AAE 354

Lesson 00-1

Rotorcraft Aerodynamics

Introduction

References

- Gordon Leishman: Principles of Helicopter Aerodynamics, 2nd Edition, Cambridge University Press, New York, NY, 2005.
- Wayne Johnson: Rotorcraft Aeromechanics, Cambridge University Press, New York, 2013.
- Raymond W. Prouty: Helicopter Performance, Stability, and Control, PWS Engineering, Boston, 2001.
- Gessow and Myers: Aerodynamics of the Helicopter, 8th Edition, College Park Press, MD, 1999.

Course Information

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- Consultation: Tuesday, Thursday, Friday

Learning Objectives

- Introduce students to concepts of rotary-wing aerodynamics with applications to helicopters
- Enable students to understand the flight operations of single rotor helicopters
- Enable students to estimate the relationship among thrust, power requirement, and payload

Course Goals

- Present notation for rotorcraft aerodynamics variables, forces, and moments
- Overview principles of Momentum theory, Blade Element Theory, and Vortex theory
- Apply above theories to analyze performance of helicopters in hover and vertical flight
- Extend the discussion to include forward flight
- Highlight essential features of conceptual design of a main rotor

Grades

Quizzes	10%
Homework	15%
OHT-1	20%
OHT-2	20%
Finals	35%

Course Content

- Introduction
- Momentum Theory
- Blade Element Theory
- Combined BEM Theory
- Vertical Descent and Climb
- Forward Flight – Performance
- Forward Flight – Blade Motion
- Helicopter Performance
- Conceptual Design of Main Rotor

Rotorcraft Definitions

- A rotorcraft or rotary-wing aircraft is a *heavier-than-air* flying machine that uses lift generated by wings, called rotary wings or rotor blades, that revolve around a mast.
- Several rotor blades mounted on a single mast are referred to as a rotor.
- The International Civil Aviation Organization (ICAO) defines a rotorcraft as "supported in flight by the reactions of the air on one or more rotors".
- " Any flying machine that produces lift from rotors turning in a plane that is normally close to the horizontal. "

A helicopter flies by actively generating its own thrust through its spinning rotor blades.

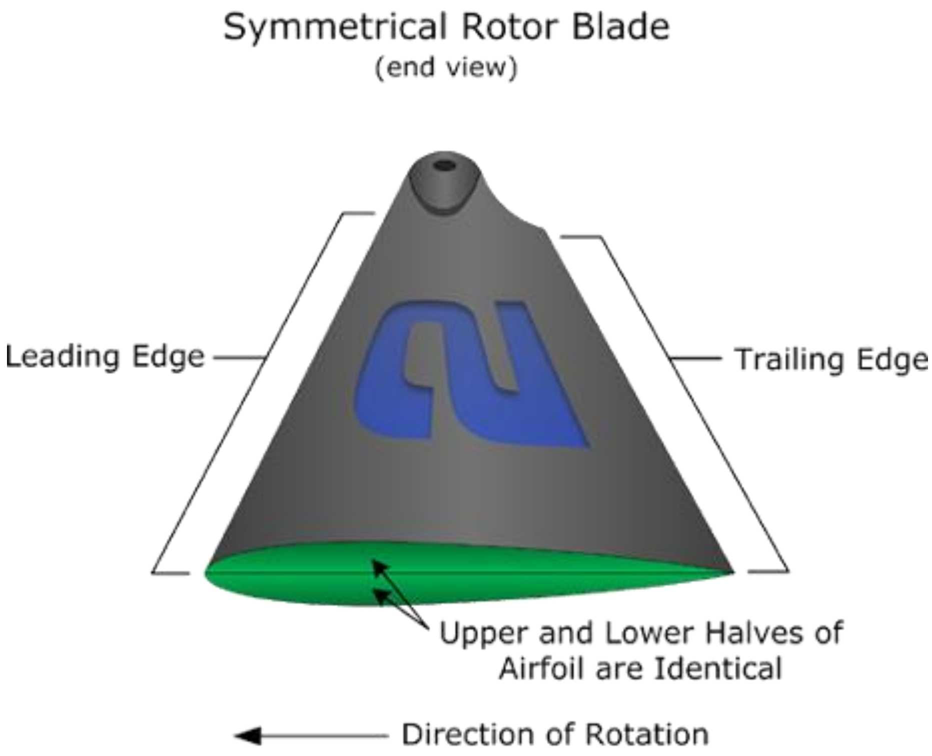
Rotorcraft

- Rotorcraft generally include those aircraft where one or more rotors are required to provide lift throughout the entire flight, such as *helicopters*, *gyroplane*, *gyrodyne*, *autodyne*, *cyclocopter etc*.
- Compound rotorcraft may also include:
  - additional thrust engines
  - or propellers
  - and static lifting surfaces.

Main Rotor

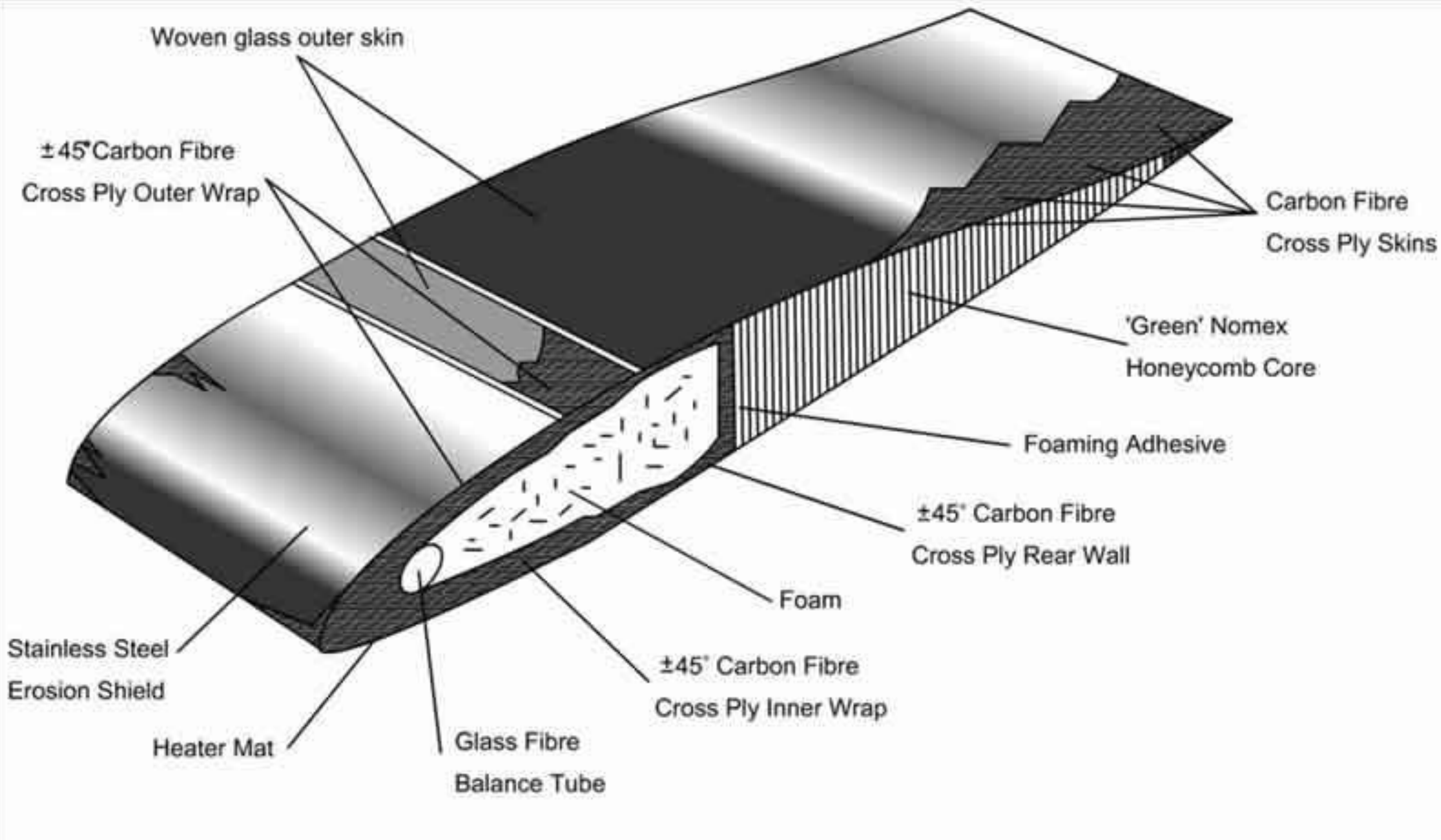
A helicopter's main rotor is the most important part of the vehicle. It generates lift to oppose weight, horizontal propulsive force for flight, and forces and moments to control the attitude and position of the helicopter.

Main Rotor



Symmetrical Rotor Blade
(end view)
Leading Edge
Trailing Edge
Upper and Lower Halves of Airfoil are Identical
Direction of Rotation

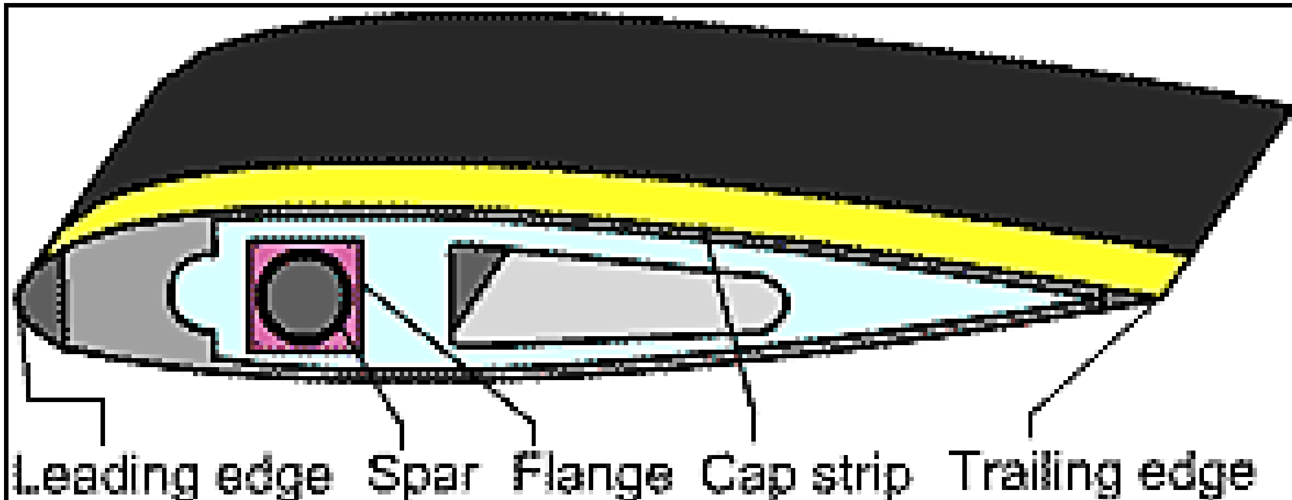
Rotor Blade Construction



Cross-Sectional View of a Composite Blade

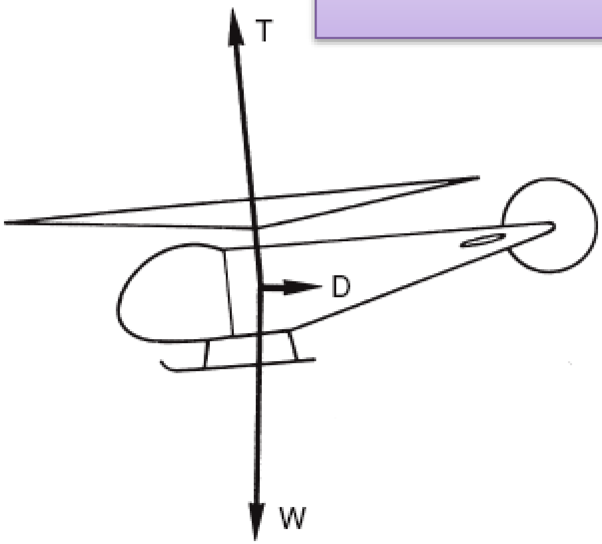
Rotor Blade Construction

Metal



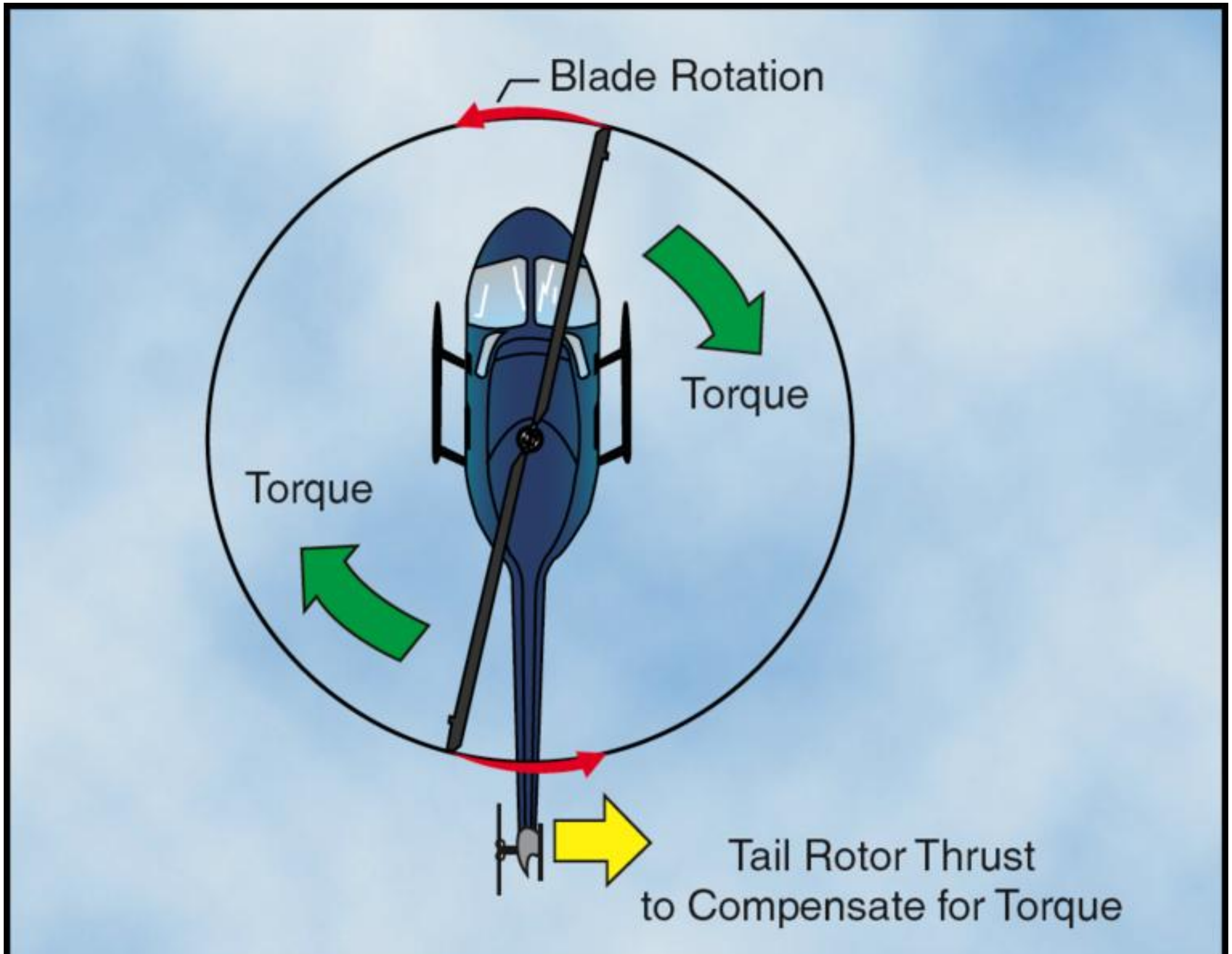
Cross-sectional view of a typical rotor blade

Types of Rotorcraft



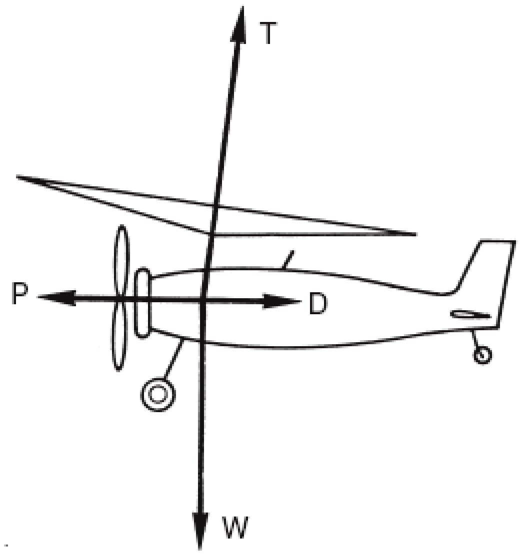
A helicopter is a type of rotorcraft in which lift and thrust are supplied by rotors. This allows the helicopter to take off and land vertically, to hover, and to fly forward, backward, and laterally.

Torque Compensation



Tail Rotor Failure.mp4

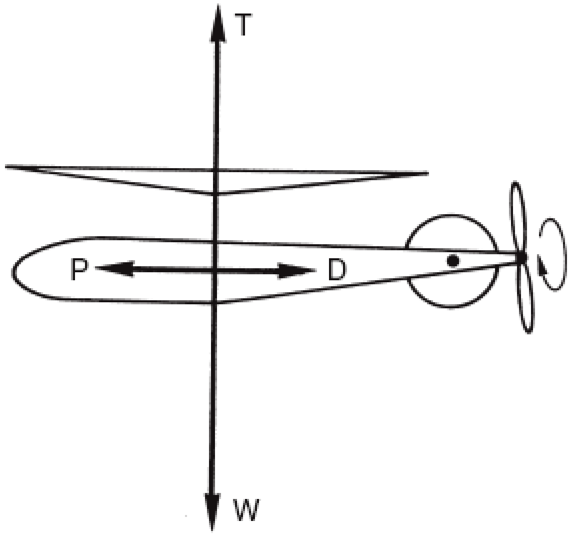
Types of Rotorcraft



The gyroplane (or autogyro) obtains lift from an undriven rotor that must be tilted *away* from the direction of flight to make air flow up through it.

autogyro.mp4

Types of Rotorcraft



The gyrodyne obtains lift from a power driven rotor. Unlike the pure helicopter, the gyrodyne maintains the rotor disc parallel to the direction of flight, and propels itself with a conventional airscrew.

Lockheed Cheyenne

Types of Rotorcraft

The Rotodyne hovered as a tip jet powered helicopter and cruised as a compound gyroplane. (Augusta Westland)

Technical History

- The history of the helicopter has been very short indeed.
- Early helicopters lacked enough power to fly.
- Once helicopters were powerful enough to leave the ground, they were found to be uncontrollable.

Sikorsky.mp4

- Once the principles of control were understood, they were found to vibrate and to need a lot of maintenance and so on.
- Today's helicopters represent the sum of a tremendous number of achievements in overcoming one obstacle after another.

Technical History

The first turbine-powered helicopter to fly was a modified Kaman K-225 in 1951 and in 1954 Kaman HTK-1 the first twin-turbine machine flew.

Introduction of the turbine engine which was much lighter than the piston engine for the same power, yet had fewer moving parts, allowed greater payload and a reduction in maintenance.

Technical History

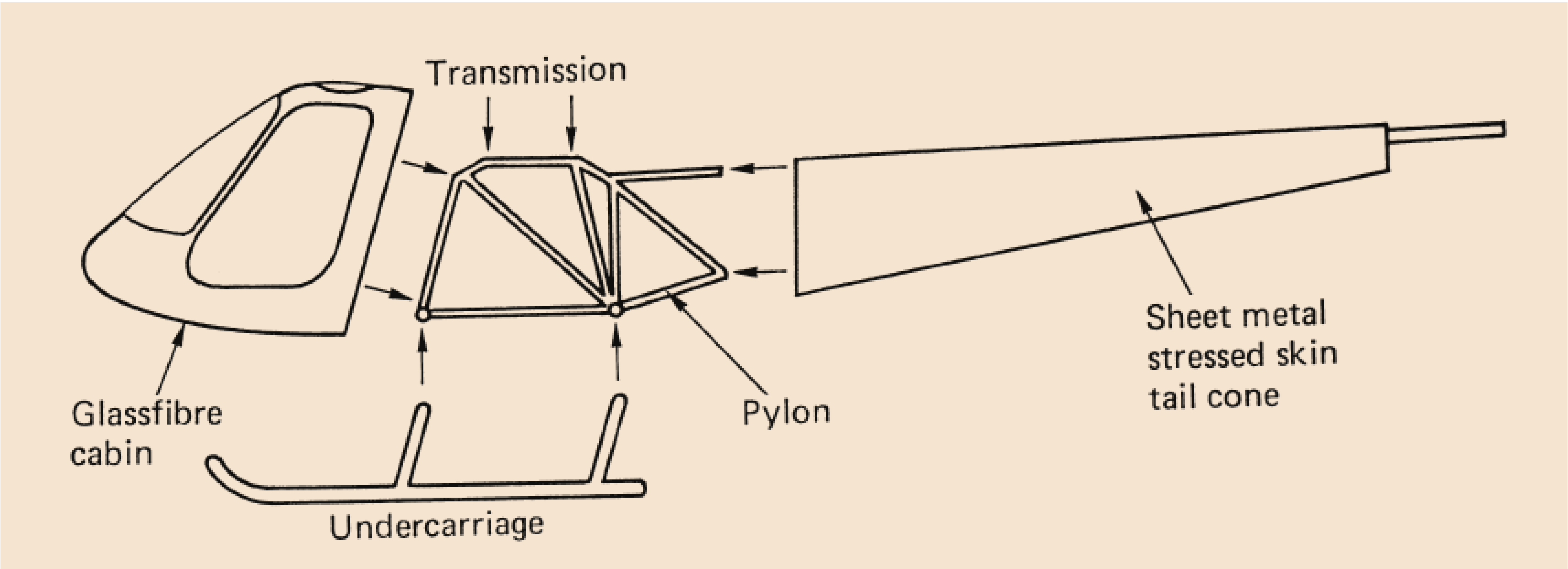
It was in the 1960s that the many disciplines in helicopter design were finally mastered. Some designs that emerged during that period have remained in service to the present day. Sikorsky's S-61 and Boeing's Chinook are good examples of longevity.

Technical History

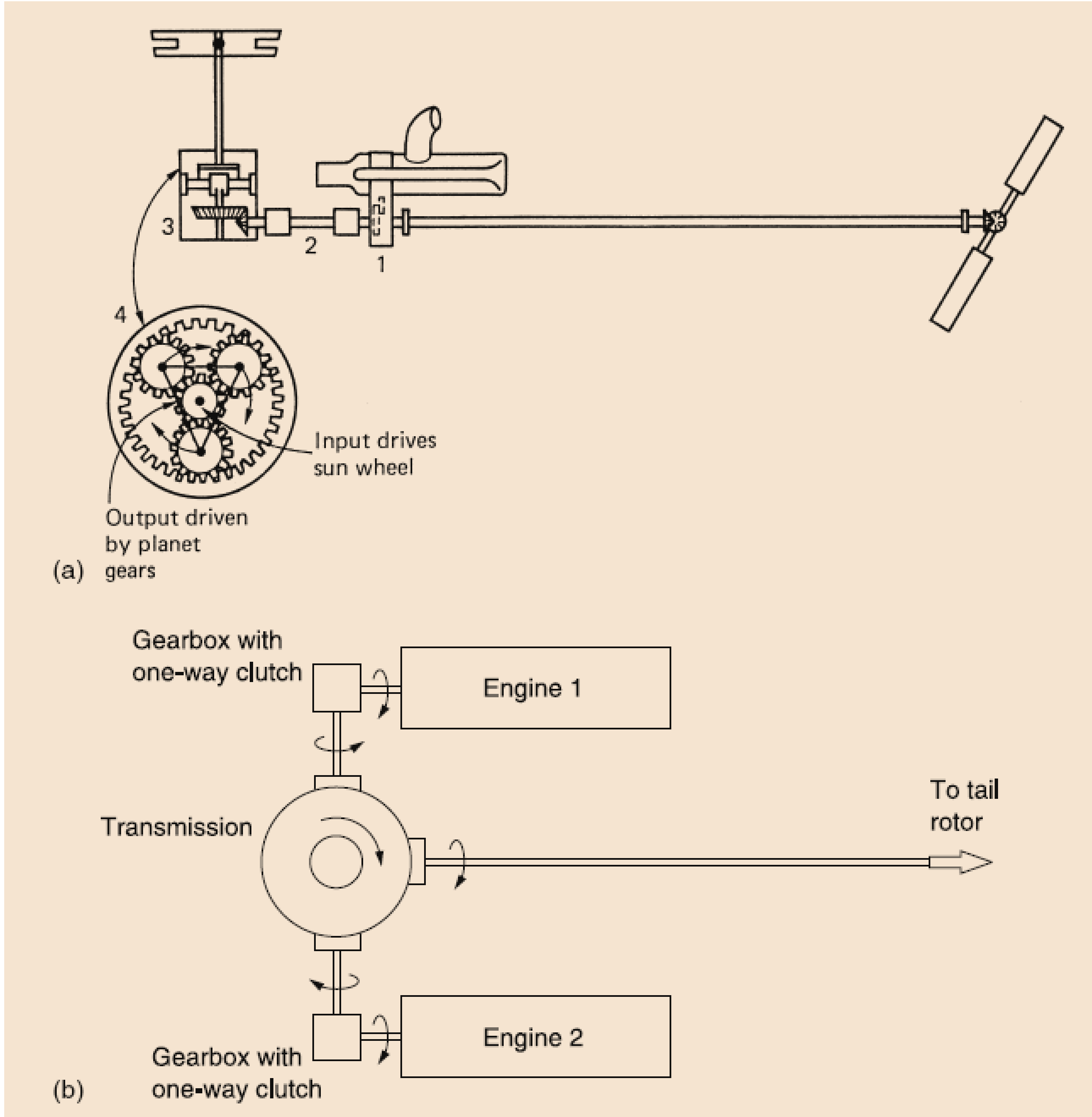
Refinements

- **Introduction of composite materials** in blades, rotor heads and body parts has reduced weight and extended service life
- **Refinements in mechanical engineering** have produced lighter engines and transmissions having longer life
- **Production engineering** to reduce the amount of labour needed to build machines
- **Increased employment of electronics and computers** for items such as turbine engine controllers and rotor rpm governors along with stability augmentation systems
- **Electronic monitoring** of critical components to improve safety

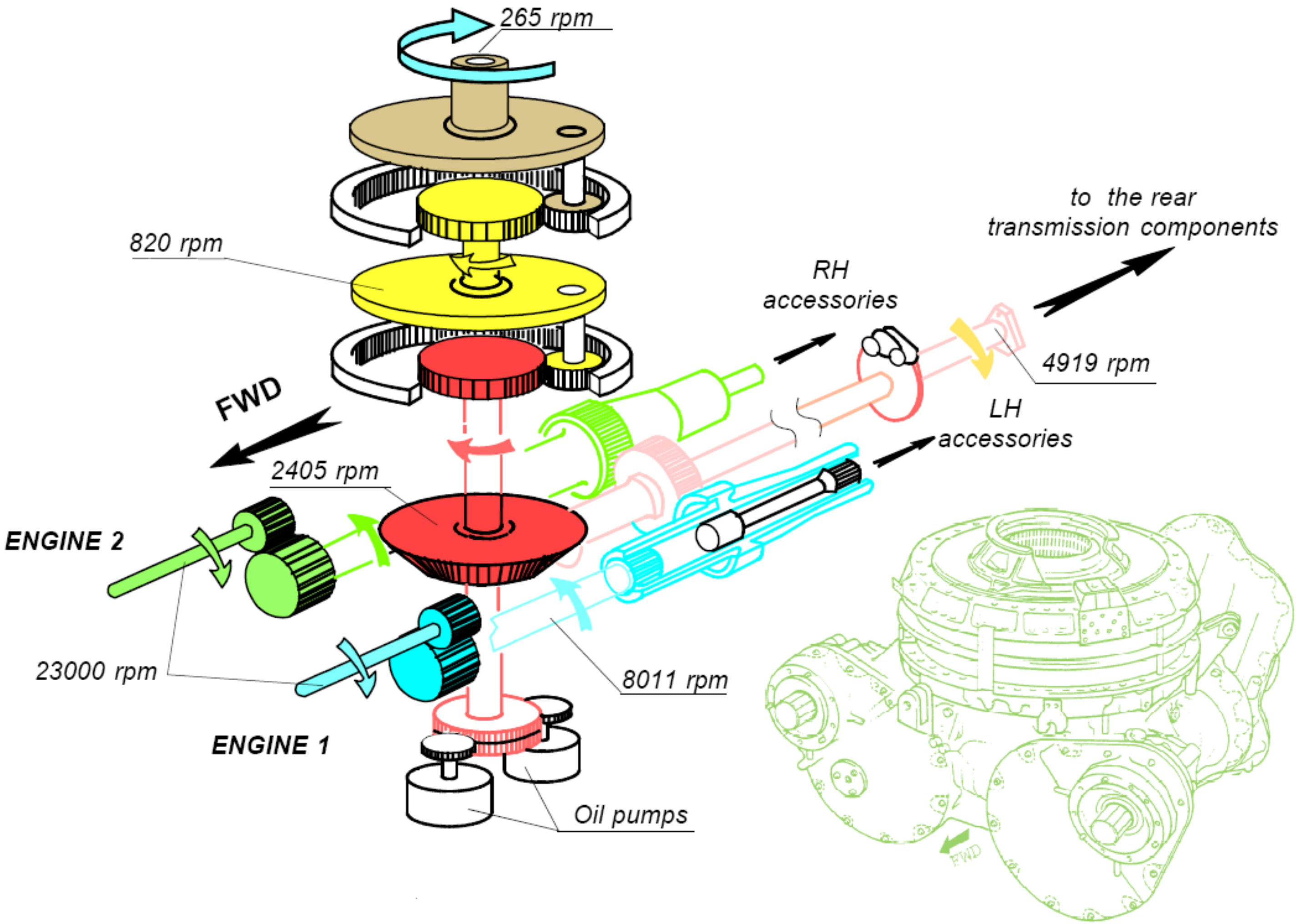
Airframe


Transmission
Glassfibre
cabin
Pylon
Sheet metal
stressed skin
tail cone
Undercarriage

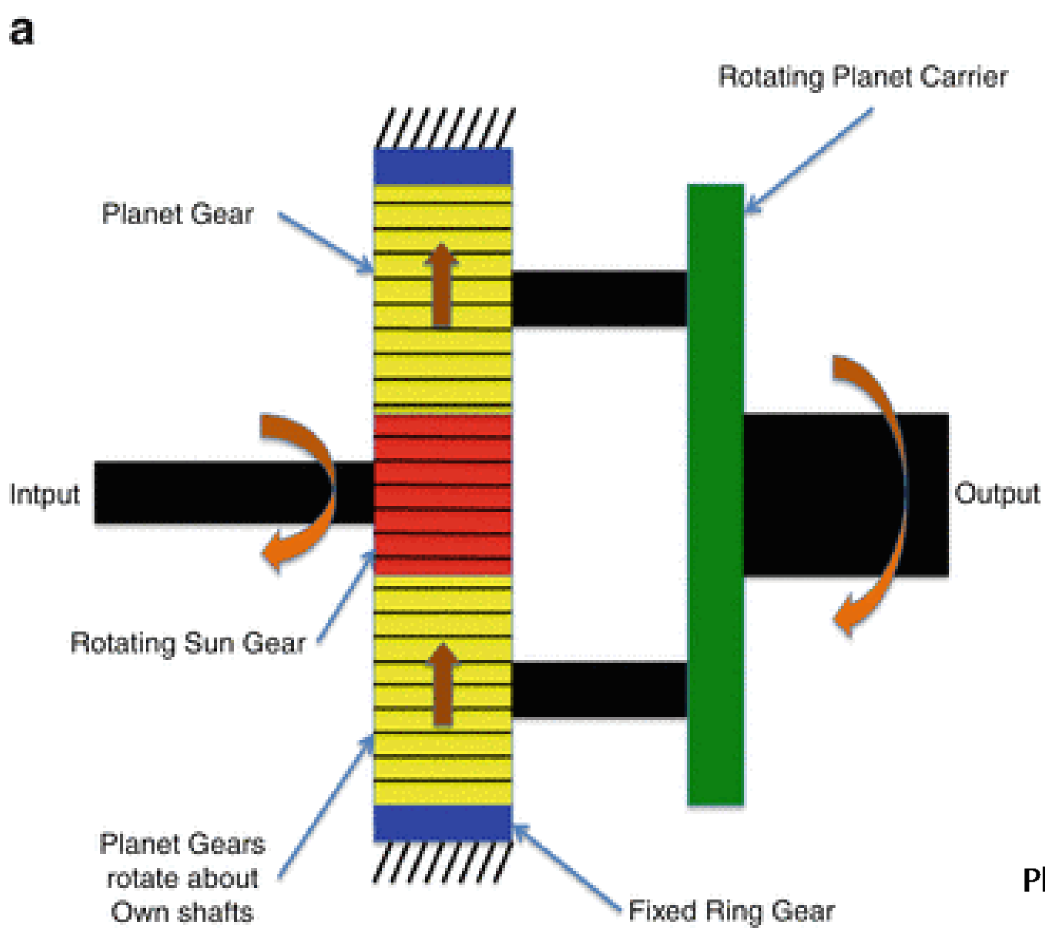
Engine & Transmission



Helicopter Drivetrain

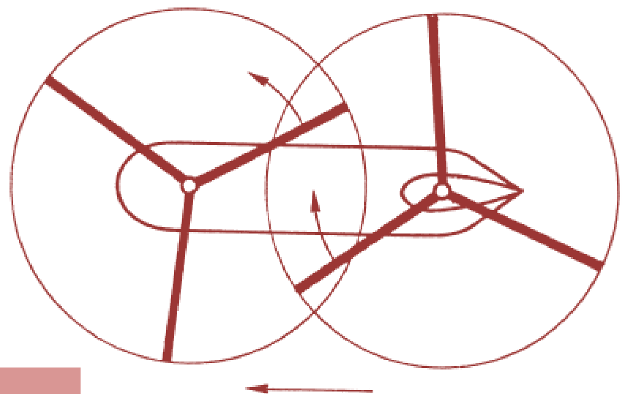


Planetary Transmission

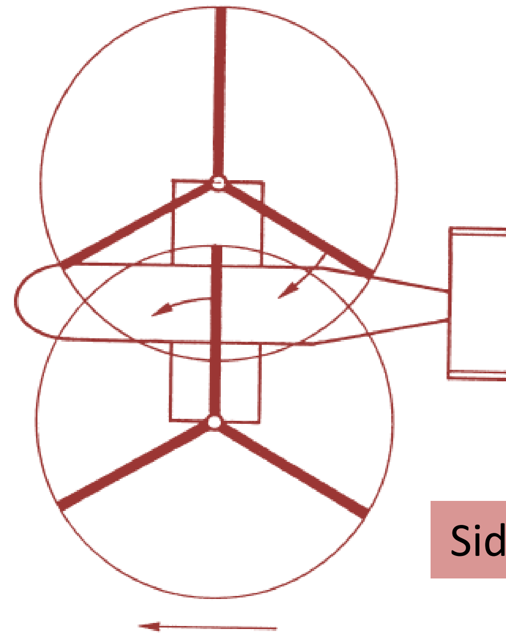


Planetary Gears.mp4

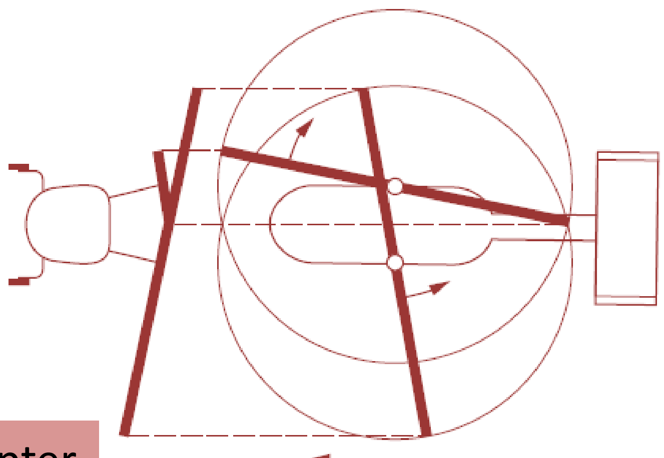
Rotorcraft Configurations



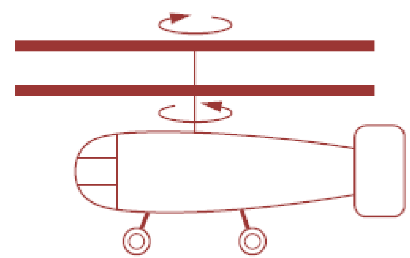
Tandem



Side-by-side



Synchropter



Coaxial

Rotorcraft Configurations

The Chinook is the definitive tandem rotor helicopter and has been produced in large numbers.

Rotorcraft Configurations

The Kaman HH-43 Huskie is the most successful synchropter design.

Rotorcraft Configurations

The contra-rotating coaxial principle is used extensively by Kamov.

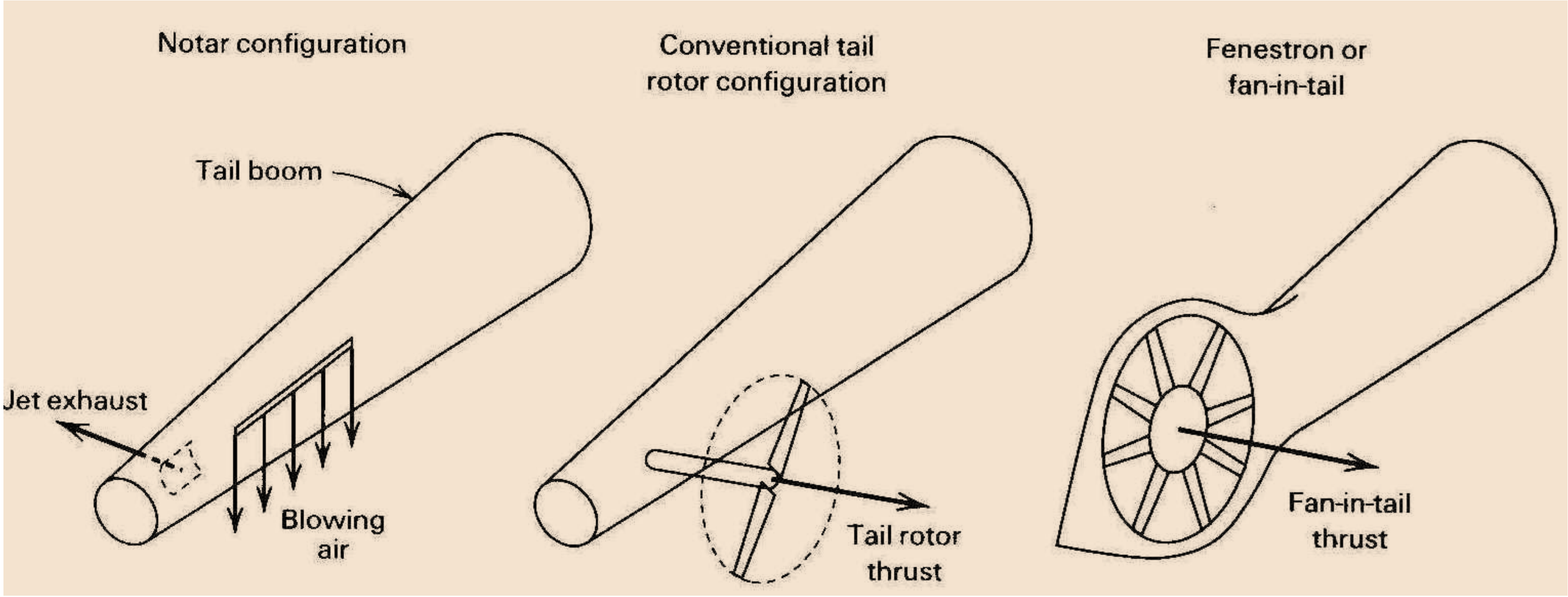
Rotorcraft Configurations

Tilt Rotor BA (609)

R.mp4

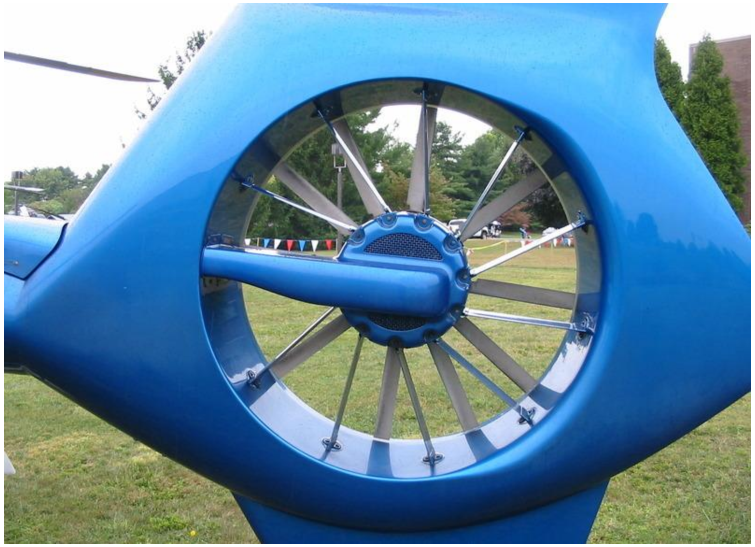
Tail Rotor Configurations

Tail Thrusters



Tail Rotor Configurations

Dauphin

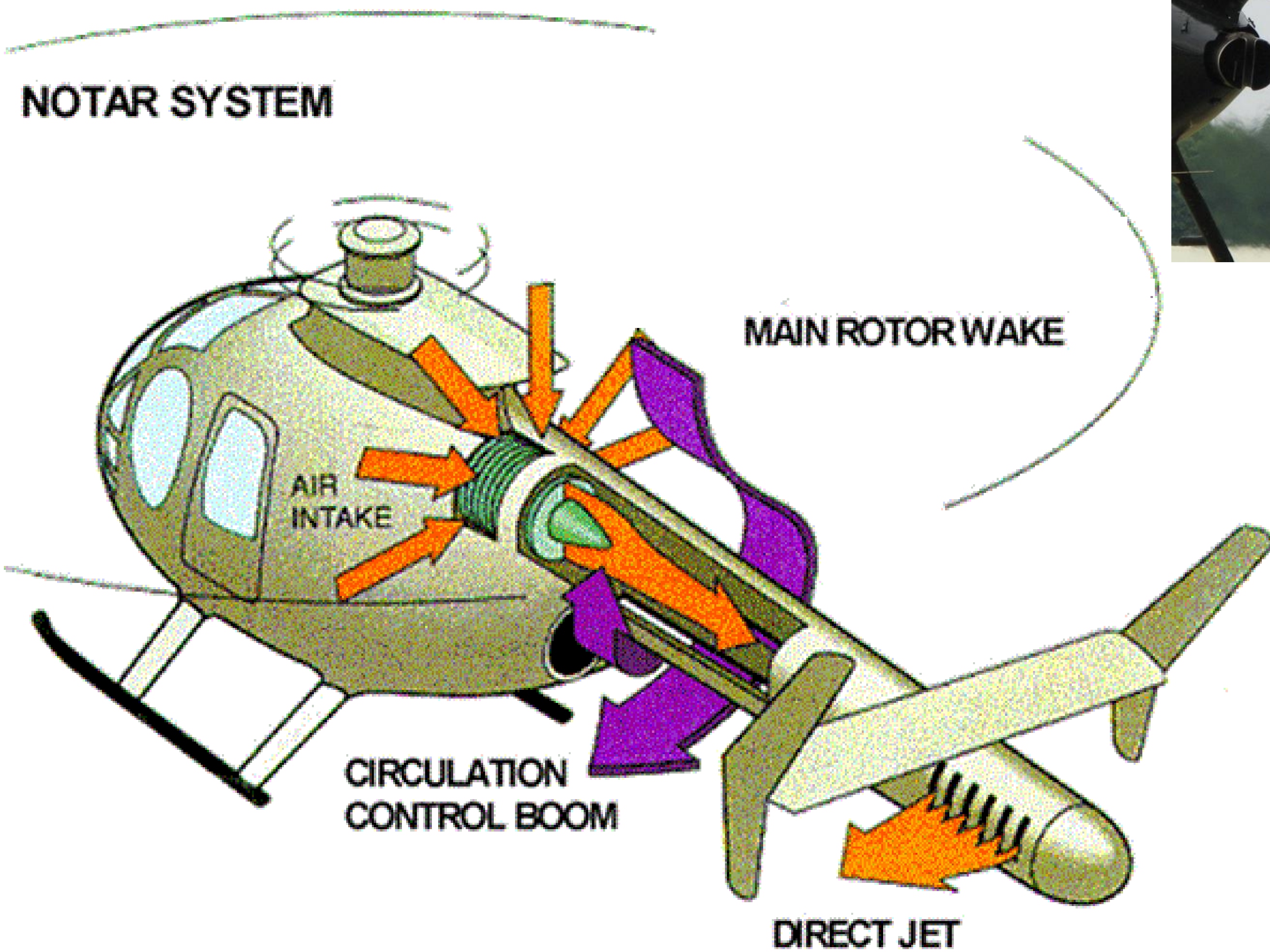


Fenestron

Comanche

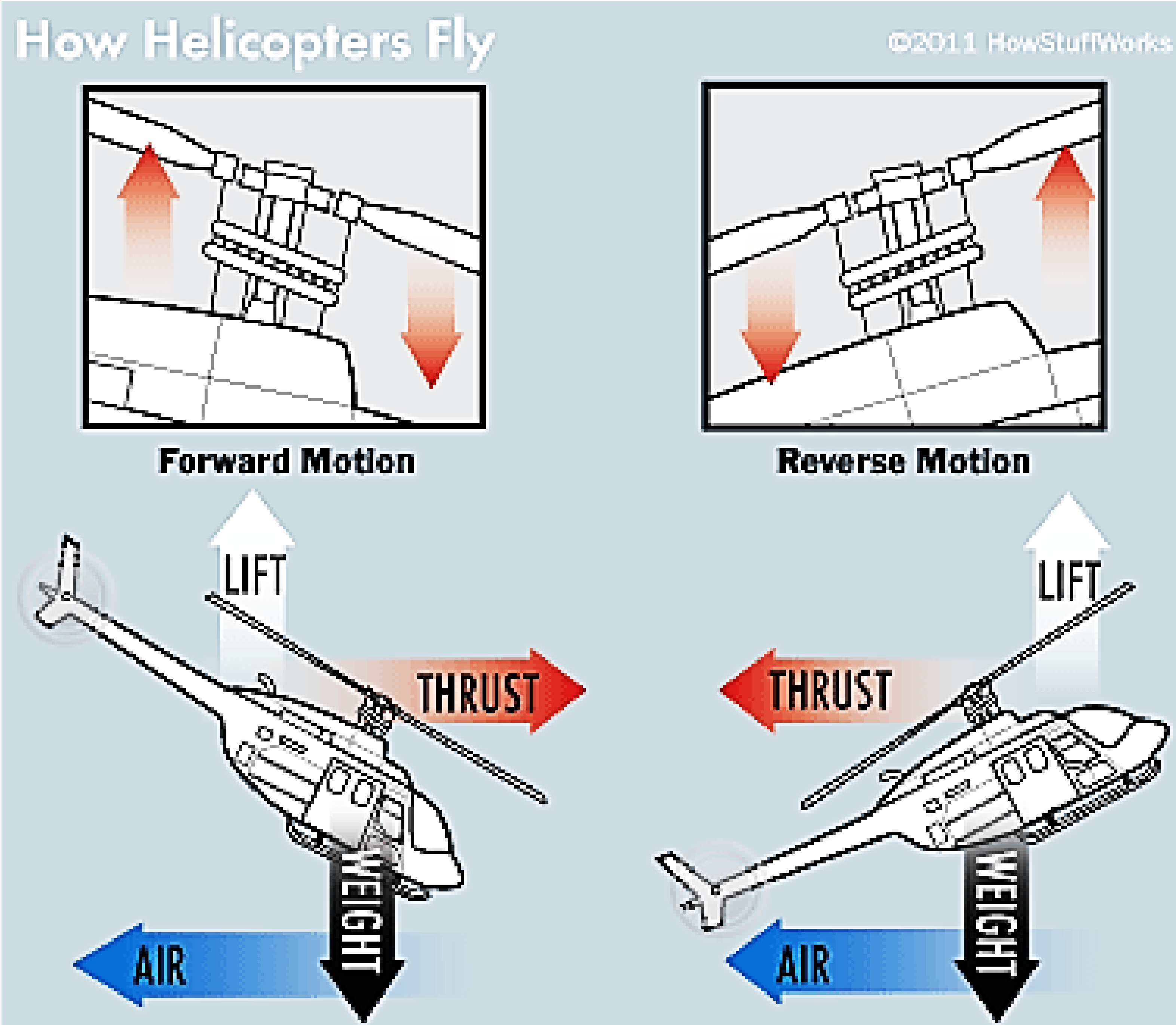
Fan-in-Tail

NOTAR

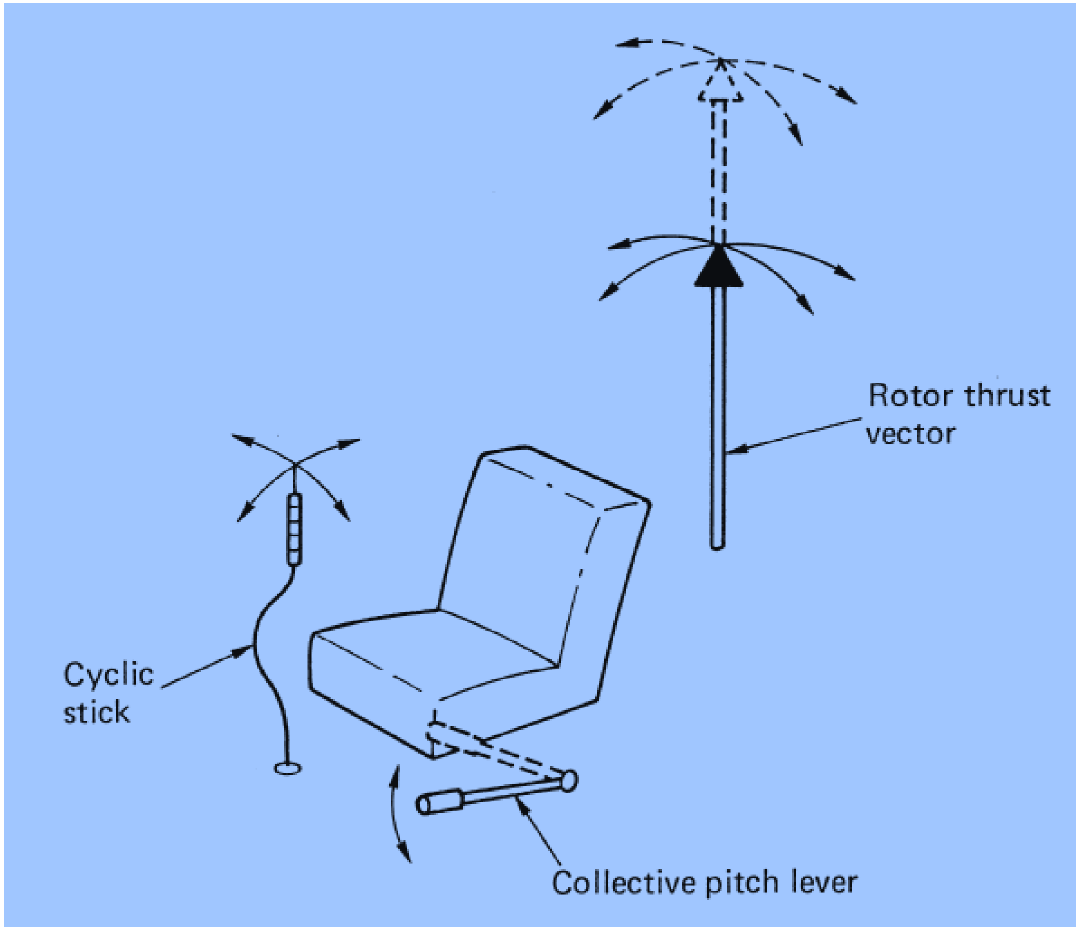


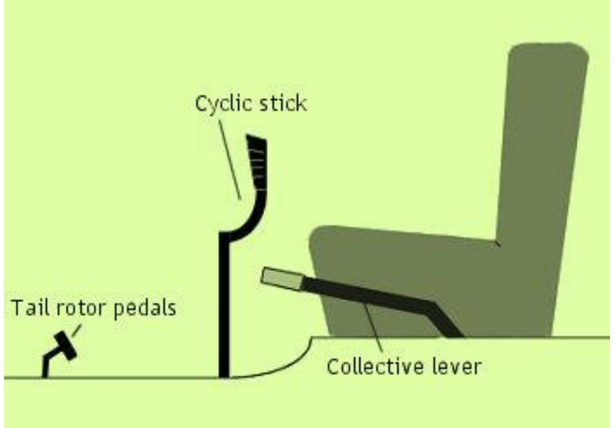
MD Helicopters
520N

MD900 Helicopter hovering 360.mp4


How Helicopters Fly
©2011 HowStuffWorks
Forward Motion
Reverse Motion
LIFT
THRUST
WEIGHT
AIR
LIFT
THRUST
WEIGHT
AIR

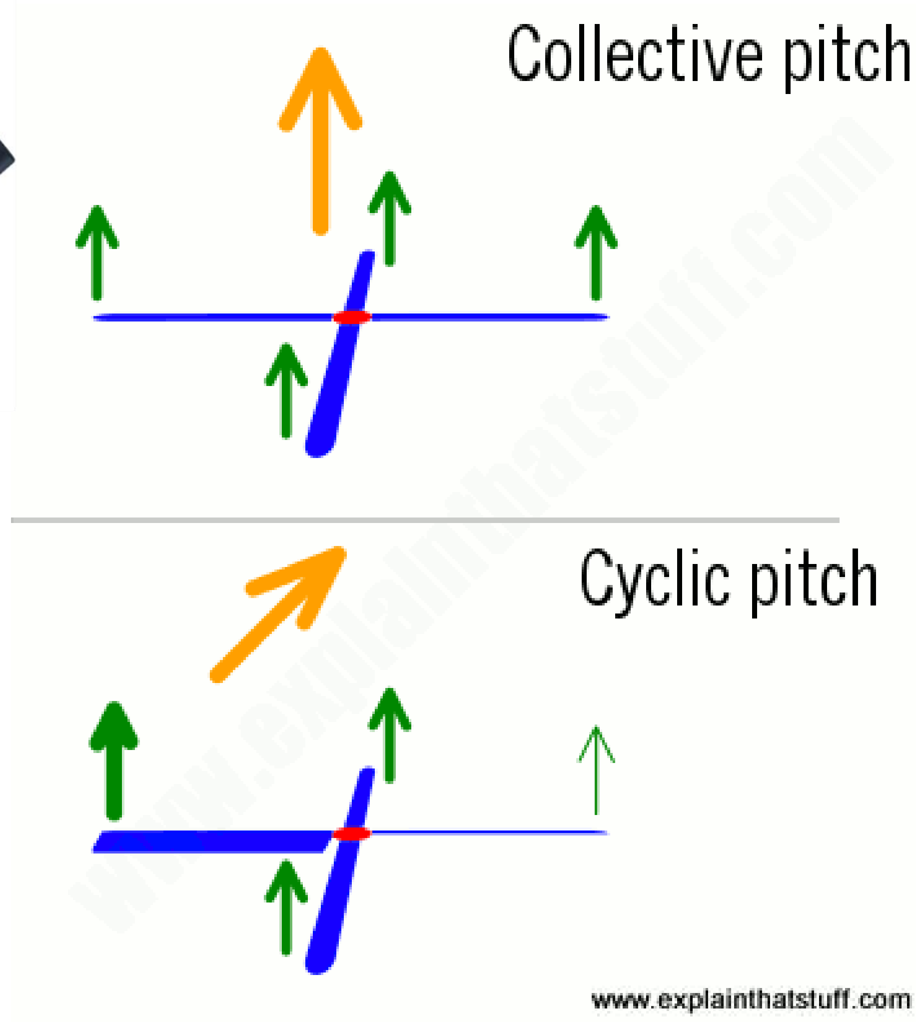
The Control System



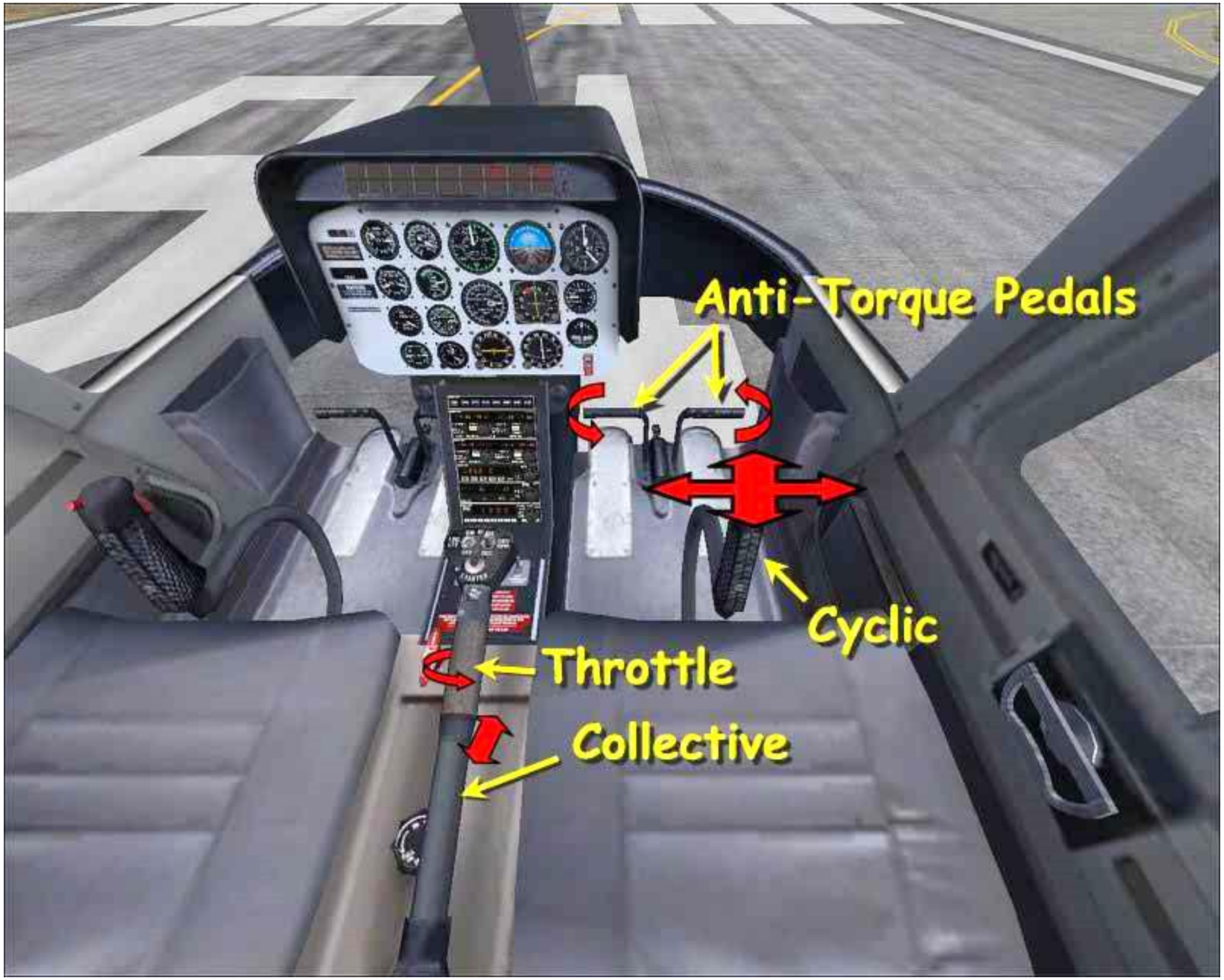


The cyclic stick tilts the rotor in the direction it is moved, whereas the collective lever changes the magnitude of the thrust. The tail rotor pedals alter the magnitude of the tail rotor thrust.

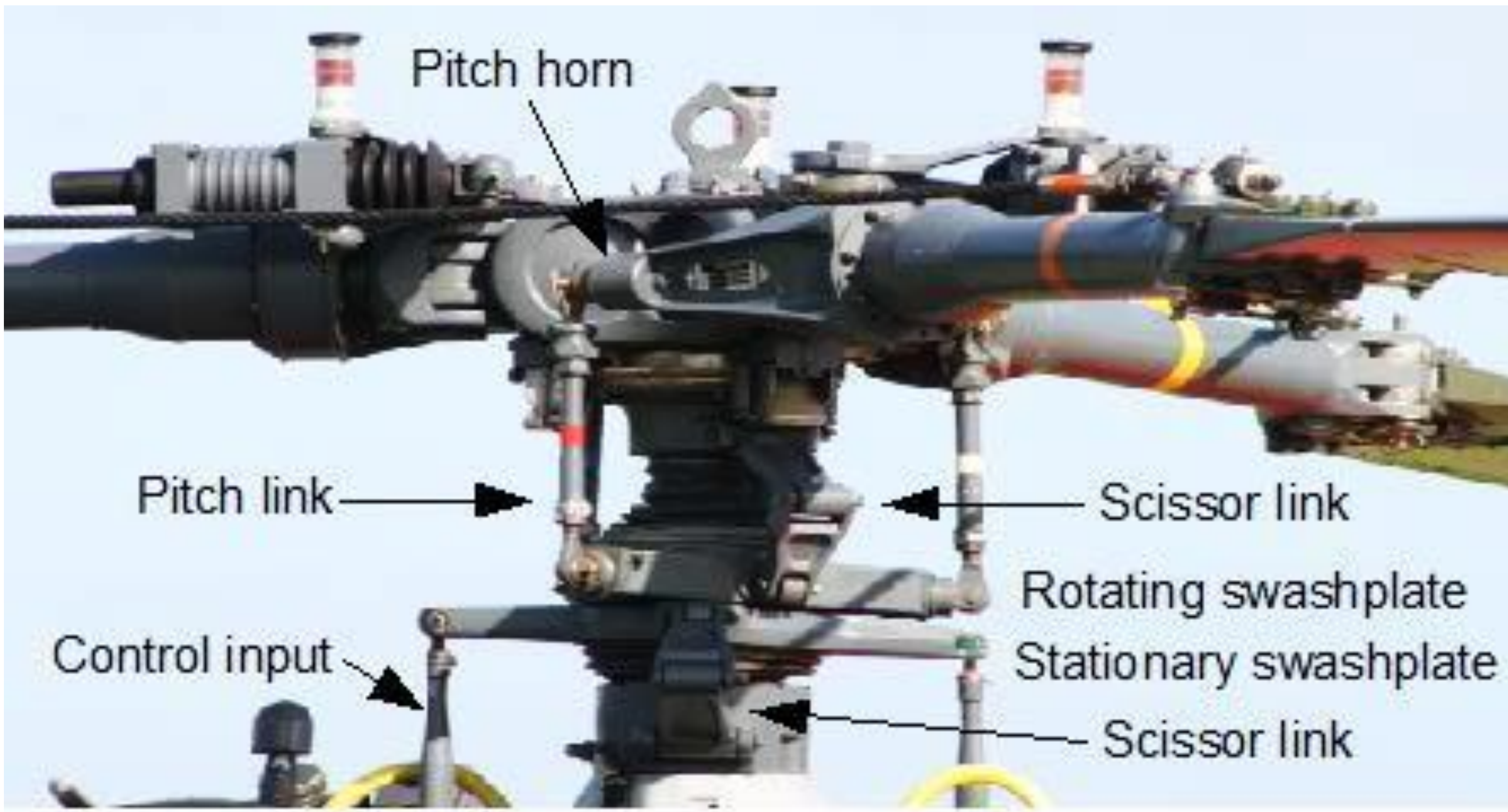
Collective and Cyclic



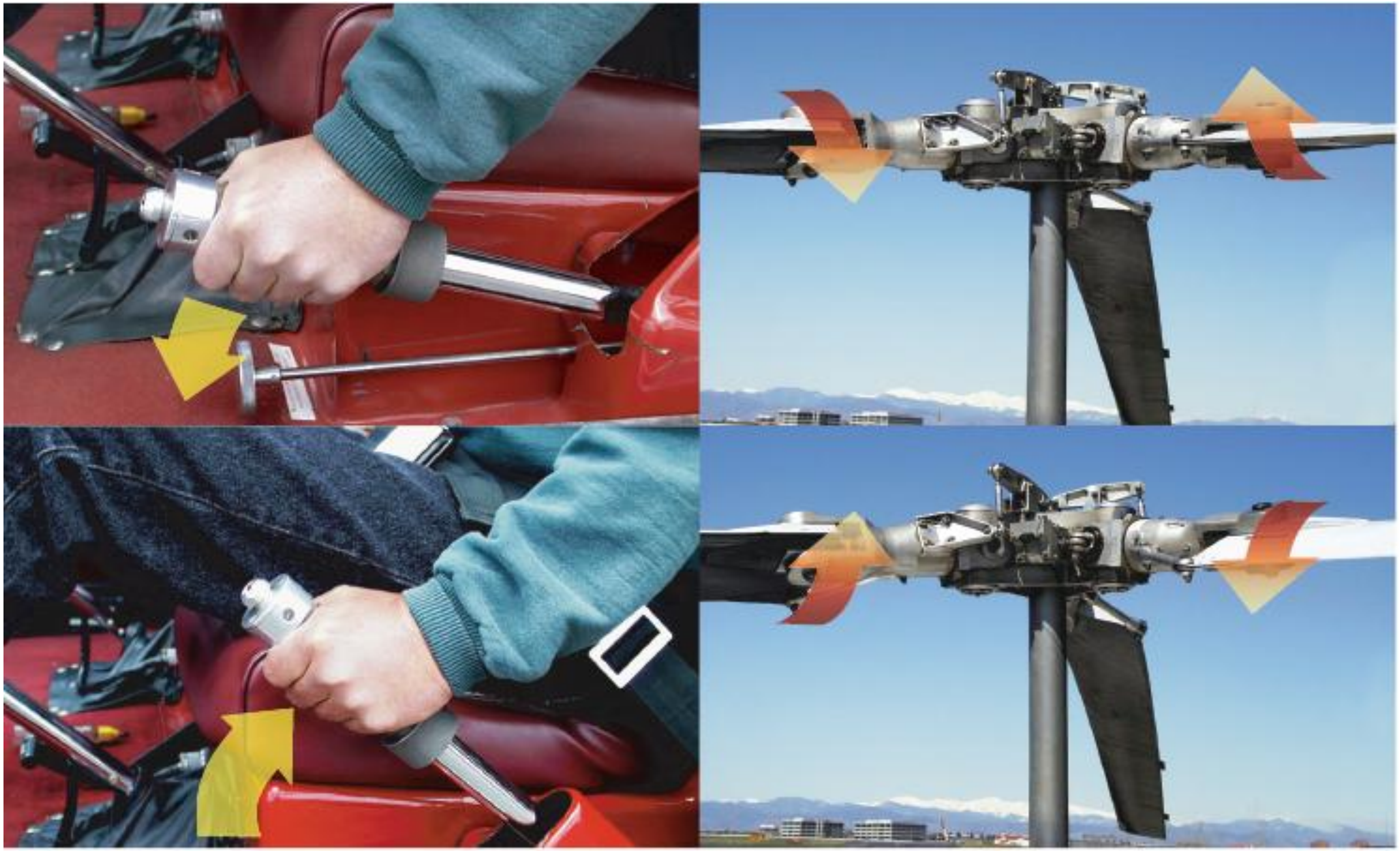
Collective and Cyclic



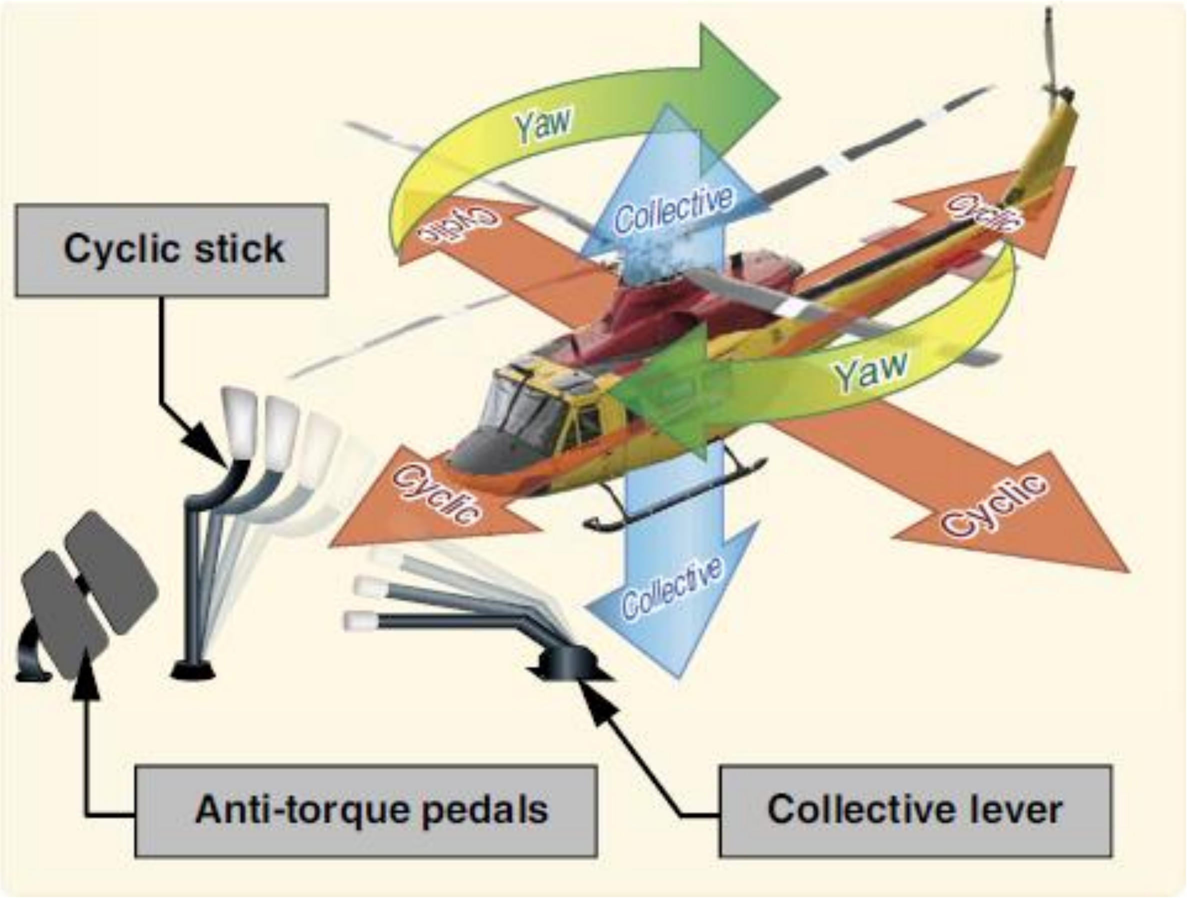
Swash Plate


Pitch horn
Pitch link
Scissor link
Rotating swashplate
Control input
Stationary swashplate
Scissor link

Collective Control



Three Axes of Flight

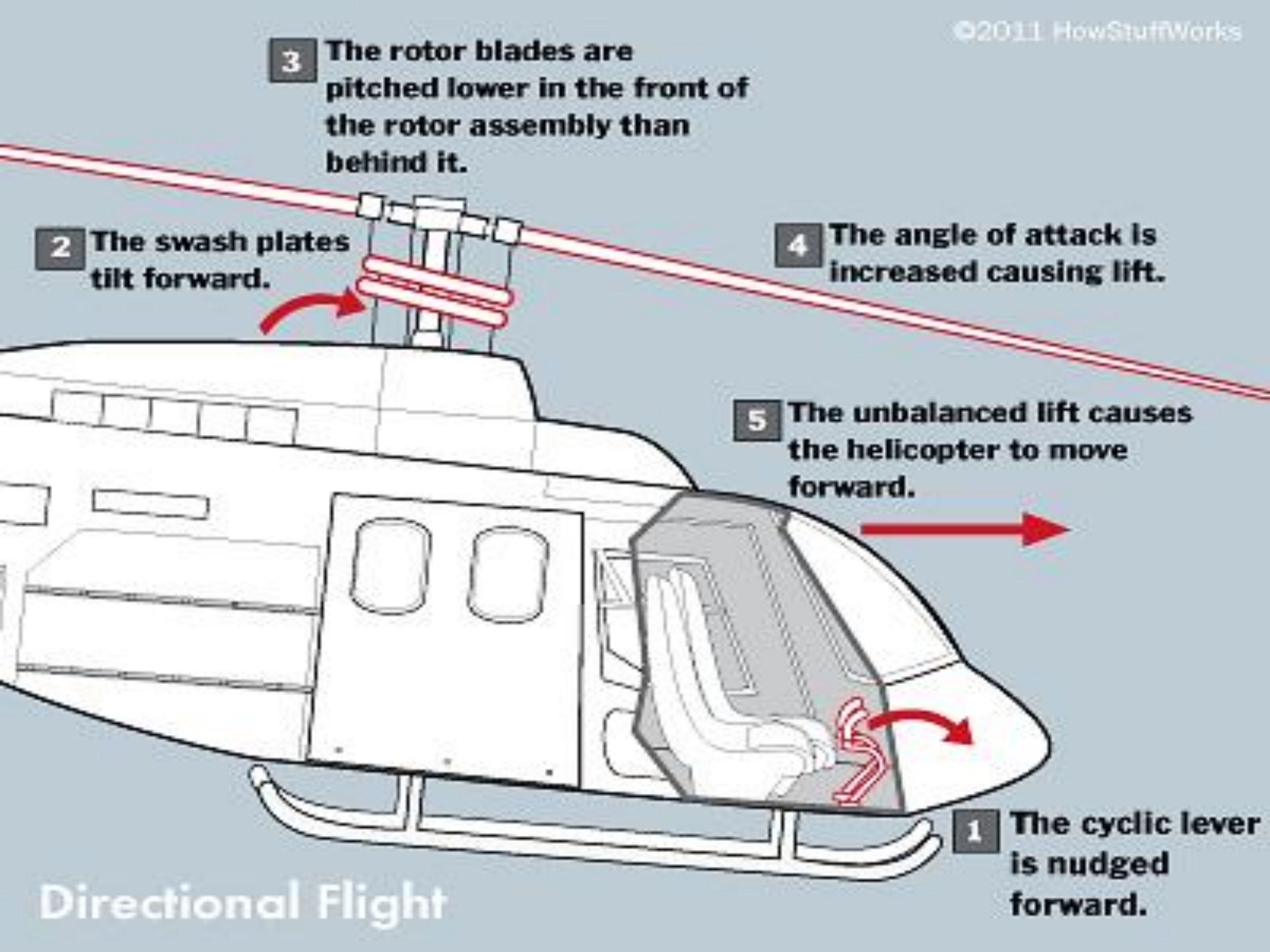


Hover

- First, open the throttle slowly until you reach proper operating RPM.
- Pull the collective gradually up. As collective pitch increases, push the left pedal (right pedal for non-American models). Continue pulling on the collective and depressing the left pedal. Adjust the pedal if the aircraft is turning to the left or right.
- The helicopter will leave the ground and you'll be able to use the cyclic. As you continue to pull the collective and depress the pedal, adjust the cyclic to level the aircraft as you take off. Push forward slightly to start moving forward.

Take-Off

- While hovering, adjust the cyclic to level the aircraft as you take off. Push forward slightly to start moving forward.
- As the helicopter transitions from vertical to forward motion, it will shudder. Push the cyclic forward a little more to make sure you keep going forward. The phenomenon that causes the shudder is called effective translational lift (ETL).
- As you progress through ETL, reduce the collective lever and apply less pressure to the pedal. Push the cyclic forward to avoid an abrupt nose high attitude and reduction in forward speed.
- Once you've taken off, slightly release forward cyclic pressure. The aircraft will then begin to climb and gain airspeed. From this point, the pedals are primarily used to trim the aircraft.


©2011 HowStuffWorks
3 The rotor blades are pitched lower in the front of the rotor assembly than behind it.
2 The swash plates tilt forward.
4 The angle of attack is increased causing lift.
5 The unbalanced lift causes the helicopter to move forward.
1 The cyclic lever is nudged forward.
Directional Flight

Take-Off Positions

Take-Off & Flight Video

Mil Mi-26 (World's largest helicopter) take off at Budaörs.mp4

Running Take-Off

Running Take-Off Video

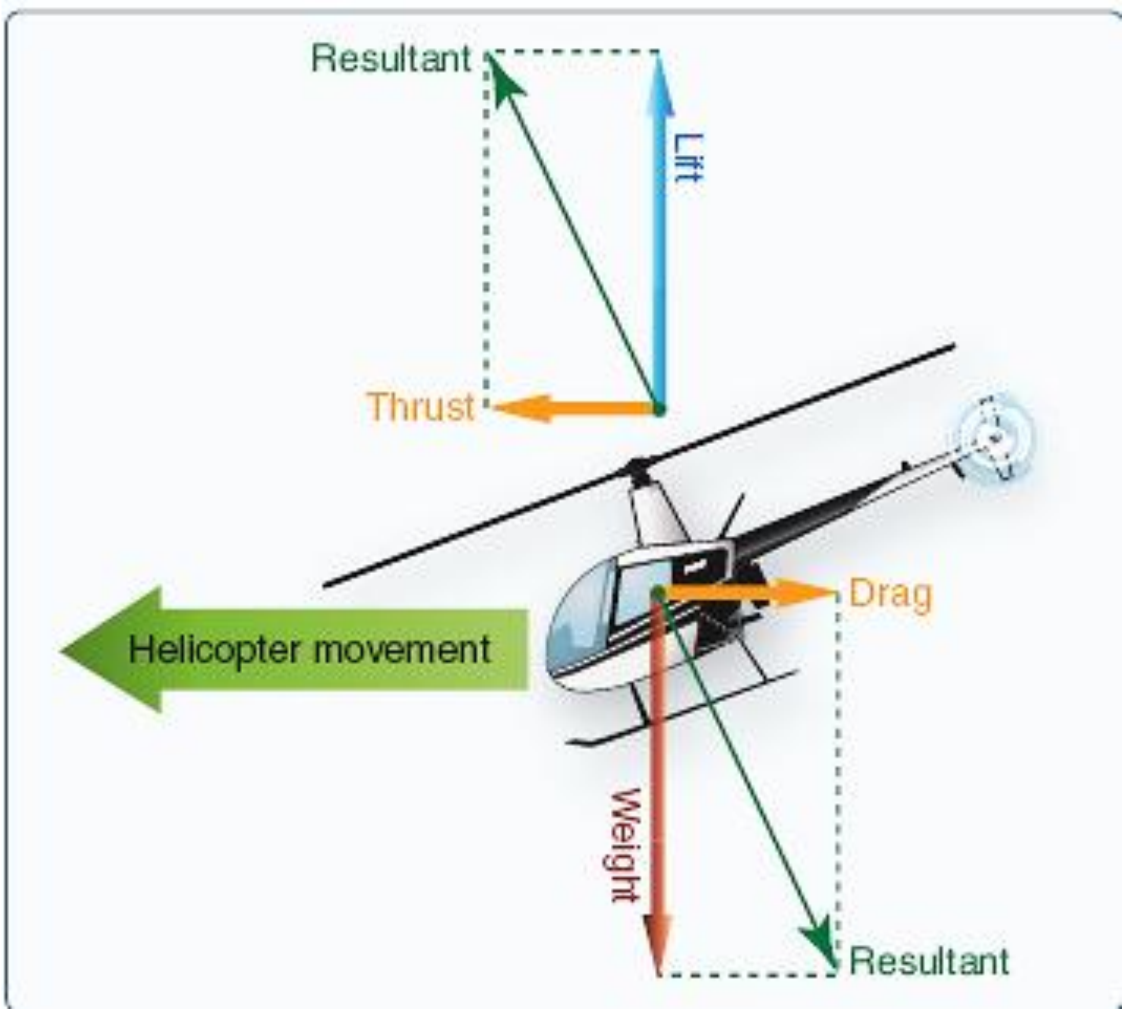
MI-24 running take off.mp4

Lift and Thrust Vectoring

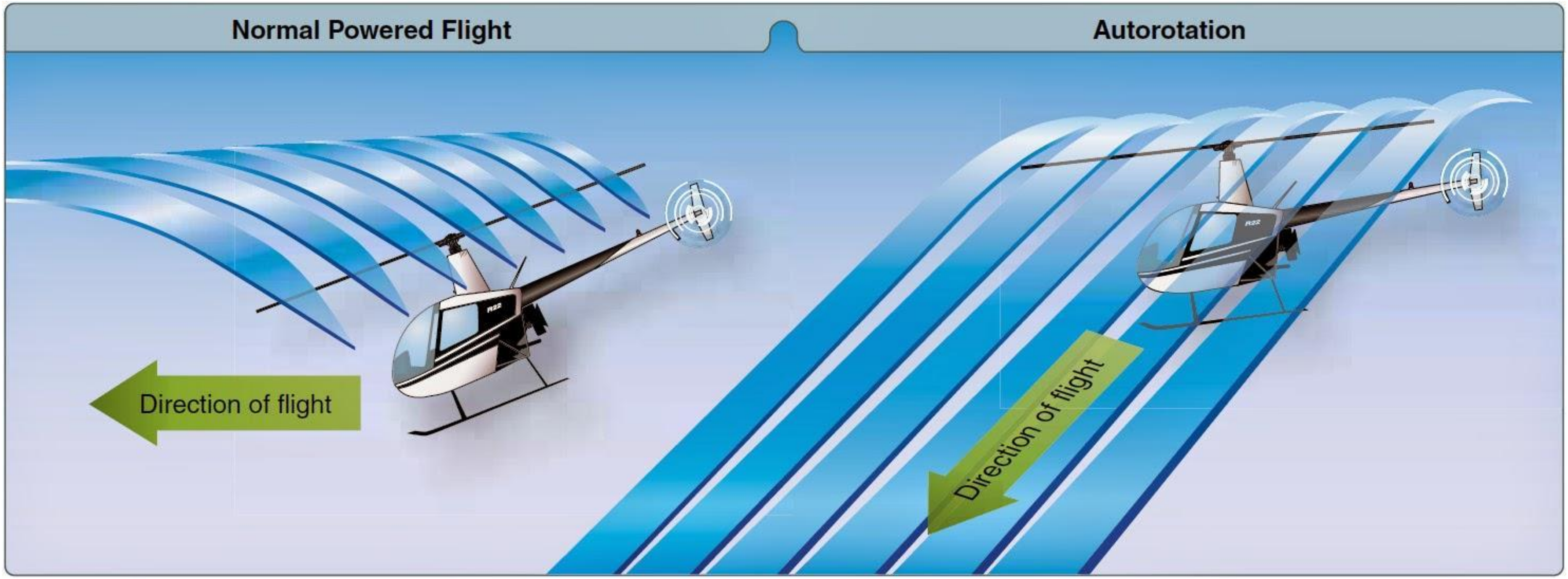
"The pilot should always remember that the total lift and thrust vectoring is controlled by the cyclic. If a certain airspeed is desired, it will require a certain amount of cyclic and collective movement for level flight. If the cyclic is moved, the thrust-versus-lift ration is changed. Aft cyclic directs more power to lift, and altitude increases. Forward cyclic directs more power to thrust, and airspeed increases. If the collective is not changed and there is a change only in cyclic, the total thrust to lift ration does not change; aft cyclic results in a climb, and forward cyclic results in a descent with the corresponding airspeed changes."

– FAA Helicopter Flying Handbook

Lift and Thrust Vectoring



Autorotation

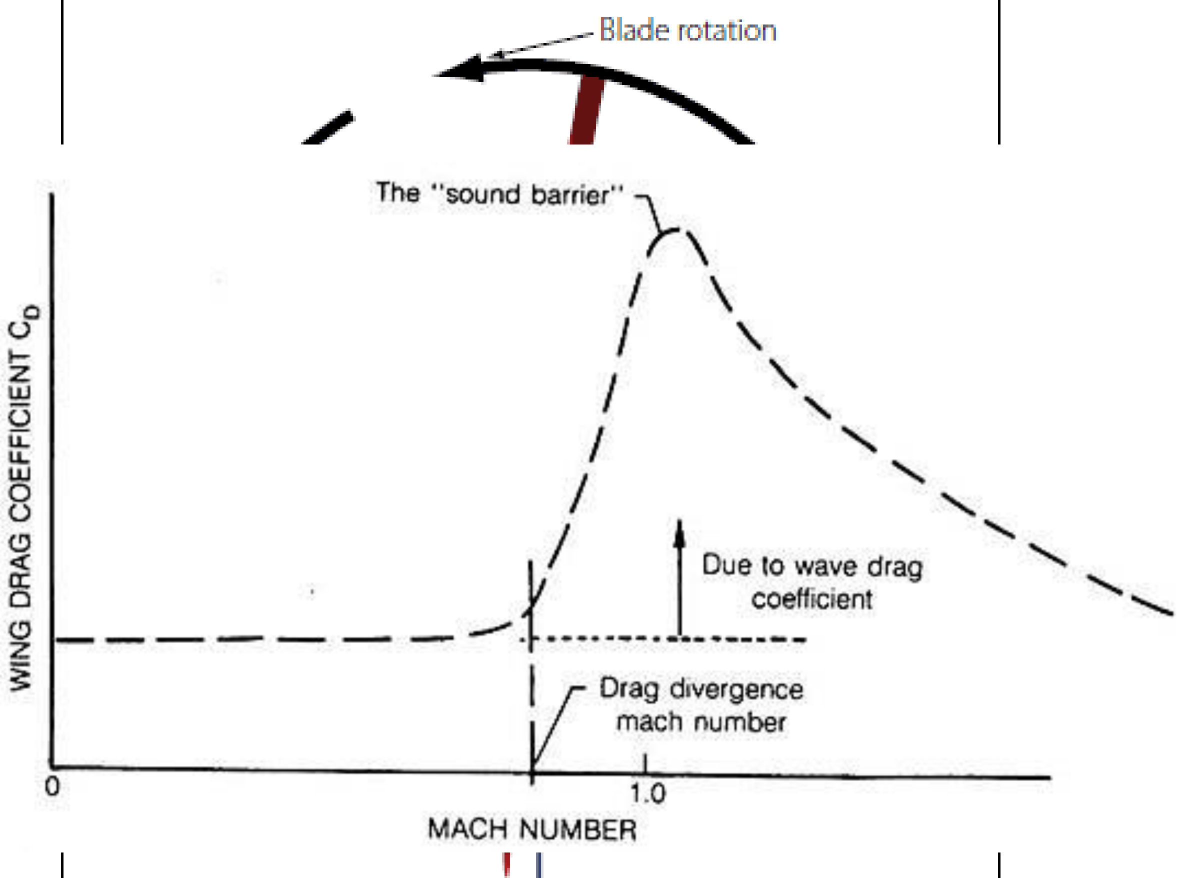


Instrument Panel

Limitations

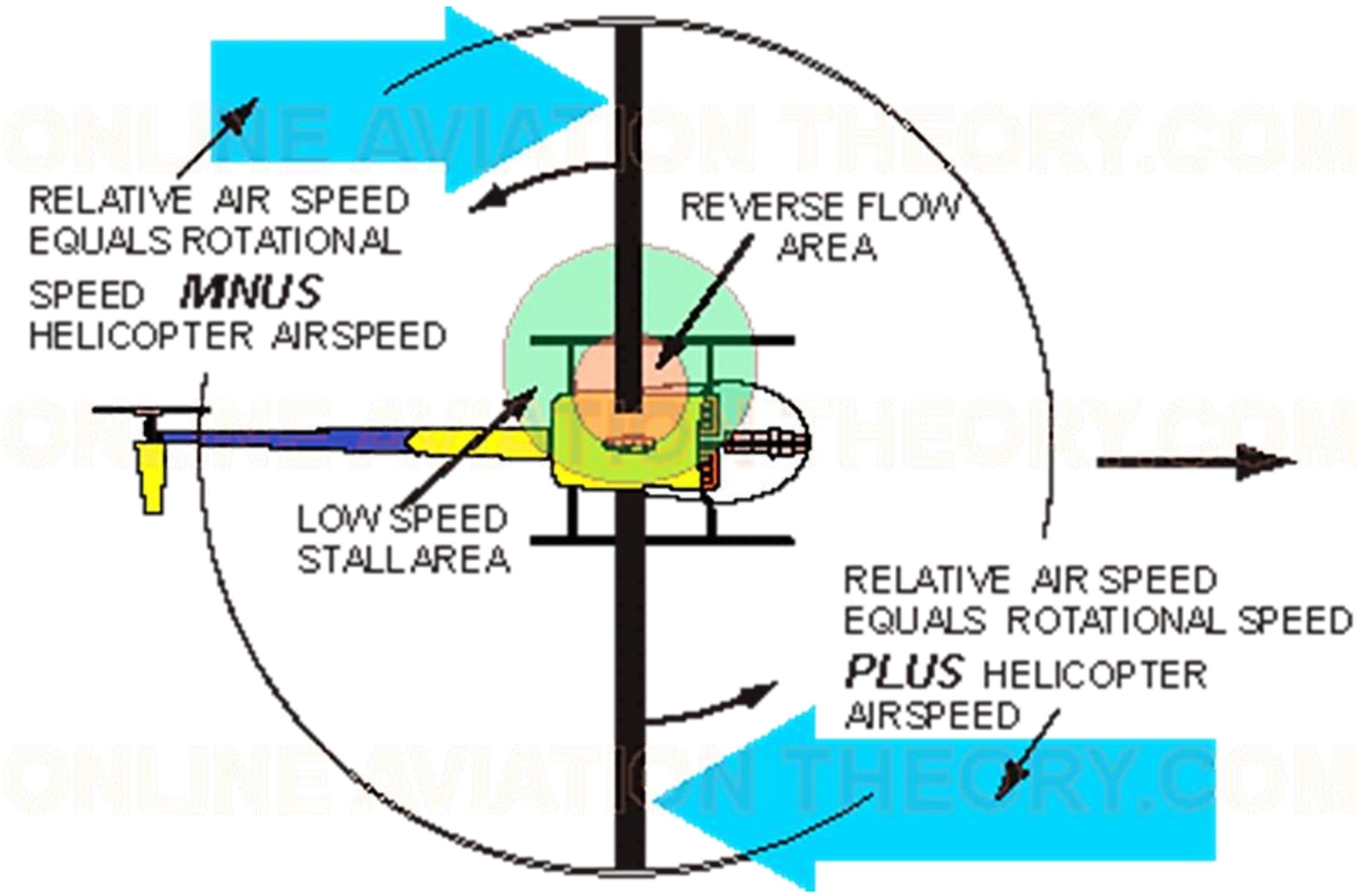
- Low Speed
- Dissymmetry of Lift
- Vibrations
- Noise

Low Speed

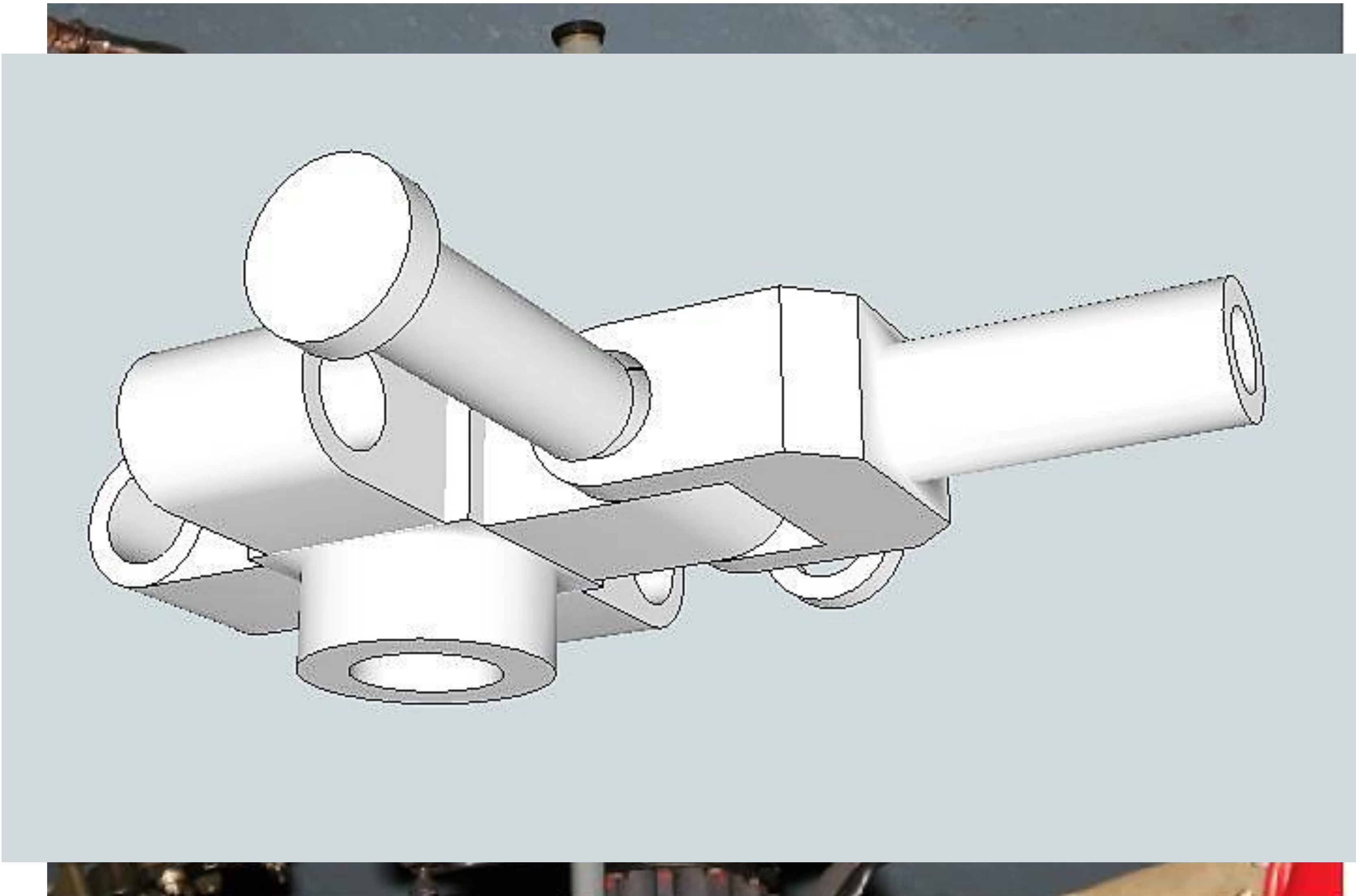


Blade #1 experiences 300 mph airflow (Tip speed – airspeed)
Blade #2 experiences 500 mph airflow (Tip speed + airspeed)

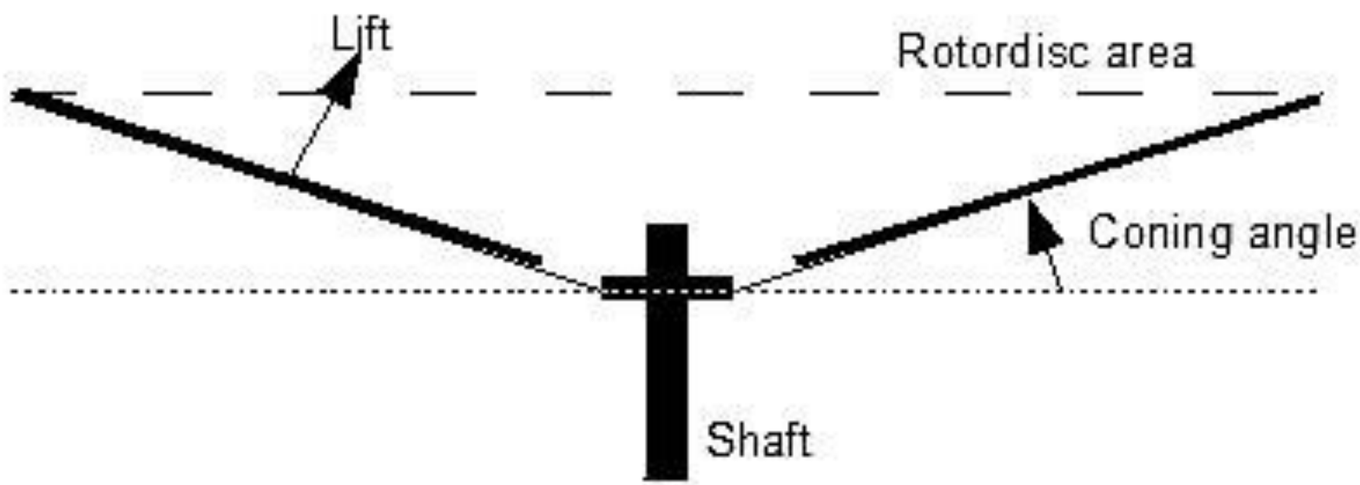
Dissymmetry of Lift



Flapping Hinge



Coning Angle

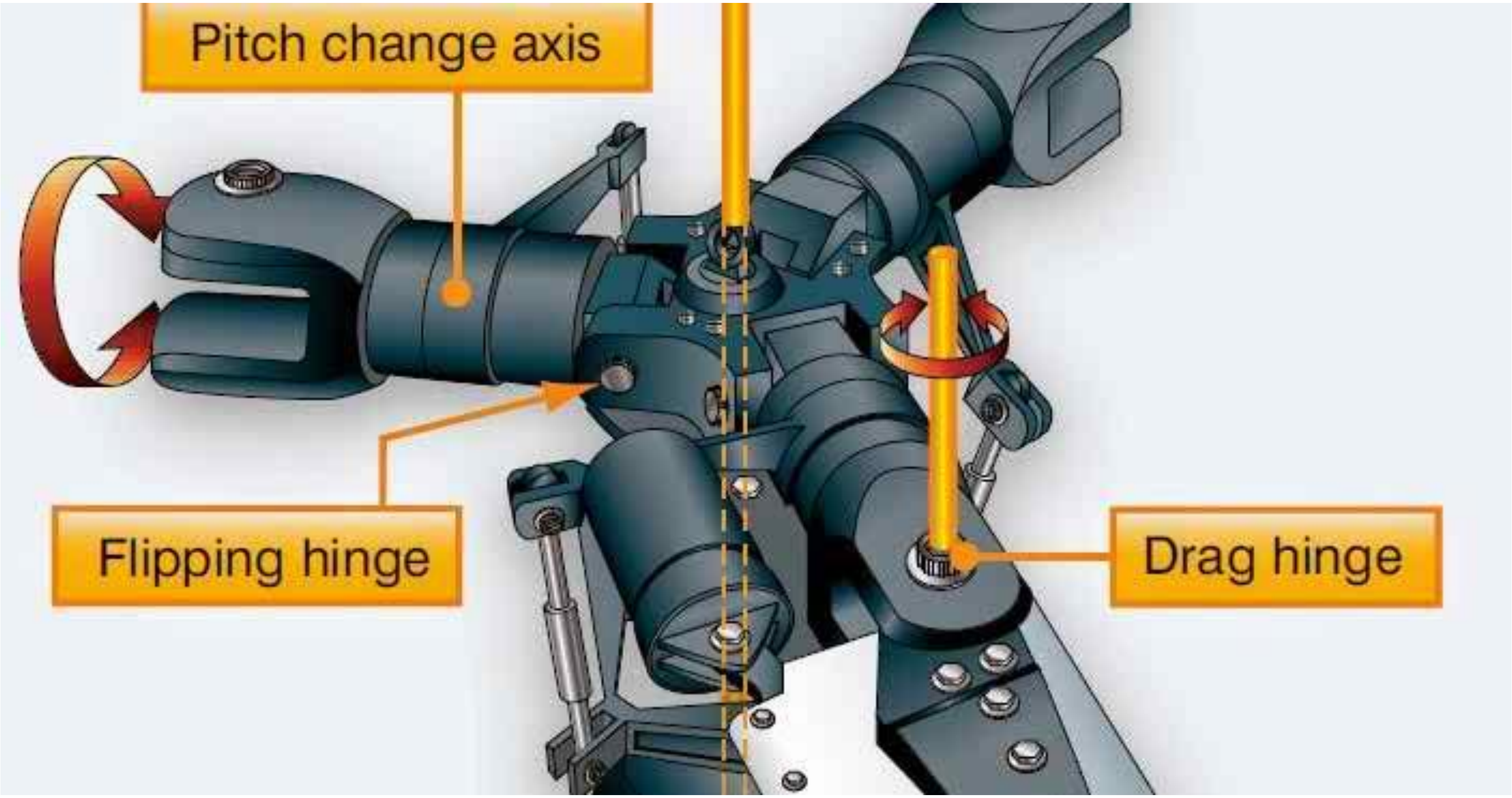


Main Rotor Configurations

Teetering Hub Design

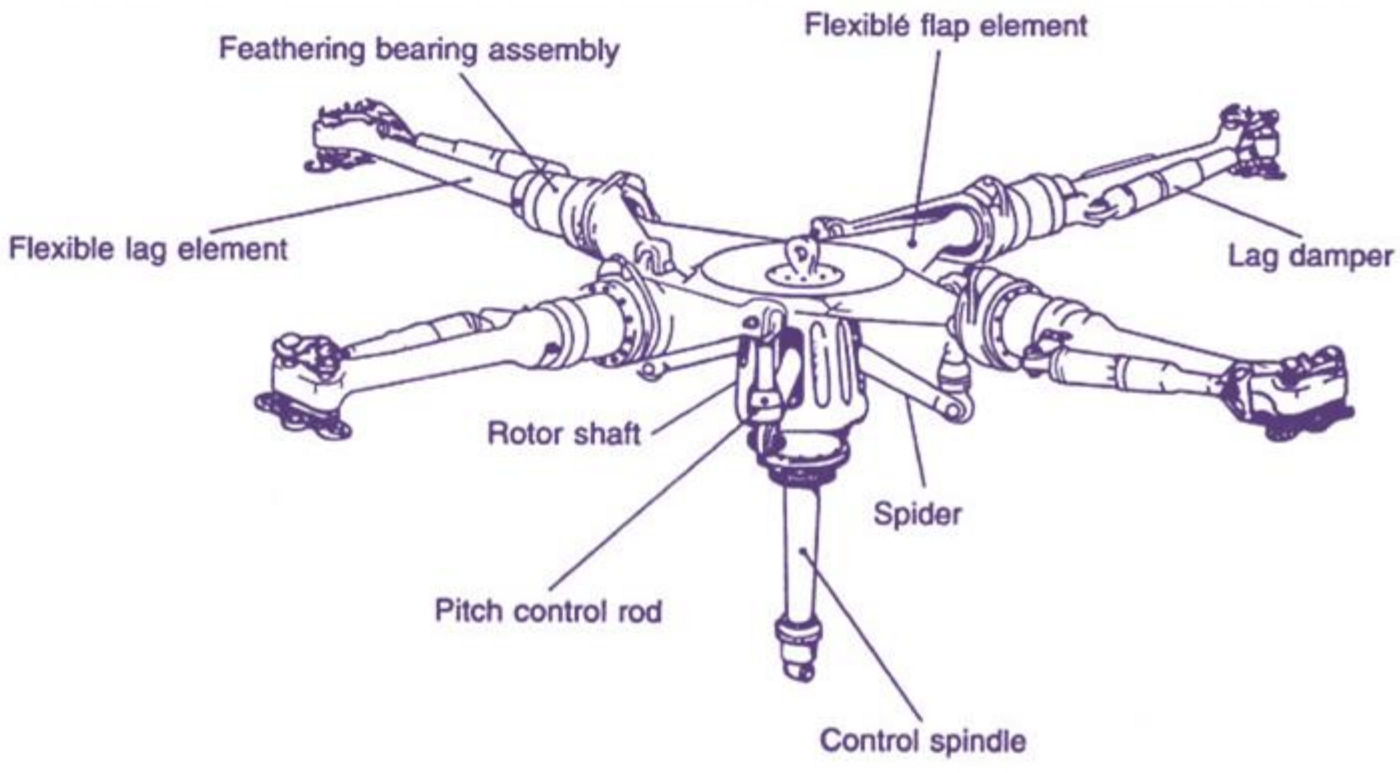
Main Rotor Configurations

Articulated Hub Design



Main Rotor Configurations

Hingeless Hub Design



Main Rotor Configurations

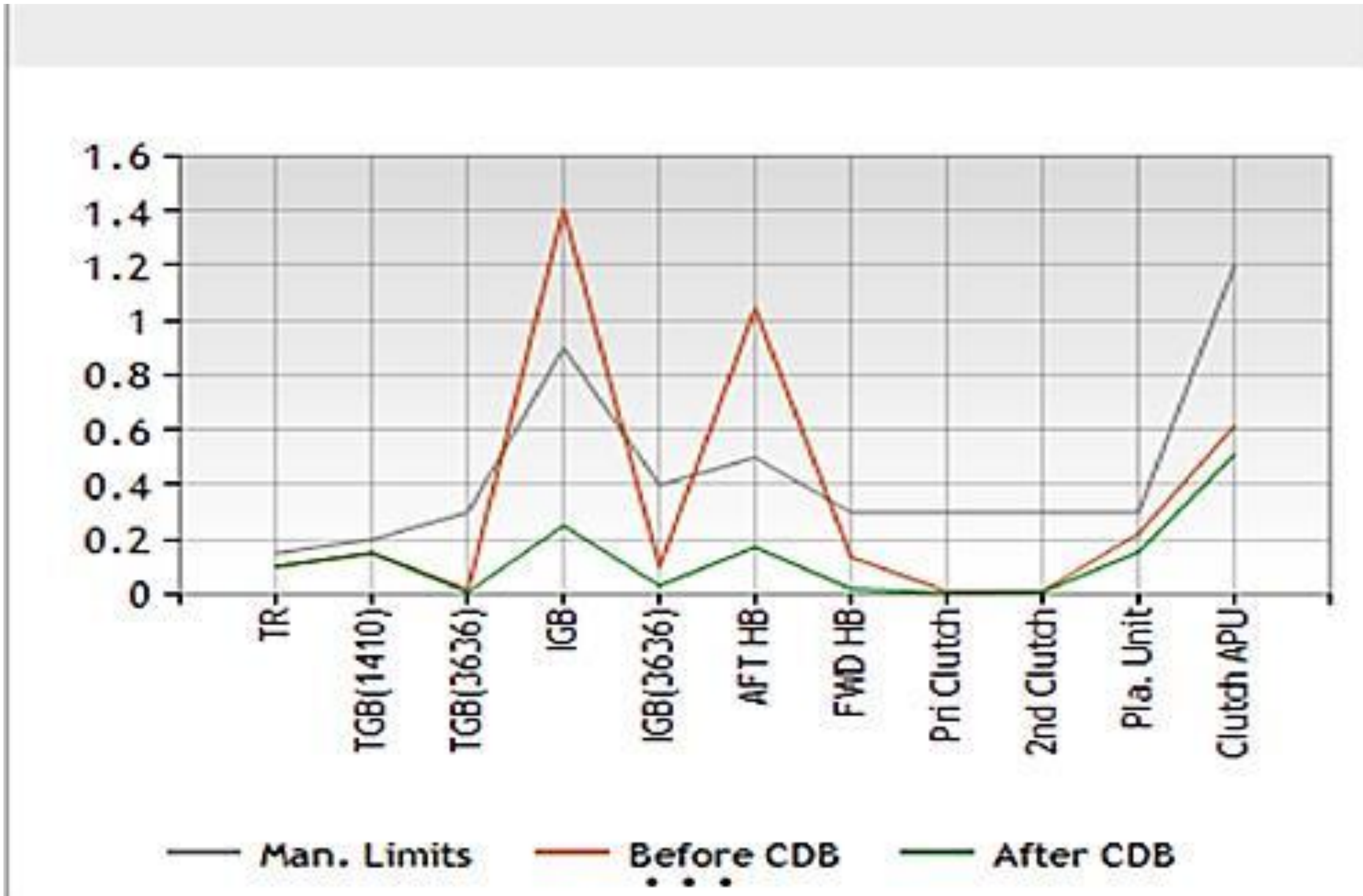
Bearingless Hub Design

Vibrations

- LATERAL: Evident in side-to-side swinging rhythms caused by an out-of-balance rotor blade.
- VERTICAL: Evident in up-and-down movement that produces a thumping effect, caused by an out-of-track rotor blade.
- HIGH-FREQUENCY: Evident in buzzing and a numbing effect on the feet and fingers of crew members. High-frequency vibrations are caused by an out-of-balance condition or a high-speed, moving part that has been torqued incorrectly.

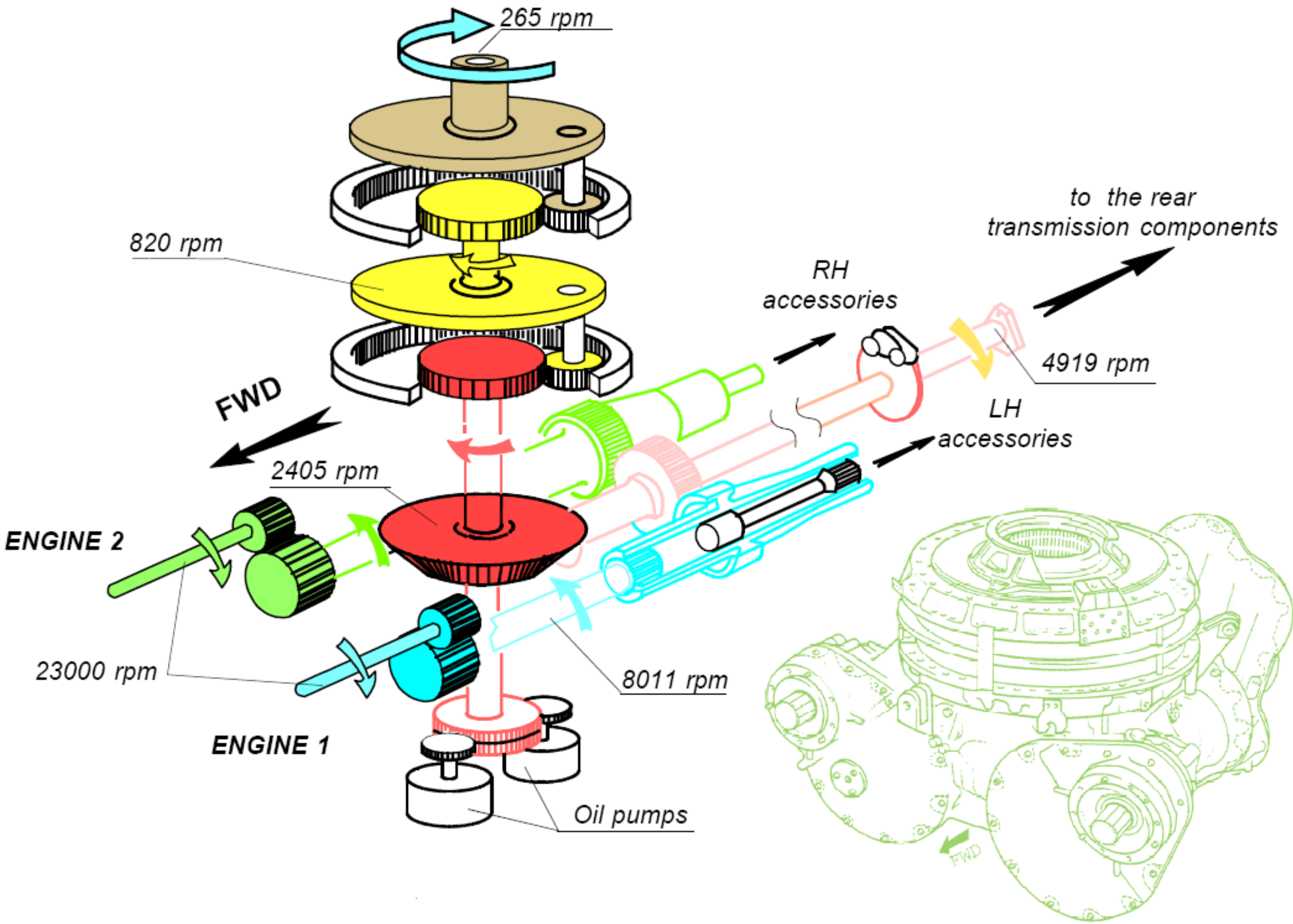
AS350 Eurocopter .mp4

Vibrations

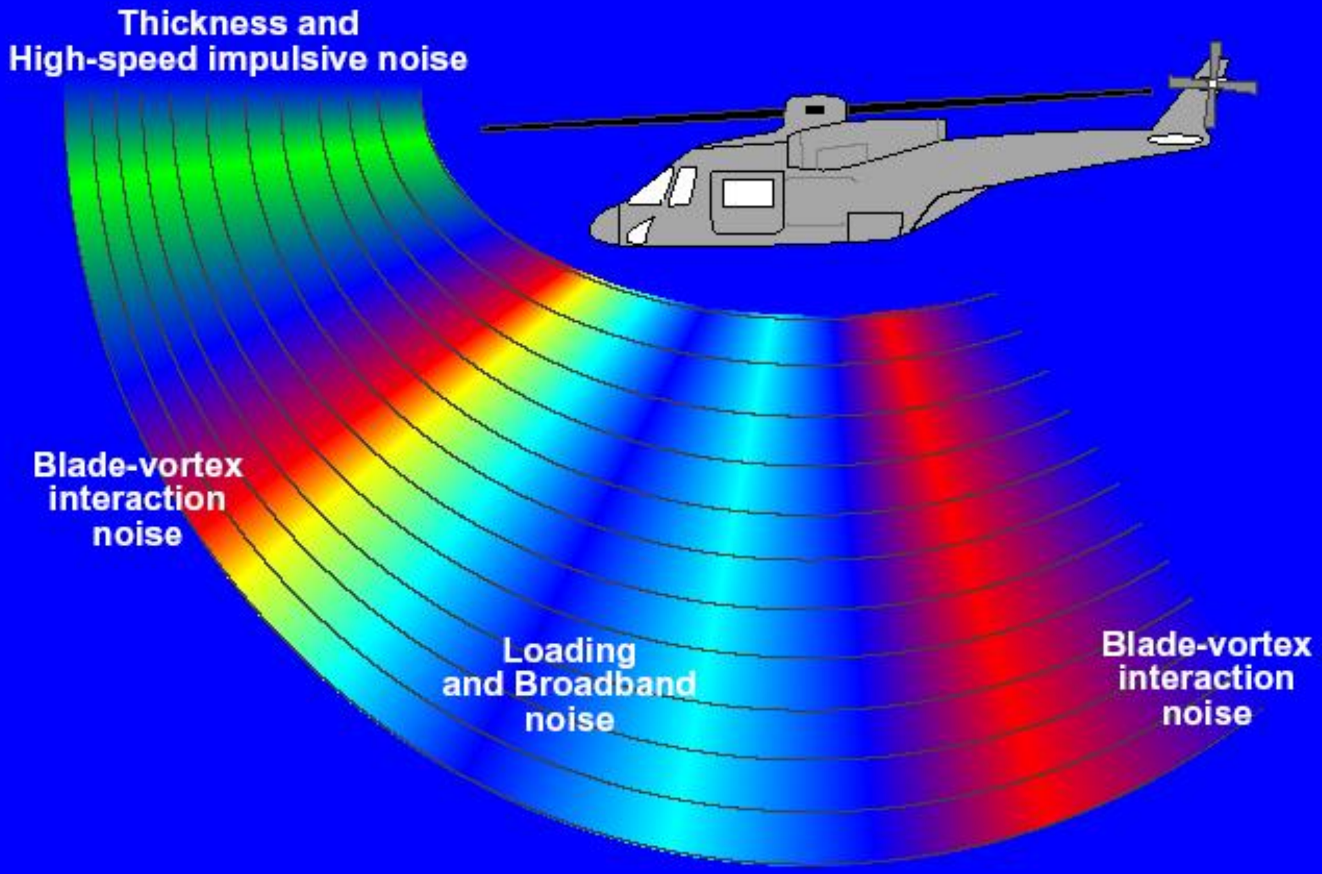


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
TR
TGB(1410)
TGB(3636)
IGB
IGB(3636)
AFT HB
FWD HB
Pri Clutch
2nd Clutch
Pla. Unit
Clutch APU
Man. Limits
Before CDB
After CDB

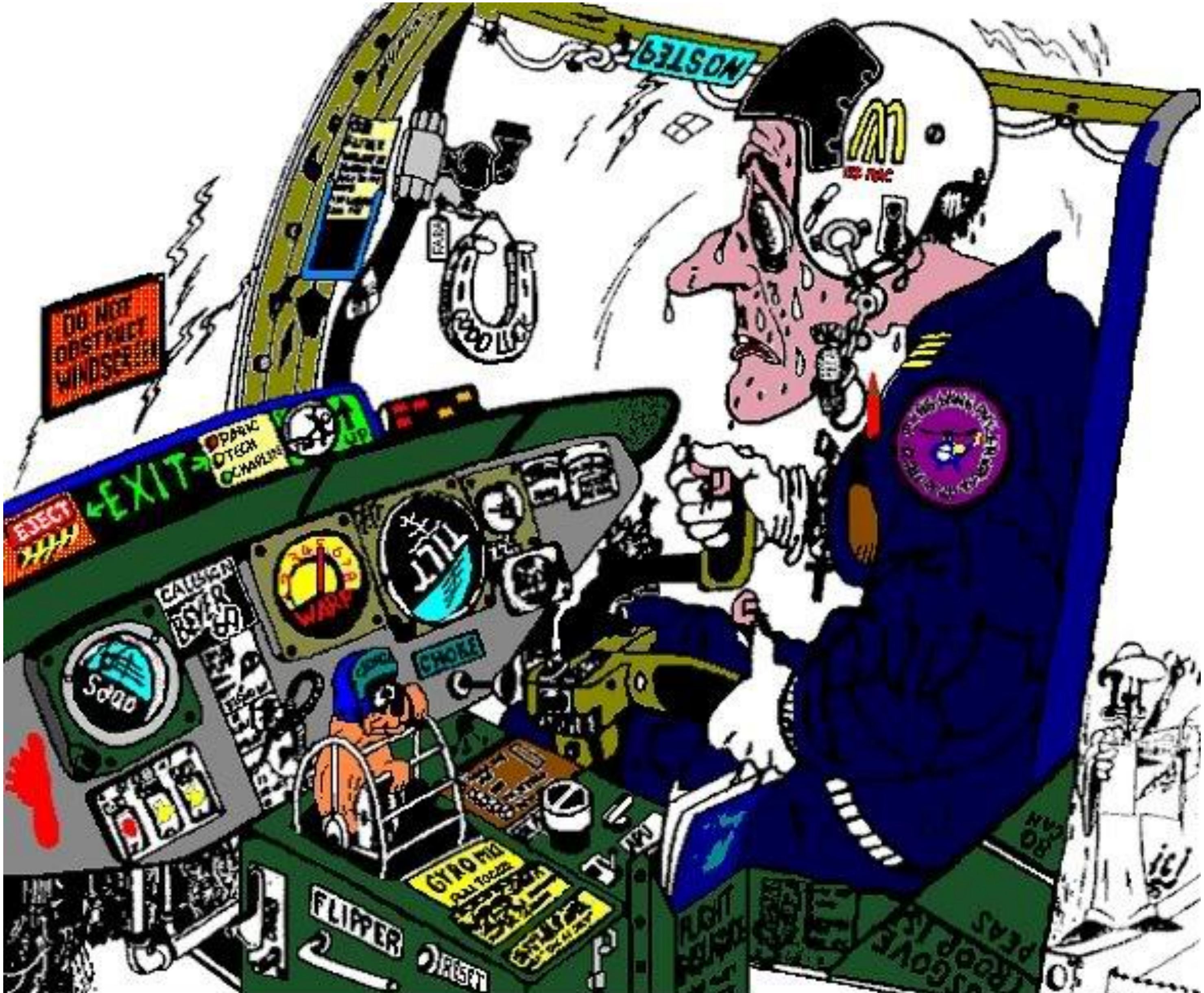
Helicopter Drivetrain



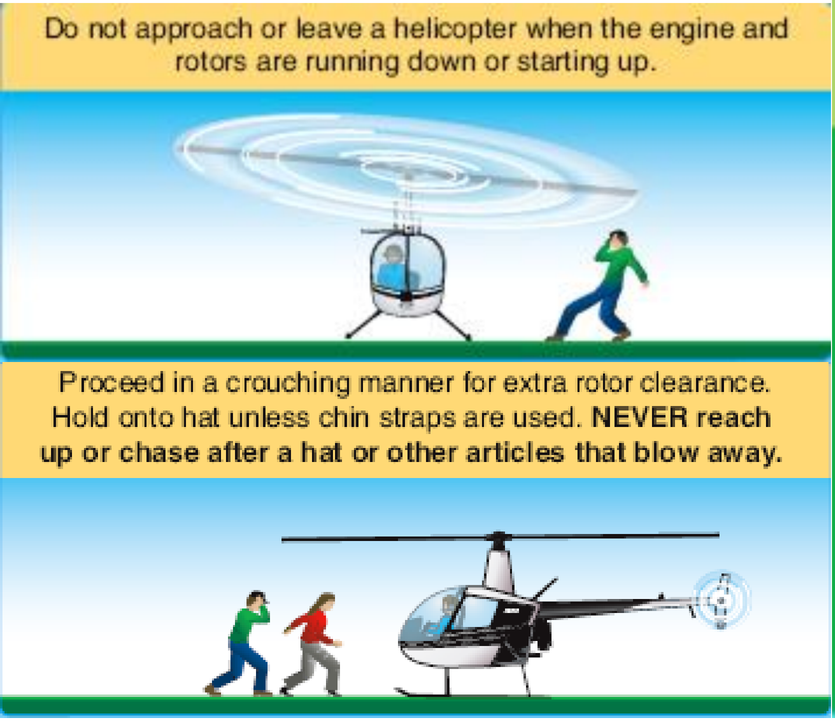
Rotor Source Noise

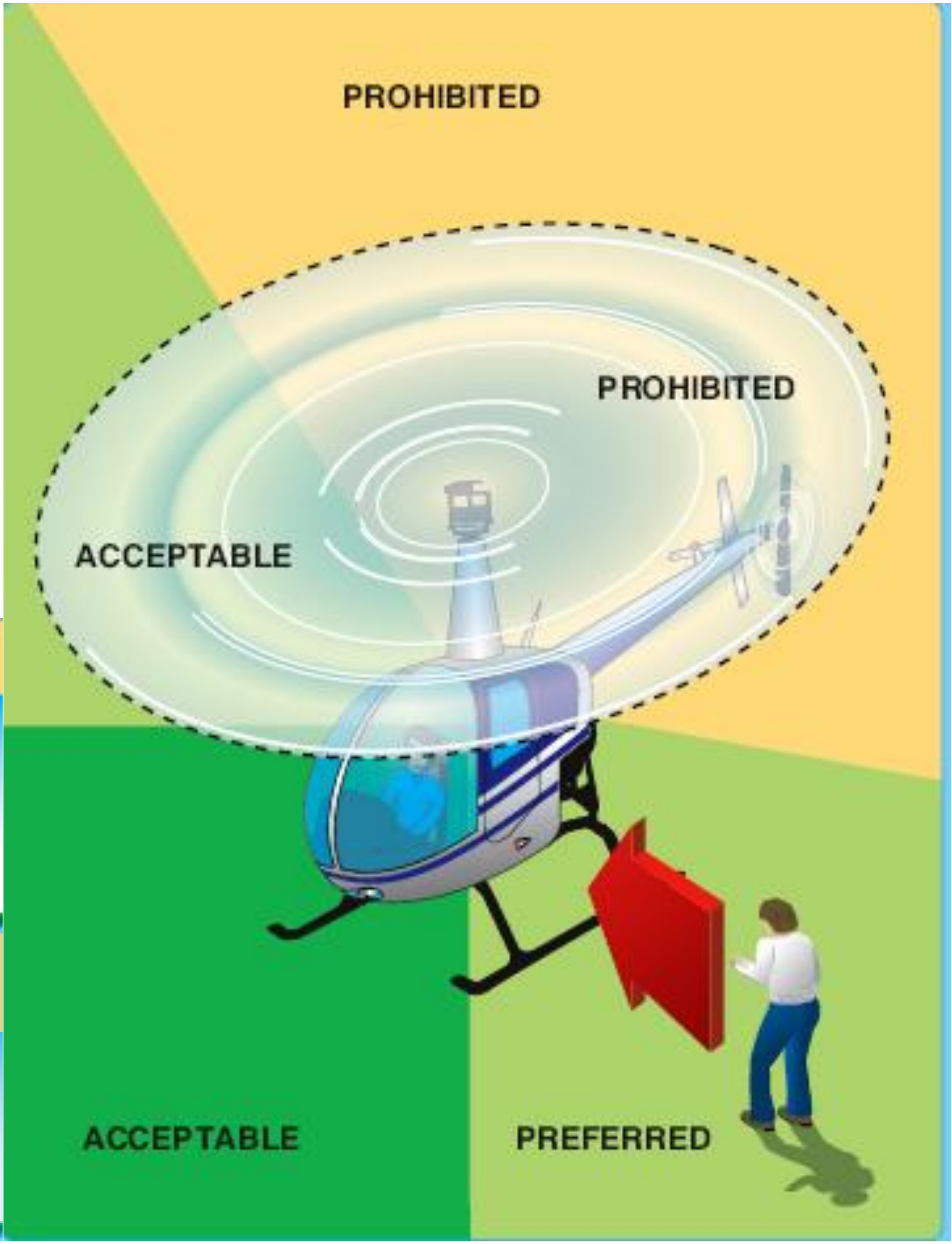


K. S. Brentner


DO NOT OBSTRUCT WINDSCREEN
EJECT
EXIT
GOOD LUCK
WARP
TILT
CHOKE
GYRO FIX
FLIPPER
RESET

Safety Around Helicopters





Applications of the Helicopter

- Helicopters must have a high power to weight ratio limiting load carrying capability and range.
- Demand a lot of maintenance
- More expensive to move a given load
- Cannot compete economically with aeroplanes

Applications of the Helicopter

- Can land almost anywhere a fairly flat firm surface exists
- Can transfer goods and passengers whilst in the hover which also makes it an ideal rescue vehicle
- Can operate in bad weather