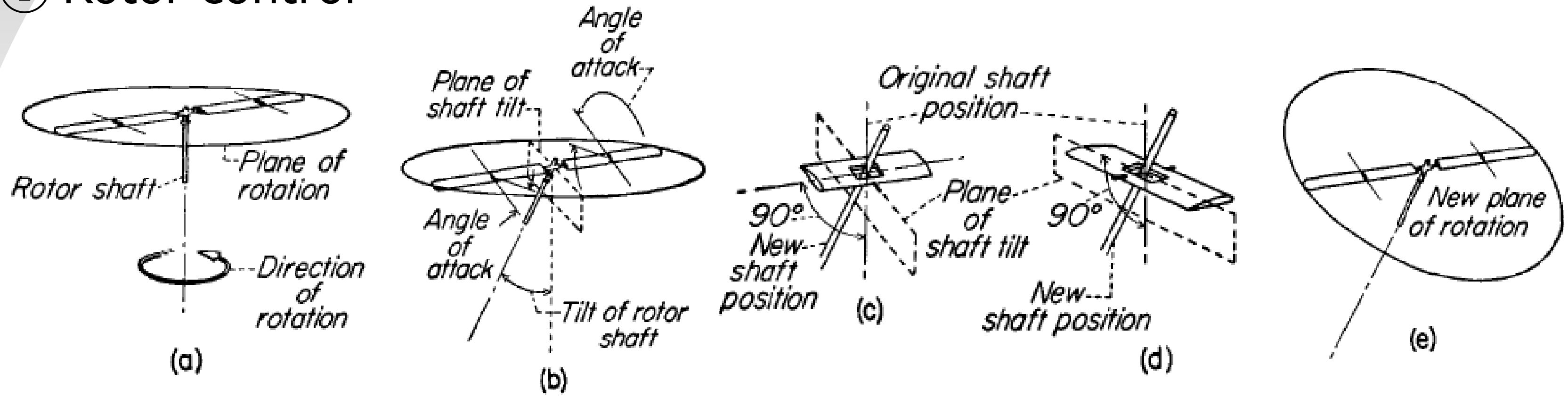

Fig. 11–2 The effect of a rotor shaft tilt on the plane of rotation.

- Fig. 11-2a ··· shaft rotating counterclockwise, 2 blades which are free to flap
- Sudden tilt of the shaft → in vacuum, no aerodynamic forces

  TPP would remain in its original position
- In air, AoA of the blades change cyclically

Blade moving to the left ··· increased lift, max. (+) displacement after ¼ revolution after max. lift position

to the right ··· decreased lift, max. (-) max. lift position

→ a short time later, plane of rotation ⊥ rotor shaft (Fig. 11-2e)

∴ tilt → cyclic change in blade AoA → proper alignment

III. Rotor characteristics

- Control stick movement is equivalent to the shaft tilt
- Rotor shaft tilt w.r.t. fuselage → moment about helicopter CG

  * Rotor T ⊥ TPP (qualitatively true, but not quantitatively correct)
- Another source of moment ⋯ flapping hinge offset, caused by CF on the blades

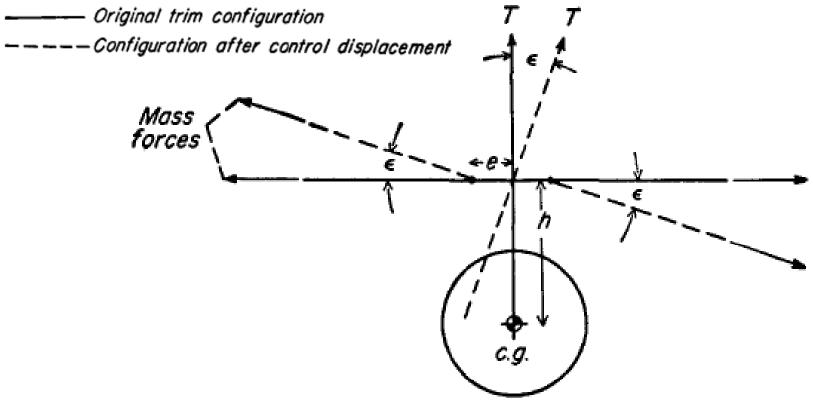

Fig. 11-3 Aerodynamic and mass moments about helicopter center of gravity.

- Fig. 11-3 ⋯ 2 sources of moments, can be increased by

  vertical distance between rotor hub and helicopter CG
  flapping hinge offset (← main design variable)
  → control power increase

Flapping hinge offset → permits an increase in the allowable CG range

III. Rotor characteristics

② Damping in pitch (or roll)

❖ Foregoing discussion ··· some delay exists between

$$\begin{cases} \text{rapid shaft tilt} \rightarrow \text{blade inertia} \\ \text{realignment of the rotor w/ the shaft} \end{cases}$$

- TPP will continue to lag behind the rotor shaft

→ aerodynamic moment to overcome continuously the flapping inertia during steady pitching or rolling

- For hover, angular displacement of the rotor plane w.r.t. the shaft per unit tilting velocity

$$\frac{\delta}{\omega} = \frac{16}{\gamma\Omega} \qquad (1)$$

Dimension : time

··· if the rotor shaft is tilting at any const. angular velocity, the thrust vector reaches a given attitude in space $\frac{16}{\gamma\Omega}$ sec. after the rotor shaft has reached that attitude.

III. Rotor characteristics

- Fig. 11-4 ⋯ helicopter is tilted at angular velocity, ensuring lag of the rotor plane

  → thrust vector movement → moment about CG
- Hinge offset → additional moment

} "damping in pitch (or rolling)"

➡ $\frac{\Delta M}{\Delta \omega}$, M_ω ⋯ opposite to the tilting velocity → stabilizing, (-)

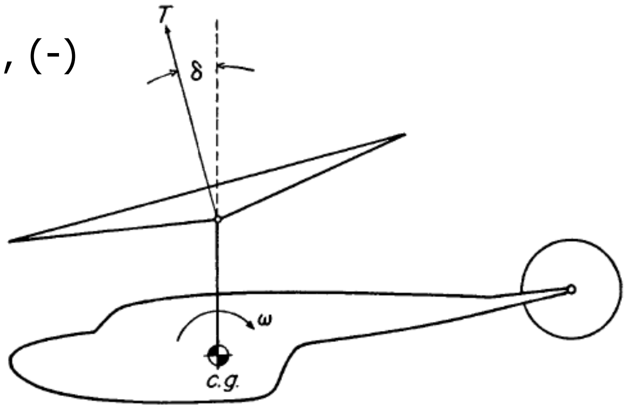

Fig. 11–4 Damping moment arising from pitching velocity.

$$\frac{\delta}{\omega} = \frac{16}{\gamma\Omega} \quad \cdots (1)$$

- As in Eq. (1), δ is inversely proportional to Ω and γ,

  directly proportional to blade moment of inertia

Ex) small helicopter ⋯ high Ω will tend to have less damping

blade tip-jet helicopters ⋯ reduced γ, more damping

- In addition to γ and Ω, damping may be increased by devices to increase the rotor displacement due to a given rate of roll / pitch

Ex) rate gyro ⋯ apply opposite control

increased effective damping ⋯ Bell stabilizer bar, Hiller control rotor

IV. Control sensitivity

❖ $\left.\begin{array}{l}\text{Control power}\\ \text{Damping in roll (or pitch)}\end{array}\right\}$ "control sensitivity"

⋯ max. rate of roll (or pitch) achieved by a unit displacement of the controls

- Definition $= \dfrac{\text{control power}}{\text{rotor damping}} = \dfrac{\dfrac{\text{control moment}}{\text{stick displacement}}}{\dfrac{\text{damping moment}}{\text{angular velocity}}} = \dfrac{\text{angular velocity}}{\text{stick displacement}}$
- Mechanism

displacement in stick (lateral) → initial angular acceleration at a const. rate

→ opposing damping-in-roll moment increase until damping moment = control moment

→ stabilized at that angular velocity

- If rotor damping > control power, max. rate of roll : small

  rotor damping < control power, max. rate of roll : large

IV. Control sensitivity

- ❖ Small two-place helicopter ⋯ similar rate of roll as that in modern fighter airplanes

  But, high control sensitivity → overcontrolling → short-period, pilot-induced lateral oscillation

- ❖ Physical characteristics to reduce excessive control sensitivity

  ⋯ Not { rotor height, flapping hinge offset } → change control power and rotor damping in proportion

  but { design factors → large helicopter @ low rotor speed, tip-jet units, Bell
  devices Stabilizer Bar, Hiller Control Rotor : more desirable }

  → Ratio to the fuselage MoI will determine the time to reach max. angular velocity

V. Rotor static stability w/ speed and w/ AoA

- ❖ Displacement in $\begin{cases} \text{pitch (AoA change)} \\ \text{forward speed} \end{cases}$ → 2 aspects of static stability due to 2 sets of forces / moments

① Rotor stability w/ speed

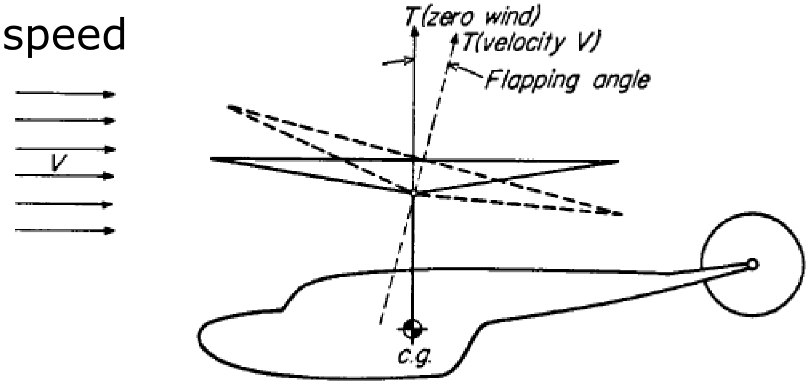

Fig. 11–5 Source of moment due to speed change.

- Fig. 11-5 ··· translation velocity → tilt of TPP in a direction away from the velocity of translation away from the velocity of translation
- Rotor plane will tilt farther backwards w/ translation speed ↗
  ← velocity of the advancing side increases
- Nose-up moment when speed ↗, Nose-down speed ↘
- $\frac{\Delta M}{\Delta v}$, M_v : measure of stability w/ speed
  ↘ always (+)

V. Rotor static stability w/ speed and w/ AoA

② Rotor stability w/ AoA

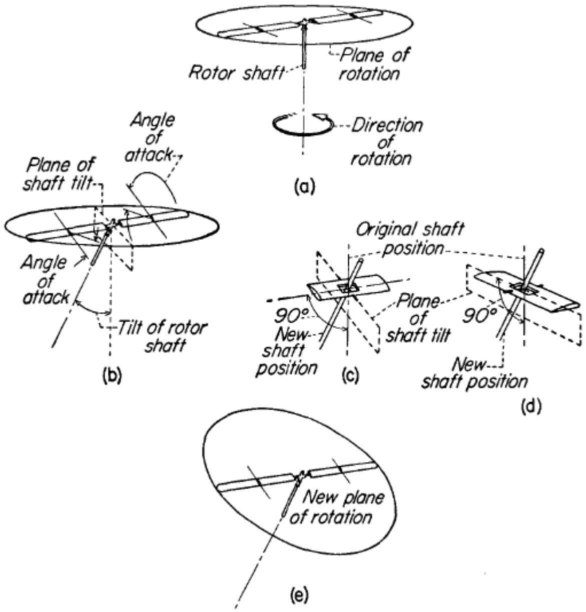

Fig. 11–2 The effect of a rotor shaft tilt on the plane of rotation.

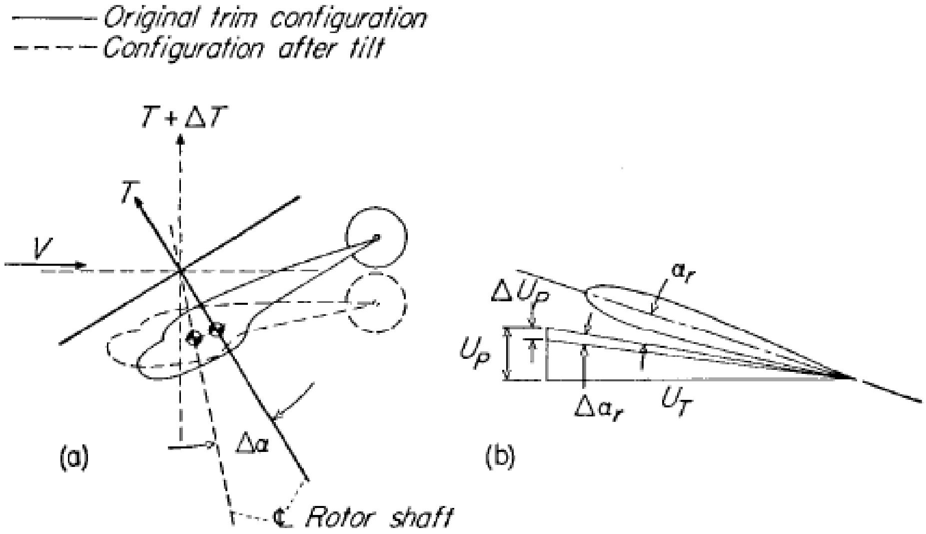

Fig. 11–6 Source of moment due to angle change.
(a) Side view of helicopter
(b) Typical blade element

- Change in attitude in hover (Fig. 11-2) → equal tilt of the rotor plane

  ⋯ no rotor moment or change in thrust → neutral stability

- Forward flight ⋯ no rotor moment and thrust change

  fuselage AoA change → change in flapping → rotor moment (Fig. 11-6)

V. Rotor static stability w/ speed and w/ AoA

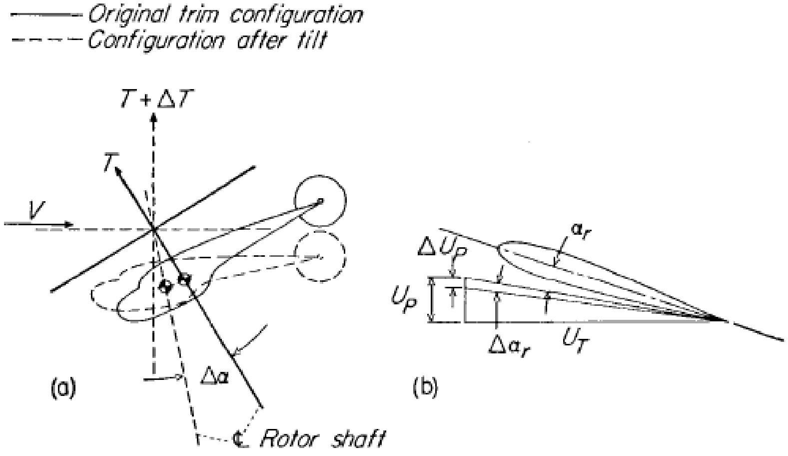

Fig. 11-6 Source of moment due to angle change.
(a) Side view of helicopter
(b) Typical blade element

- Fig. 11-6 ⋯ nose-up change in fuselage AoA (a)

  → (b) changes in relative velocities and AoA of a blade element

- Change in blade-section AoA, $\Delta\alpha_r = \frac{\Delta U_p}{U_T}$

- Change in lift $\simeq \Delta\alpha_r U_T^2 \rightarrow \ \propto \Delta U_p U_T$

  ⋯ greater on the advancing side since U_T is highest

  ← compensated by flapping or backward tilt of the rotor cone

i) Unequal increase in lift between advancing and retreating side

ii) Increased lift at all sections

→ increase in thrust

V. Rotor static stability w/ speed and w/ AoA

- Nose-up change in fuselage angle $\left\{ \begin{array}{l} \text{nose-up moment about fuselage CG} \\ \text{increase in thrust} \end{array} \right.$

- Nose-down change in fuselage angle $\left\{ \begin{array}{l} \text{nose-down moment about fuselage CG} \\ \text{decrease in thrust} \end{array} \right.$

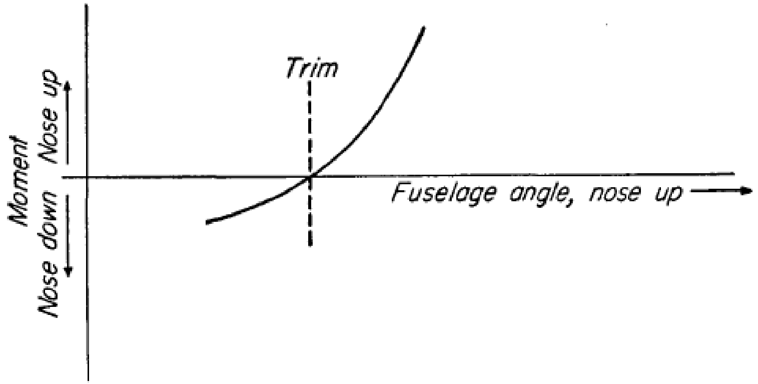

Fig. 11–7 Moment contributed by rotor about center of gravity as a function of fuselage angle of attack.

- Fig. 11-7 ⋯ rotor is unstable w/ fuselage AoA,

  greater moment produced for nose-up than nose-down

$\frac{\Delta M}{\Delta \alpha}$, M_α ⋯ measure of static stability, always (+)

$\frac{\Delta T}{\Delta \alpha}$, T_α ⋯ always (+)

VI. Stability in hovering flight

① Static stability

- Helicopter possesses neutral static stability in hover if it is displaced in roll or pitch

  → no restoring moment to its original position

  resultant rotor thrust always passes through the helicopter CG

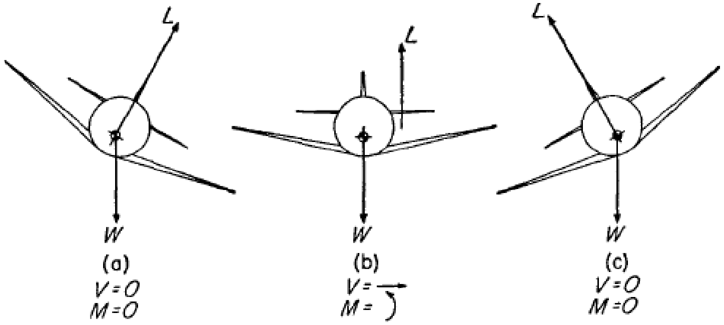

Fig. 11–8 Lateral motion of a fixed-wing airplane.

- Fixed wing A/C in FF ··· neutrally stable in roll, no restoring or upsetting moment in roll.

However, displacement in roll → lateral velocity due to unbalanced lift

→ dihedral + side slip velocity → produces a moment tending to reduce its lateral velocity by tilting the A/c in opposite direction

··· A/C w/ wing dihedral is statically stable w/ lateral velocity

VI. Stability in hovering flight

- Hovering helicopter ··· similar situation

Angular displacement → no restoring moment, but translational velocity due to unbalanced horizontal components of thrust

→ moment produced to tilt the helicopter

→ reduce the translation speed to its initial 0

∴ helicopter is statically stable w/ changes in translation velocity

VI. Stability in hovering flight

② Dynamic stability in hover

- Many similarities in a fixed-wing A/C

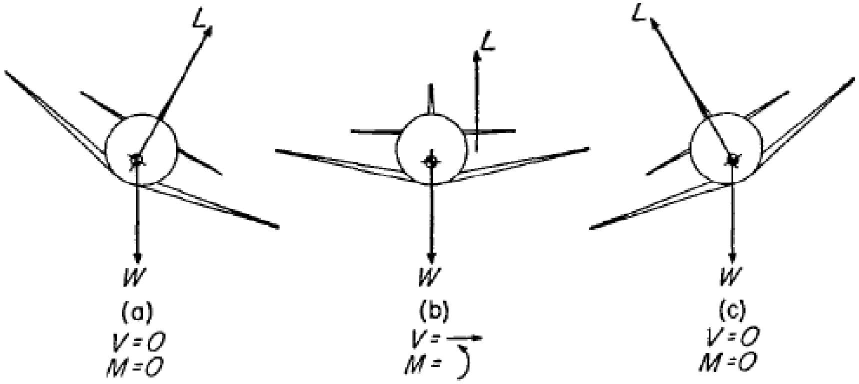

Fig. 11-8 Lateral motion of a fixed-wing airplane.

❖ Analogy with A/C

- Fig. 11-8 ⋯ A/C behavior when displaced in roll to the right (a)

$$(b)\left\{\begin{matrix}\text{wing dihedral}\\ \text{sideslip}\end{matrix}\right\}\rightarrow \text{restoring moment to a level attitude}$$

when reaching a level attitude , still lateral velocity to continue to roll

(c) zero lateral velocity, but displaced in roll to the left

→ cycle of event is repeated in the form of oscillation

→ either dynamically stable or unstable

VI. Stability in hovering flight

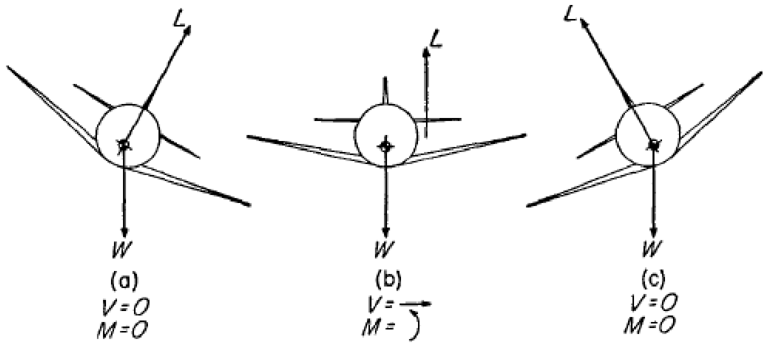

Fig. 11–8 Lateral motion of a fixed-wing airplane.

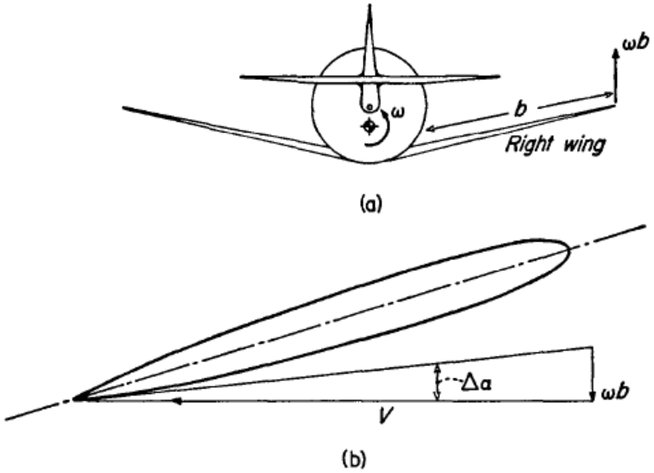

Fig. 11–9 Airplane damping due to roll.
(a) Rear view
(b) Side view of right wing

❖ Fig. 11-8 (b), rolling velocity will reduce AoA of the right wing

(Fig. 11-9), increased AoA in the left wing → clockwise moment

→ clockwise moment ··· oppose the counterclockwise angular velocity

∴ initial angular displacement in A/C → oscillation, but 2 opposing moment

$\left\{ \begin{array}{l} \text{Moment by the sideslip velocity} \\ \text{Damping moment by the angular velocity of A/C} \end{array} \right.$

VI. Stability in hovering flight

❖ Helicopter motion following a disturbance

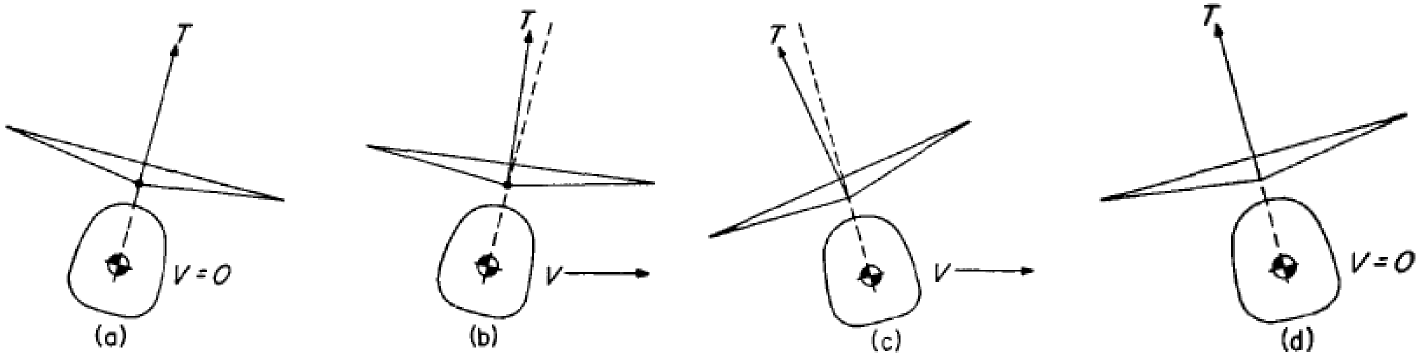

Fig. 11–10 Oscillation of a helicopter following an angular displacement in hovering (damping neglected).

- Helicopter ⋯ analogous motion
- Fig. 11-10 (a) ⋯ displaced in roll to the right

(b) ⋯ resultant force to the right → cause to move

but subjected to a counterclockwise moment due to stability w/ speed

→ rolls the helicopter until (c) configuration

(d) horizontal force → slow down the helicopter, zero horizontal velocity

But, still horizontal force to the left still present → starts to move to the left

→ the whole process repeats

VI. Stability in hovering flight

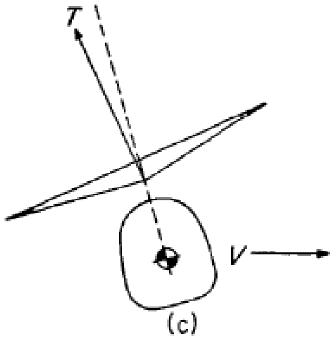

Fig. 11–10 Oscillation of a helicopter following an angular displacement in hovering (damping neglected).

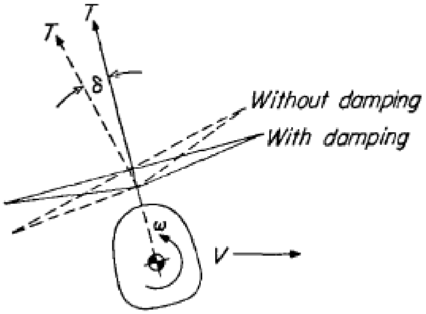

Fig. 11–11 Position of rotor cone with and without damping for helicopter of Fig. 11–10c.

- Lateral oscillation, angular velocity about its own axis
  → moment due to damping in roll

Fig. 11-10 (c) ⋯ counterclockwise angular velocity

→ small clockwise tilt of the rotor cone w/ damping included (Fig. 11-11)

⋯ rotor cone lags behind the position it would have if no damping were present

- Initial angular displacement in helicopter → oscillation, but

$\left\{ \begin{array}{l} \text{stability w/ speed} \\ \text{damping in pitch (or roll)} \end{array} \right\}$ → influences on the oscillation period

VI. Stability in hovering flight

- Combined effects of $\left\{ \begin{array}{l} \text{stability w/ speed} \\ \text{damping in roll} \end{array} \right.$

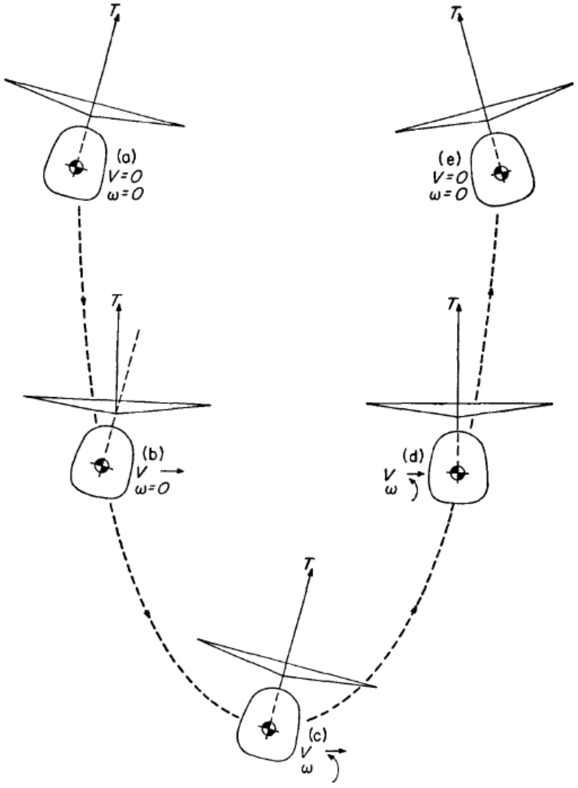

Fig. 11-12 Lateral oscillation of a helicopter following an angular displacement in hovering (damping included).

Fig. 11-12 (a) initial roll angle displacement → no moment about CG,
but velocity to the right → displaced to (b) configuration
(b) Thrust vector inclination → counterclockwise moment about CG
due to stability w/ speed → if fuselage MoI negligible,
counterclockwise angular velocity → (c) configuration
(c) Damping in roll → fuselage overtakes the rotor cone,
rotor tilt due to stability w/ speed is neutralized
but horizontal component of the forces to the right exists
→ accelerates to the right, and then process is repeated
additional translation velocity → additional thrust vector tilt to the left
→ counterclockwise moment → increased angular velocity
→ due to damping in roll, fuselage align itself w/ thrust vector
→ additional tilt due to stability w/ speed neutralized
(d) Returns to a level attitude, but repeats the previous cycles
until (e) where $V = 0,\ \omega = 0$, Then =(a)
still horizontal component to the left, move the left,
(a)-(e) process will be repeated → oscillation
← Half period of the oscillation

VI. Stability in hovering flight

- Period of oscillation for hovering helicopter w/o fuselage MOI

$$P = \frac{2\pi}{\sqrt{g}}\sqrt{\frac{-M_\omega}{M_v}} \qquad (2)$$

$M_\omega = -Th(\frac{\delta}{\omega})$: damping in roll

M_V: speed stability ~ variation of longitudinal flapping w/ translation velocity

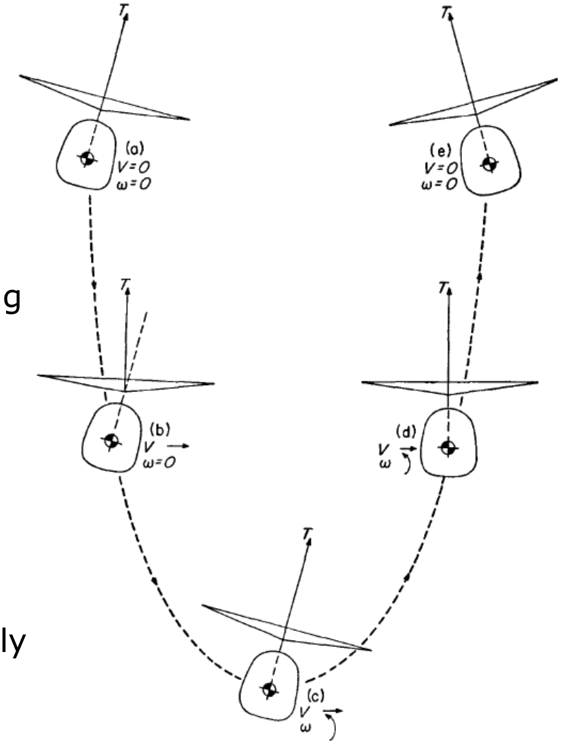

Fig. 11–12 Lateral oscillation of a helicopter following an angular displacement in hovering (damping included).

- Effect of { ① stability w/ speed, ② damping in pitch } on the period

Fig. 11-2(a) → (b) ⋯ ① larger → larger thrust vector → larger angular velocity → reaches (c) quickly

∴ reduces the period (denominator in Eq. (2))

- TR shaft mount location ⋯ above helicopter CG, TR adds to the stability w/ speed → reduces the period, due to the difference in TR inflow related with lateral velocity

VI. Stability in hovering flight

$$P = \frac{2\pi}{\sqrt{g}}\sqrt{\frac{-M_{\omega}}{M_{v}}} \qquad (2)$$

(b) → (c) ··· ② larger → smaller angular velocity needed to neutralize thrust vector tilt due to speed stability

→ slower change in attitude

→ reaches (c) late

∴ damping ↗ → period ↗ (numerator in Eq.(2))

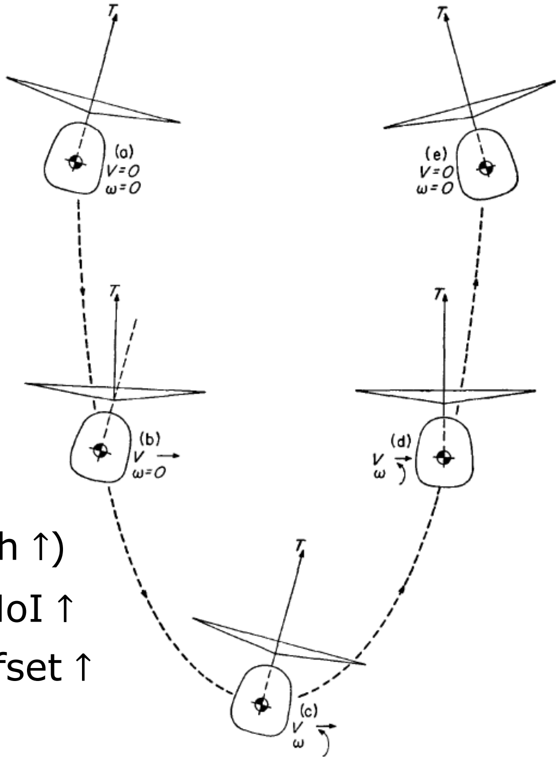

Fig. 11–12 Lateral oscillation of a helicopter following an angular displacement in hovering (damping included).

(damping in pitch ↑)

- Dynamic instability ↓ ⟵ fuselage MoI ↓, blade flapping MoI ↑
  rotor height ↑, flapping hinge offset ↑

- Single-rotor helicopter w/ conventional control systems
  ··· dynamically unstable, ← improved by additional devices

VII. Longitudinal stability in forward flight

① Static stability

❖ Analogy with the airplane

- Initial A/C displacement from trim in $\begin{cases} \text{pitch (AoA change)} \\ \text{forward speed} \end{cases}$

  → 2 aspects of static stability → 2 sets of forces/moments

- Incerase in AoA, const. speed ⋯ A/C is statically stable w.r.t. AoA
  if it is a nose-down moment
  (also dependent upon CG position)

- Change in speed, const. AoA ⋯ no aerodynamic moment → neutral stability
  (no change in lift or moment coeff.)

  No changes in all aero. forces and moments acting in the same proportion
  → maintain the trim

VII. Longitudinal stability in forward flight

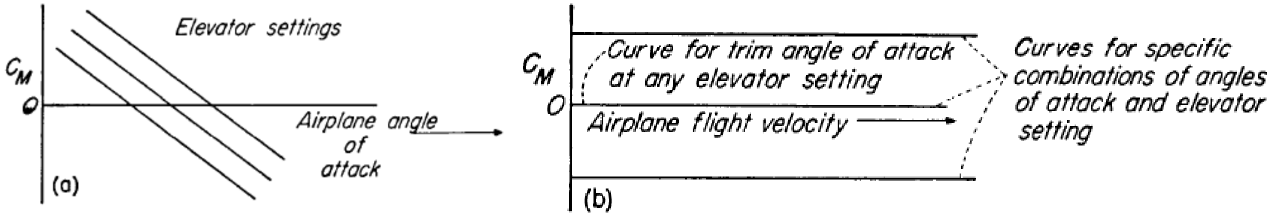

Fig. 11–13 Basic static stability curves of airplane in gliding flight.
(a) C_m against α
(b) C_m against V

Fig. 11-13 ⋯ plot of the moment coeff. against AoA and speed

(b) Moment coeff. Independent of speed

➡ (a) → Fig. 11-14 : const. elevator setting, corresponding trim AoA → trim AoA converted to lift coeff.

(+) slope ⋯ forward movement of stick (or down elevator) is required

at a decreased airplane AoA (or C_L)

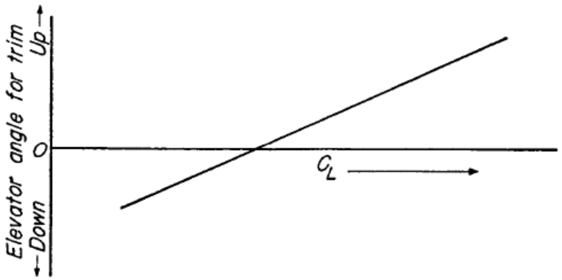

Fig. 11–14 Static stability of airplane as measured in gliding flight.

Fig. 11-14 ⋯ static stability of A/C of fixed CG → single curve

But, when including the propeller effect, no longer sufficient

helicopter ⋯ (+), not neutral static stability w/ speed → not sufficient for a single curve

VII. Longitudinal stability in forward flight

❖ Static stability of the helicopter

- Depends on the moments produced by rotor ← by change in speed at const. AoA
  ← by change in AoA at const. speed

"Rotor characterictics" ↗

- Depends on the moments by fuselage and control surfaces → 3 different ways

i) Variation of moment coeff. w/ AoA

Fuselage ⋯ unstable w/ AoA → adds to rotor AoA instability

Tail surface ⋯ stabilizing variation of moment

ii) Const. moment coeff. on stability w/ speed

Fuselage ⋯ nose-down moment in steady flight,
speed change → destabilizing

Stabilizing surfaces → nose-up moment → stabilizing

iii) Thrust-axis offset from helicopter CG or stabilizing w/ AoA

Offset of thrust axis ⋯ to compensate for an aero. pitching moment or fuselage or stabilizing surfaces

VII. Longitudinal stability in forward flight

- fuselage ··· nose-down moment ← compensated by thrust vector offset ahead of CG

→ additional unstable moment variation w/ AoA (Fig. 11-15)

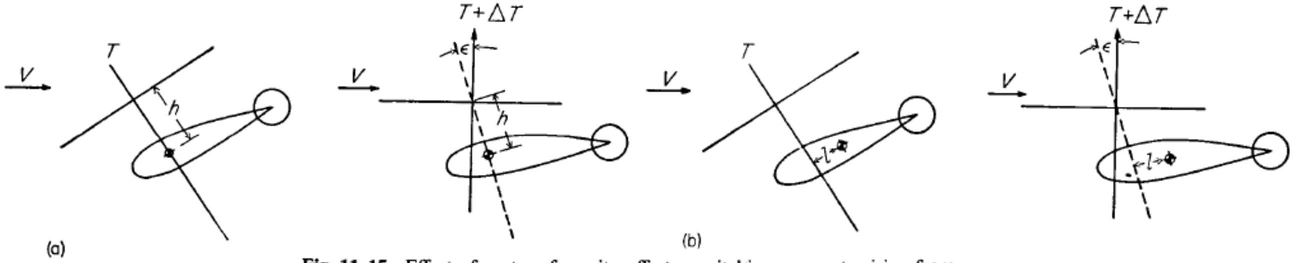

Fig. 11-15 Effect of center-of-gravity offset on pitching moment arising from fuselage angle-of-attack change.
(a) No center-of-gravity offset
(b) Center-of-gravity offset aft of thrust vector

- Increase in fuselage AoA

→ nose-up rotor moment (=thrust increase × initial CG offset) > rotor moment w/ no CG offset

Nose-down fuselage moment → thrust axis forward offset from CG → add to AoA instability of the rotor

stabilizing surfaces ··· nose-up moment by a down load

∴ offset between $\left\{\begin{matrix}\text{thrust vector}\\ \text{helicopter CG}\end{matrix}\right\}$ counteracts rotor instability w/ AoA

if great enough offset, statically stable w/ AoA

- Flapping hinge offset ··· similar contribution on static stability w/ AoA

if CG is forward of the rotor shaft, CG will also forward the thrust vector

→ rotor instability w/ AoA is counteracted

VII. Longitudinal stability in forward flight

- 2 types of forward-flight static stability ··· Fig. 11-16

(a) Variation of moment coeff. about helicopter CG
w/ fuselage AoA at various speeds
(b) Variation of moment coeff. about helicopter CG
w/ speed for each trim AoA

- Fig. 11-16 (a) helicopter ··· separate curve for each speed
11-13 (a) A/C ··· single curve

Trim points and curves are shifted (Fig. 11-16(b))

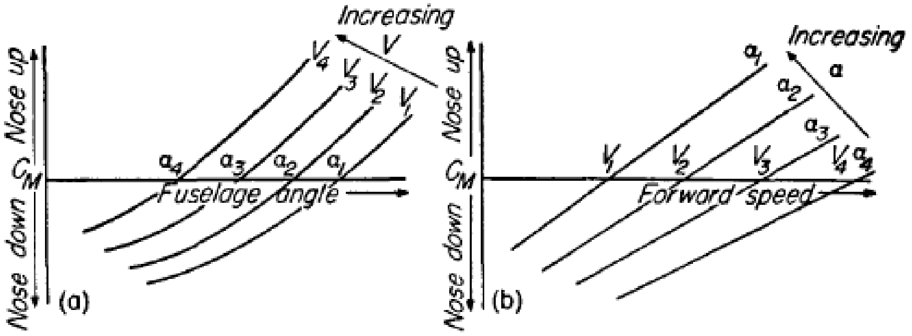

Fig. 11–16 Basic static stability curves for typical tailless helicopter.
(a) C_m against α
(b) C_m against V

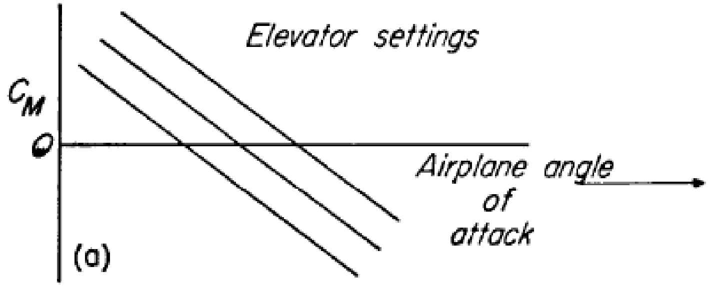

Fig. 11–13 Basic static stability curves of airplane in gliding flight.
(a) C_m against α

VII. Longitudinal stability in forward flight

❖ Amount of static stability or instability

→ curves in Fig. 11-17, slopes of the curves in Fig. 11-16

- Fig. 11-17(a) ⋯ $\frac{\Delta C_m}{\Delta\alpha}$ $at\ C_m = 0$ from Fig. 11-16 (a)

  (b) ⋯ $\frac{\Delta C_m}{\Delta\alpha}$ $at\ C_m = 0$ from Fig. 11-16 (b)

  → a typical tailess helicopter (w/ no horizontal tail surface)

- In power-on flight ← { unstable w/ AoA ← principal stability deficiency

  stable w/ speed

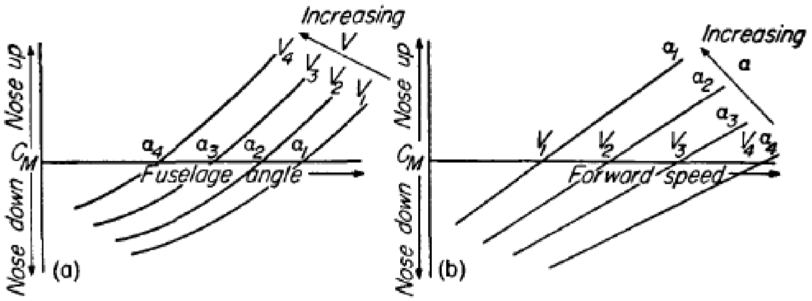

Fig. 11–16 Basic static stability curves for typical tailless helicopter.
(a) C_m against α
(b) C_m against V

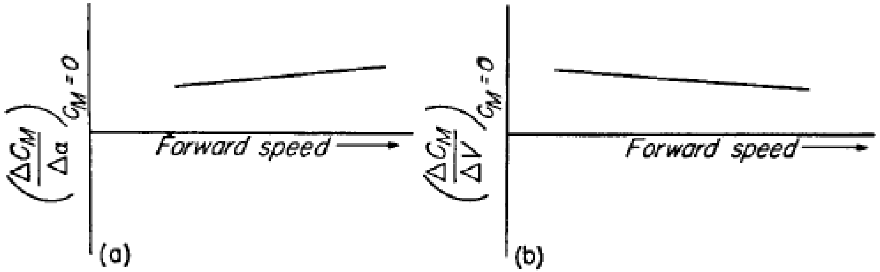

Fig. 11–17 Slopes of curves of Fig. 11–16 at $C_m = 0$.
(a) Stability with angle of attack
(b) Stability with speed

VII. Longitudinal stability in forward flight

- Effects of variations in GW, Ω, altitude ··· stability plot in non-dim. form (Figs. 11-18, 19)
  - variation in stick position
  - variation in CG w/ fixed stick position
  - variation in collective pitch
  - variation of rotor speed ··· autorotation, Ω is free to vary w/ speed or AoA,

    → power-speed characteristics of the engine affect the stability

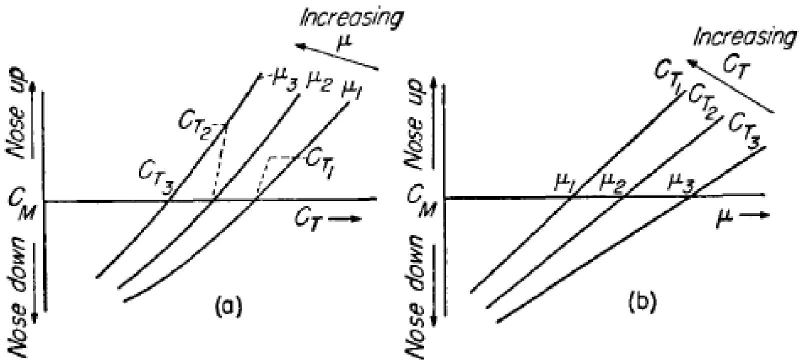

Fig. 11–18 Basic nondimensional static-stability curves for typical tailless helicopter.
(a) C_m against C_T
(b) C_m against μ

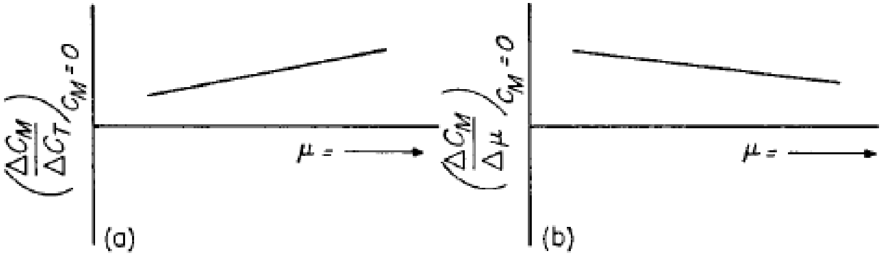

Fig. 11–19 Slopes of curves of Fig. 18 at $C_m = 0$.
(a) Stability with angle of attack.
(b) Stability with speed

VIII. Dynamic stability in forward flight

❖ If assumed to have neutral static stability w/ AoA

→ period of longitudinal oscillation depends
- static stability w/ speed
- damping in pitch

- Period of longitudinal oscillation

$$P = 2\pi\sqrt{\frac{(-M_\omega - \frac{WV}{g}\frac{M_\alpha}{T_\alpha})}{M_V g}} \qquad (3)$$

if $M_\alpha = 0$, (3) → (2)

① Helicopter motion following a disturbance

- Importance of
  - speed stability
  - damping in pitch

- Assumption ⋯ neutral stability w/ AoA

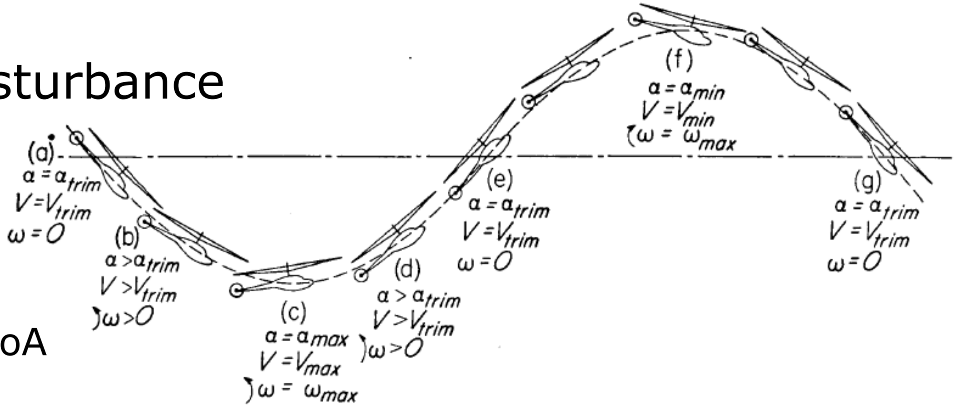

Fig. 11-20 Longitudinal oscillation of typical helicopter in forward flight.

- Initial disturbance → trimmed helicopter → nose-down, descend (Fig. 11-20(a))

VIII. Dynamic stability in forward flight

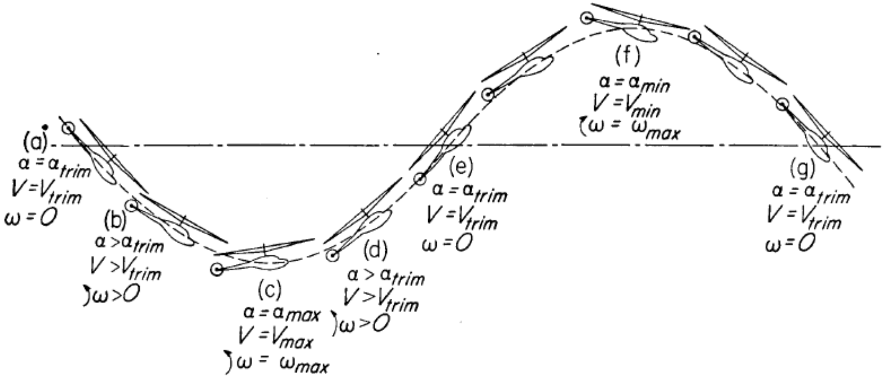

Fig. 11-20 Longitudinal oscillation of typical helicopter in forward flight.

Fig. 11-20 (a) weight component along the flight path →accelerate

(b) speed stability → backward tilt of the rotor plane

→ nose-up moment → nose-up angular acceleration

→ damping in pitch ··· thrust vector tilt due to stability w/ speed is neutralized,

But continuously increasing angular velocity until off the glide path → (c)

(C) max. forward speed, max. nose-up angular velocity, max. fuselage AoA,

Since T>W, climb weight opposes forward motion

→ decelerate, backward tilt reduced

Rotor plane forward tilt ··· forward tilt due to damping in pitch> rearward tilt due to speed stability

Nose-down moment reduces nose-up angular velocity

Damping in pitch neutralizes remaining backward tilt of the rotor plane due to speed stability → (d)

VIII. Dynamic stability in forward flight

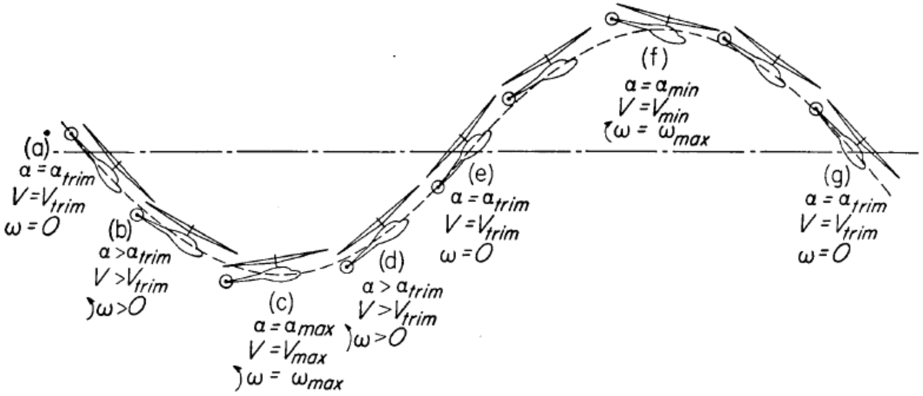

Fig. 11-20 Longitudinal oscillation of typical helicopter in forward flight.

Fig. 11-20 (d) weight component → decelerate, preceding steps repeated

(e) velocity, AoA = trim values, 0 angular velocity, but climbing continue to decelerate,
(a)-(e) will be repeated except that all changes in opposite direction

(f) min. forward speed, min. nose-down angular velocity
min. fuselage AoA, (a)-(e) is repeated

VIII. Dynamic stability in forward flight

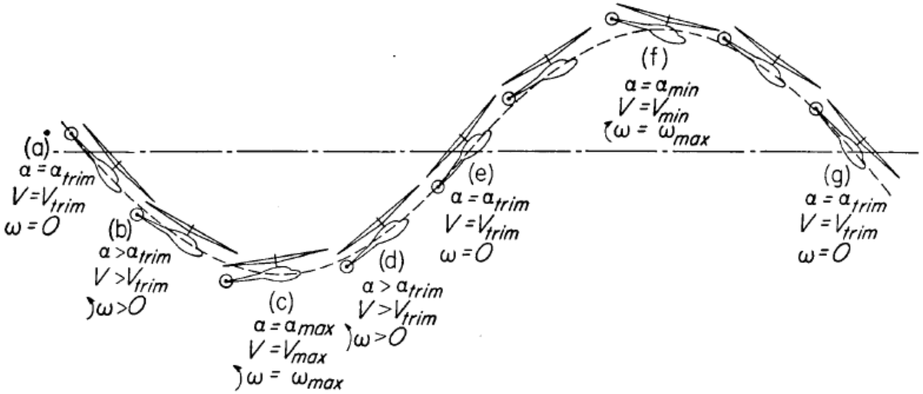

Fig. 11-20 Longitudinal oscillation of typical helicopter in forward flight.

② Effect of $\left\{\begin{array}{c}\text{static stability w/ speed}\\ \text{damping in pitch}\end{array}\right\}$ on period of oscillation

- Increase in speed stability → larger nose-up moment in (b)

  → reaches (c) sooner

  ∴ reduces period (M_v denominator in (3))

- Increase in damping in pitch → smaller angular velocity in (b)

  → longer time necessary to reach (c)

  ∴ increase period (-M_ω numerator in (3))

VIII. Dynamic stability in forward flight

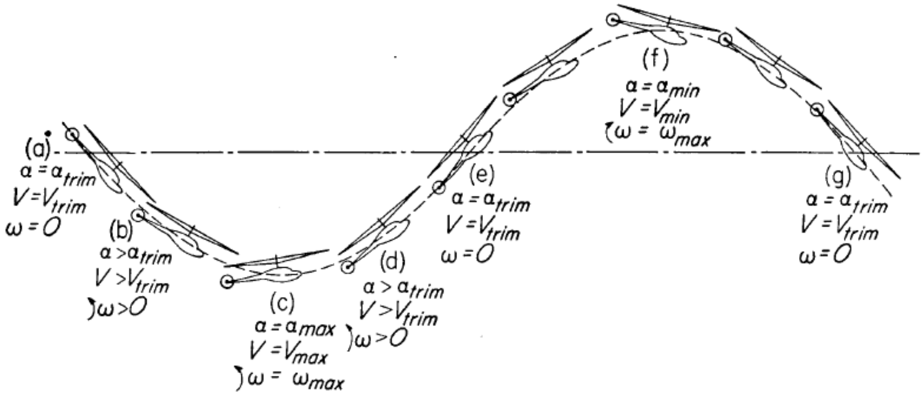

Fig. 11-20 Longitudinal oscillation of typical helicopter in forward flight.

③ Effect of AoA stability on period of oscillation

⋯ M_α is to add to, or subtract from, damping in pitch M_ω in (3)

- If statically unstable w/ AoA, M_α (+), T_α (+)

$(\frac{WV}{g})(\frac{M_\alpha}{T_\alpha})$ (+) → numerator in (3) reduced, P reduced

- M_α on stability w/ AoA

reduce the effect → reduce period

Fig. 11-20 (c) ⋯ max nose-up angular velocity → max nose-down moment due to damping in pitch

Max. AoA → max. nose-down moment due to instability w/ AoA

- If stabilizing device longer time necessary to reach (c)

→ statically stable w/ AoA → increased period

VIII. Dynamic stability in forward flight

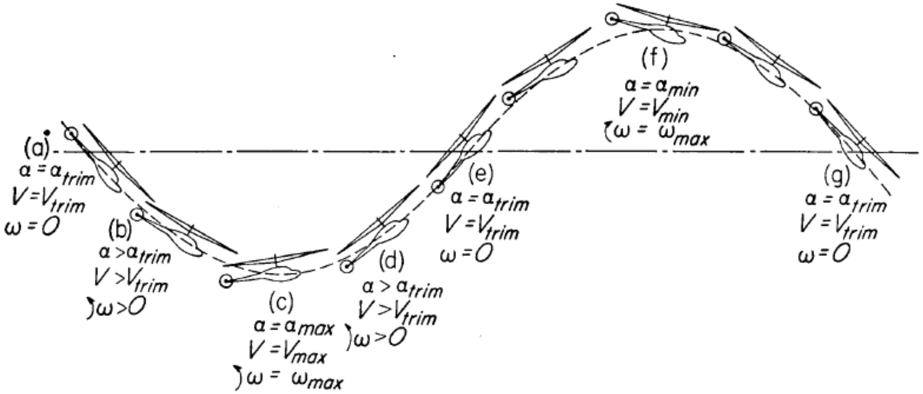

Fig. 11-20 Longitudinal oscillation of typical helicopter in forward flight.

④ Influence of $(\frac{WV}{g})$ and T_α on period of oscillation

M_α { if stable, adds to / if unstable, subtracts from } the effect of M_ω

→ depends on { AoA change / pitch velocity } ← $(\frac{WV}{g})$, T_α will determine this

⑤ Effect of stability parameters on divergence of oscillation

- statically unstable w/ AoA → also dynamically unstable, but

{ large amount of damping in pitch / sacrifice in speed stability } → will reduce the influence