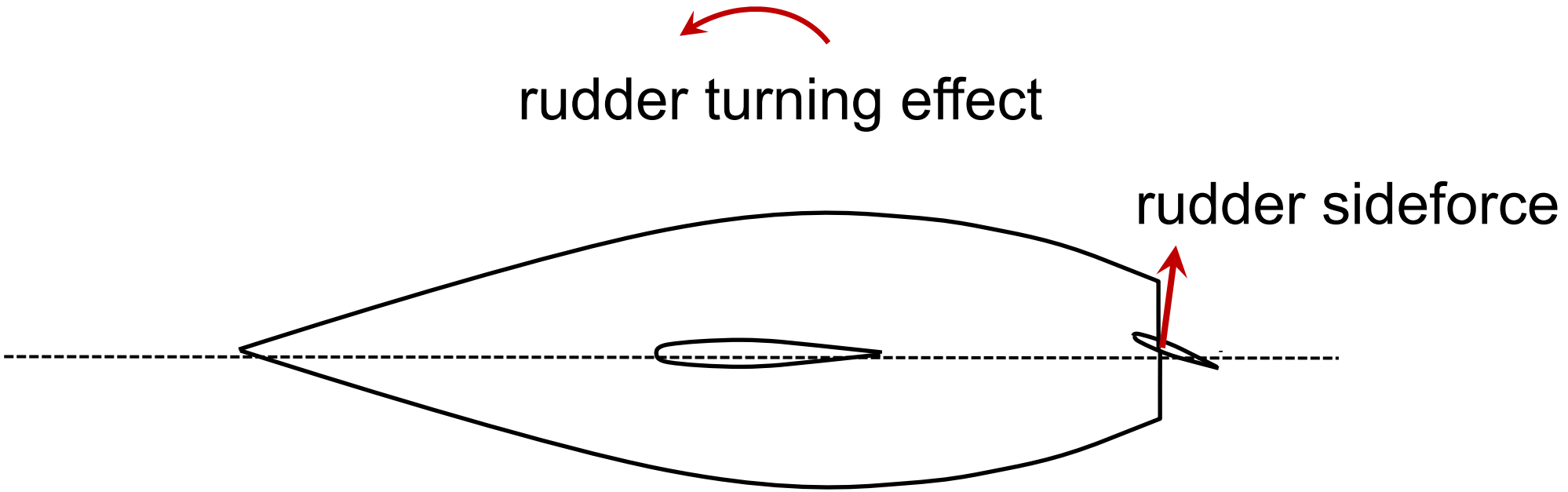
Rudder mysteries

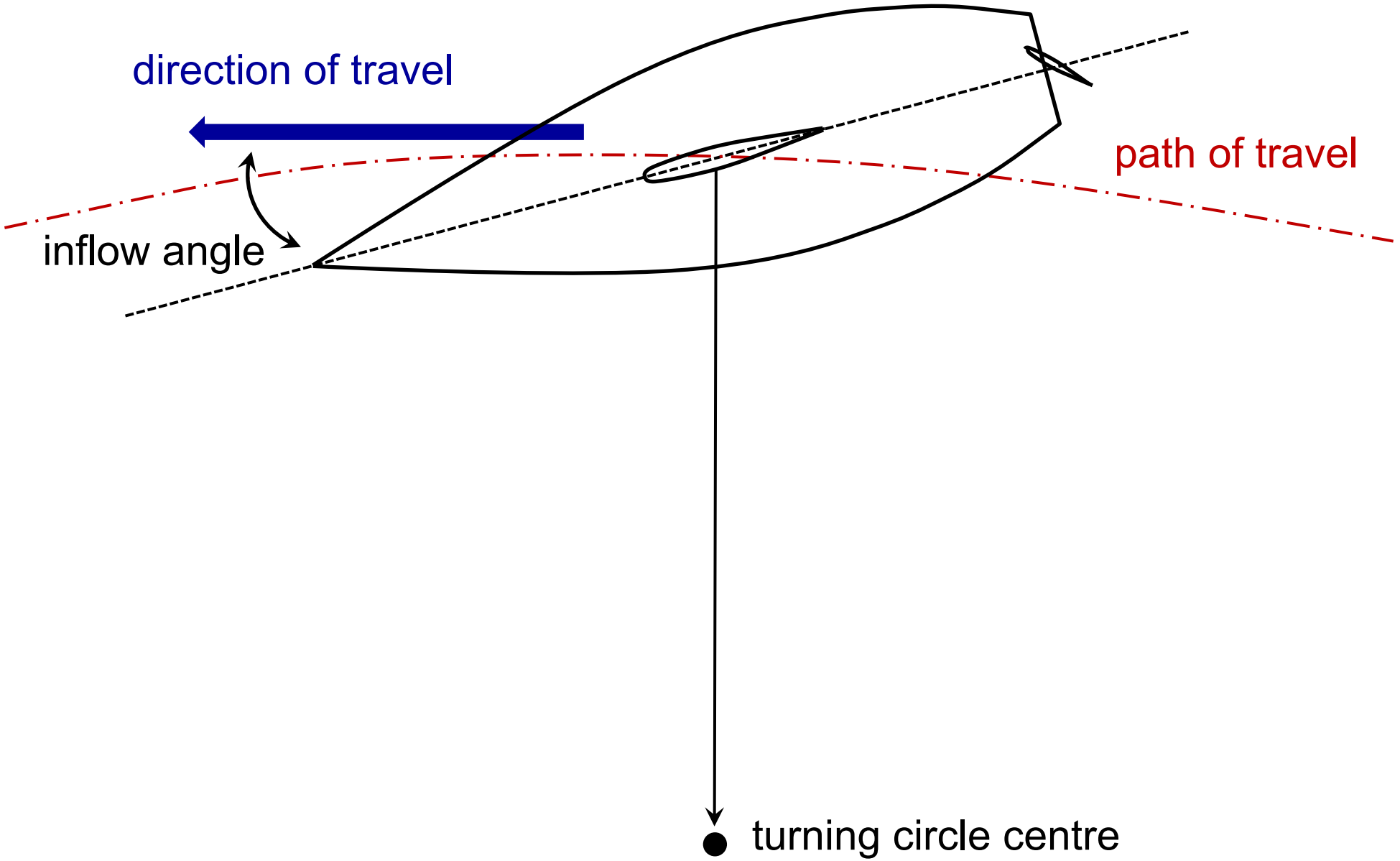
Kim Klaka

Rudder Mysteries

1. What shape should a rudder be?
2. What is rudder balance?
3. Is my rudder cavitating?
4. Why do rudders break?

What does a rudder do?



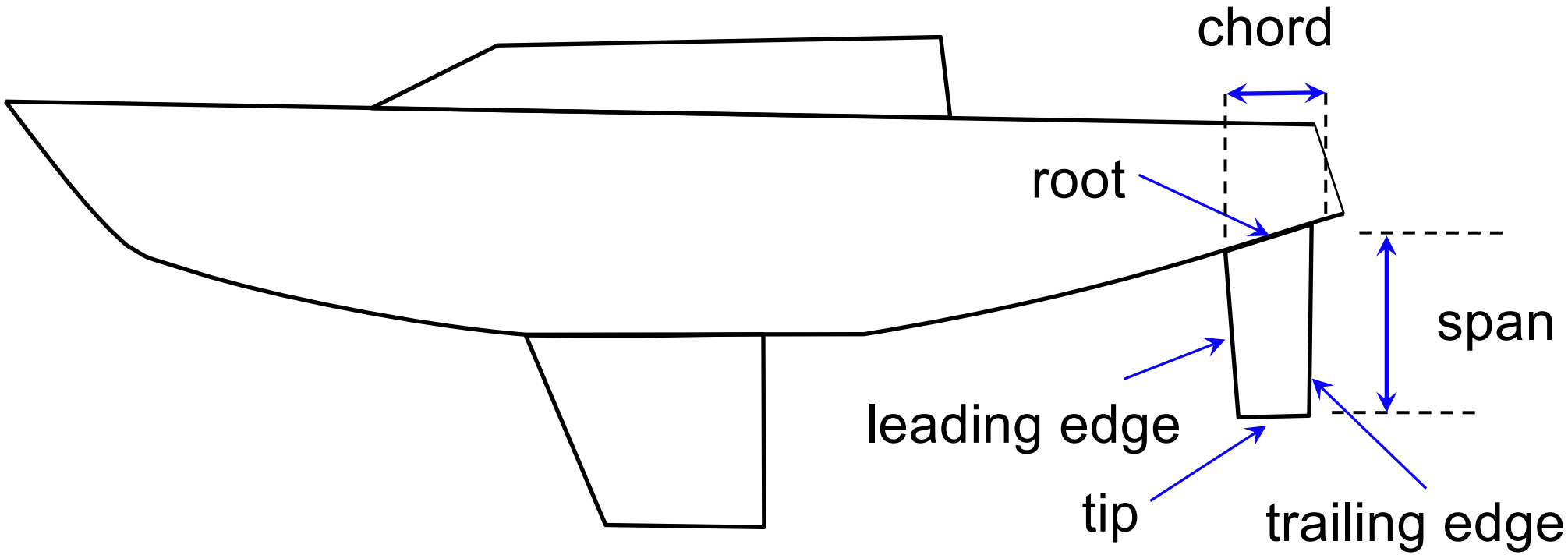

direction of travel
path of travel
inflow angle
turning circle centre

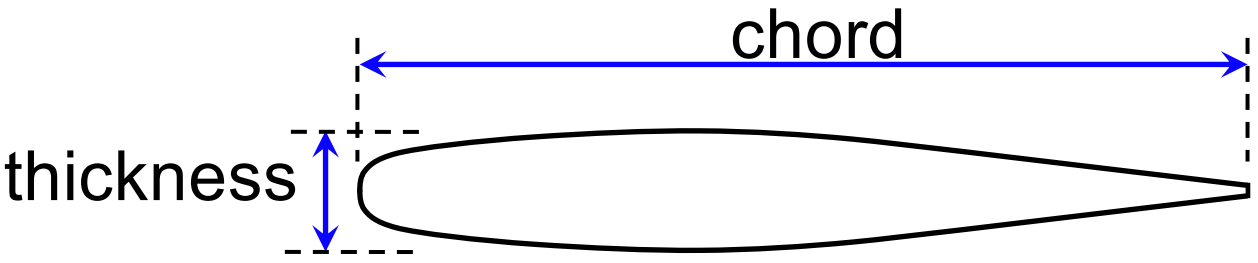
1. What shape should a rudder be?

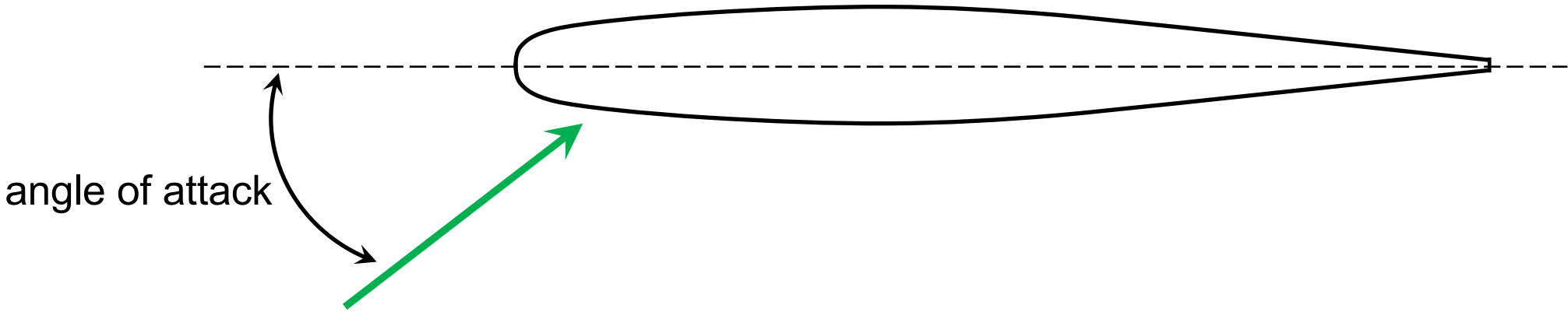
First, how is the shape described?.....

1. What shape should a rudder be?

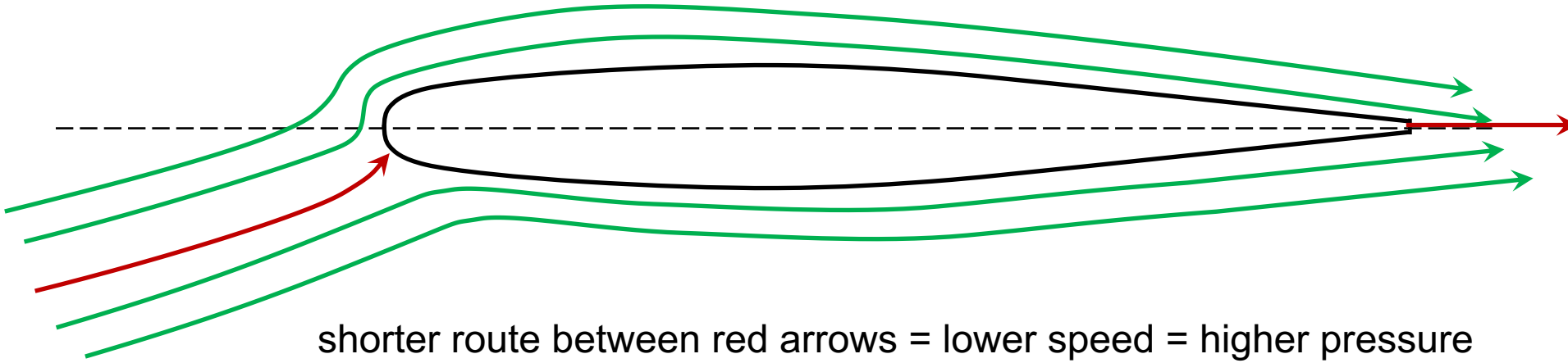
Some definitions….



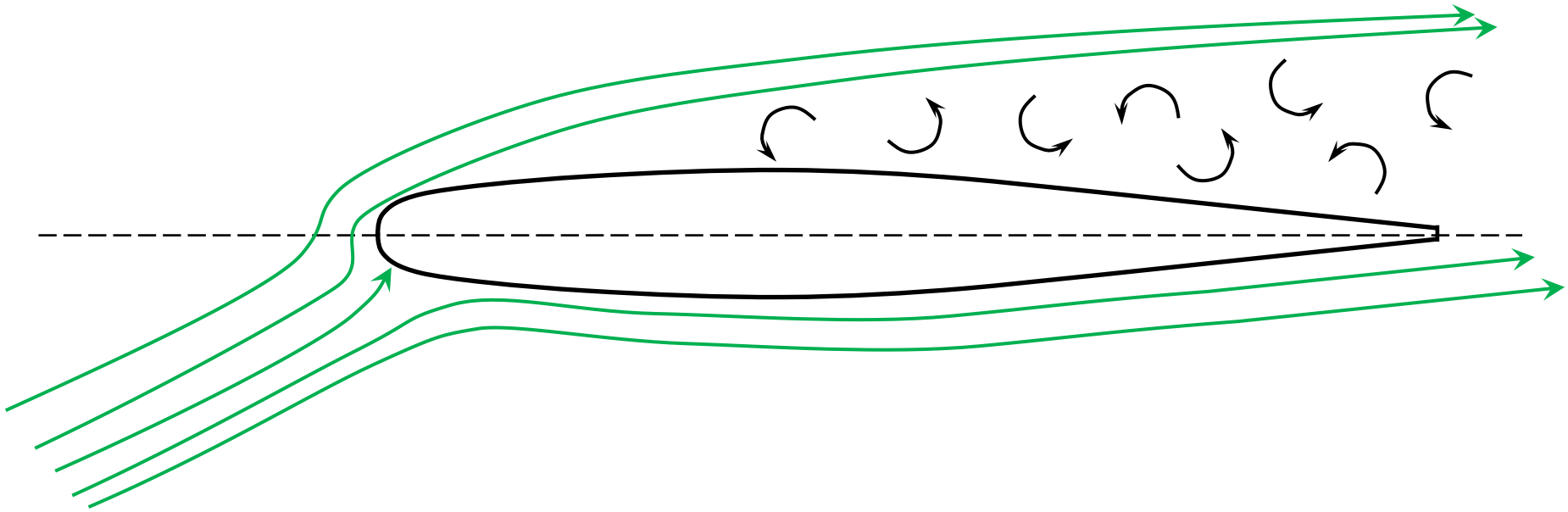


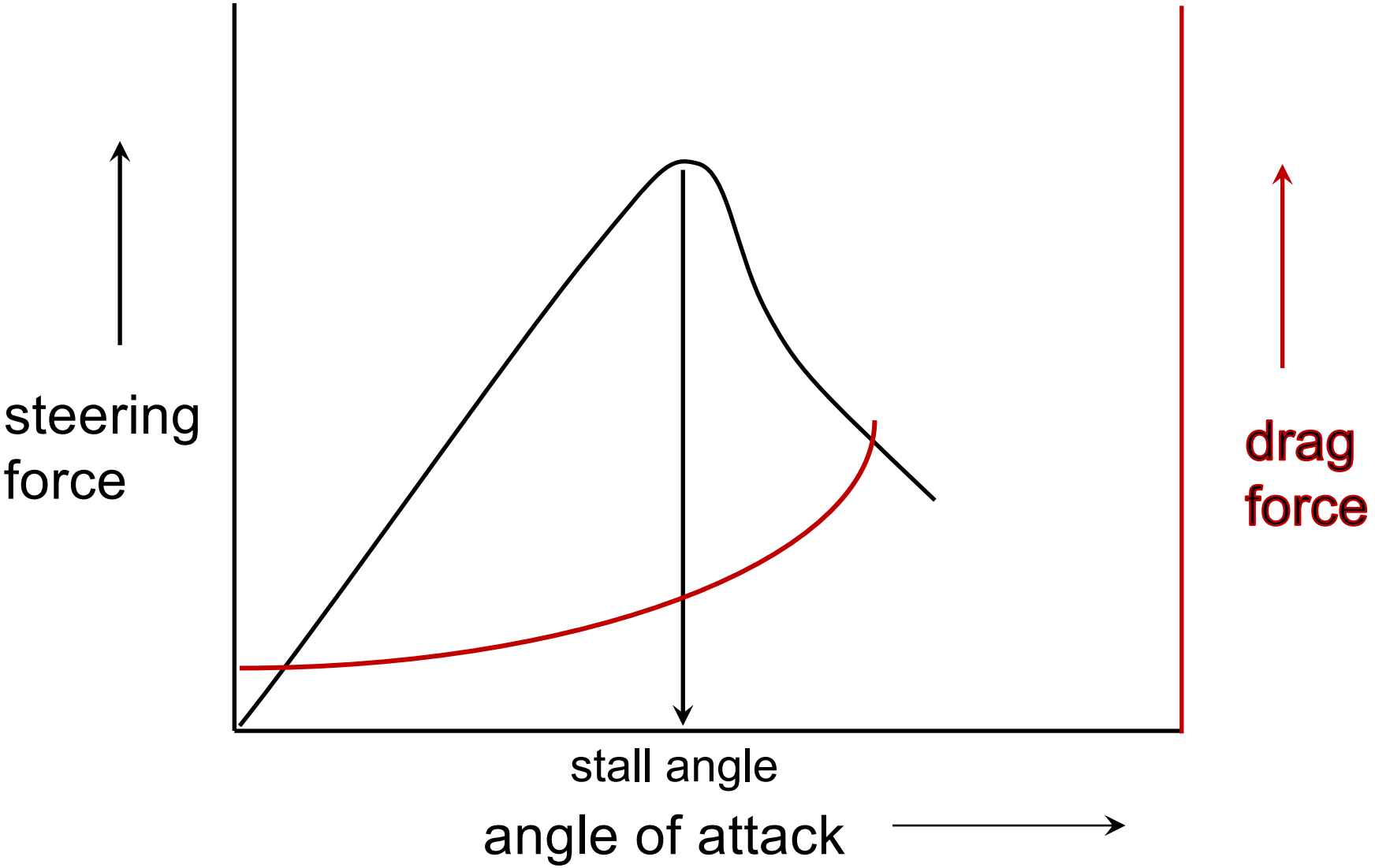

angle of attack

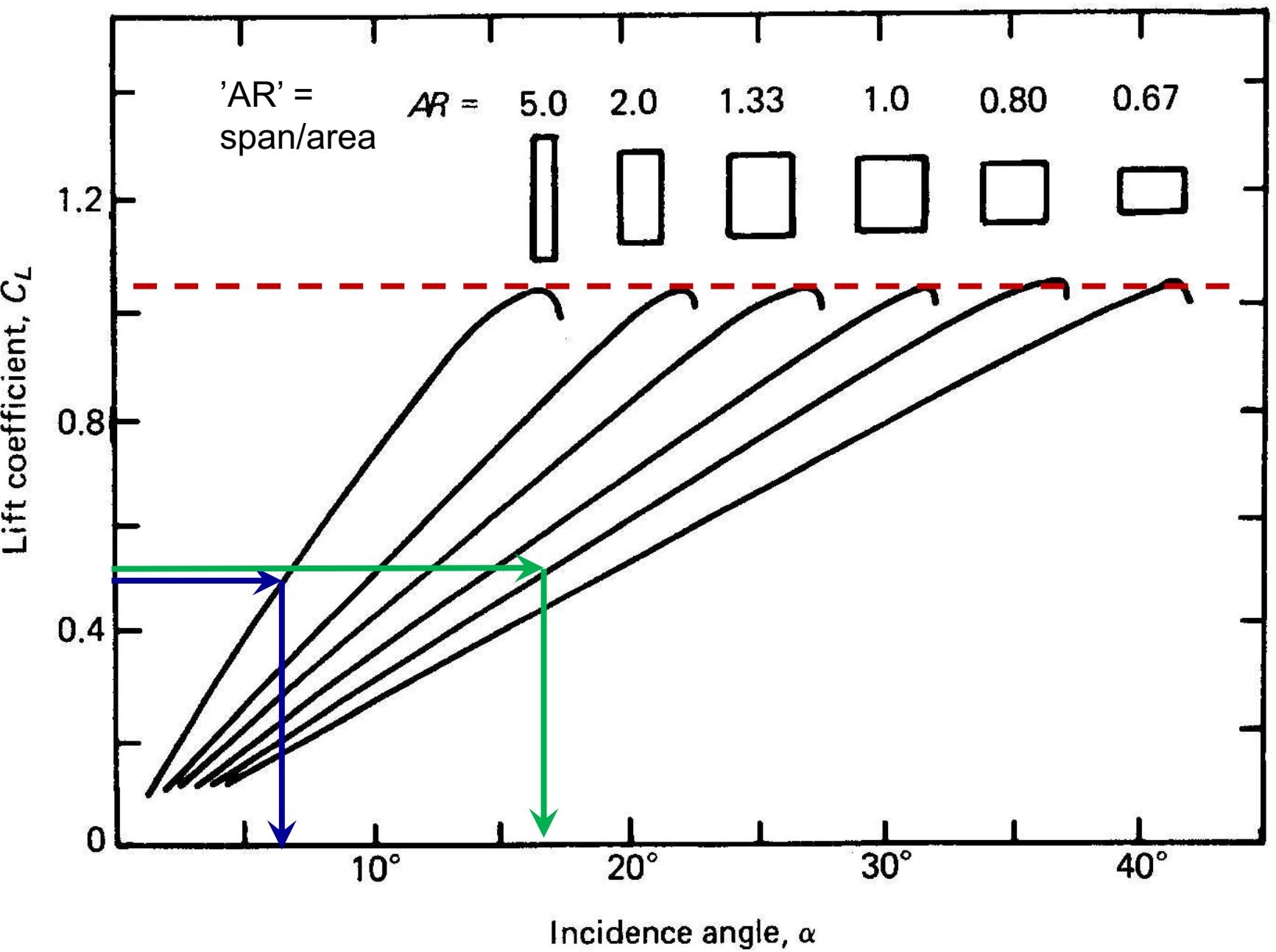
Longer route between red arrows = higher speed = lower pressure



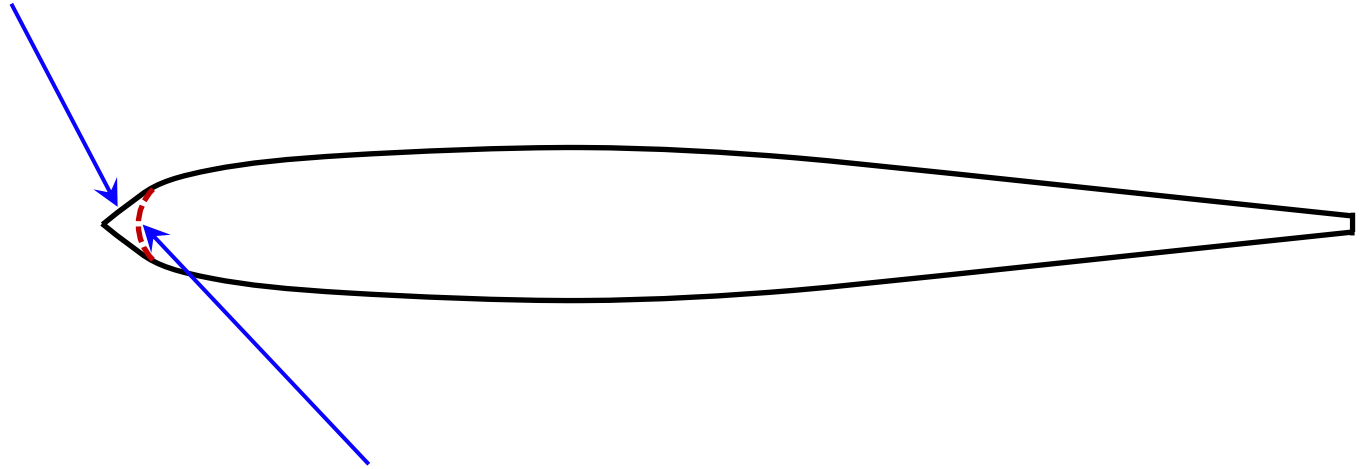
shorter route between red arrows = lower speed = higher pressure




steering force
drag force
stall angle
angle of attack

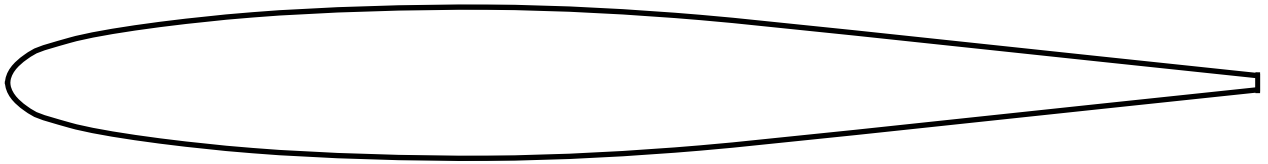

'AR' =
span/area
AR = 5.0 2.0 1.33 1.0 0.80 0.67
1.2
0.8
0.4
0
Lift coefficient, C_L
10°
20°
30°
40°
Incidence angle, α

bad sharp leading edge

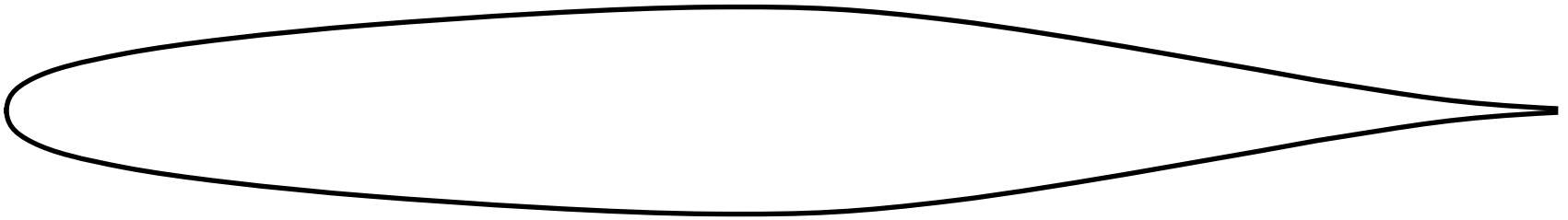


good radiused leading edge

NACA 0012

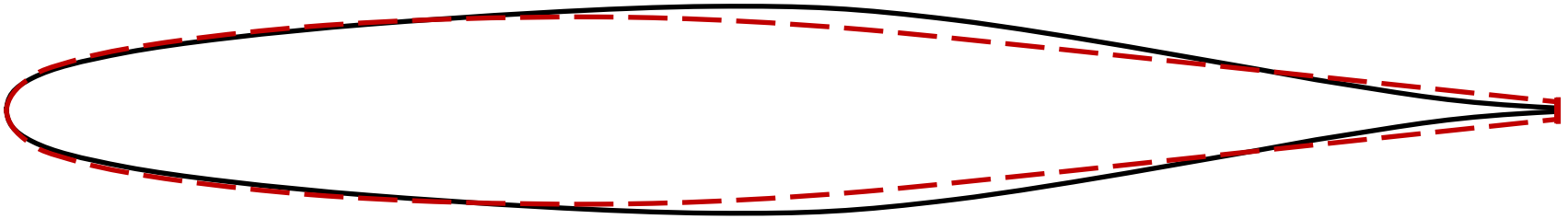


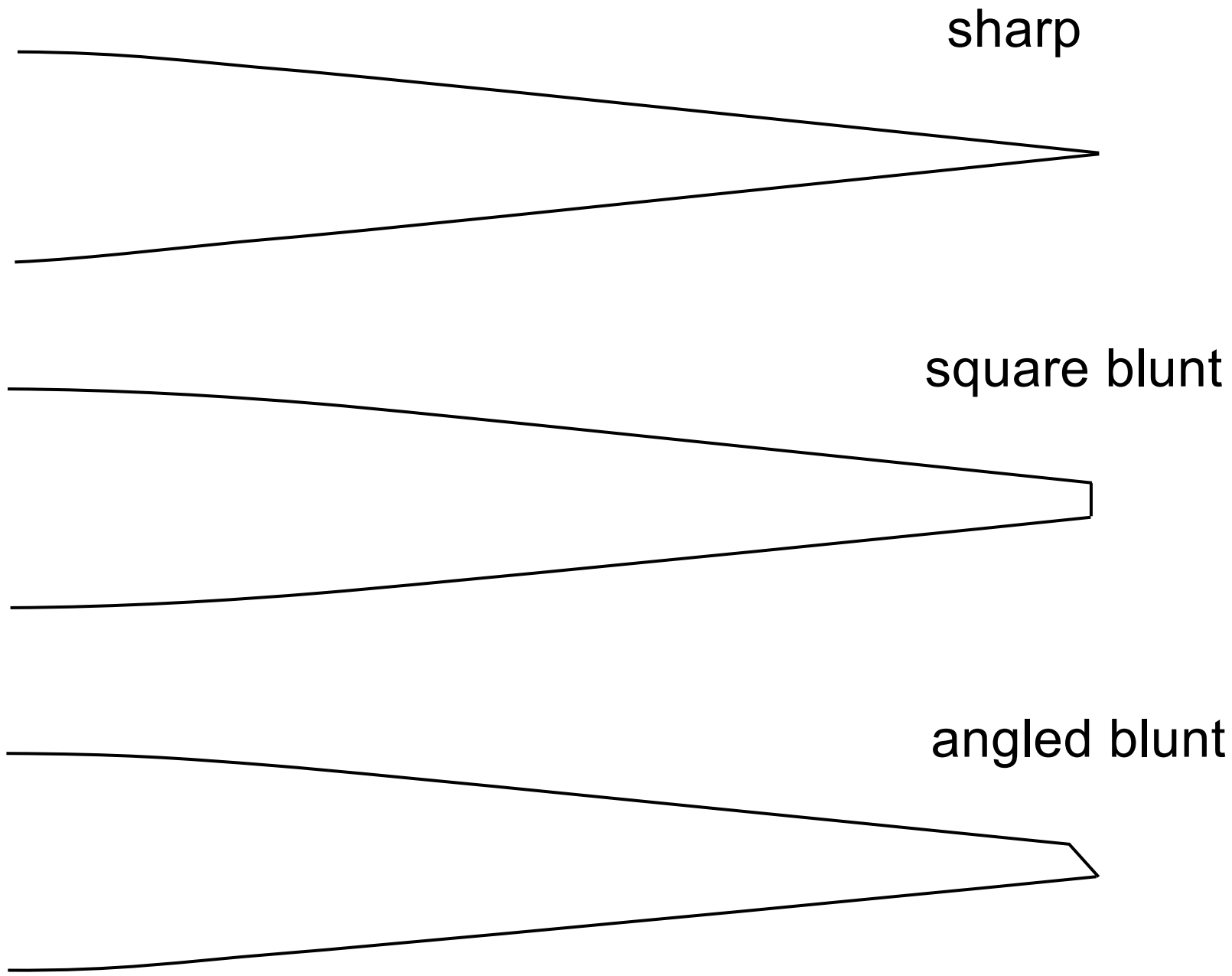
NACA 66-012



NACA 0012

NACA 66-012




sharp
square blunt
angled blunt

Conclusions on shape:

- High aspect ratio is efficient

a) Leading edge radius (front) is very important

b) Trailing edge not as important

c) Use a conventional aerofoil section e.g. 0012

a)+b)+c) ⟶ need to use templates to get shape right

2. What is rudder balance?

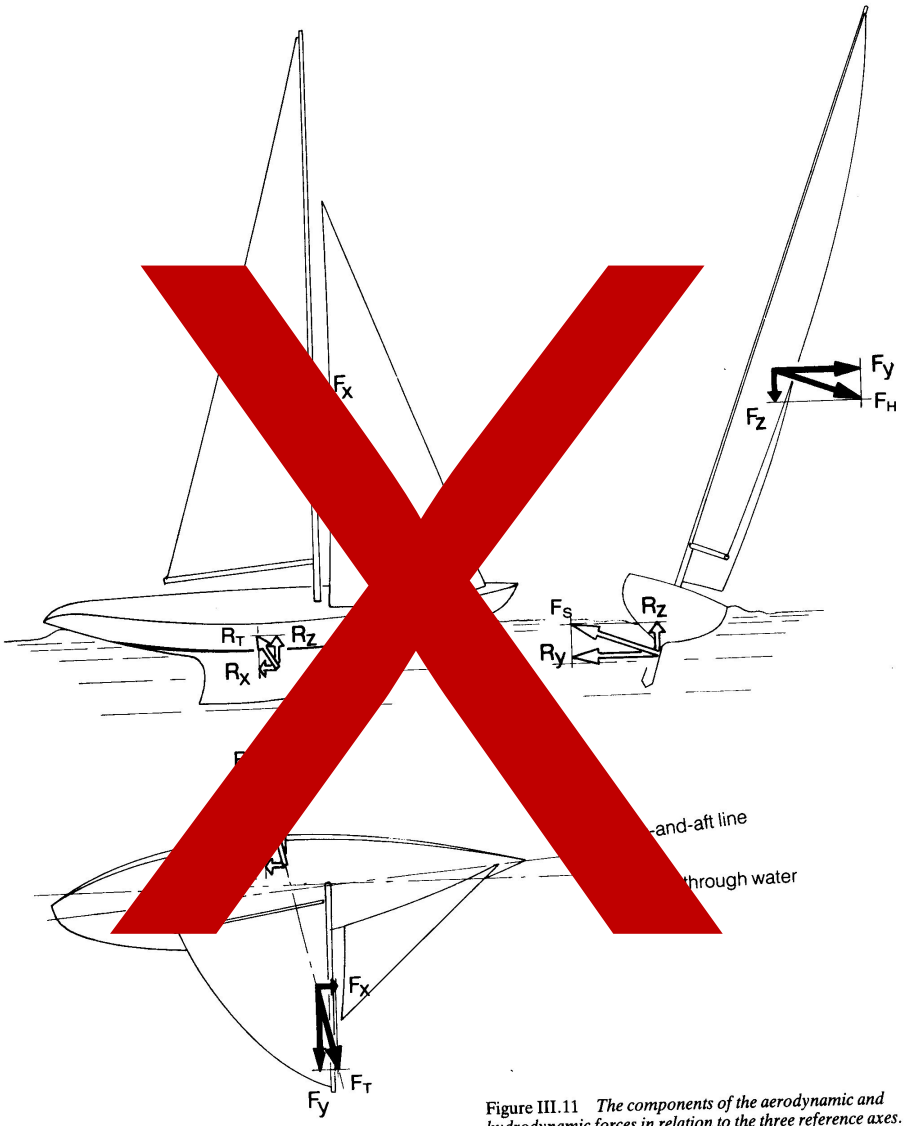
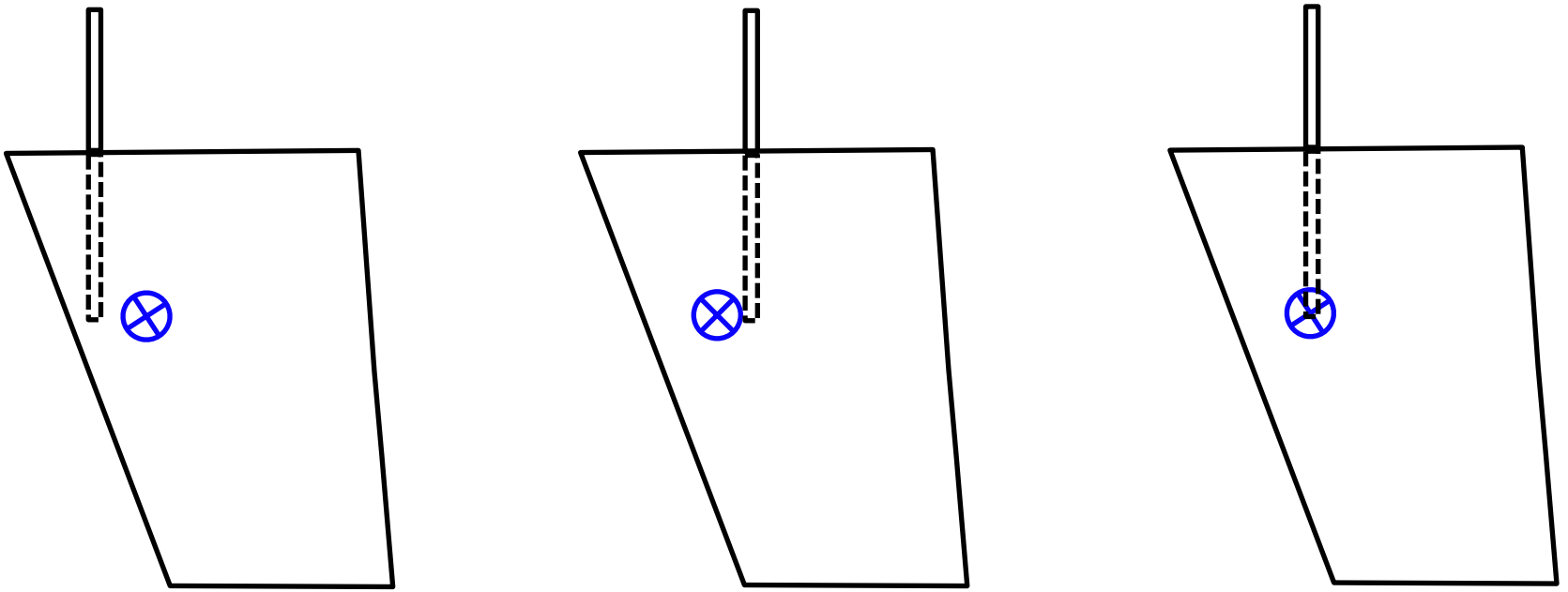


Figure III.11 *The components of the aerodynamic and hydrodynamic forces in relation to the three reference axes. In each case a couple is in equilibrium with another couple*

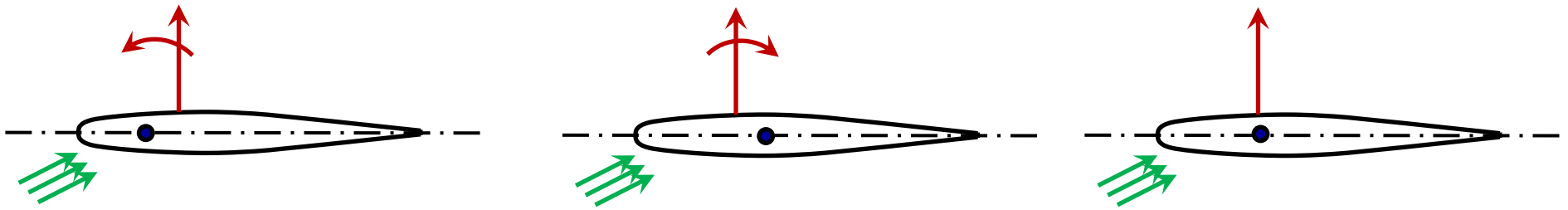
under-balance

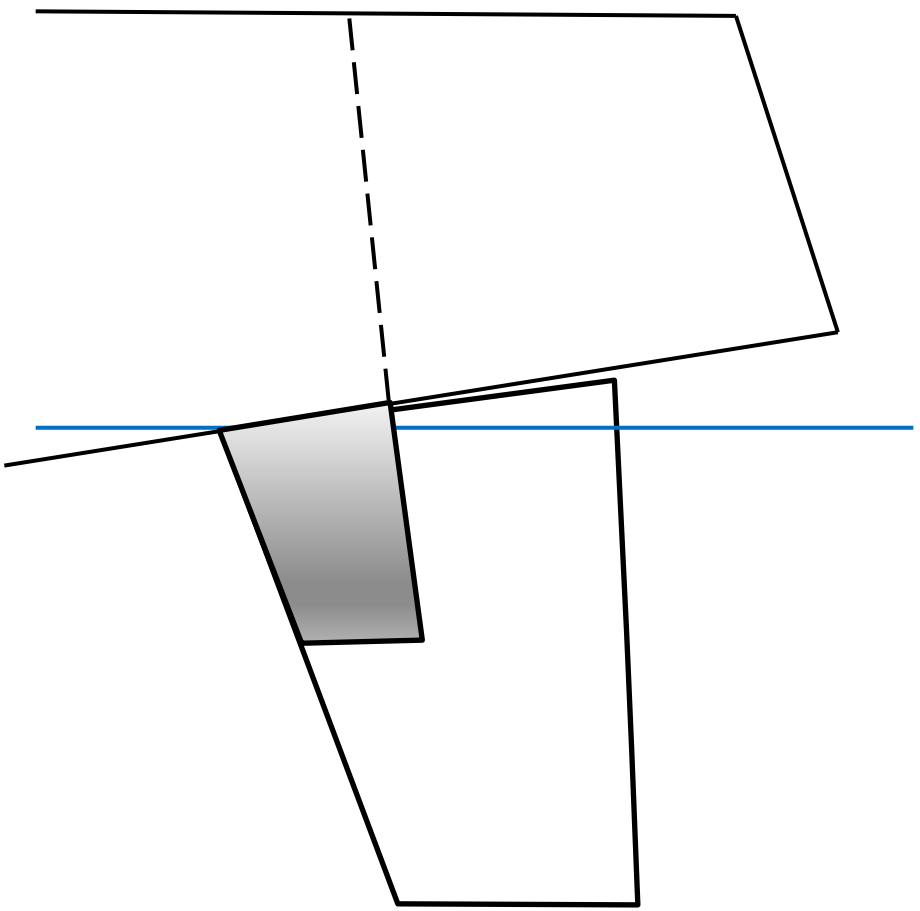
over-balance

neutral balance

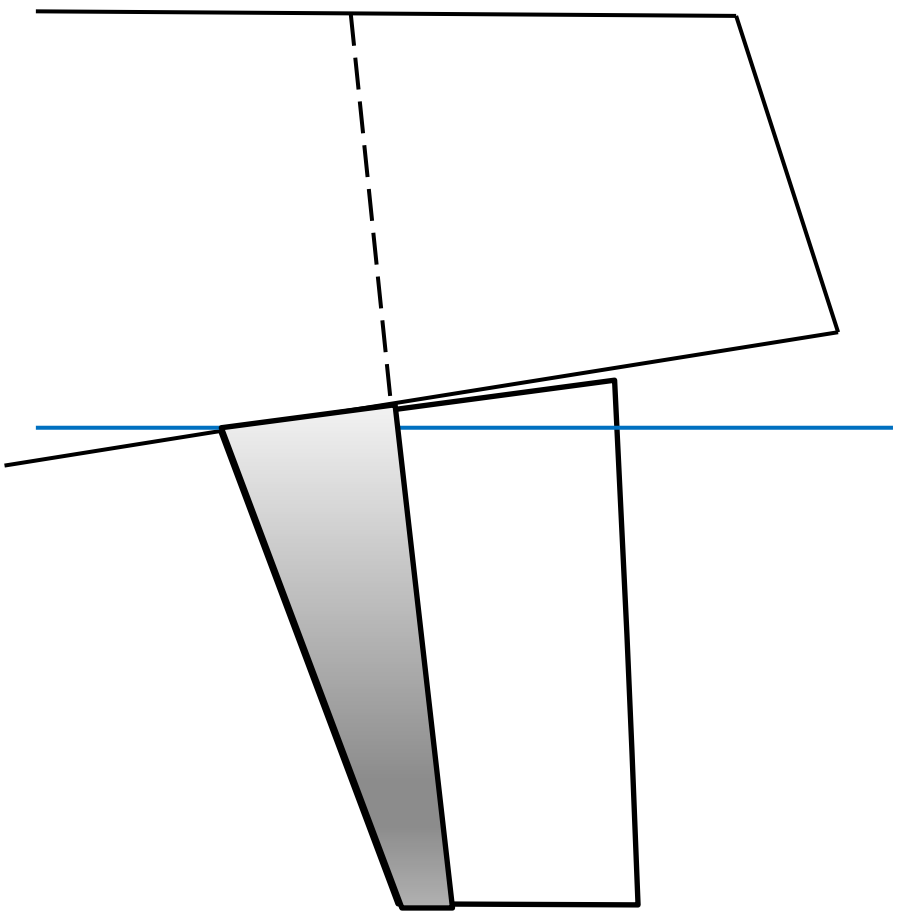


⊗ Point at which steering force acts





“semi-balanced” rudder



skeg rudder

3. Is my rudder cavitating?

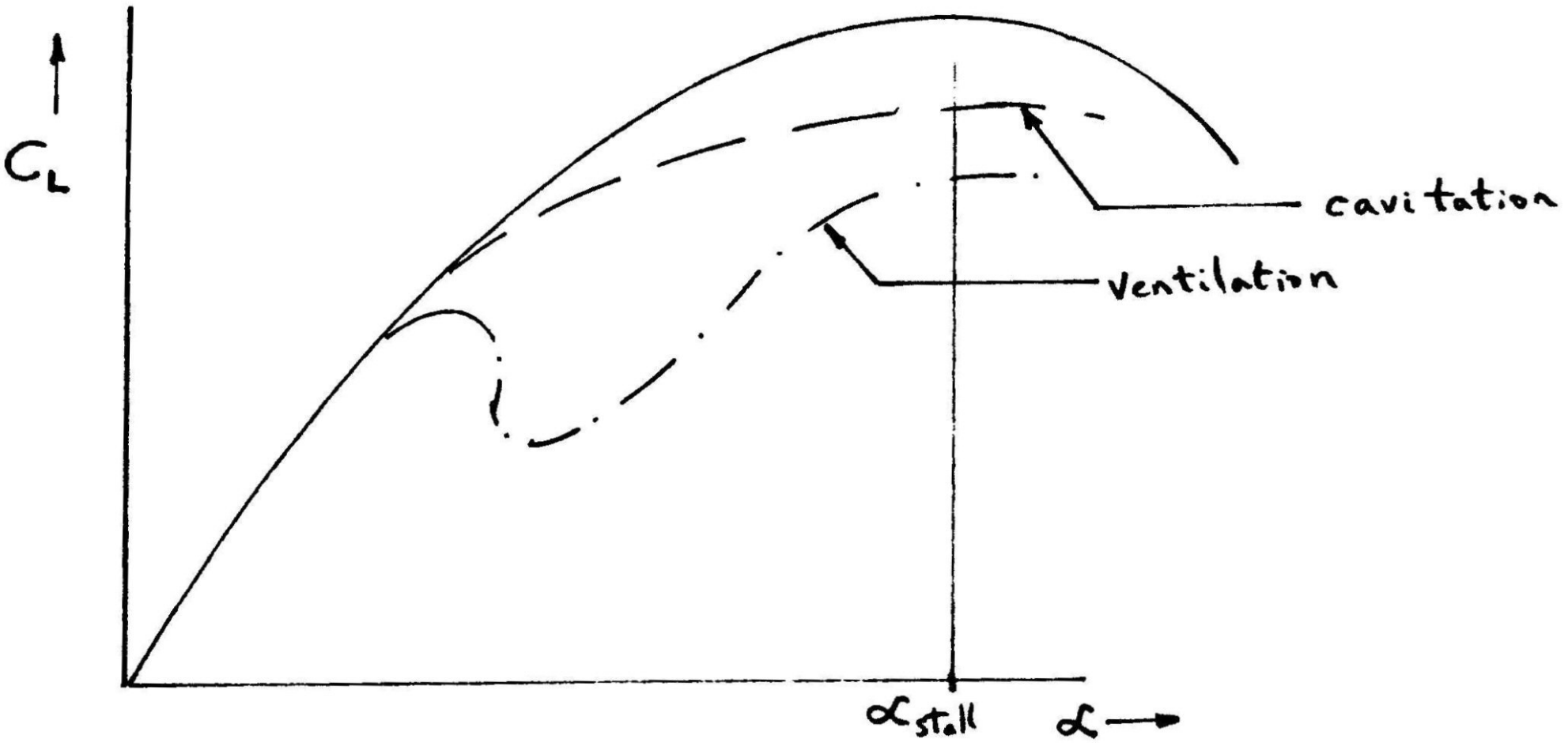
Answer: no!

Cavitation

- Boiling of water due to reduction of pressure rather than increase in temperature
- Causes structural damage due to vapour cavity imploding on the foil
- Limits amount of lift generated

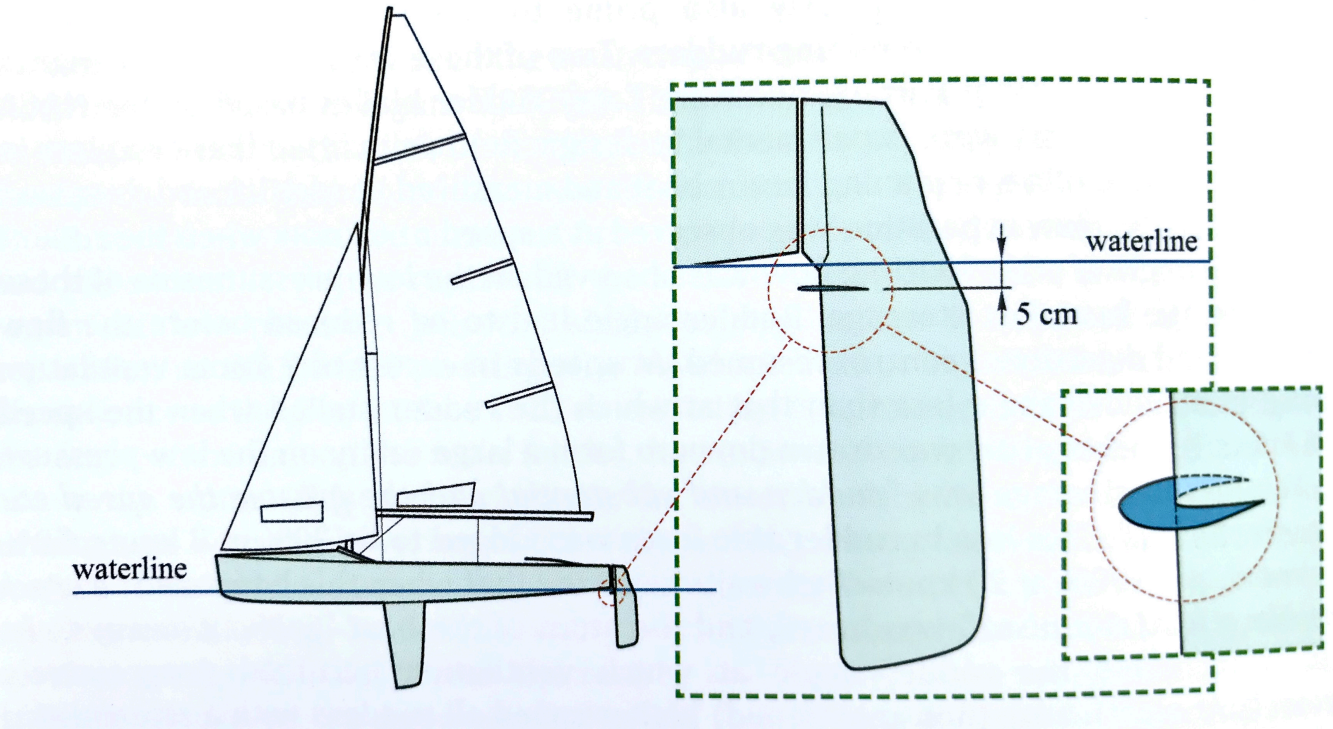
Ventilation

- Low pressure on suction face of foil may be sufficient to draw down air from free surface.
- Foil becomes enveloped in air, leading to loss of lift


C_L
cavitation
Ventilation
α_{stall}
α

Preventing ventilation

- Use smaller helm angles
- Increase rudder area
- Move rudder further below water surface
- Maybe (last resort) add a “fence”

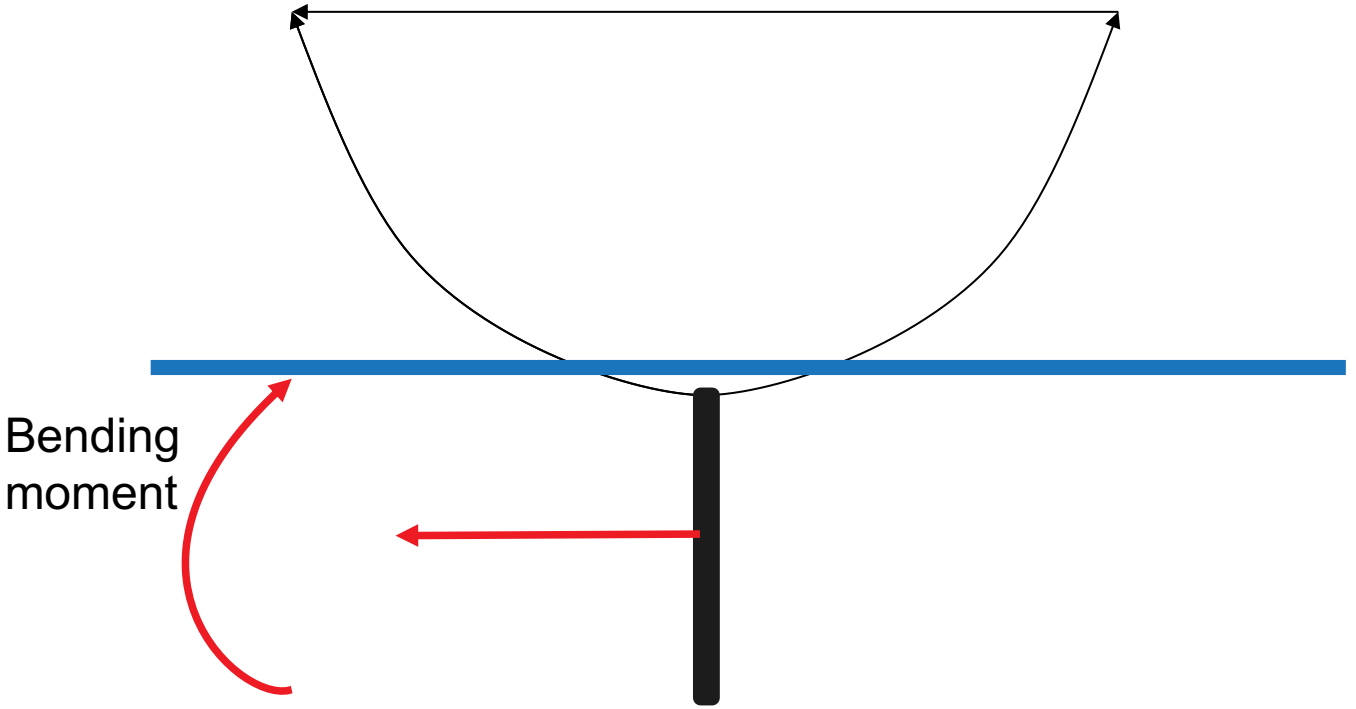


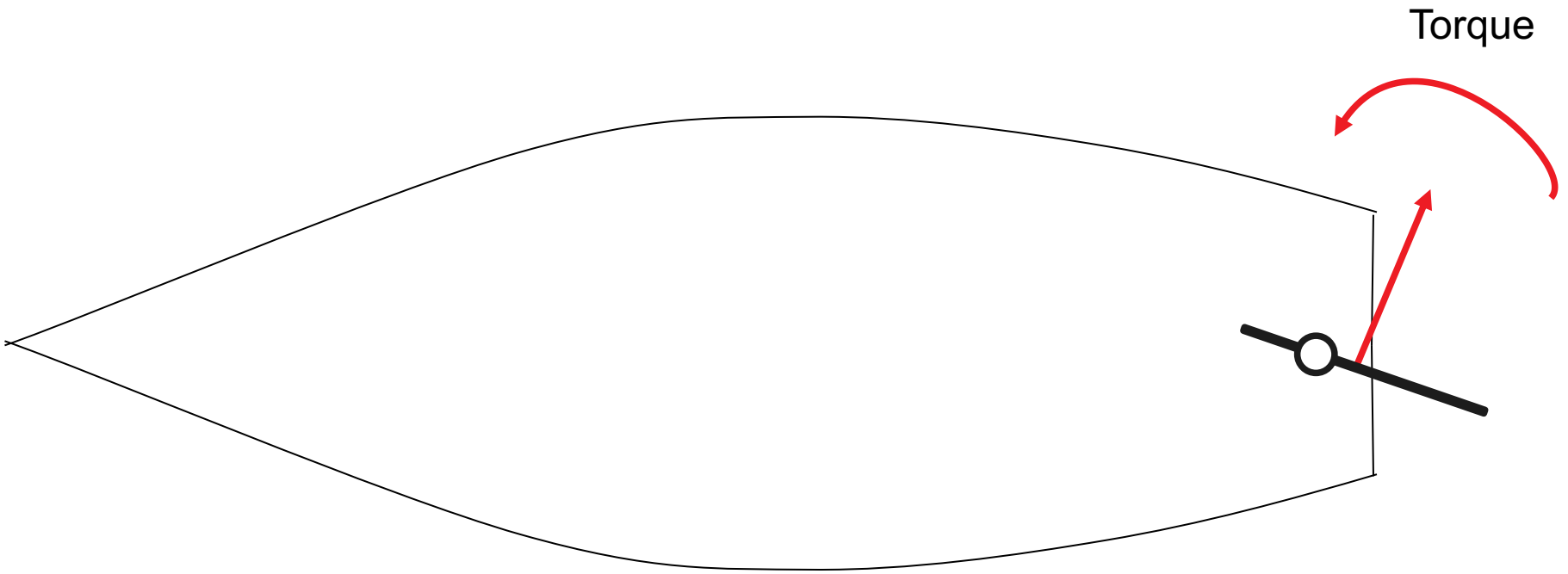
4. Why do yacht rudders break?

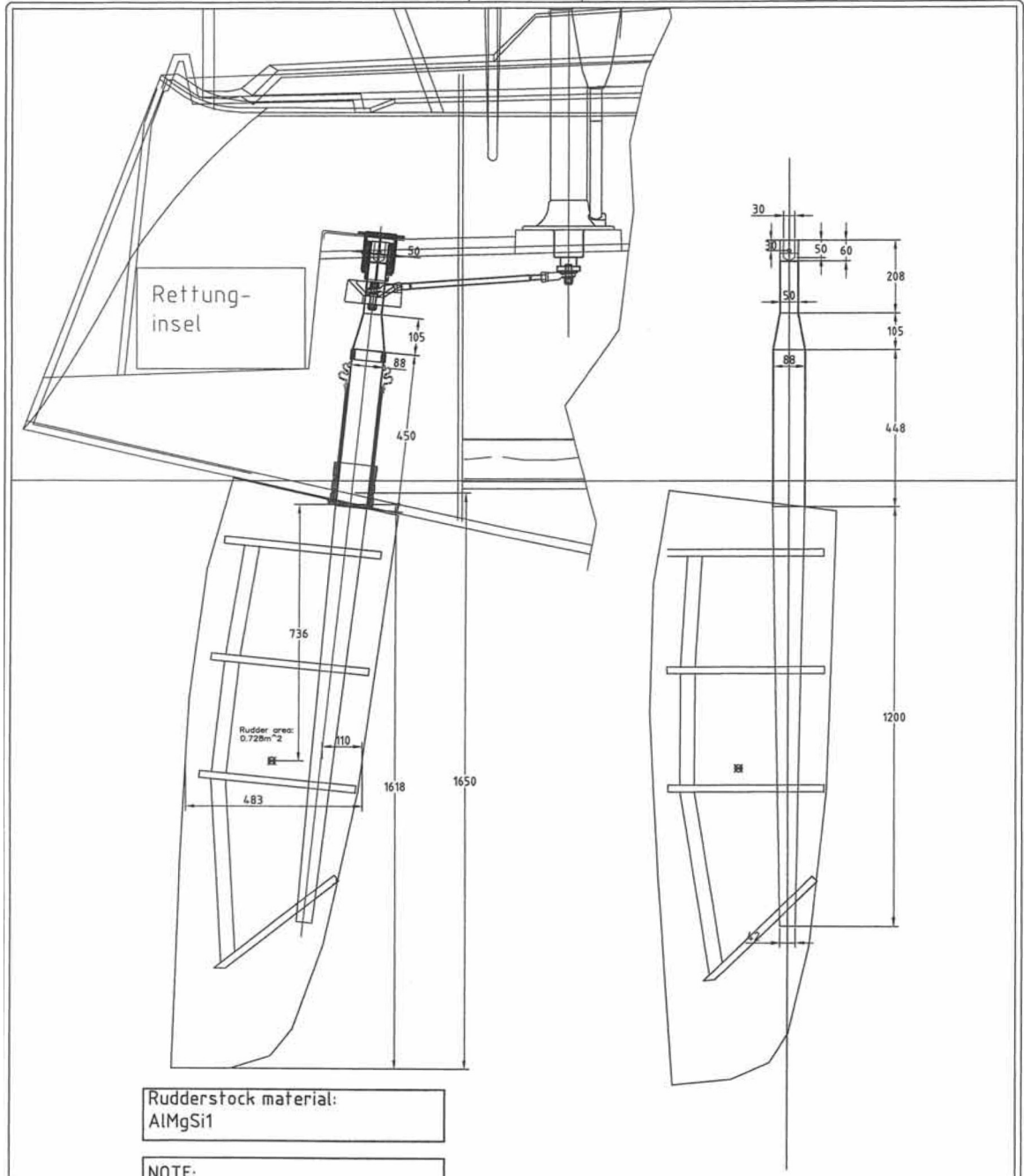
How often do rudders break?

- ARC Atlantic rallies 2001-2006: 0.3% of fleet
- 1979 Fastnet race: 6% of fleet
- 1998 Sydney-Hobart: 2% of fleet
- Casey (Sail magazine): "*close to 1 % of all ocean crossings*"

Compared with keel failures <3 per year (ISAF)


Bending
moment


Torque



Rudderstock material:
AlMgSi1

NOTE:
The finish of the rudderstock has to be smooth and free of damage. Special attention has to be given to a smooth transition in the areas of transitions and radii.

ISSUE	MODIFICATION	DATE	DRAWN BY	APPROVED
1	first issue	05-10-99	da	

DUE TO BUILDING TOLERANCES ALL DIMENSIONS GIVEN ON THIS DRAWING ARE TO BE CHECKED ON THE BOAT !
ALL DIMENSIONS IN MM.

Hanse 371

construction rudder stock HANSE371

SCALE	SHEET
1 : 10	1 OF 1

DRAWING NUMBER: HA37-cda

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Basic hydrodynamic equation

$$\mathrm{F} = 18 \times A \times V^2$$

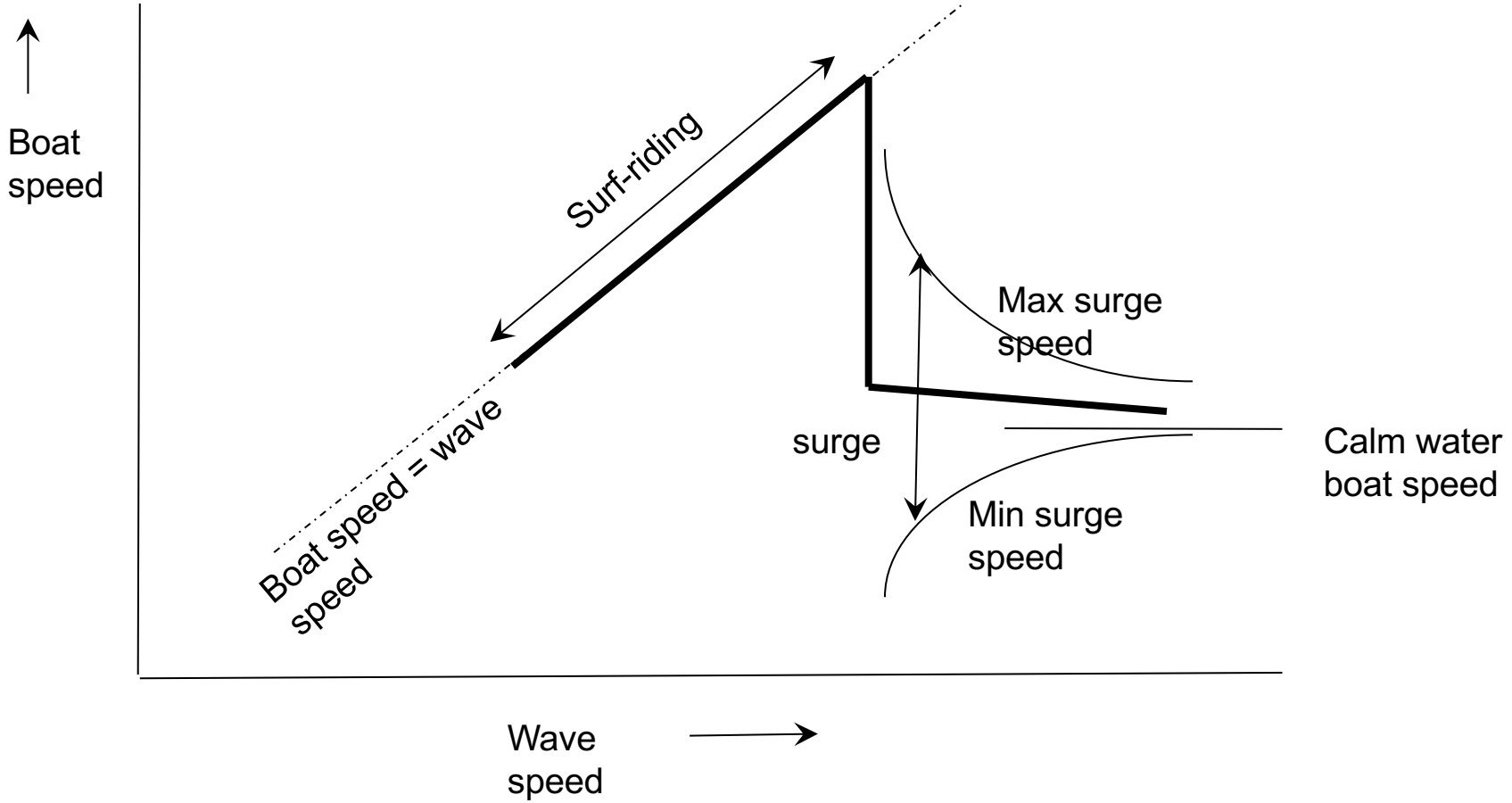
F = rudder force (kg)

A = rudder profile (side view) area (m^2)

V = flow speed (knots)

What flow speed to use?

- "Hull speed" (Fn = 0.4)?
- Surge speed down wave?
- Surfing speed?



Surge speed = approx 140% hull speed

Effect of flow speed choice

5 tonne yacht, LWL 8m

sailing condition	boat speed (kn)	rudder force* (tonnes)
“hull speed”	7.2	1.2
125% hull speed	8.9	1.8
140% hull speed	10.0	2.3
Surfing speed	15??	5.1

* using safety factor of 2.0

The allowable stress
(316L grade stainless steel)

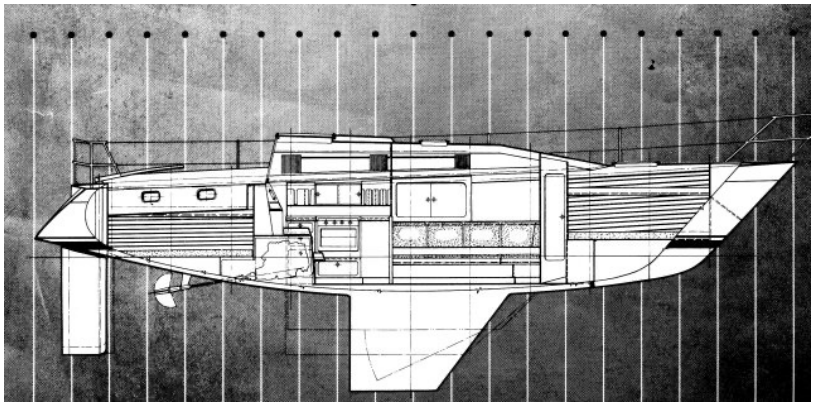
Load to permanently bend (MPa)	**Load to break(MPa)**
245 (Huang)	520-**700** (Euro Inox)
220 (Euro Inox)	525-545 (Huang)
220-**290** (Dexter)	517-558 (Dexter)
200 (Sandvik)	**485** (Atlas)
170 (Atlas)	

Aluminium alloy stresses

alloy	**0.2% proof stress (MPa)**	**Ultimate stress (MPa)**
6061-T6	241 (ADC)	289 (ADC)
6082-T6	240-250 (DNVGL, 2015) 280 (Jefa)	290-310 (DNVGL,2015) 340 (Jefa)

Example calculation

Displacement	5 tonnes
Waterline length	8 m
Safety factor	2
Max allowable stress*	220 MPa



*for permanent bending,
316L grade stainless steel

Required diameter (solid)

Speed assumption	**Speed**	**Required diameter**
125% hull speed	9 kn	81 mm
140% hull speed	10 kn	88 mm

Comparison with codes and rules

method	**Diameter (mm)**
ABS (USA)	62.9
ISO (Europe)	61.3
GL (Germany)	63.1
as built	63.5 (2.5 inches)
Klaka method	81.2

How to stop a rudder breaking?

- Get one that is designed and built properly?
- Don’t apply large helm angles at speed
- Look very carefully for corrosion and cracks
- Don’t sail fast?!

Overall Conclusions

Pay attention to leading edge shape.

A heavy helm is a rudder problem, not (only) a rig problem.

Rudders do not cavitate, but they might ventilate.

Many rudders are not designed to be strong enough.