Aerospace Vehicle Design And System Integration 3

CADE30007

(AVDASI 3 - Aircraft Propulsion, Performance and Sustainable Operations)

Aircraft Performance

Lecture 4

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Overview

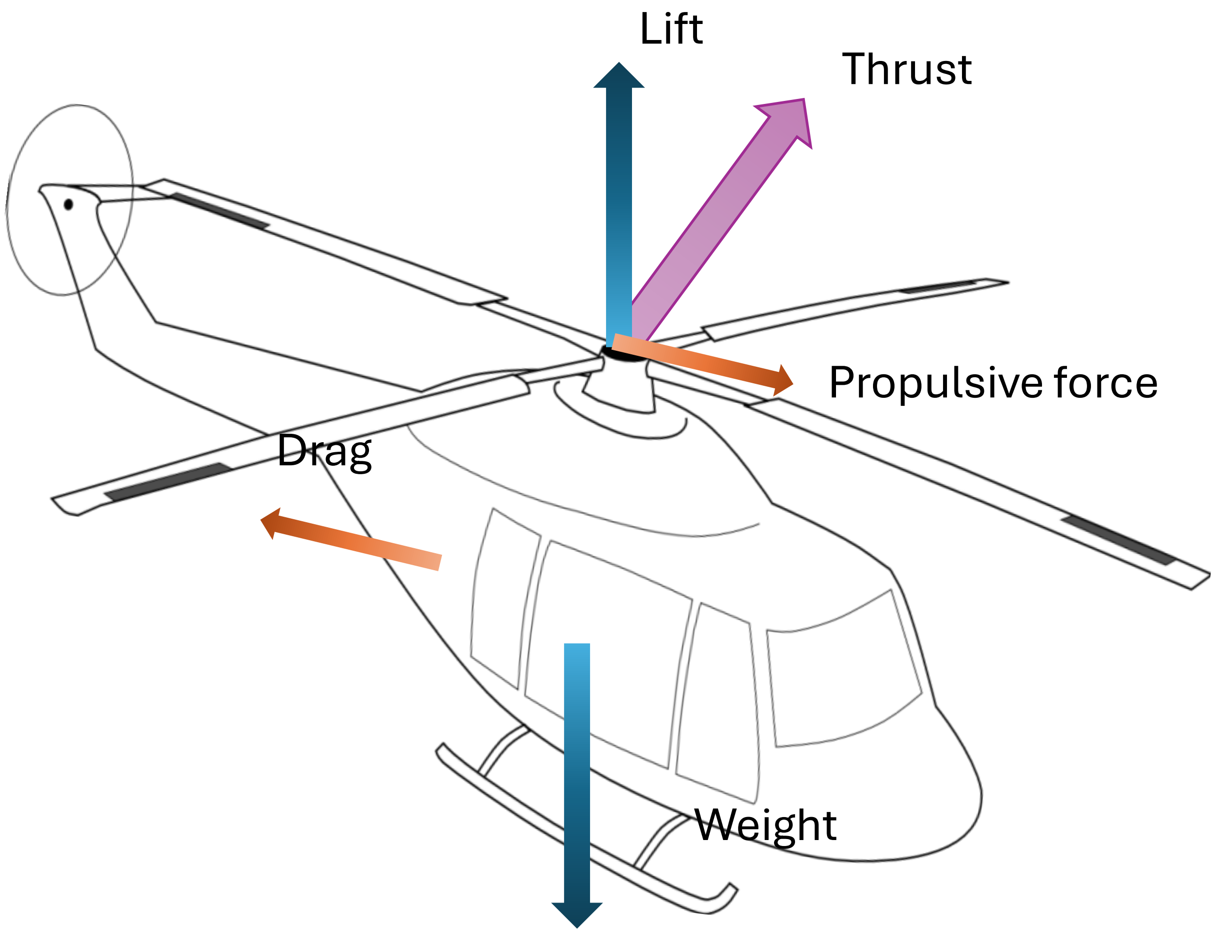
Helicopter performance in initial design

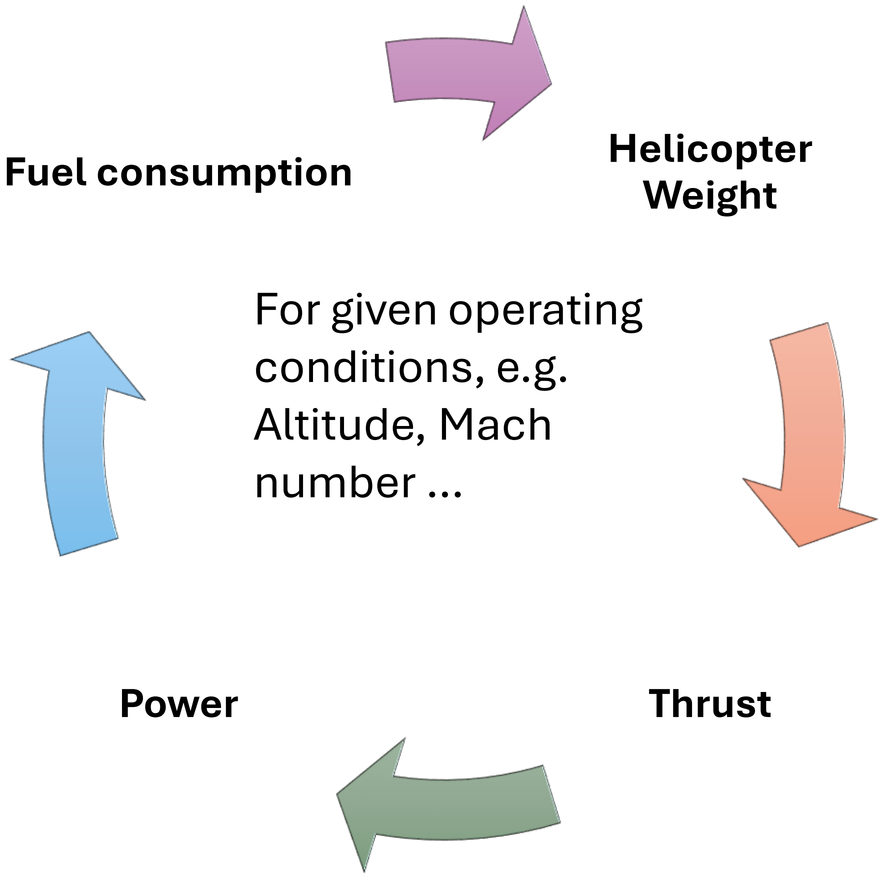
Helicopter sizing process

Helicopter Design Requirements

- **General requirements**, e.g. payload, speed, range, altitude, cost, etc.
- **Key mission requirements**, e.g. transportation, firefighting , training, surveillance, military, ...
- **Compliance with the applicable airworthiness standards** (CS27, CS29 ...)
- **Inoperable Engine requirements** (urban area, traffic controlled area, ...)

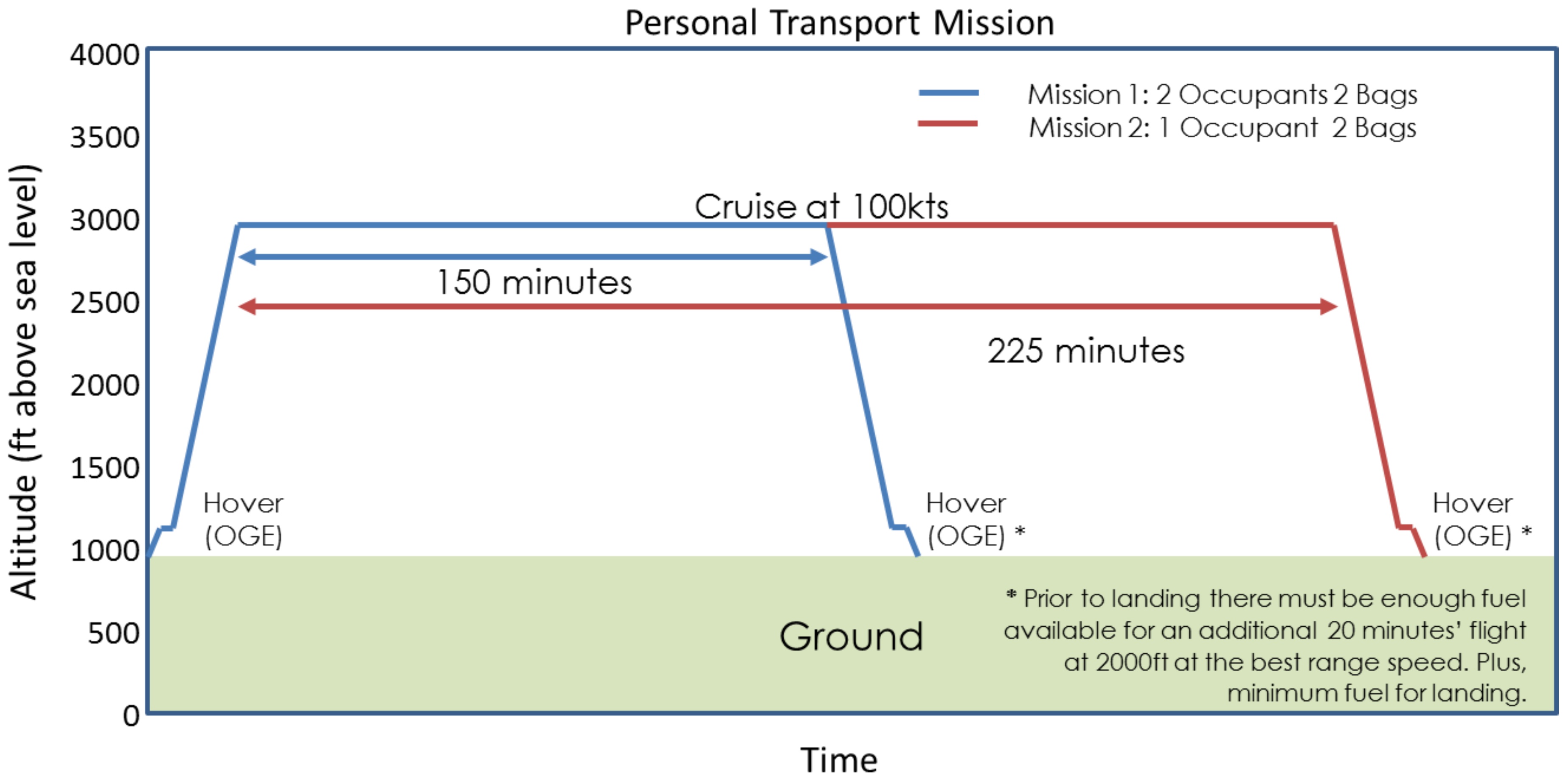
A Simplistic View of Performance Model





For given operating conditions, e.g. Altitude, Mach number …

Typical Helicopter Mission



Considerations in Helicopter Design

- **General**
  - Is the aircraft the correct size to do the task
- **Rotors**
  - Disc loading & blade loading
  - Growth potential
  - Noise
  - Maximum length with rotors turning
  - Flight envelope
- **Mission Performance**
  - Is the empty mass fraction achievable?
  - Is there sufficient space allowance for the required fuel volume?
  - Has all the necessary role equipment been accounted for?
  - Mission fuel = Trip Fuel + Reserve Fuel
- **Drive Train**
  - What engines are available and how many do I need?
  - Engine power lapses with altitude and temperature
  - Installation losses: typically 5-10%
  - What transmission limits do I need and can these be achieved within the allotted mass budget?

Initial Sizing and Power Model Calculations

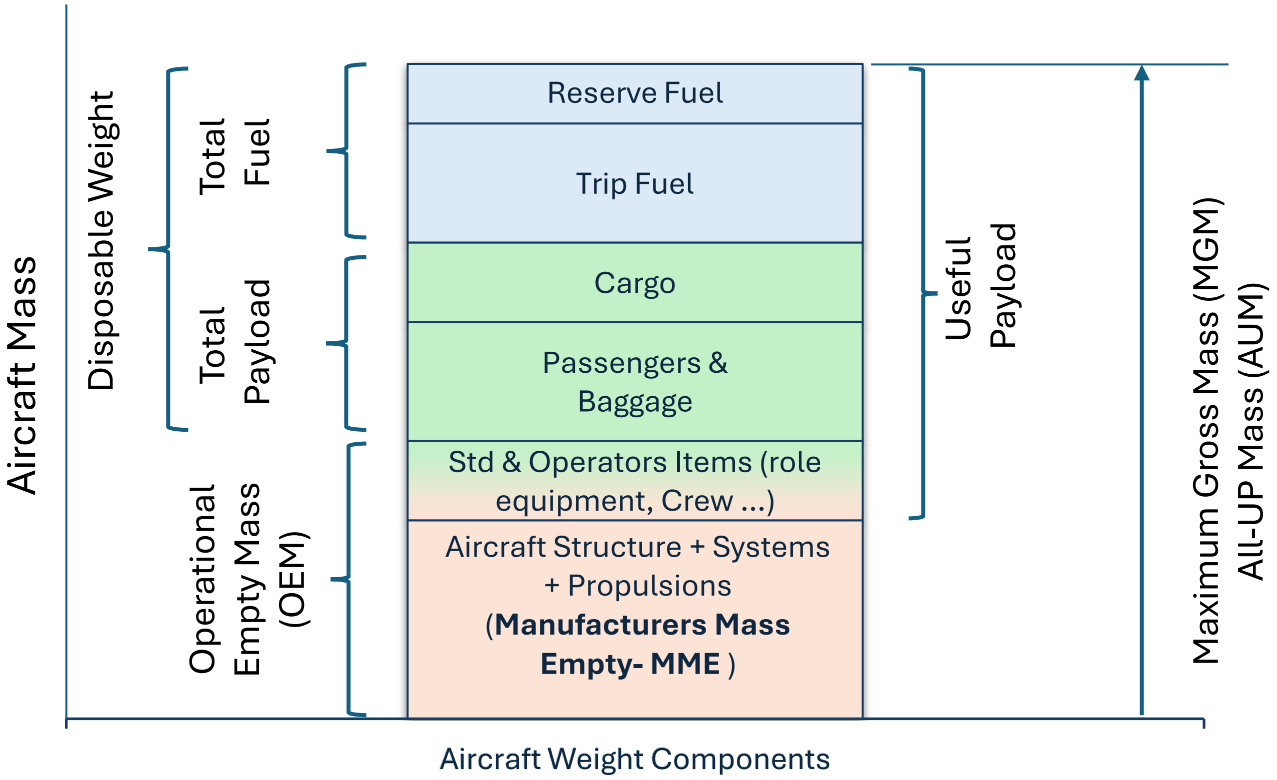
Initial Sizing - Estimate/calculate :

- Weights (payload, fuel, All Up Weight…)
- Rotor(s) parameters (disc area, blade area, diameter, rotor speed, chord, number of blades, technology …)
- Airframe drag
- Systems’ power consumption (electric, hydraulic, pneumatic)
- Engine and transmission losses

Power model:

- Calculate required power (select propulsion solution)
- Calculate mission fuel weight
- Refine weight and size of various systems (engines, transmission, rotors, etc.)

Helicopter Mass (Weight) Breakdown



Aircraft mass breakdown in one trip:

$$Mass_{final} = Mass_{initial} - \text{Trip Fuel}$$

Definitions

Disposable weight fraction (DWF)	Disposable weight (DW) / All Up Weight (AUW)
Empty weight fraction (EWF)	Empty weight (EW) / All Up Weight (AUW)
Useful weight fraction (UWF)	Useful weight (UW) / All Up Weight (AUW)
Fuel load fraction (FLF)	Fuel load (FL) / Payload (PL)

Initial Sizing

From specification

Rules of thumb/ judgments

Calculated

Disposable Weight (DW)

Payload (PL)

Fuel load
FL = 100%*PL

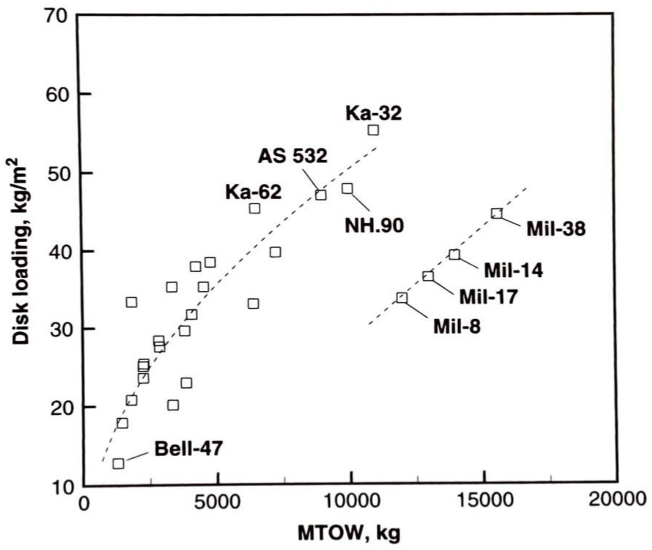
Disposable Weight Fraction (DWF)
DWF = 25% - 40%

All Up Weight (AUW)
AUW = MDW/DWF

Disc Loading (DL)
DL = AUW / A_{disc}

Rotor Disc Area (Adisc)
Adisc=AUW/DL

Rotor Diameter



(Figure adopted from Filippone 2006)

Rotor Design Process

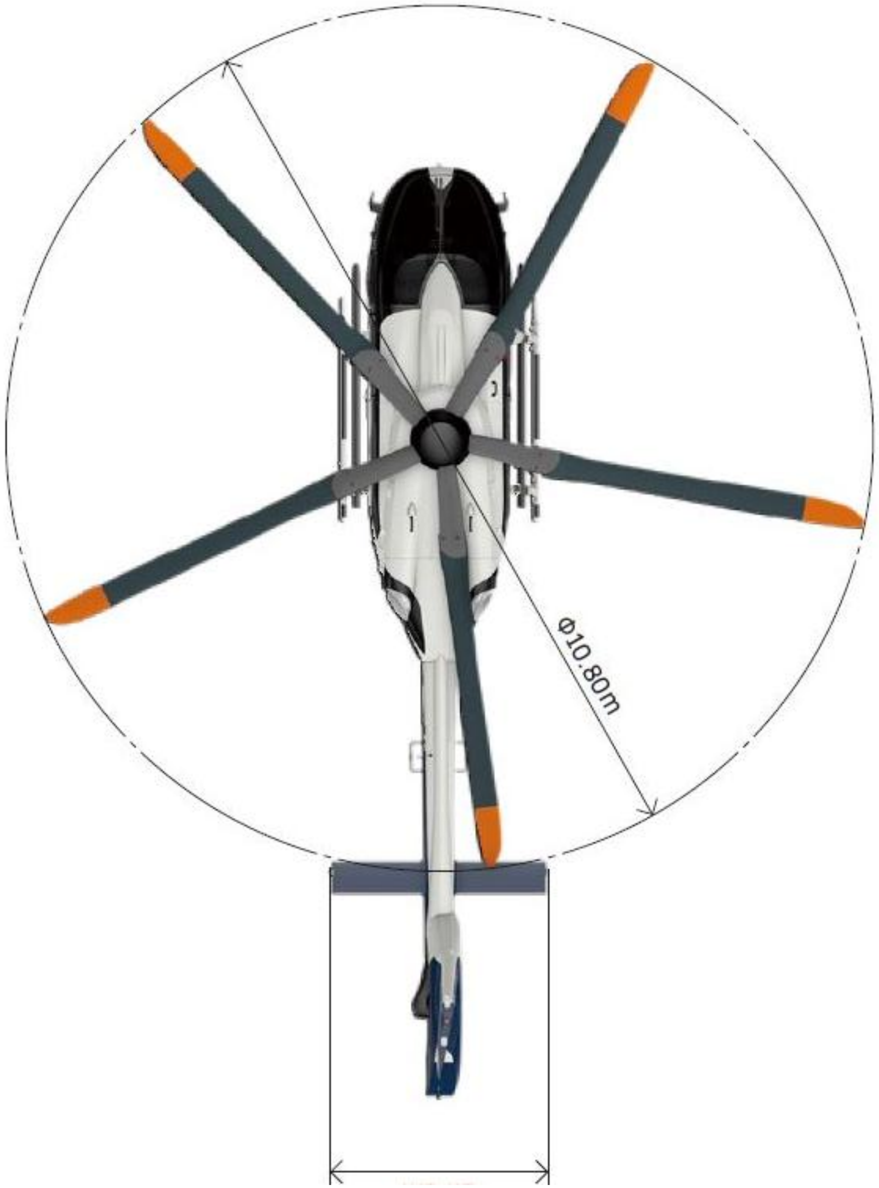
The design process is always iterative but there is a general order to the definition of rotor parameters and the various analyses required to select them:

- Rotor Diameter
- Rotor Tip Speed
- Total rotor blade area
- Number of blades – and hence blade chord

- Blade Mass
- Blade Flap Stiffness
- Blade Mode Natural Frequencies
- Lag Damping

Rotor Sizing Overview

- Rotor diameter is primarily defined to optimise aircraft hover performance.
- Rotor tip speed is defined on the basis of providing the requisite rotor performance and providing acceptable noise levels and Mach Number limits.
  - The chosen rotor speed will have a cross-discipline impact on transmission design
- The selection of blade aerodynamic technology will influence the required total blade area of the rotor.
- Blade area is to be defined on the basis of achieving a forward flight envelope to meet specification requirements. This defines the parameter which is the product of blade chord and blade number.
  - A parameter variation study of the effects of selecting different combinations of blade number and blade chord will be expected.



Rotor Diameter

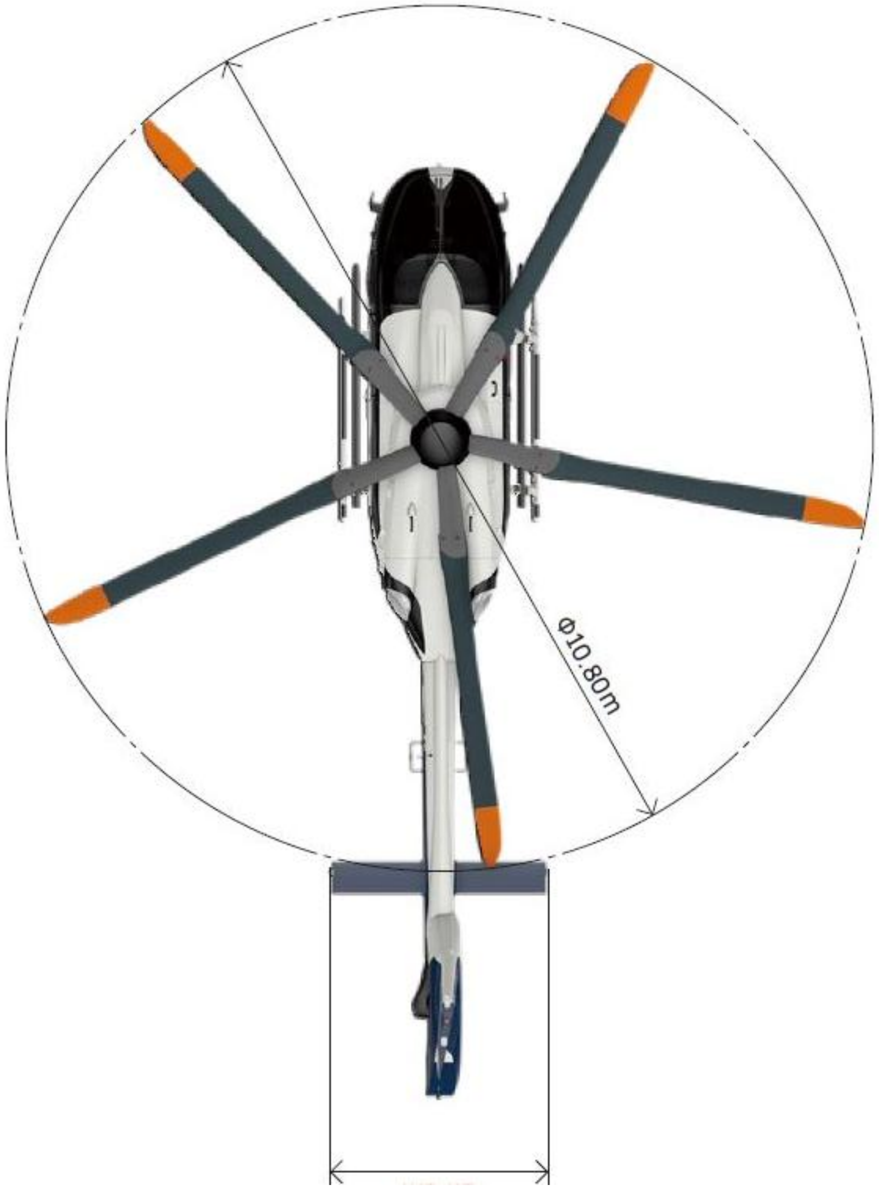
With an initial estimate of rotor area, rotor diameter is based on achieving the specified hover performance.

Blade radius can also be constrained by other limitations e.g. fuselage length, transportation stowage requirements (aircraft and ship), restricted landing zones.

- A feasible range of disc loadings will be specified

Relatively small rotor diameters will result in high Disc Loadings, wake velocities and hover powers.

Relatively large rotor diameters will require increased fuselage length (for adequate rotor separation) and hence higher aircraft weight.



Rotor Tip Speed

Rotor Tip Speed must be sufficiently high to provide the requisite rotor performance

Rotor Tip Speed must be constrained to provide acceptable noise levels to meet certification requirements

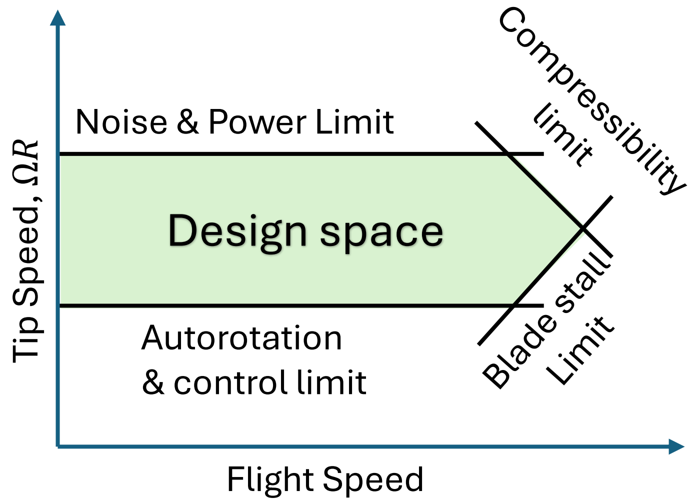
— Rotor noise is a function of the <u>sixth</u> power of tip speed!

Relatively low rotor speeds will: -

- Increase rotor torque levels and will therefore penalise transmission design.
- Require increased blade area (hence weight) to meet performance requirements.

Relatively high rotor speeds will: -

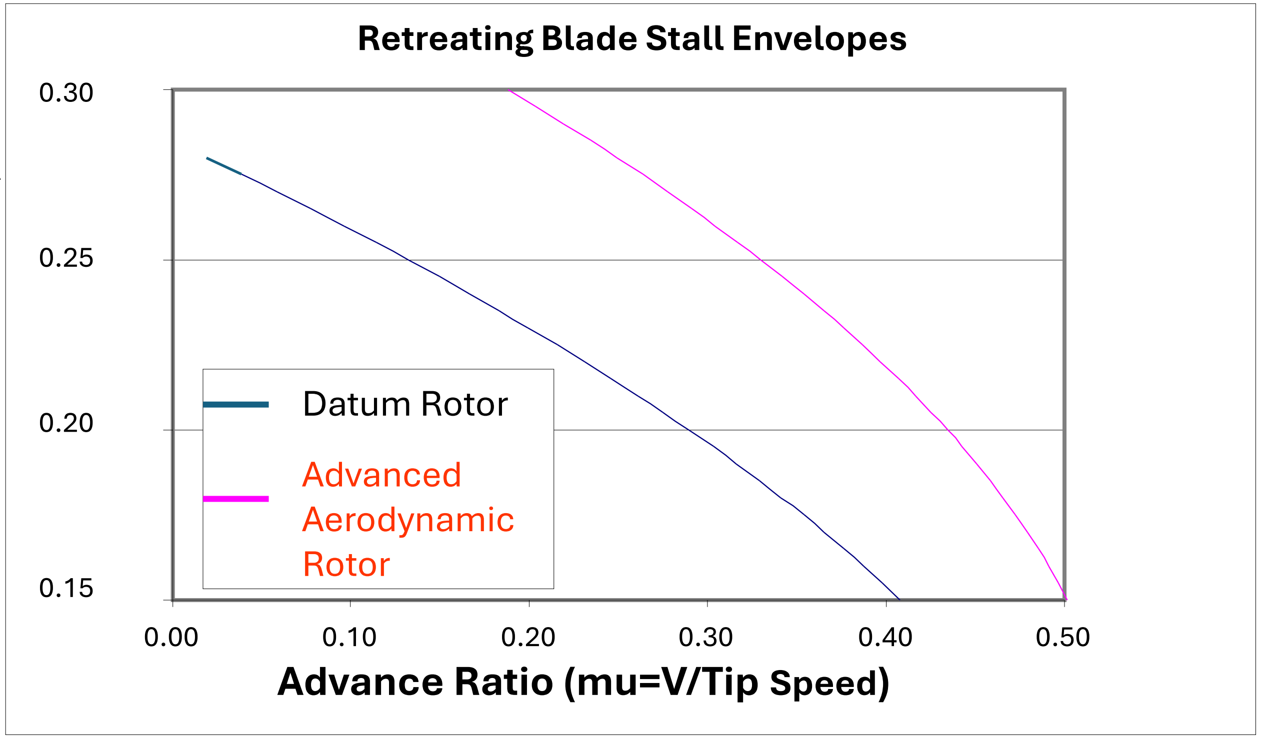
- Generate unacceptable noise levels.
- Result in unacceptably high Mach Numbers (>0.97) at high speed conditions on the advancing blade tip.



Rotor Blade Area

The total blade area (NcR) is defined on the basis of achieving the required thrust and forward speed envelope.

- The blade loading C_W/s is defined as:
  - $C_W/s = \dfrac{T}{0.5\,\rho\,N\,c\,R\,(\Omega R)^2}$
- A range of blade aerodynamic technologies are available.



- A low-level aerodynamic technology will result in increased blade area, drag and weight.
- Beware that an advanced aerodynamic technology may lead to inadequate blade area and hence rotational inertia for auto-rotation purposes.

Note that, for a given advance ratio limit, low tip speeds will also reduce maximum speed capability, as well as increase blade area

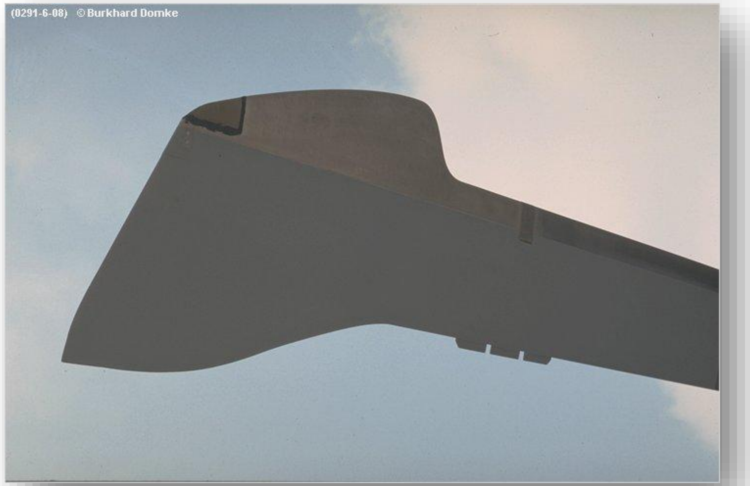
Rotor blade technology

High speed is limited by:

Advancing blade compressibility (wave drag)

Retreating blade stall (and reverse flow regions)

BERP rotor blade tip



Blue Edge Tip

Blade Number vs Blade Chord

Knowing the blade area the remaining blade sizing choice is to select the blade chord and the number of blades.

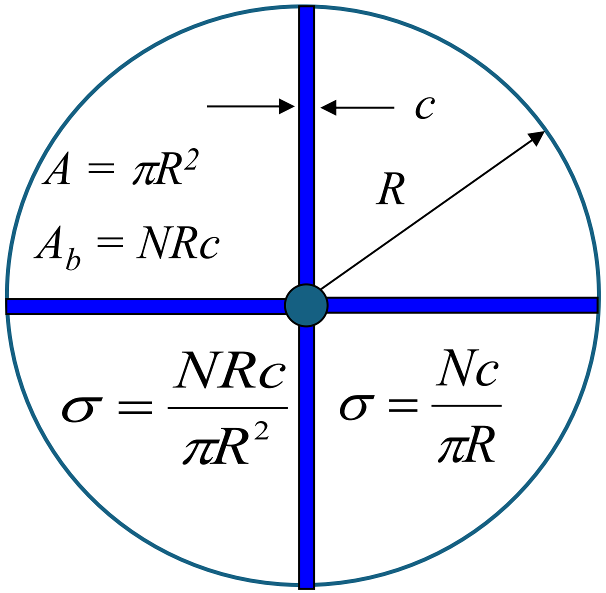
If the blade chord is too low the blade aspect (R/c) will be high

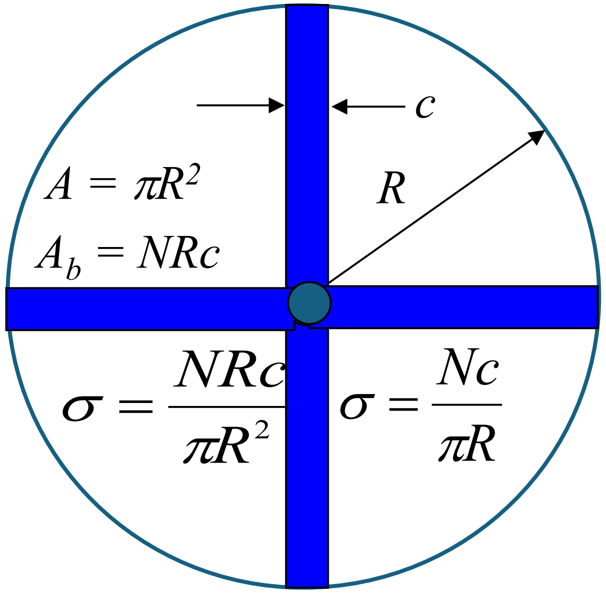
High aspect ratio blades can lead to low blade torsional stiffness with tendency towards rotor instabilities and handling problems.

- For this reason, an **Aspect Ratio limit is imposed (<21).**

A large blade chord will lead to higher profile power levels, higher blade mass and increased hub mass to withstand higher centrifugal load.

- A rotor weight limit will be prescribed.





Blade Number vs Blade Chord

A large blade chord will mean a low number of blades.

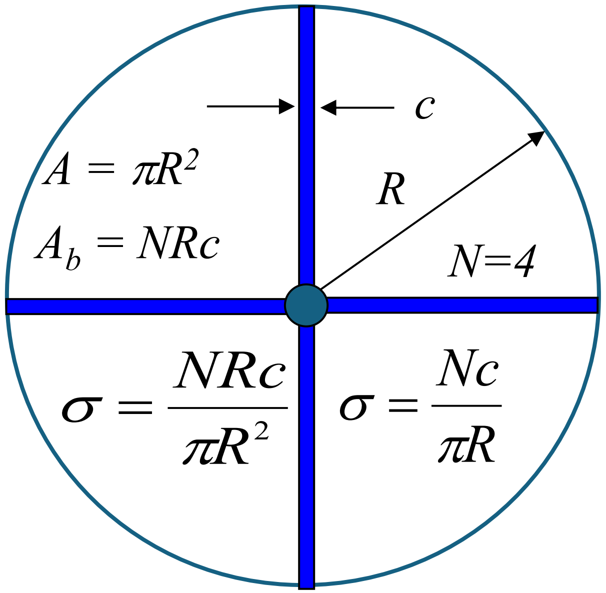
- Good for reduced part count and cost, but.....

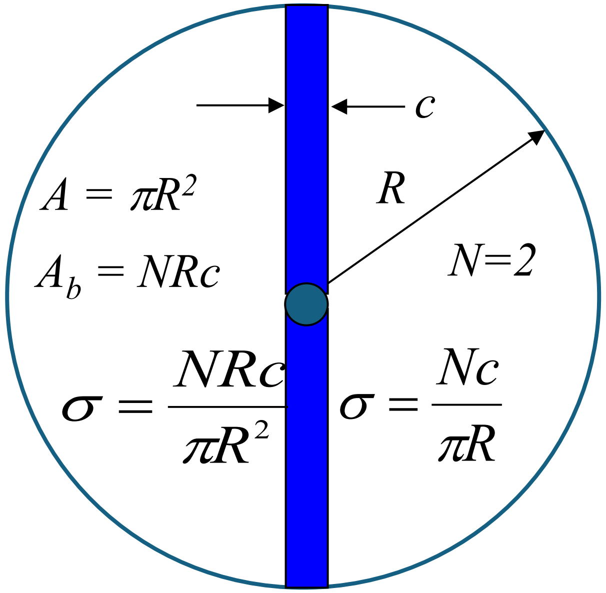
Vibration, which is a critical issue for a helicopter, increases with a lower number of blades.

Conversely, too many blades will result in a lower chord and a potentially unacceptable high blade aspect ratio.

A balanced decision should be based upon a rotor parametric variational analyses of: vibration, rotor mass, aspect ratio and rotational inertia for auto-rotational capability.

Once the rotor dimensions have been fixed the structural design of the rotor can be defined.

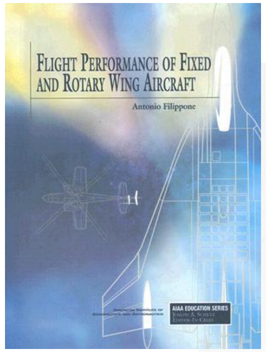




Questions

References and recommended textbooks

[1] Antonio Filippone, **Flight Performance of Fixed and Rotary Wing Aircraft**, American Institute of Aeronautics and Astronautics, Inc (AIAA) and Butterworth-Heinmann (Elsevier), 2006.



[2] Wieslaw Zenon Stepniewski and C. N. Keys, **Rotary-wing Aerodynamics**, Courier Corporation, 1984,