Why aircraft might grow bumps

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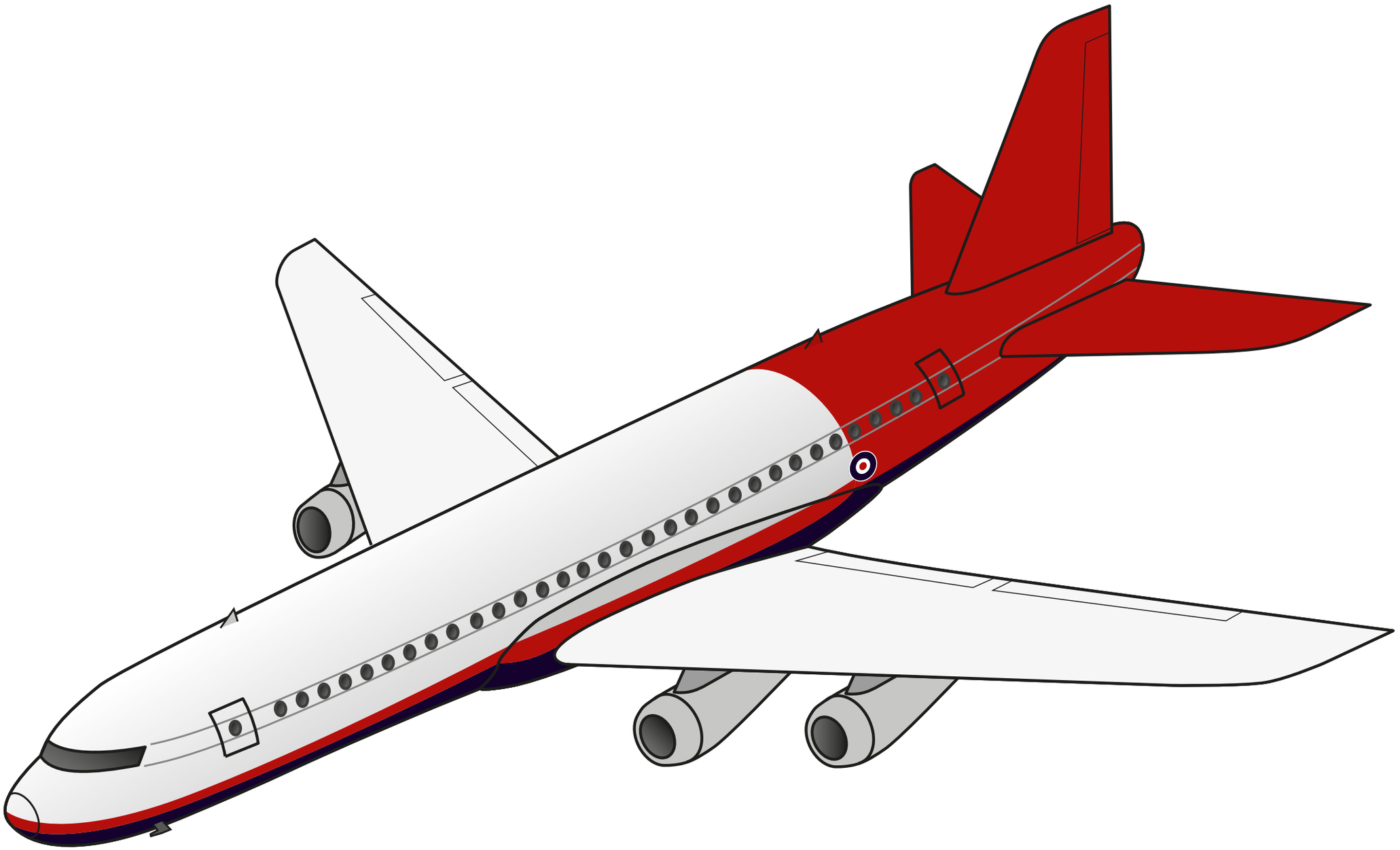
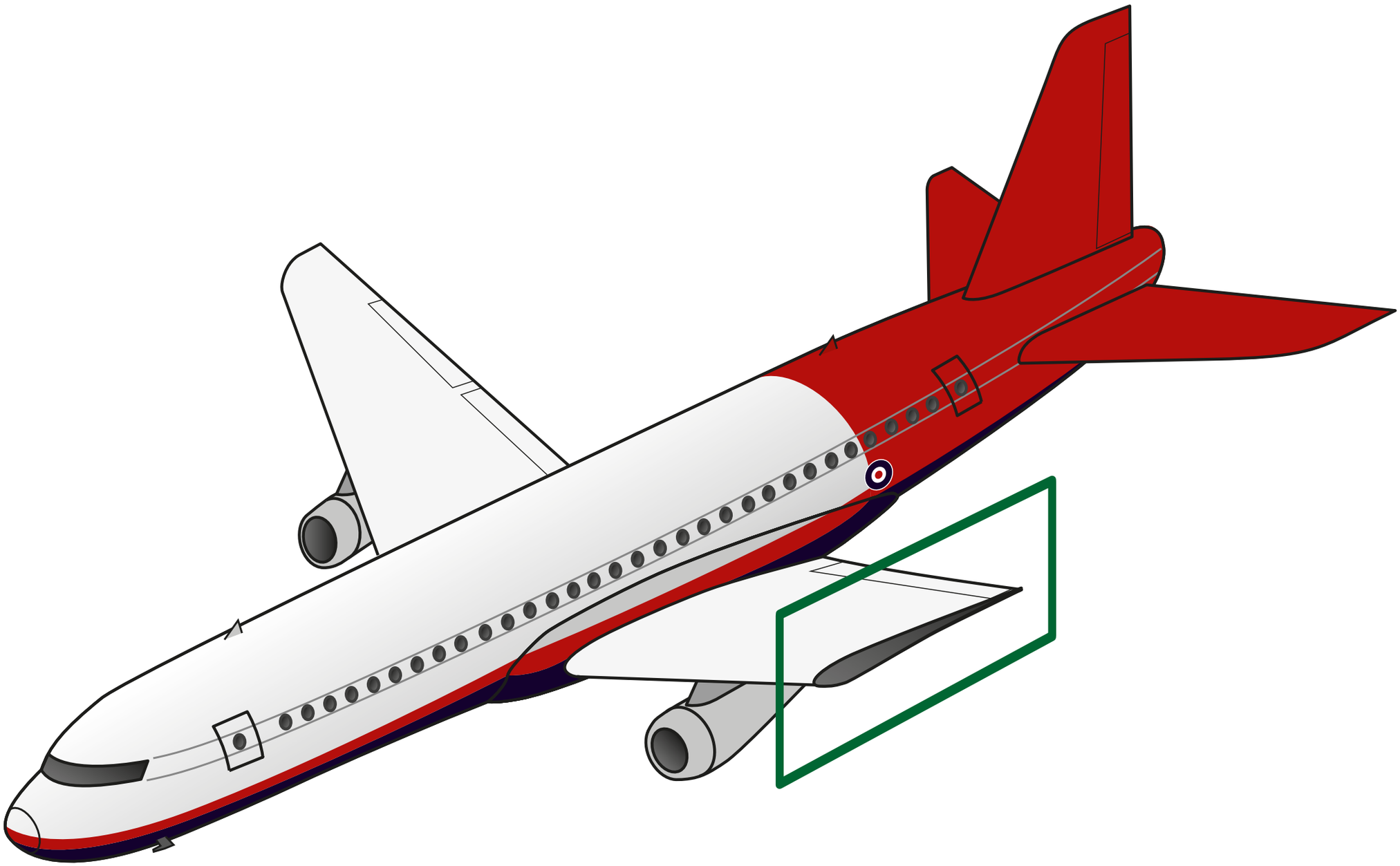
Contents

Lift

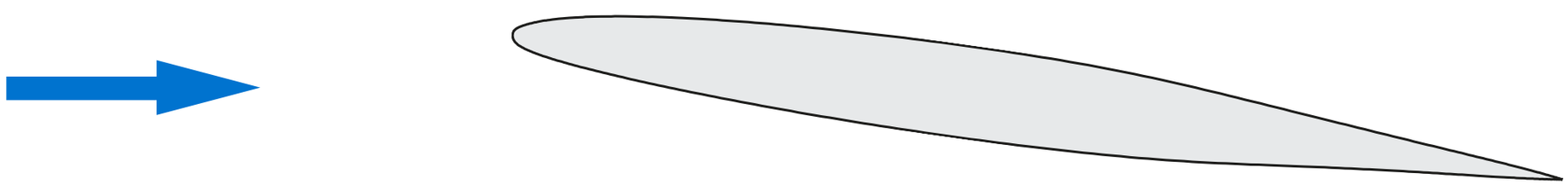
A word about Lift



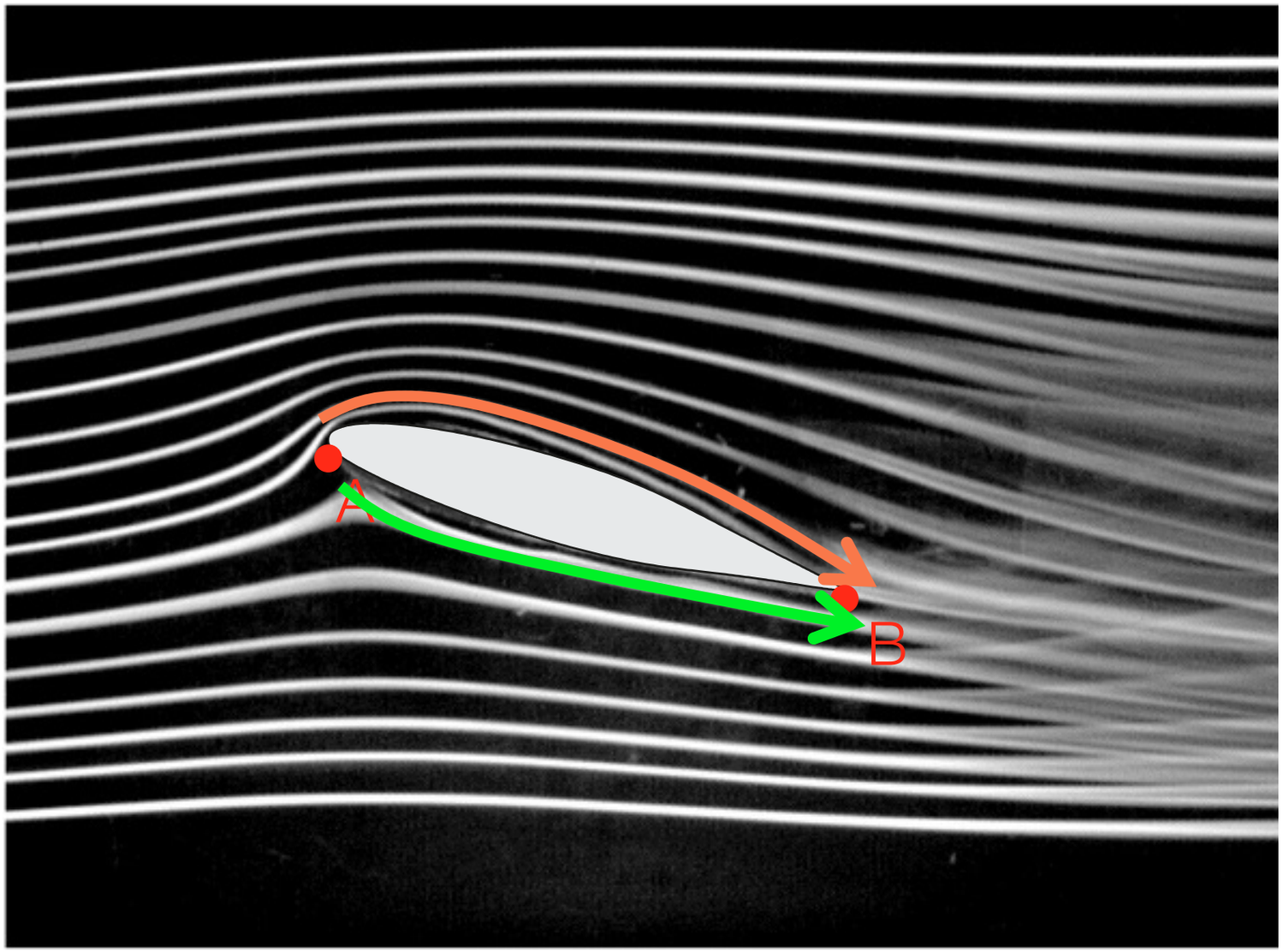
Lift comes from aerofoils



How do aerofoils generate lift?



The ‘popular’ explanation

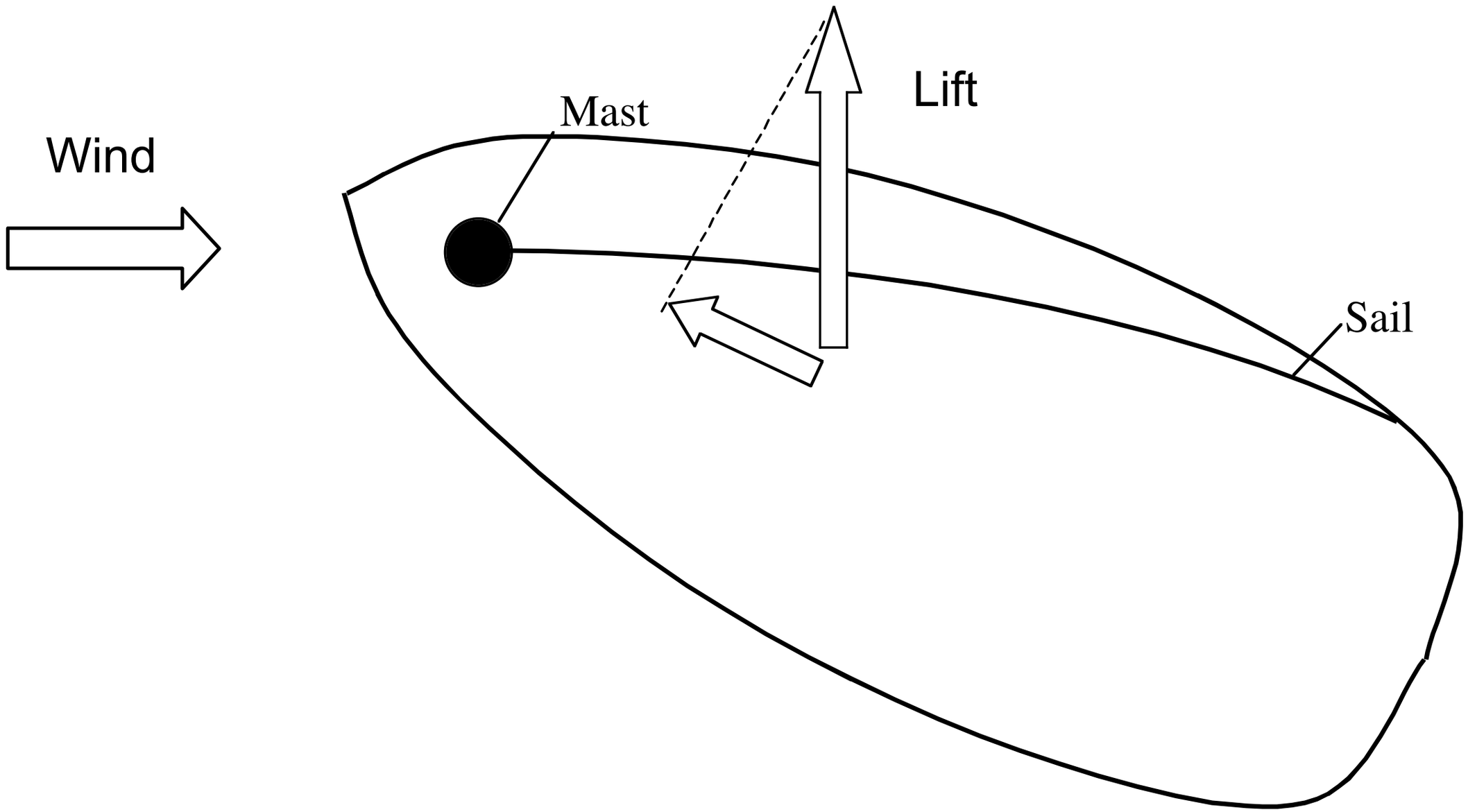


So what’s wrong with it?

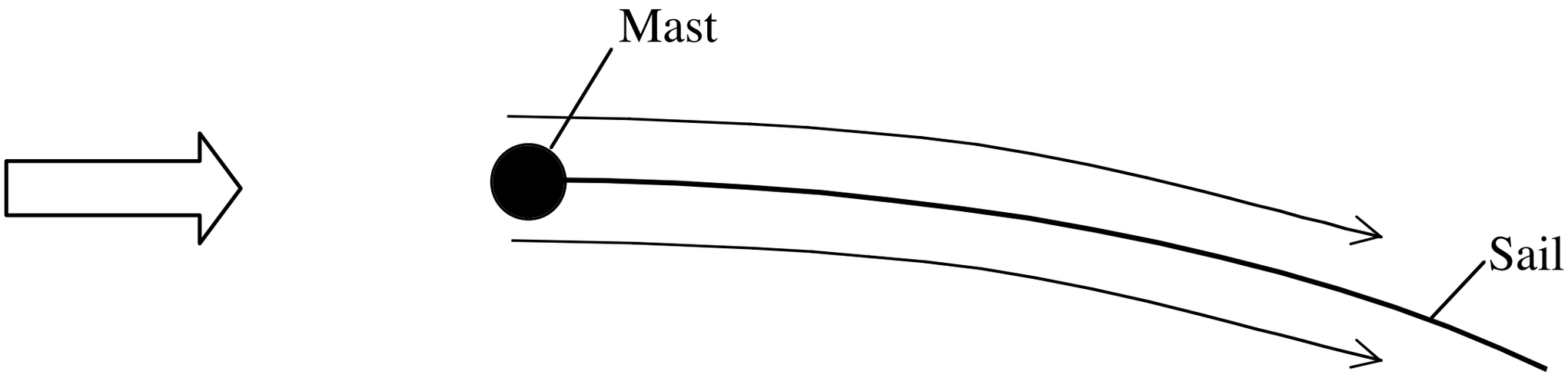
The ‘distance’ argument

Sails are wings too!

Sails are wings too!



Sails are wings too!

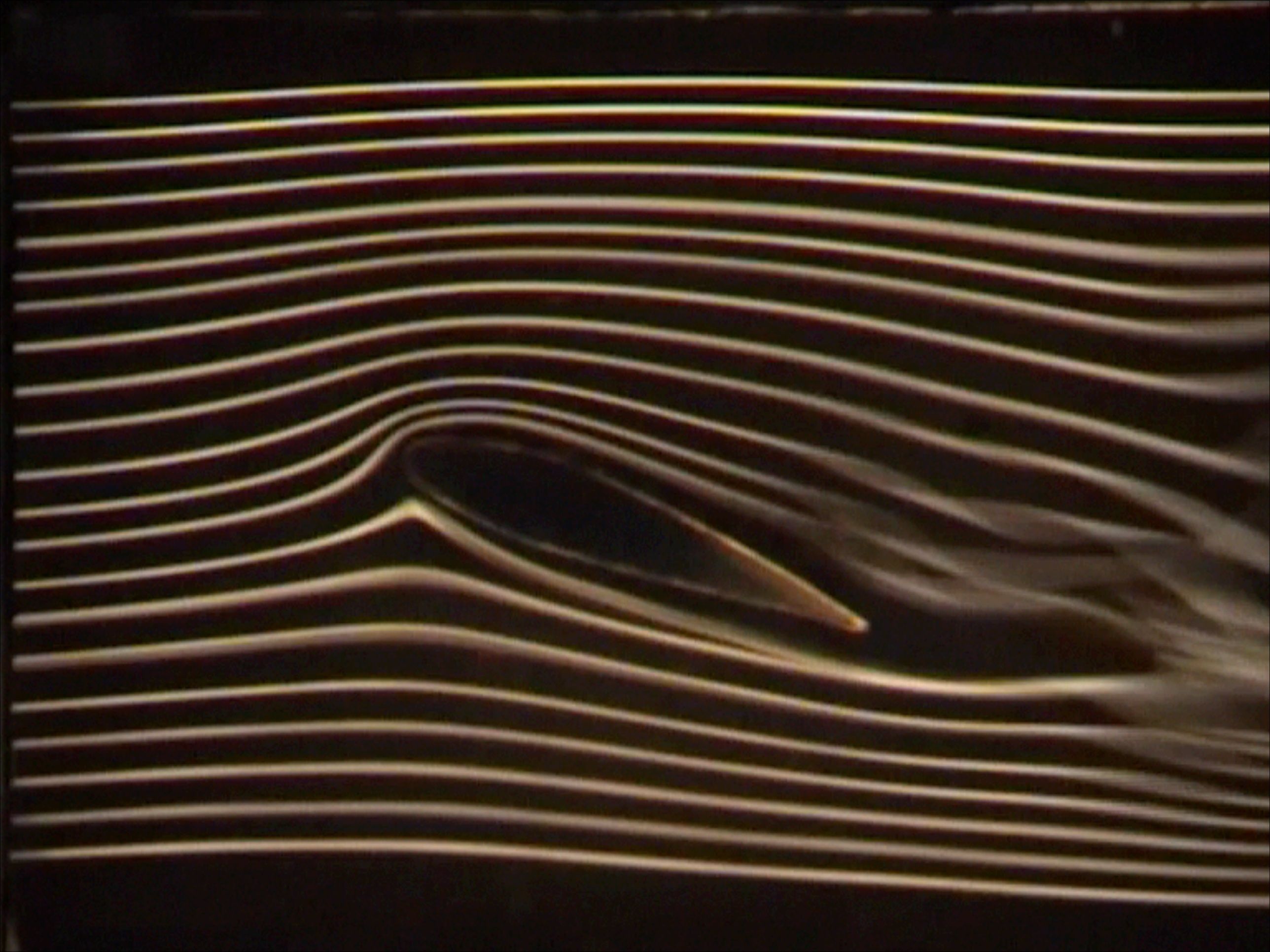


But sails have the same distance on both sides

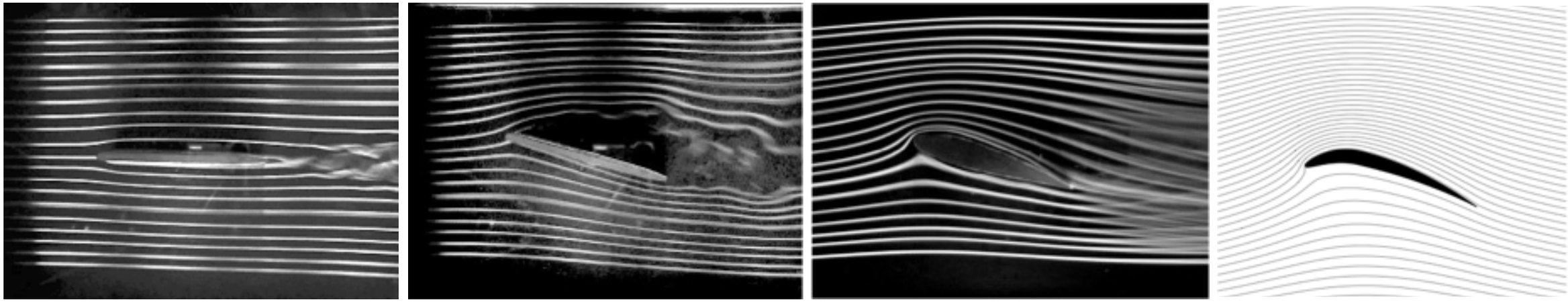
The ‘equal-time’ argument

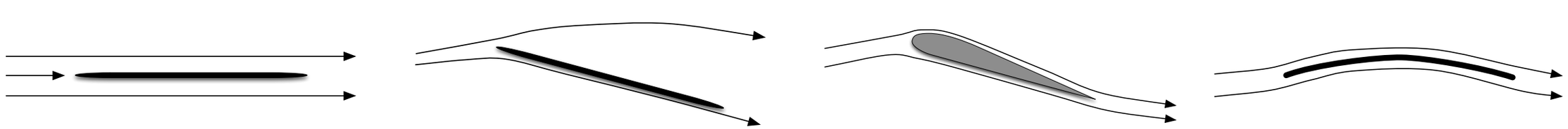
Streamlines on a lifting aerofoil

Smoke wind tunnel



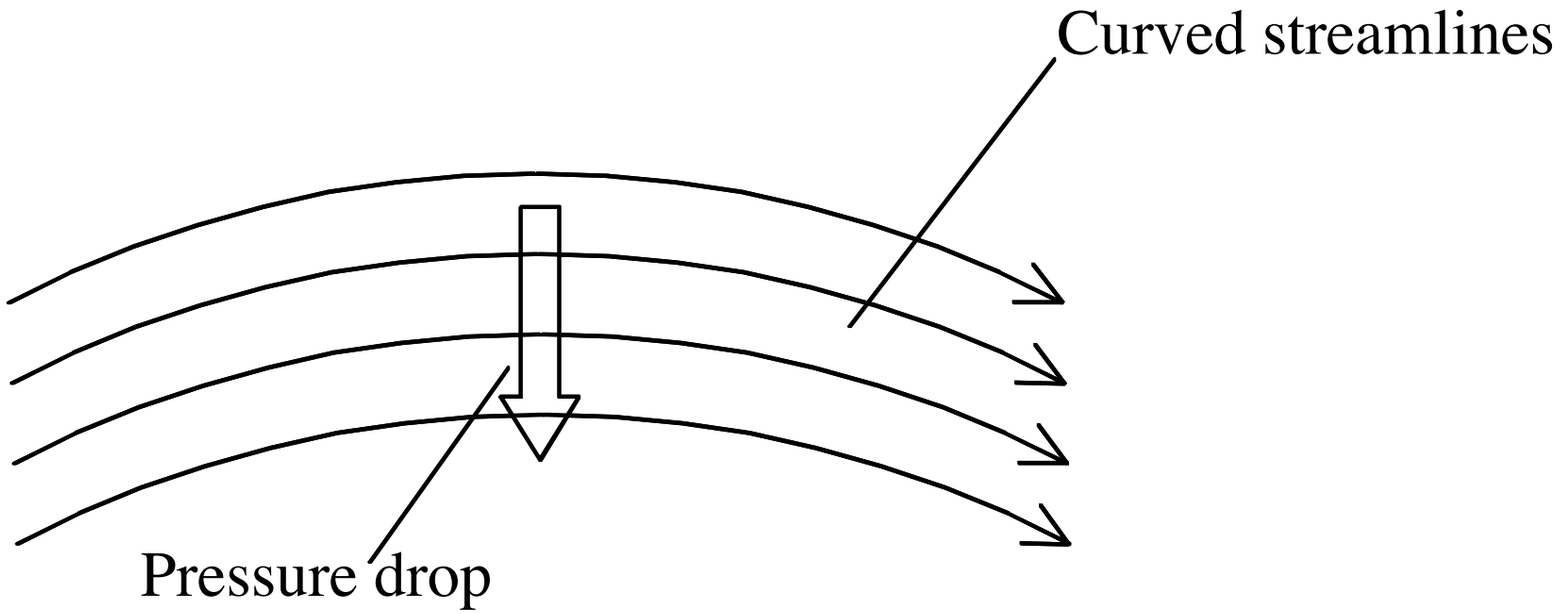
The origins of lift



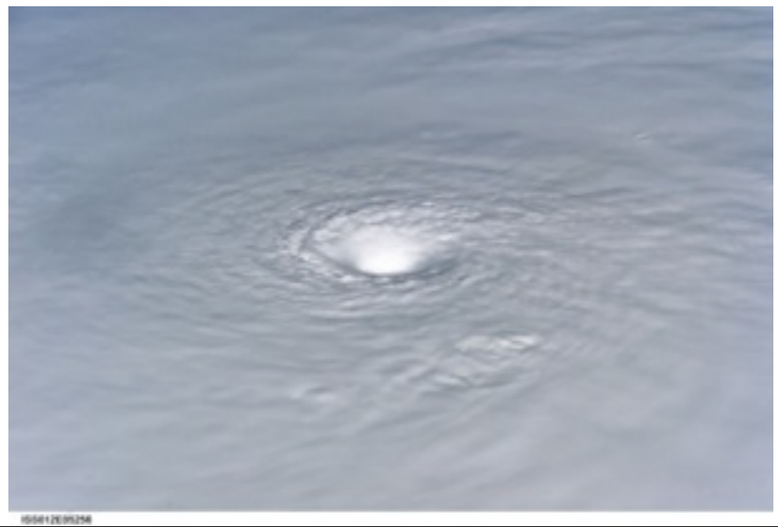


- Lift is caused by streamline curvature/deflection
  - angle of attack
  - curvature/camber

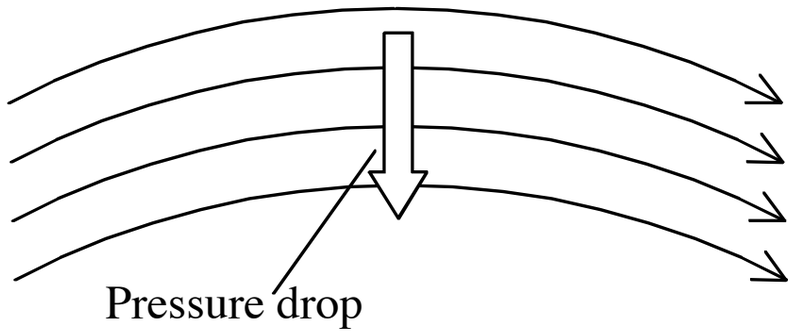
Curved streamlines

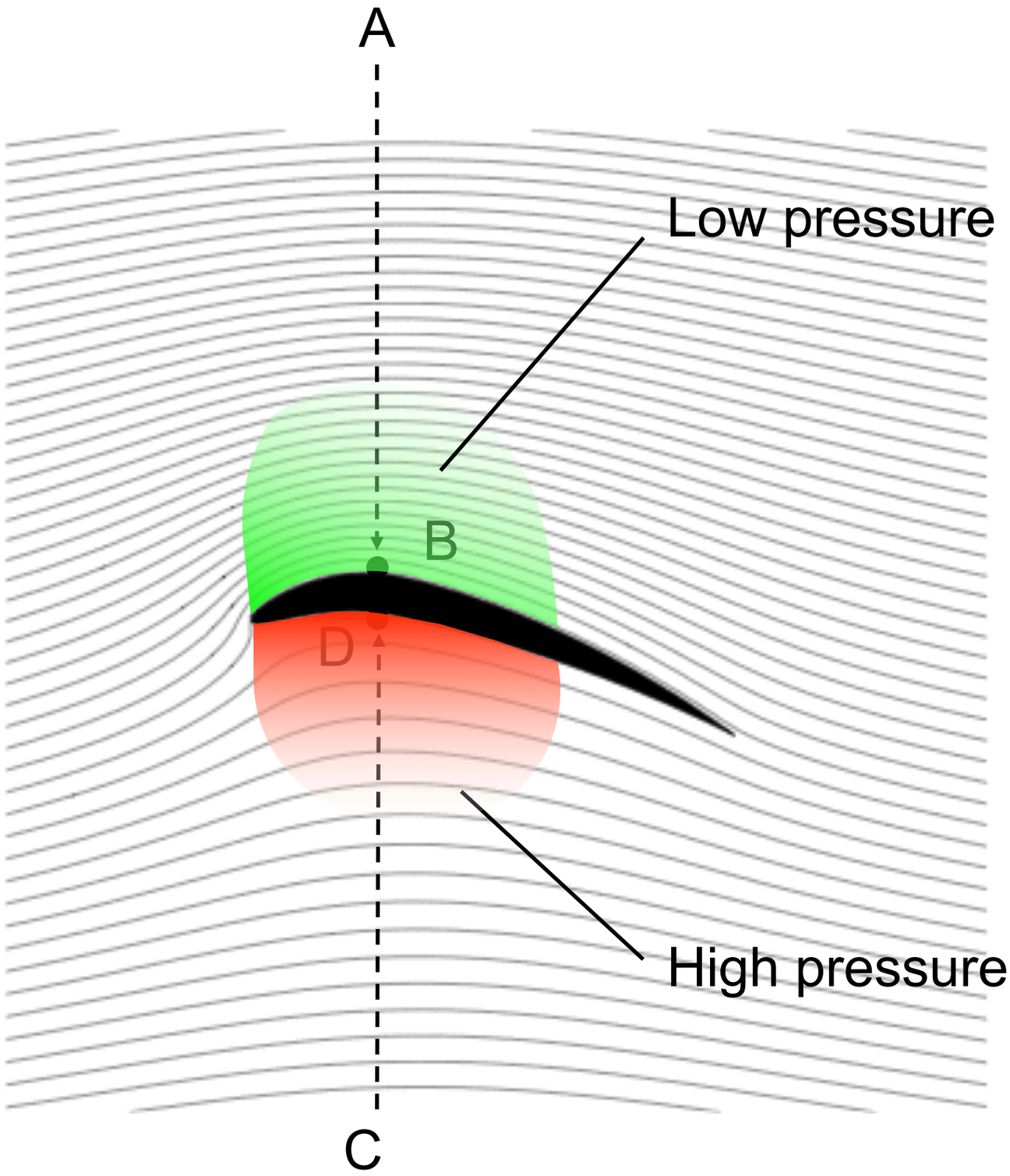


- Curved streamlines => lateral acceleration of fluid particles
- Force is caused by pressure gradient
- Pressure drops towards centre of curvature
  - think tornados

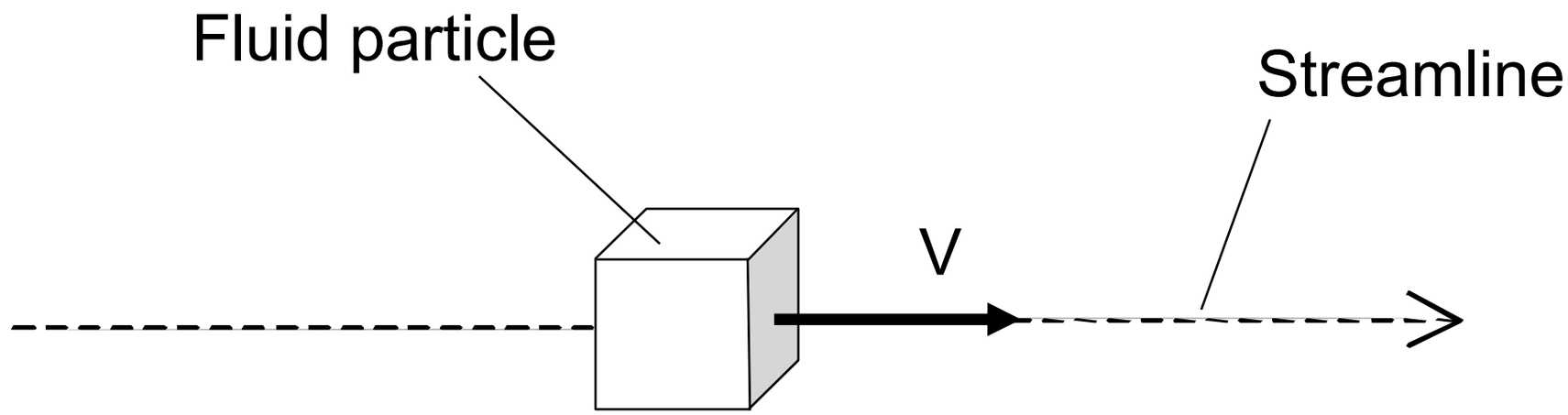


Streamlines and pressures on aerofoils





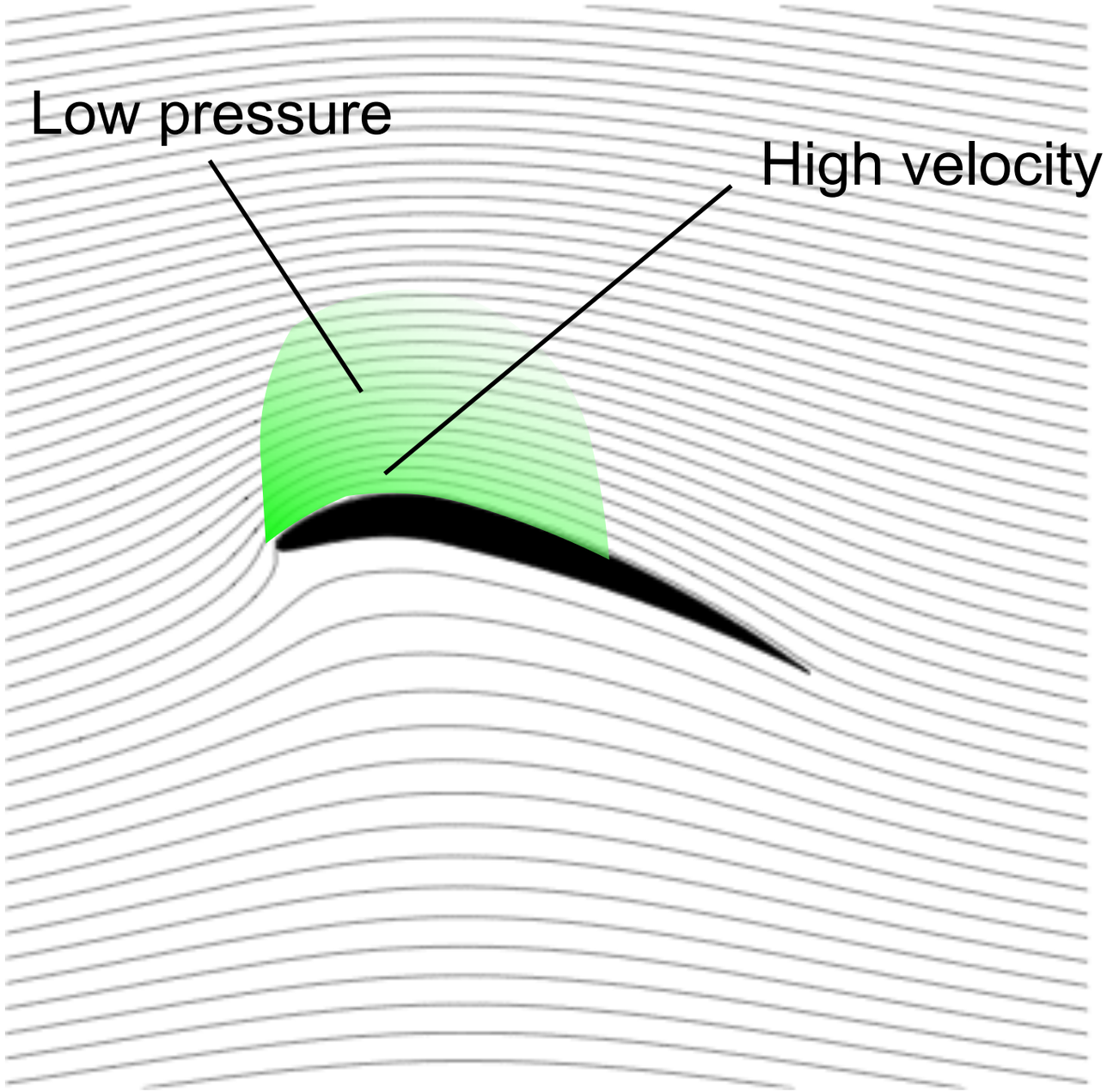
Pressure changes lead to velocity changes



Pressure change along streamline => change of velocity

(Bernoulli's equation)

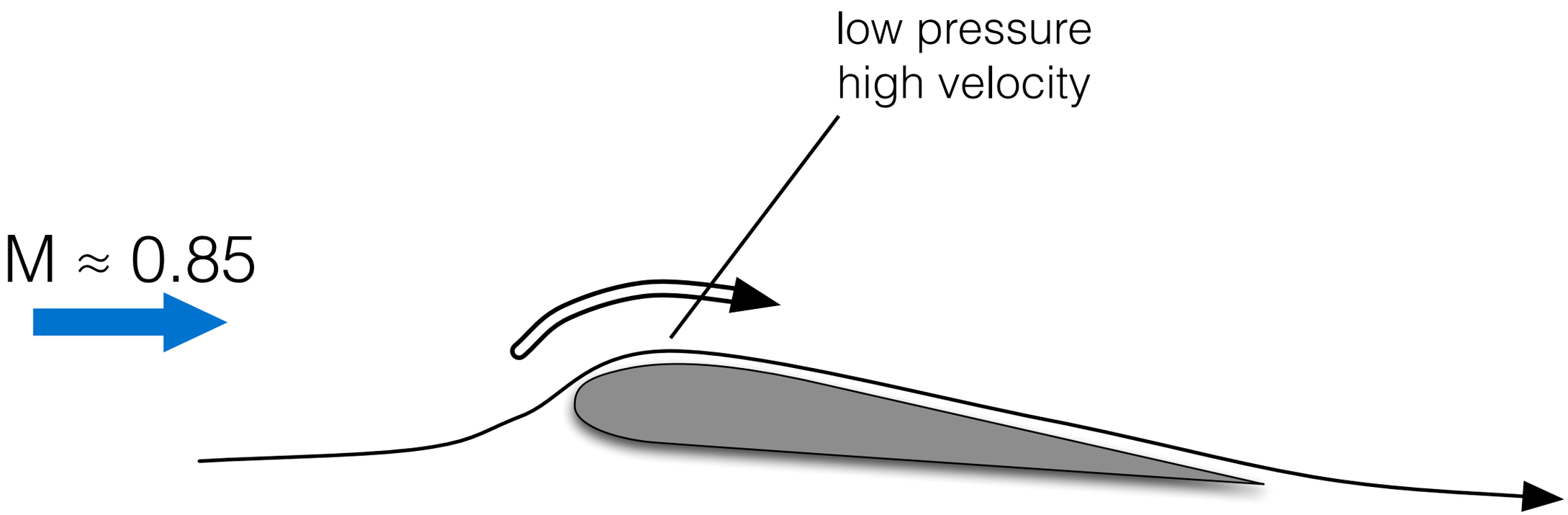
Streamlines and pressures on aerofoils



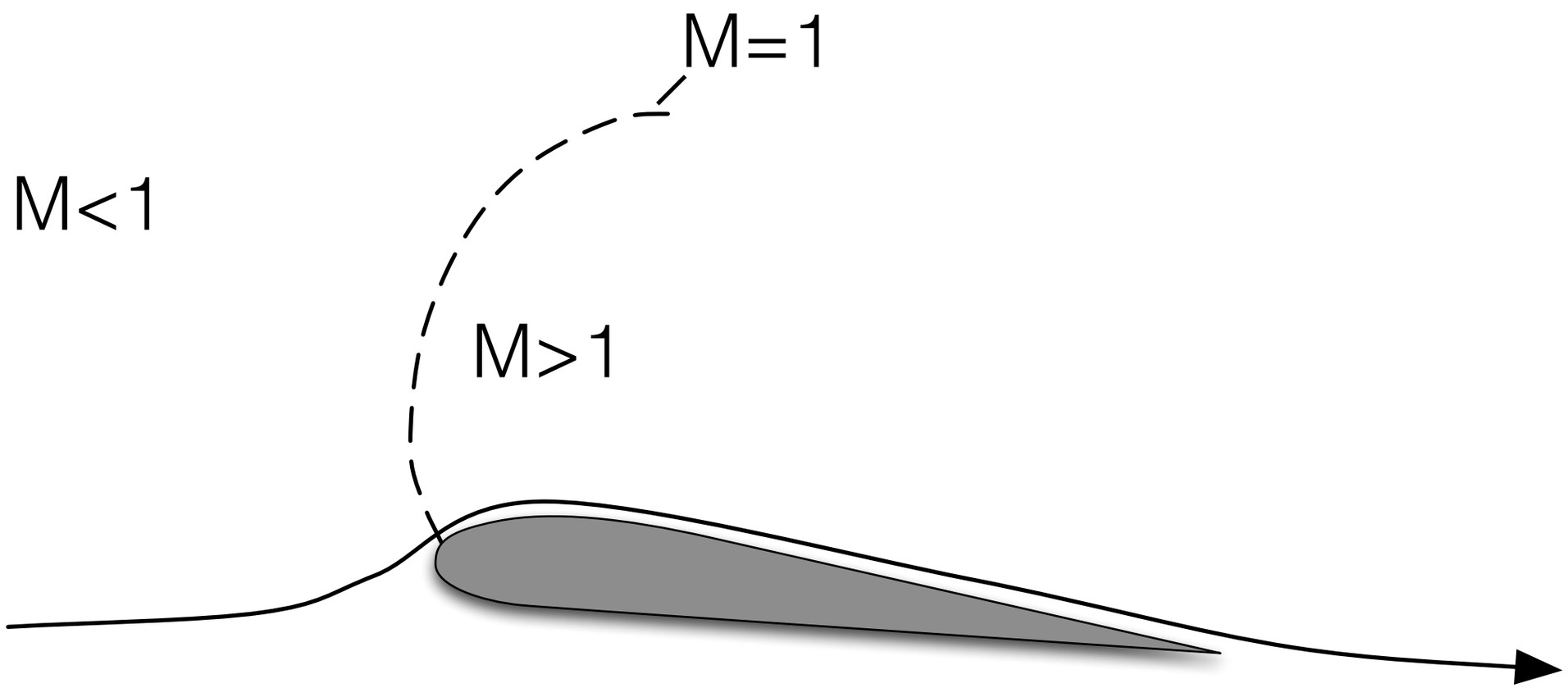
- High velocities on upper surface

Going faster

You don’t need Concorde



You don’t need Concorde: Approaching M=1



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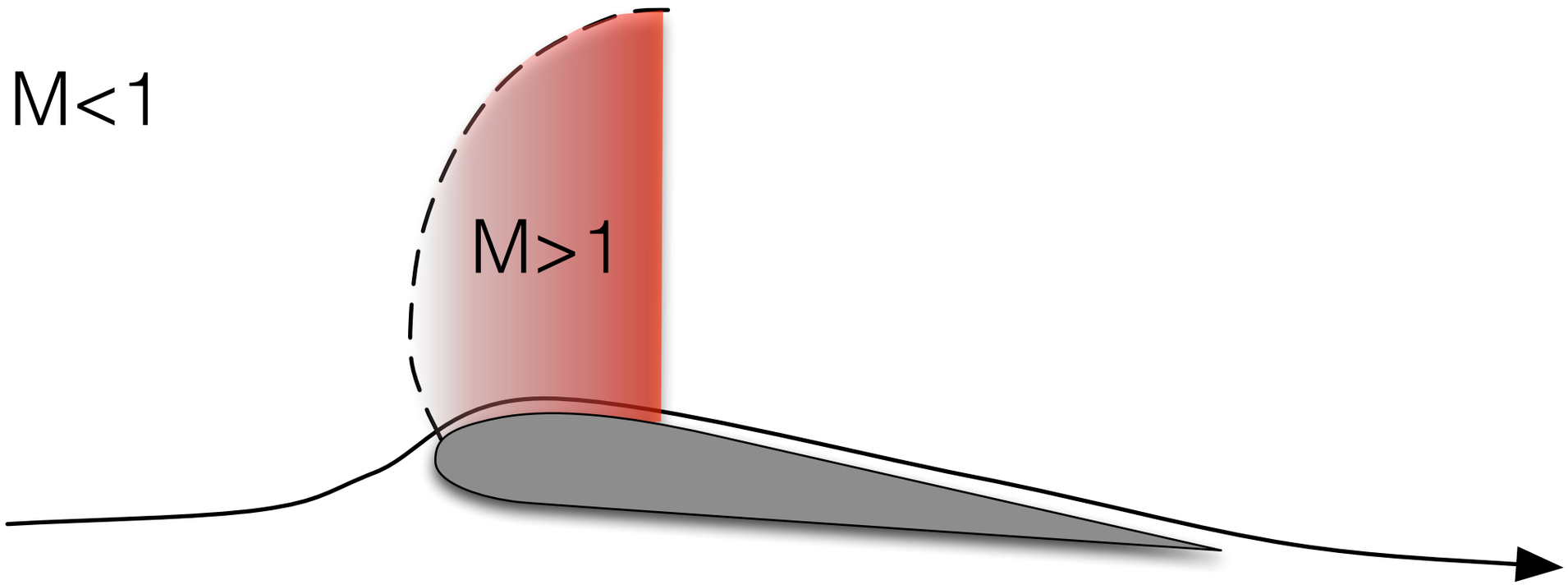

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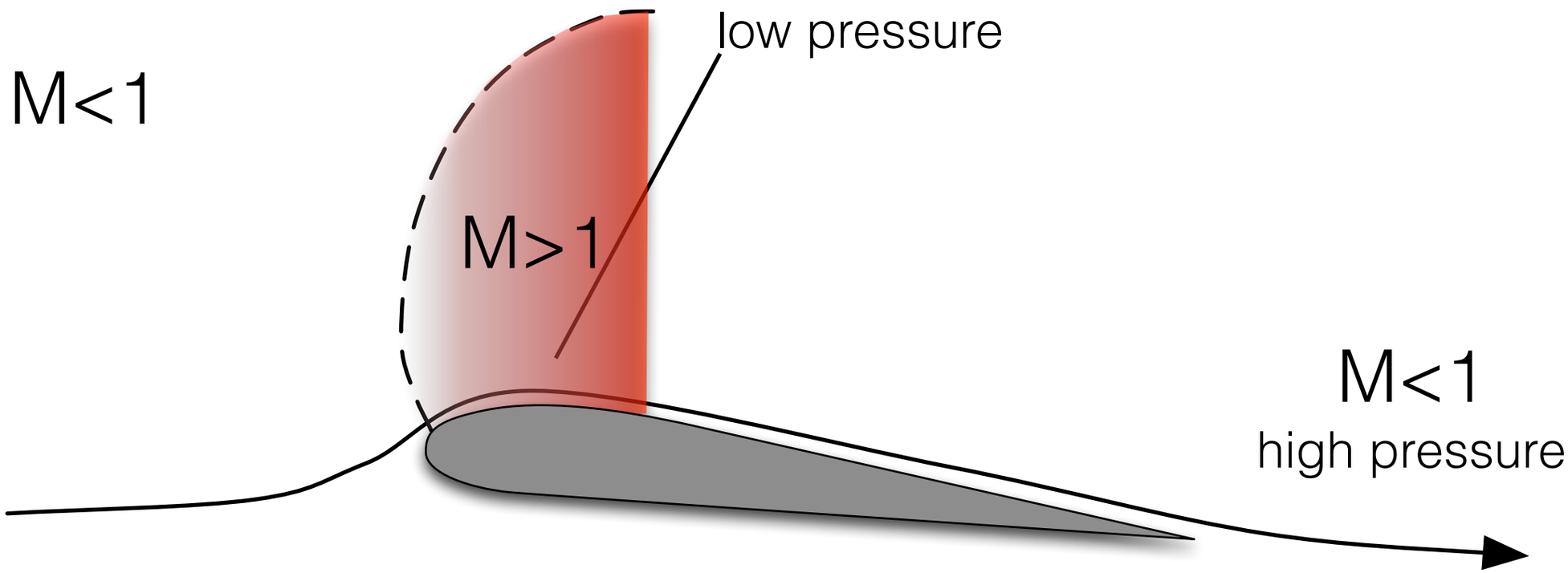
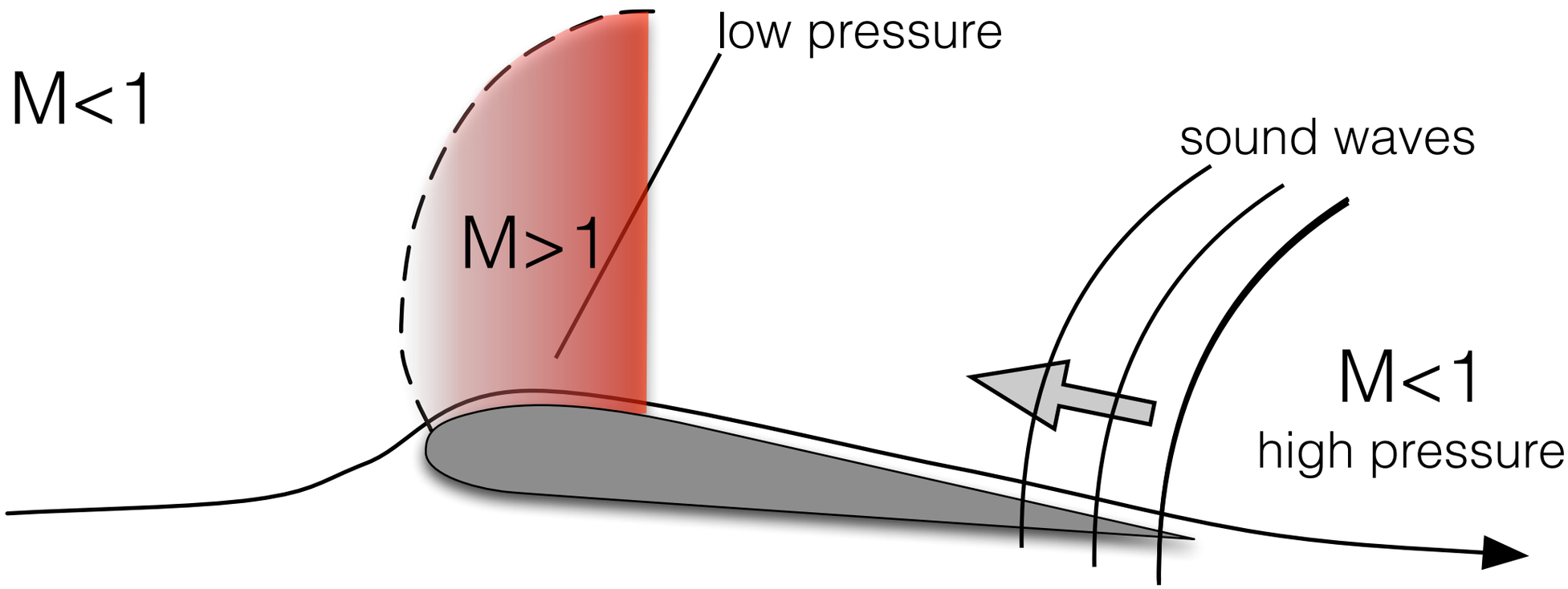


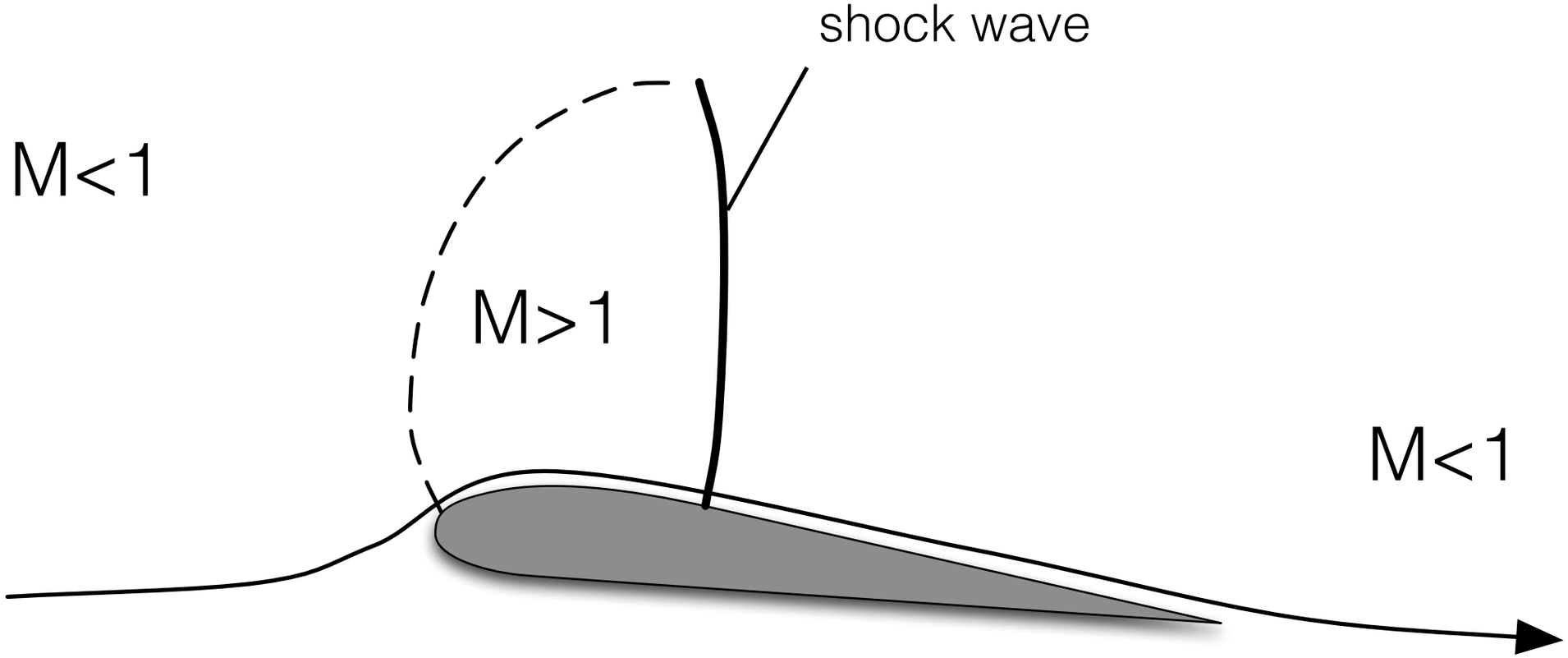
- Pressure must increase again towards ‘trailing edge’

You don’t need Concorde: Approaching M=1

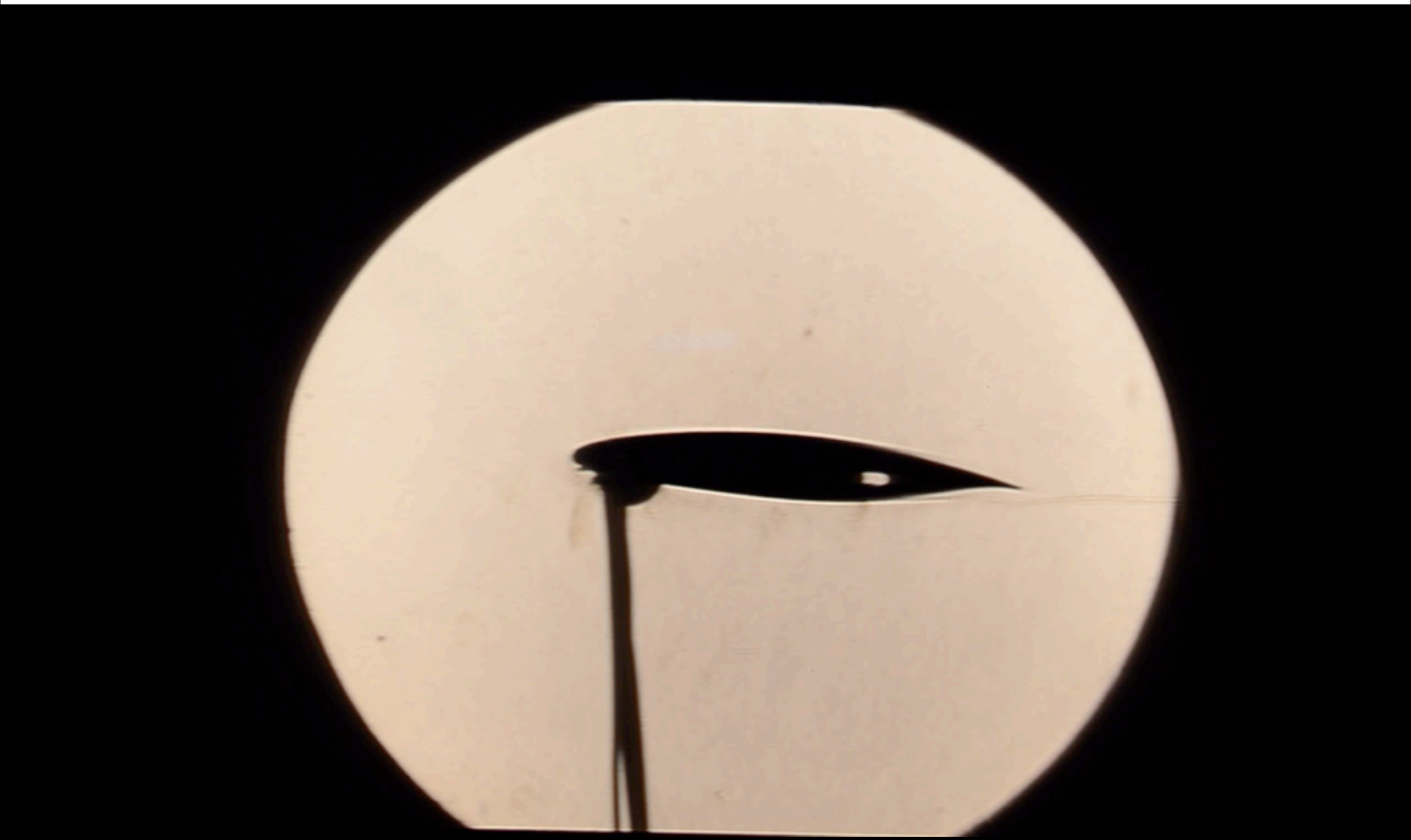


- Pressure must increase again towards ‘trailing edge’
- Normally, pressure changes are communicated by sound waves
- in supersonic flow?

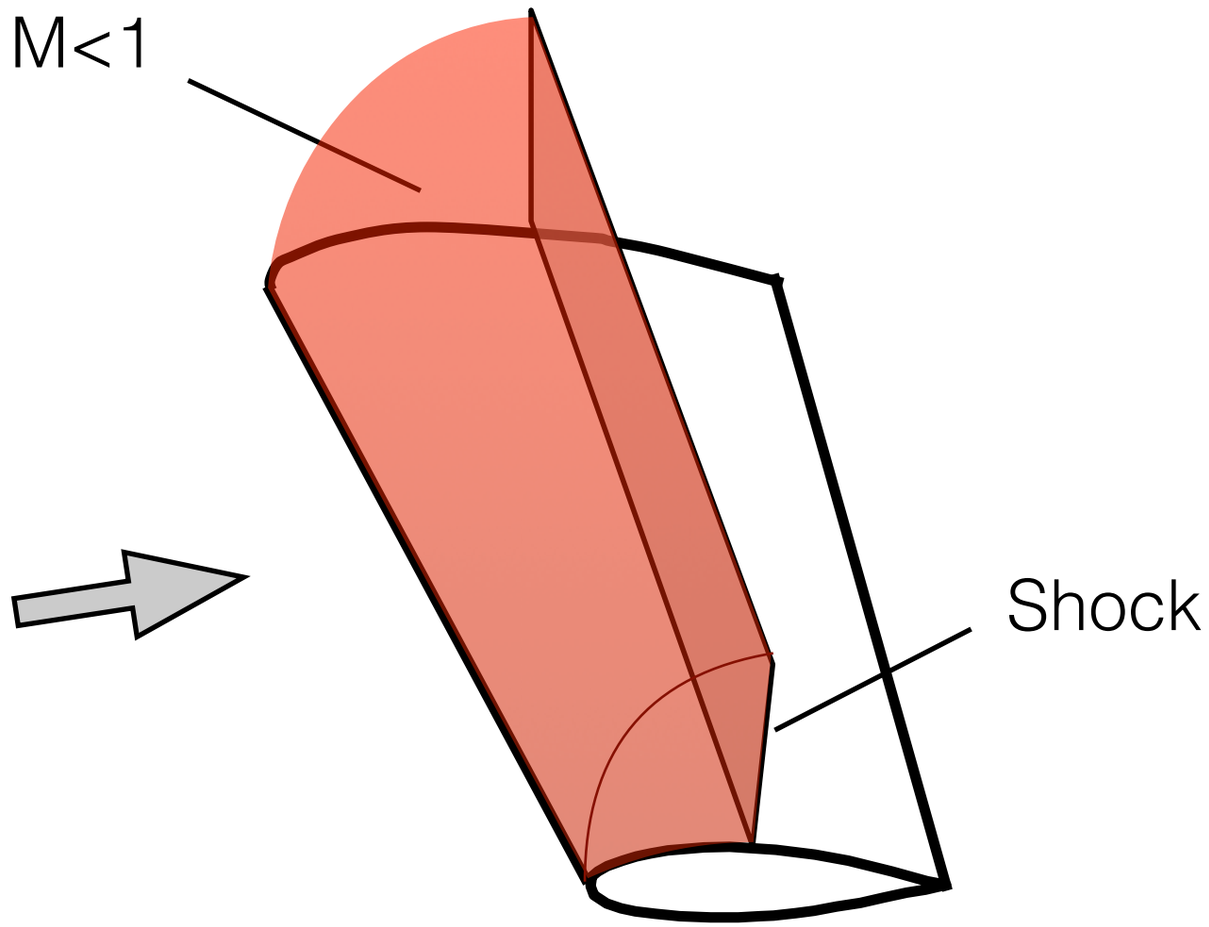
Shock!



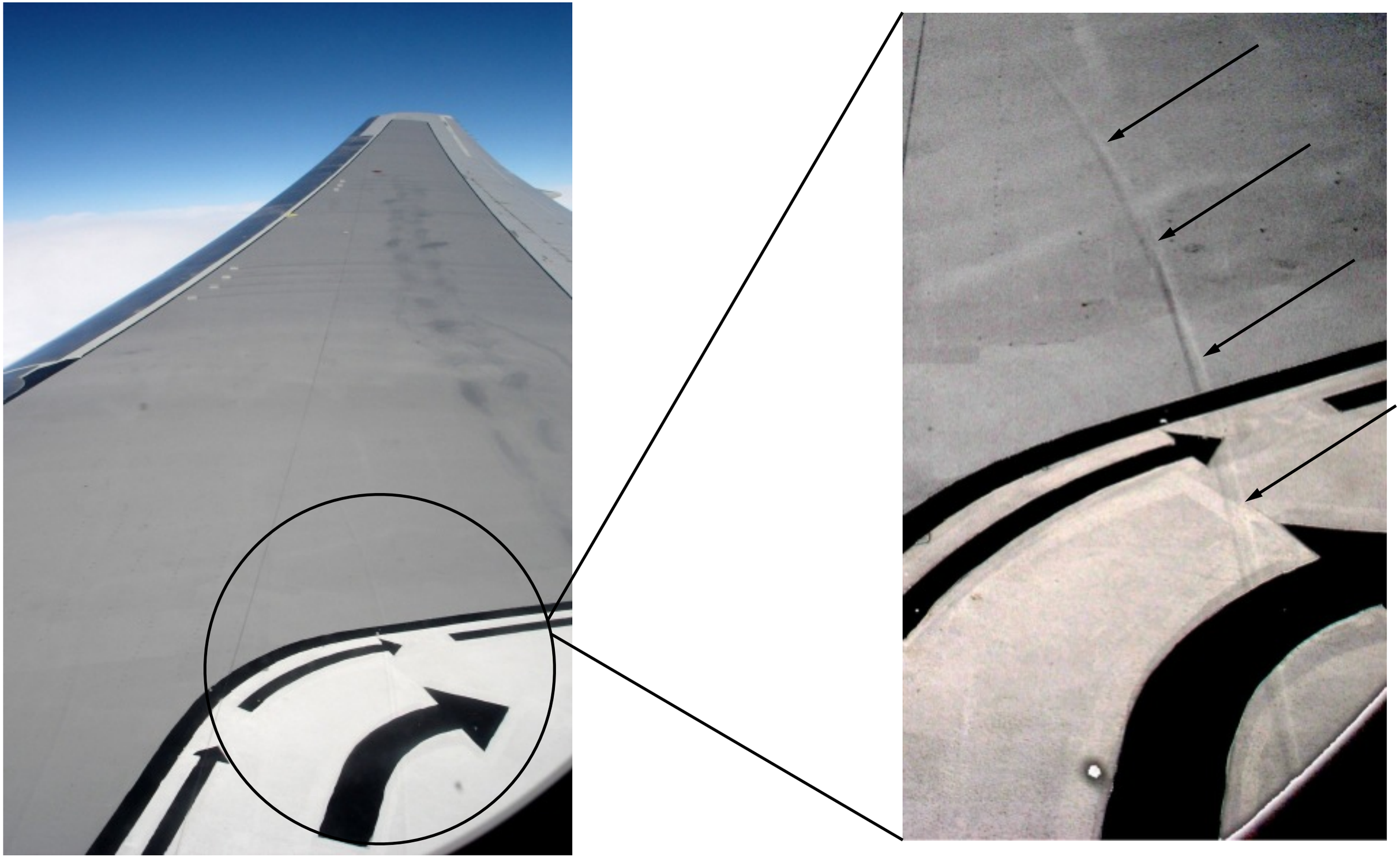
Transonic airfoil in Cambridge high-speed wind



Shock wave on transonic wing



and you can see it too…..




RYANAIR


NO STEP
NO STEP

Are shocks a problem?

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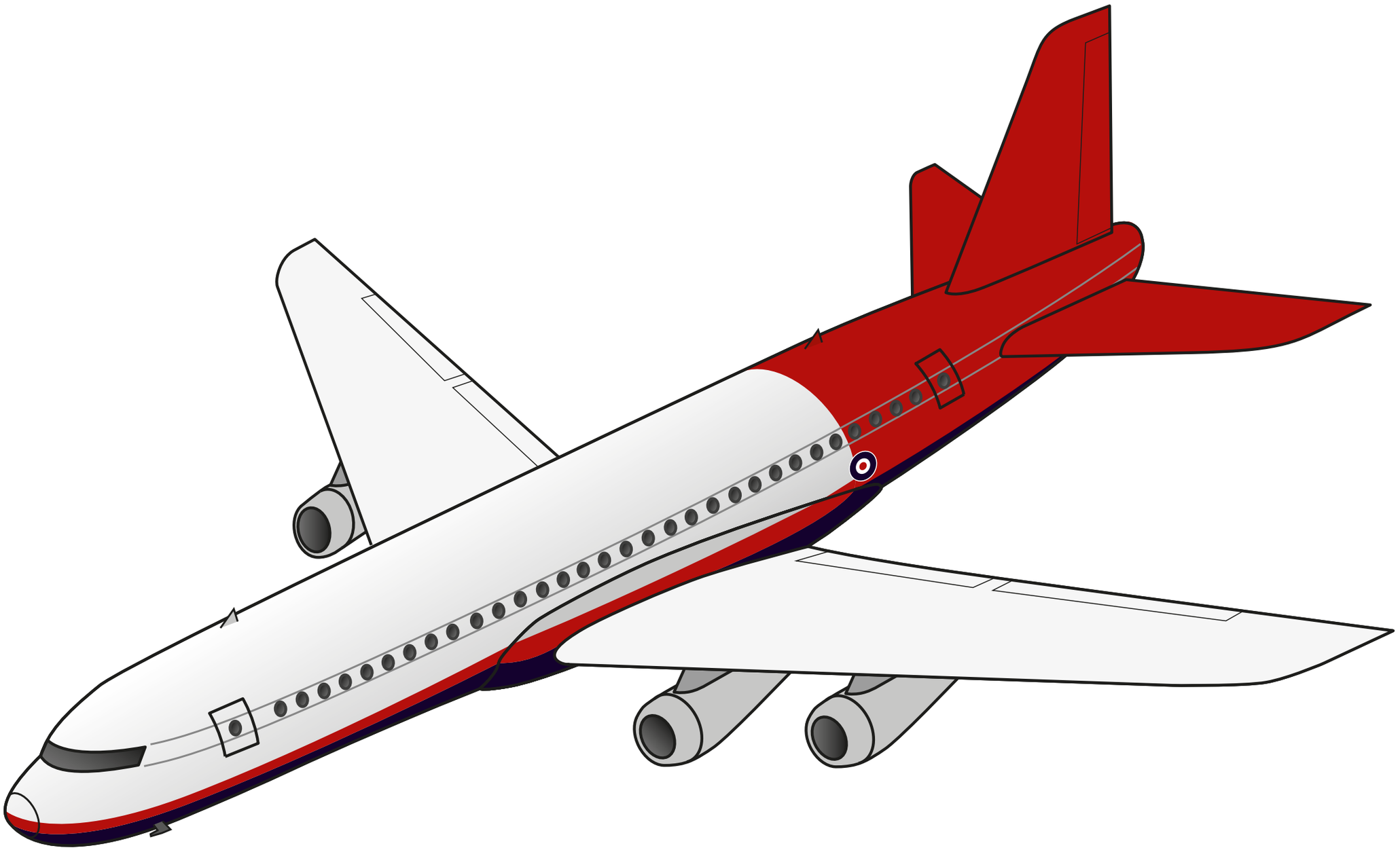

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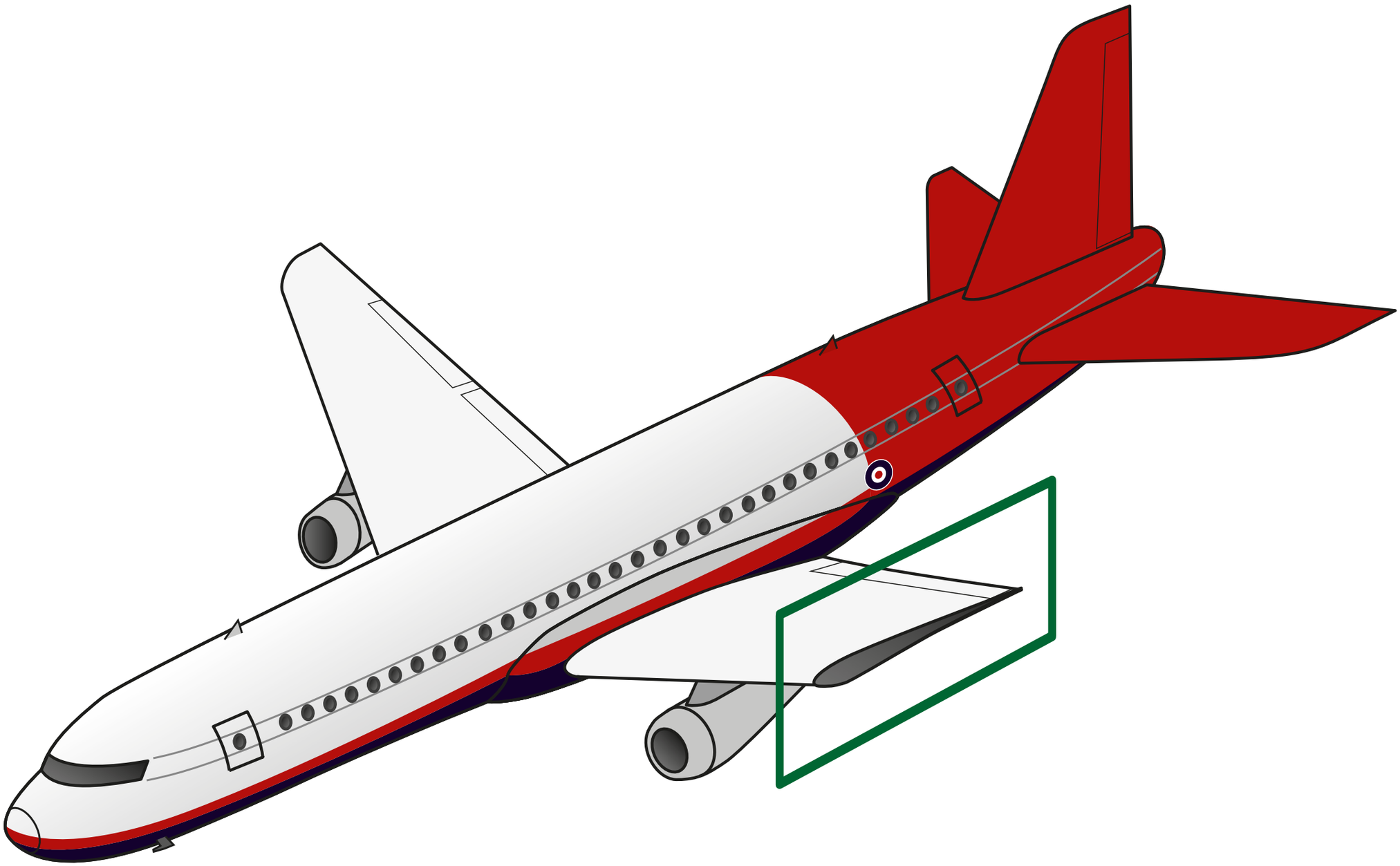
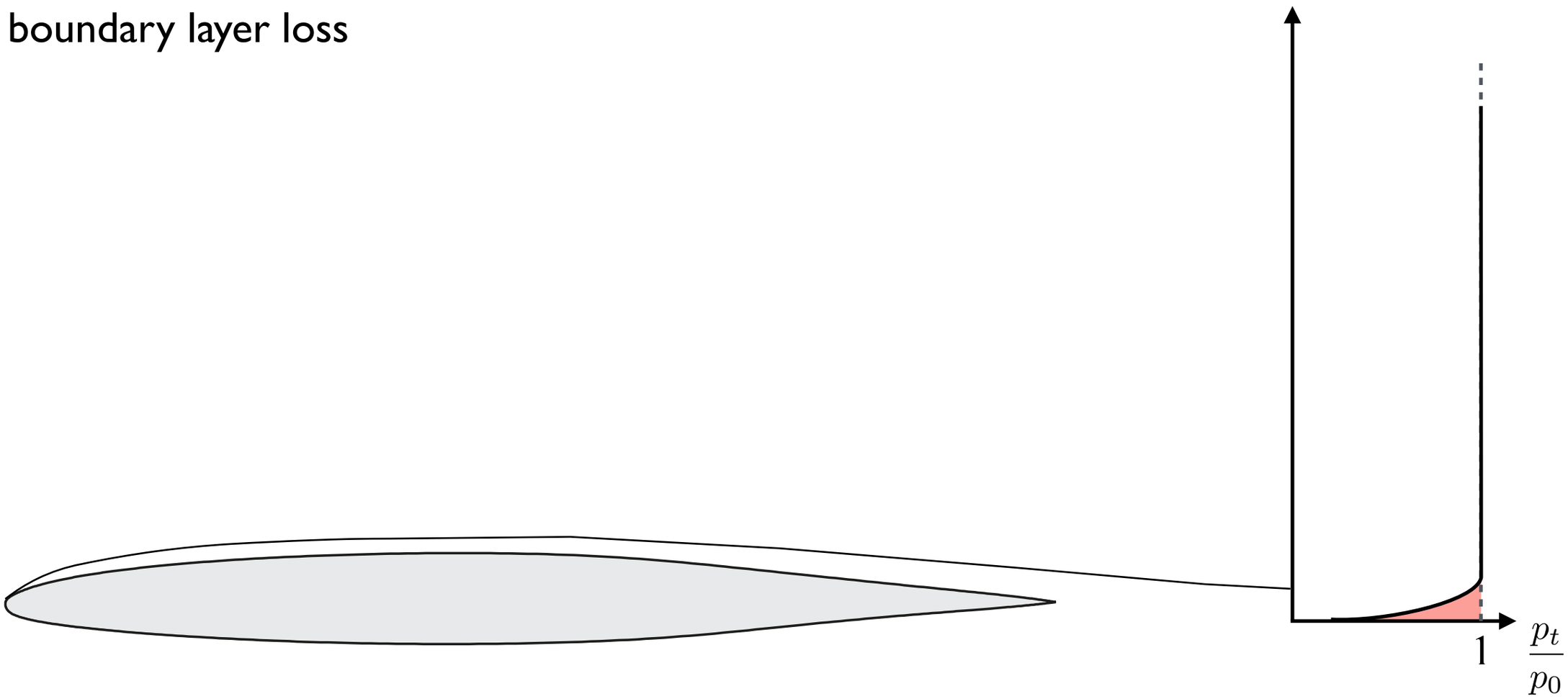


Are shocks a problem?

boundary layer loss



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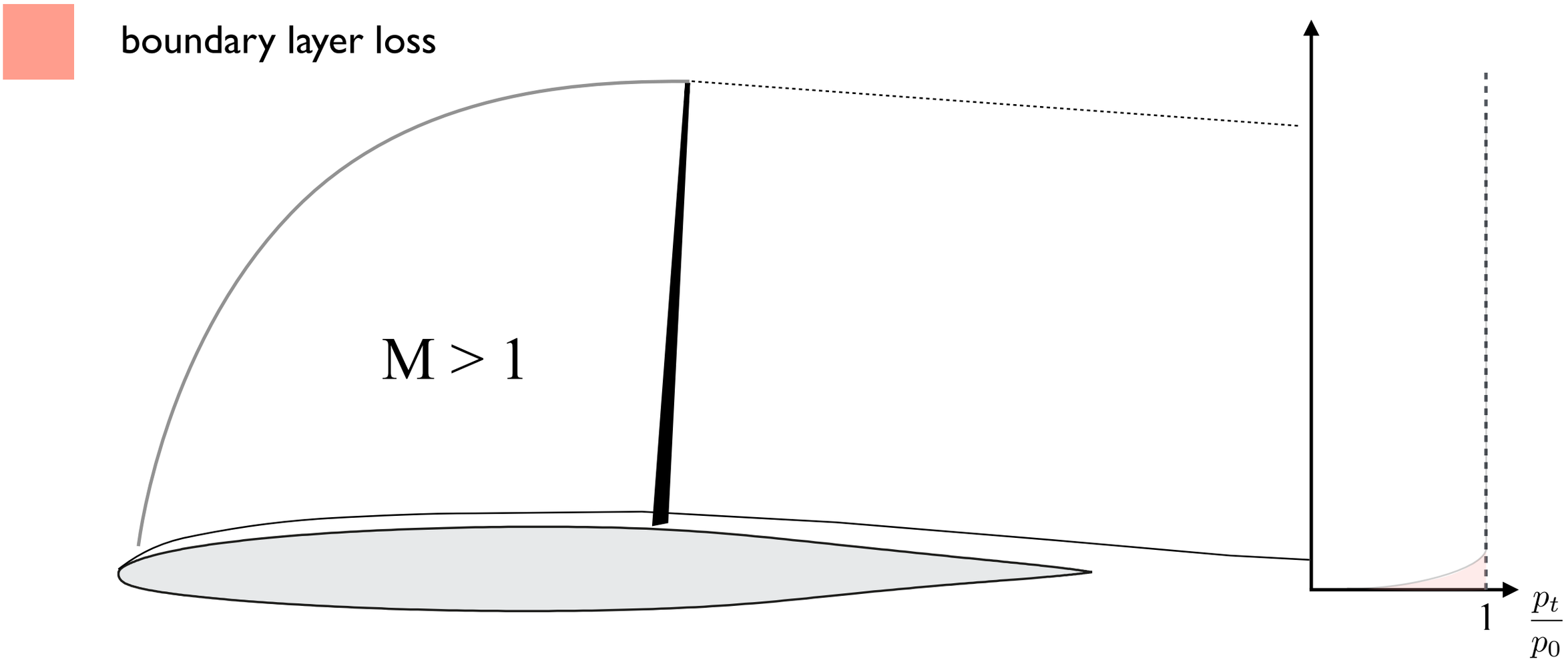
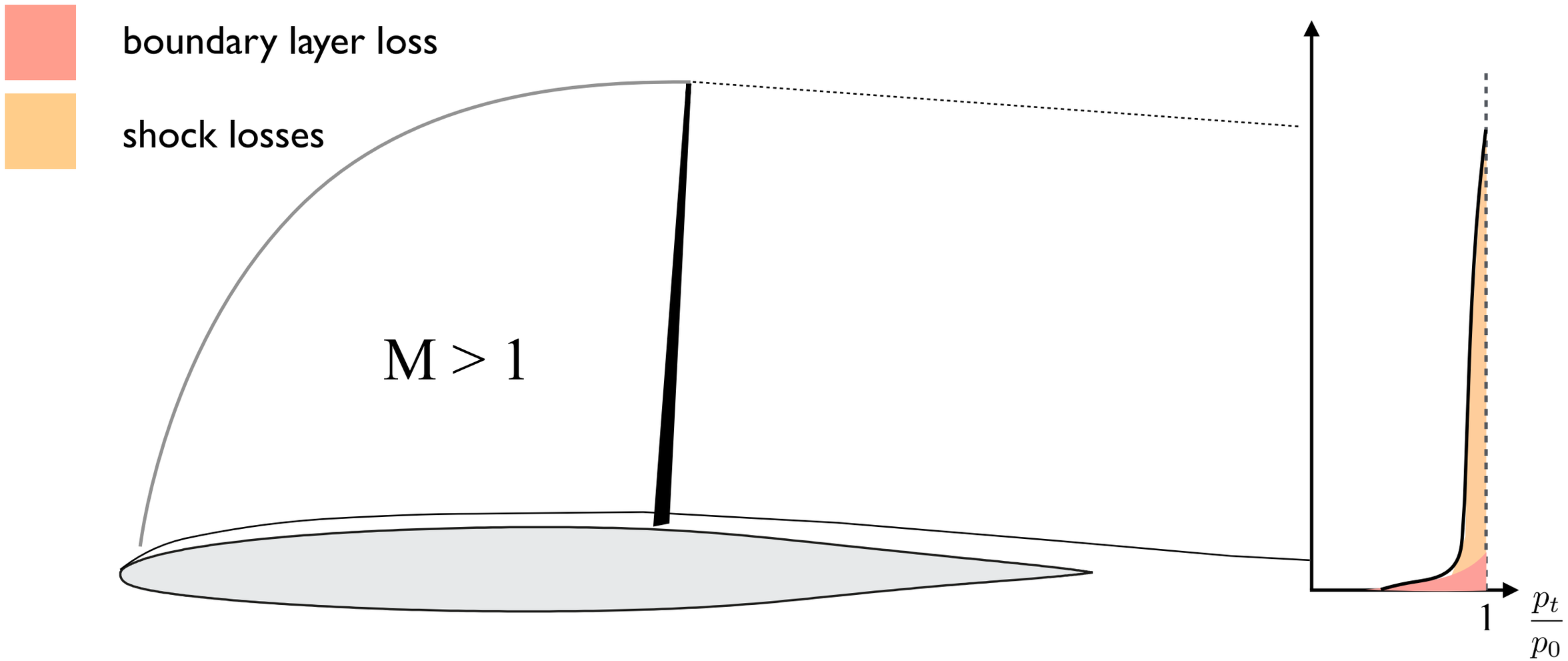


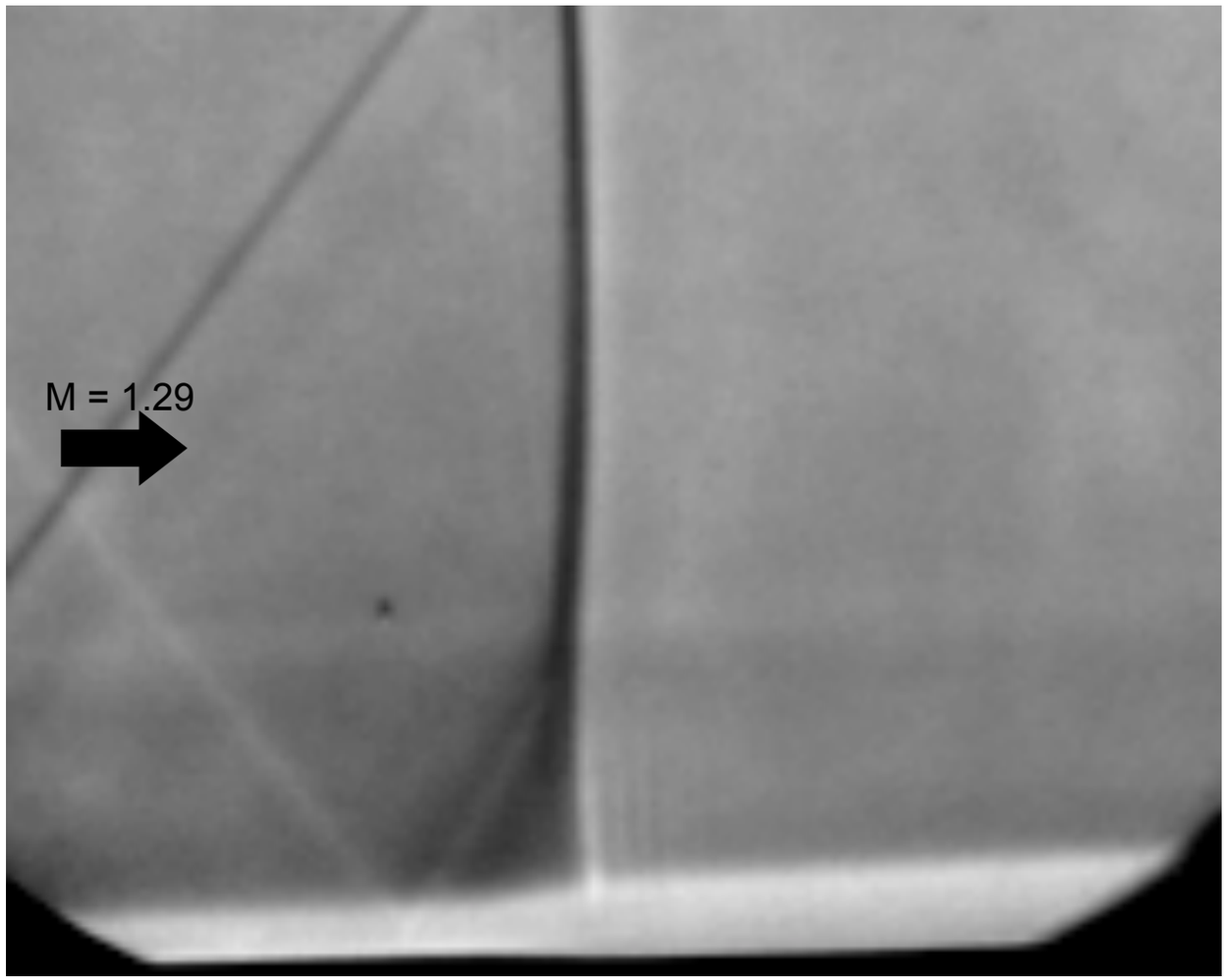
- Shocks cause rapid increase in pressure, decrease in velocity
- Shocks convert kinetic energy into heat

Are shocks a problem?



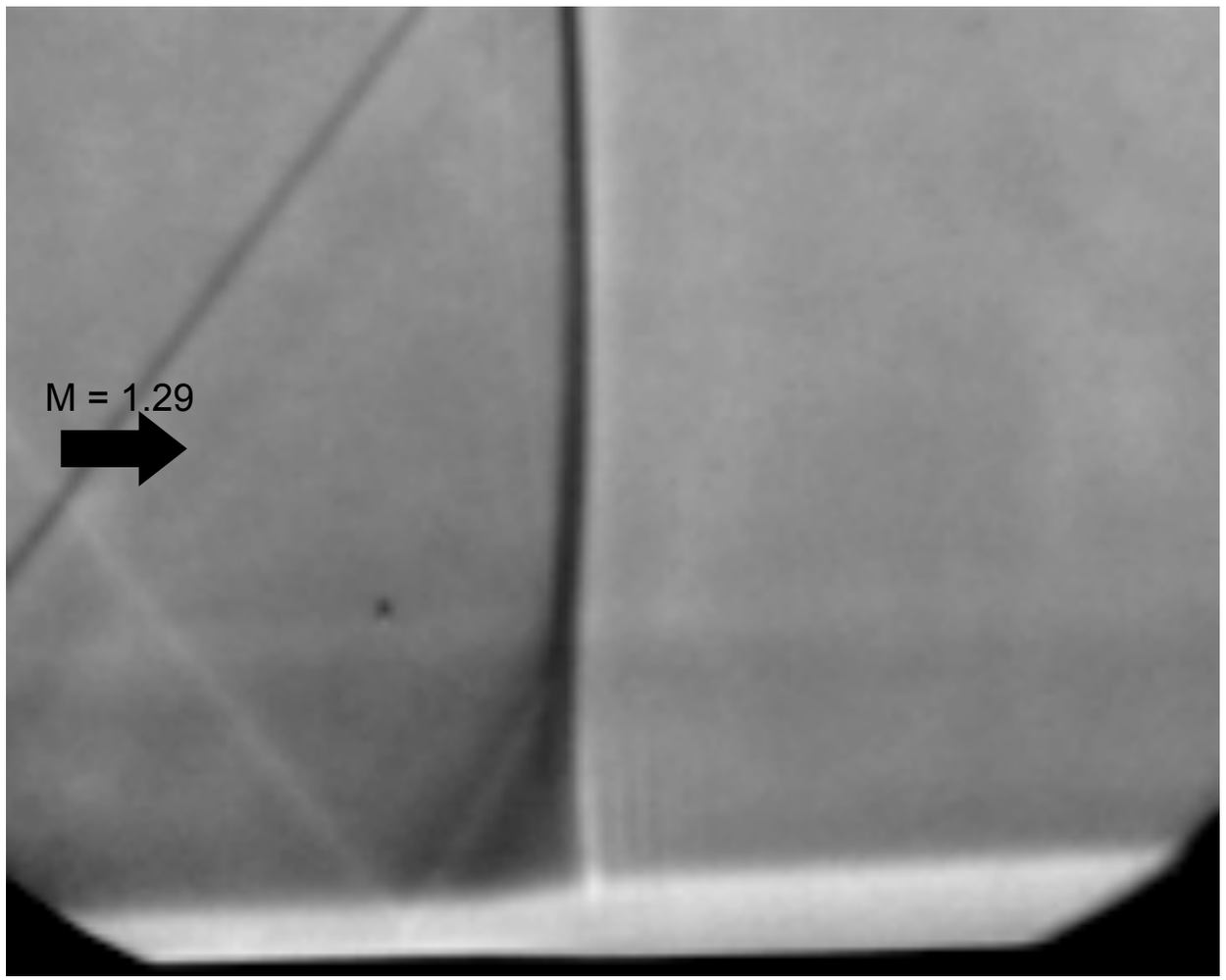
‘Wave drag’

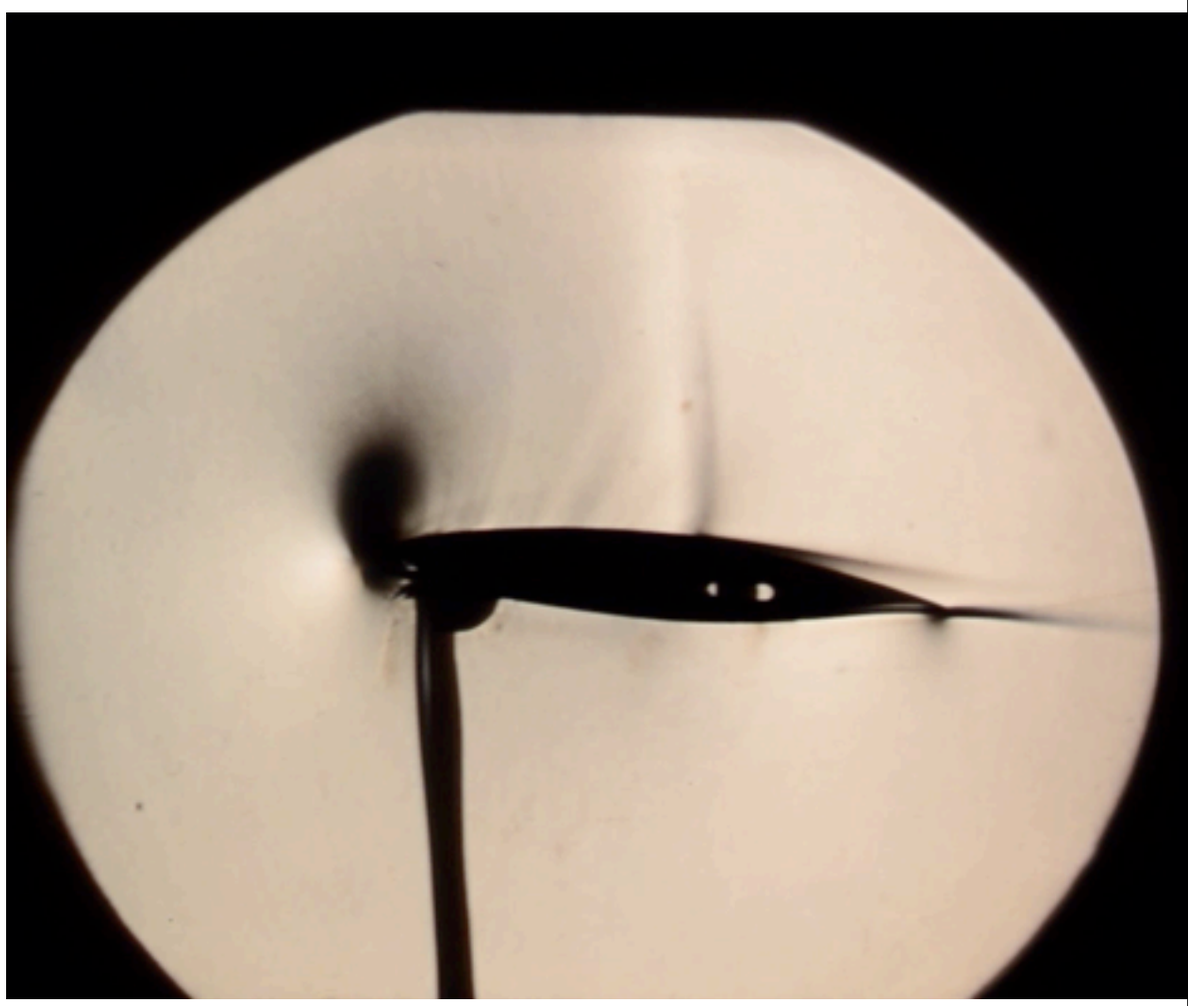
Even more problems



- Sudden pressure rise is also bad for the flow on the wing surface

Even more problems

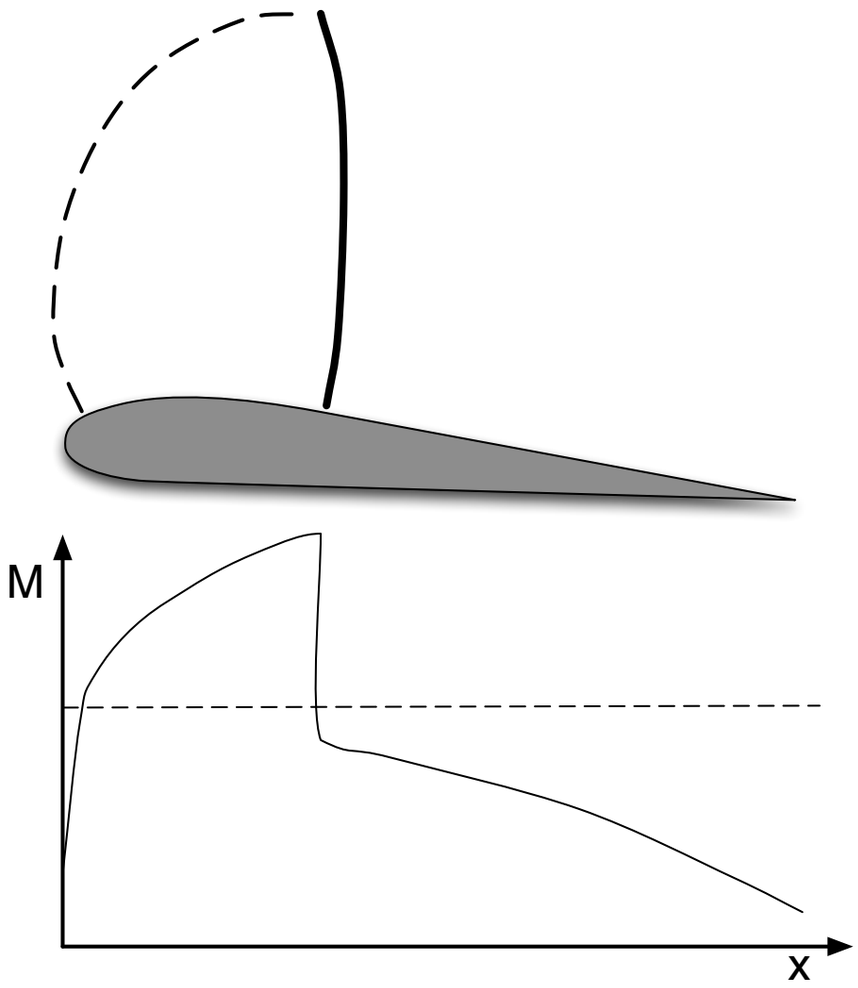


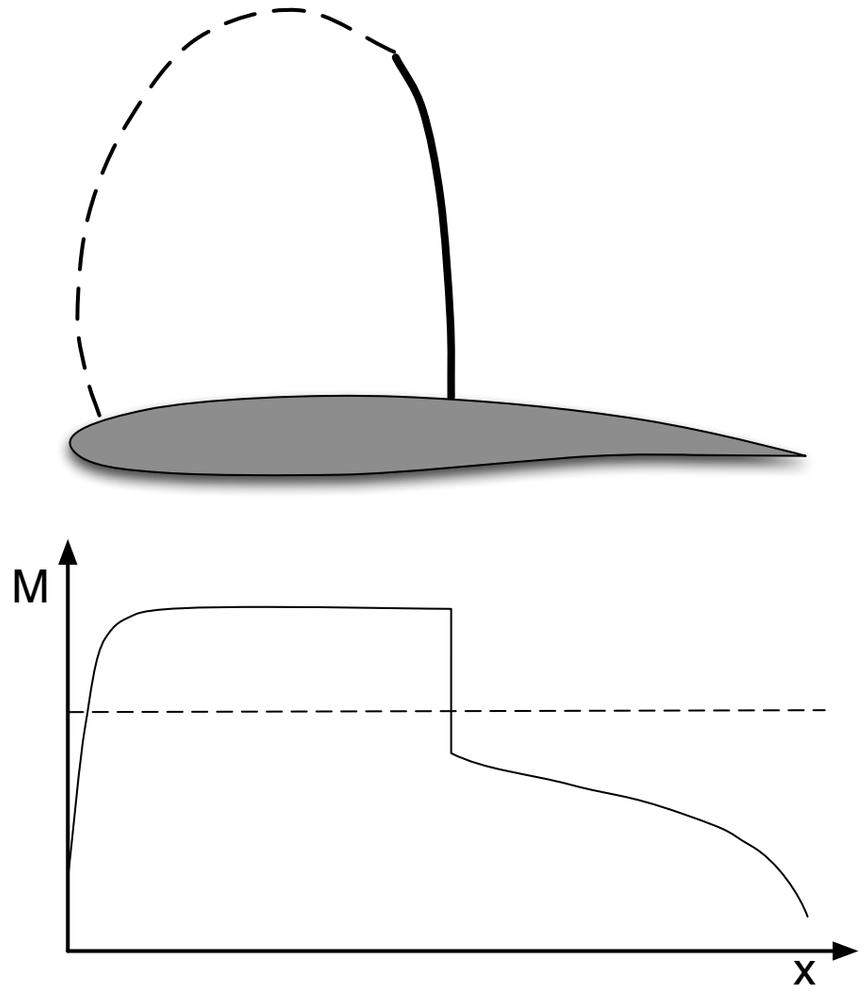


- Sudden pressure rise is also bad for the flow on the wing surface
- This can cause ‘flow separation’ and shock ‘buffet’

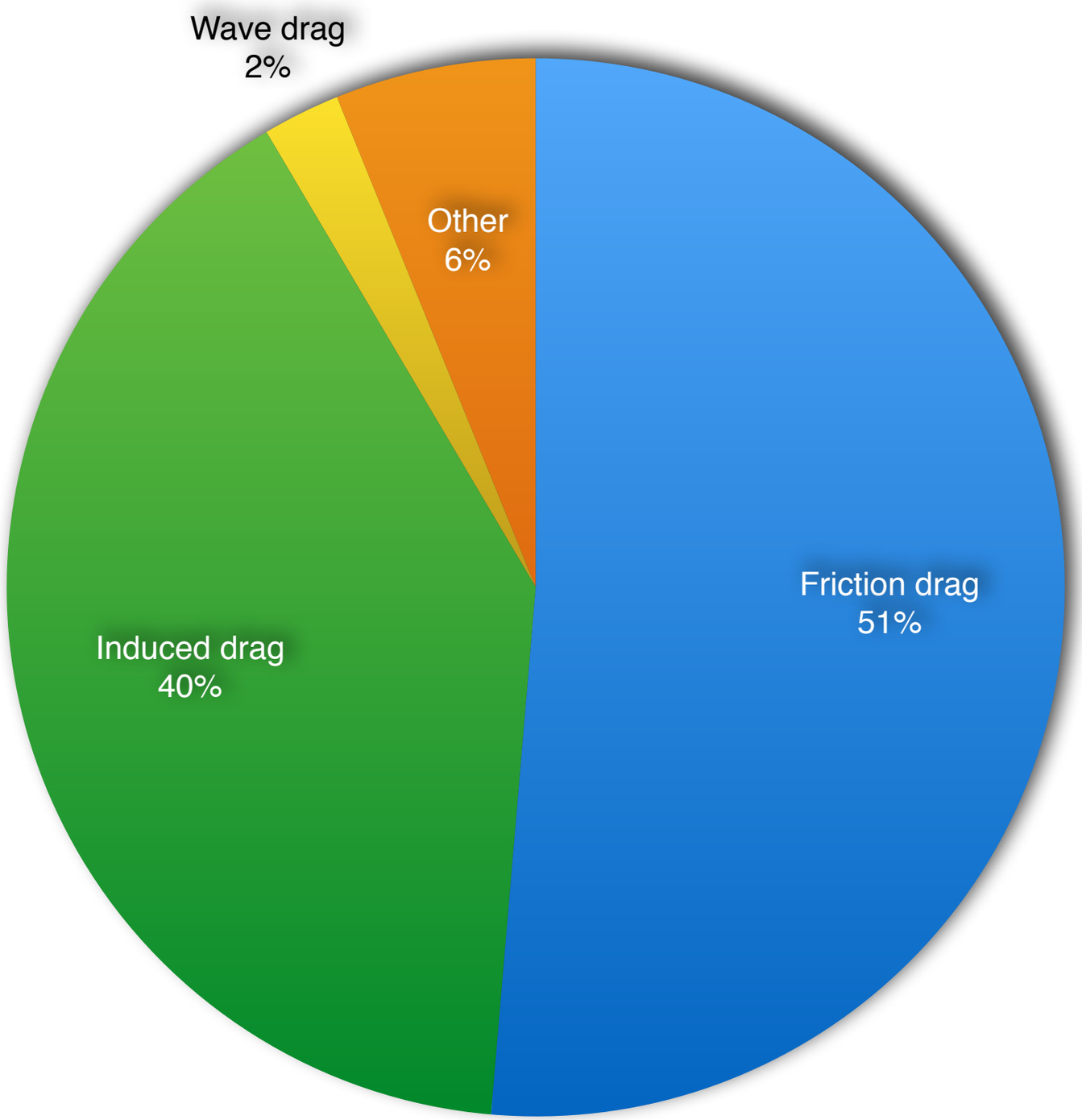
How do we deal with shocks?

- Limit top flight speed (M<0.85)
- The supercritical airfoil



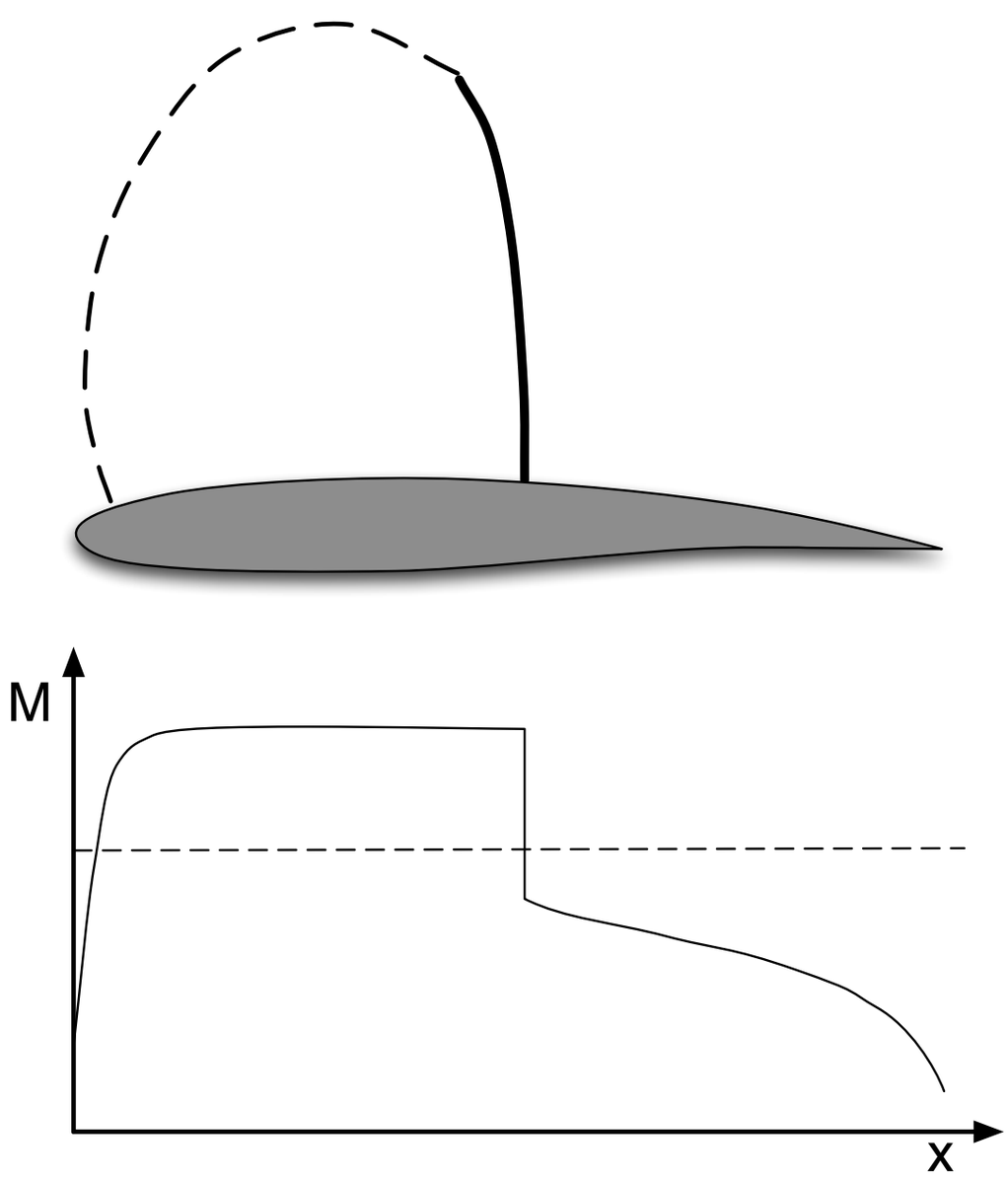


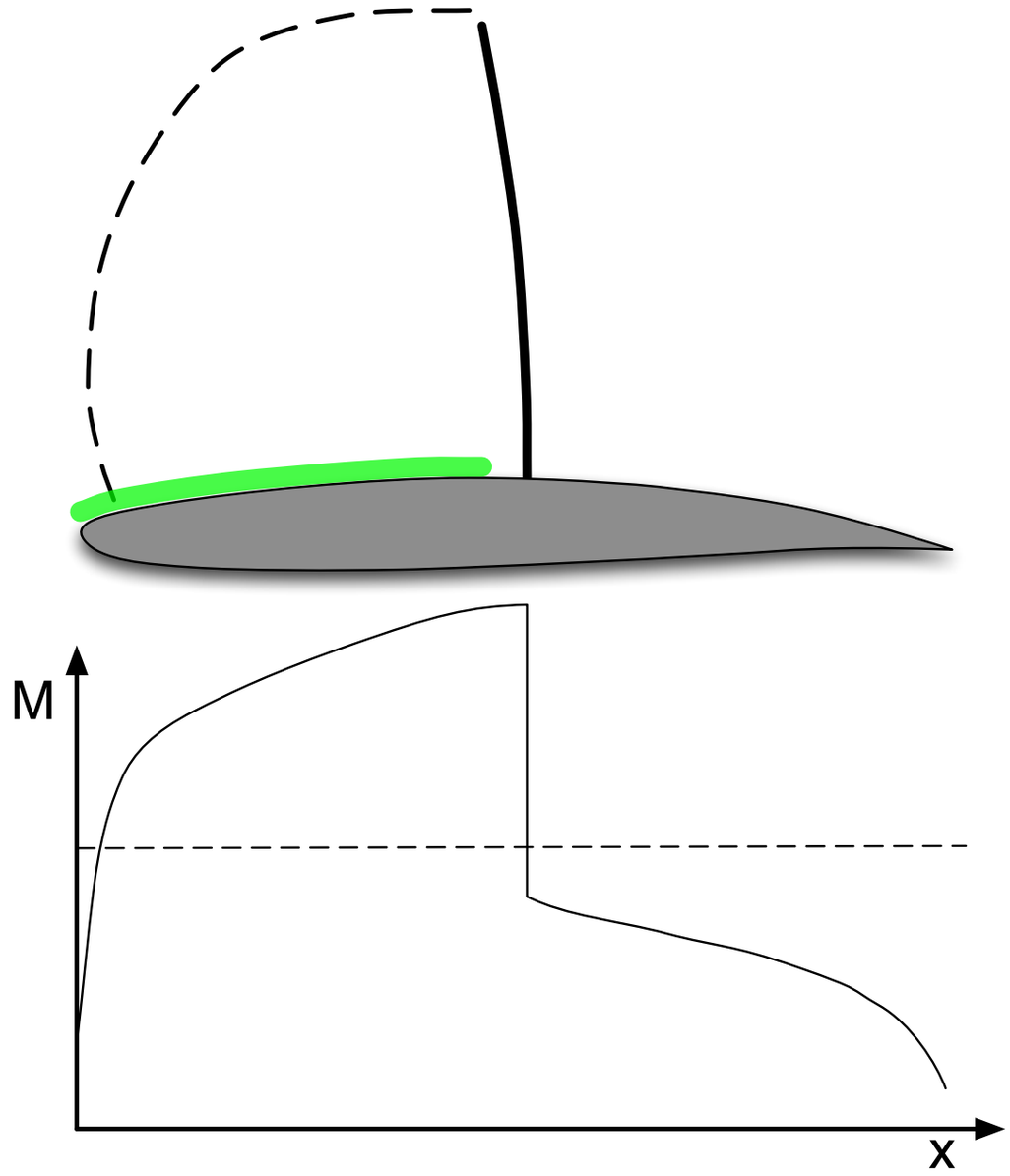
Typical drag on a modern aircraft



but shocks remain a problem

- limit speed flexibility
- new (laminar flow-) wings likely to feature stronger shocks

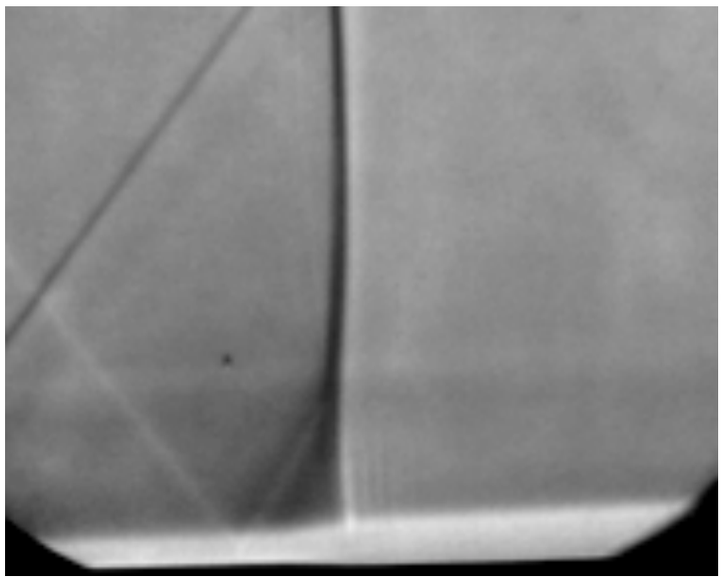


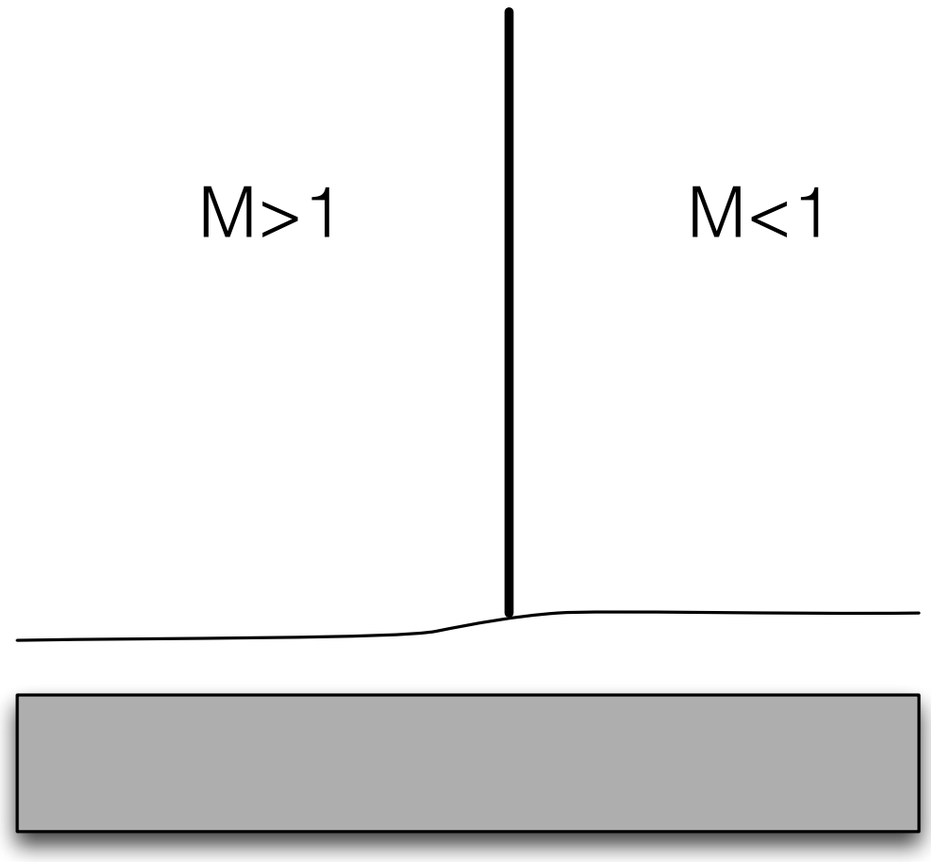


A new way to deal with shocks

what can we do to weaken shocks?

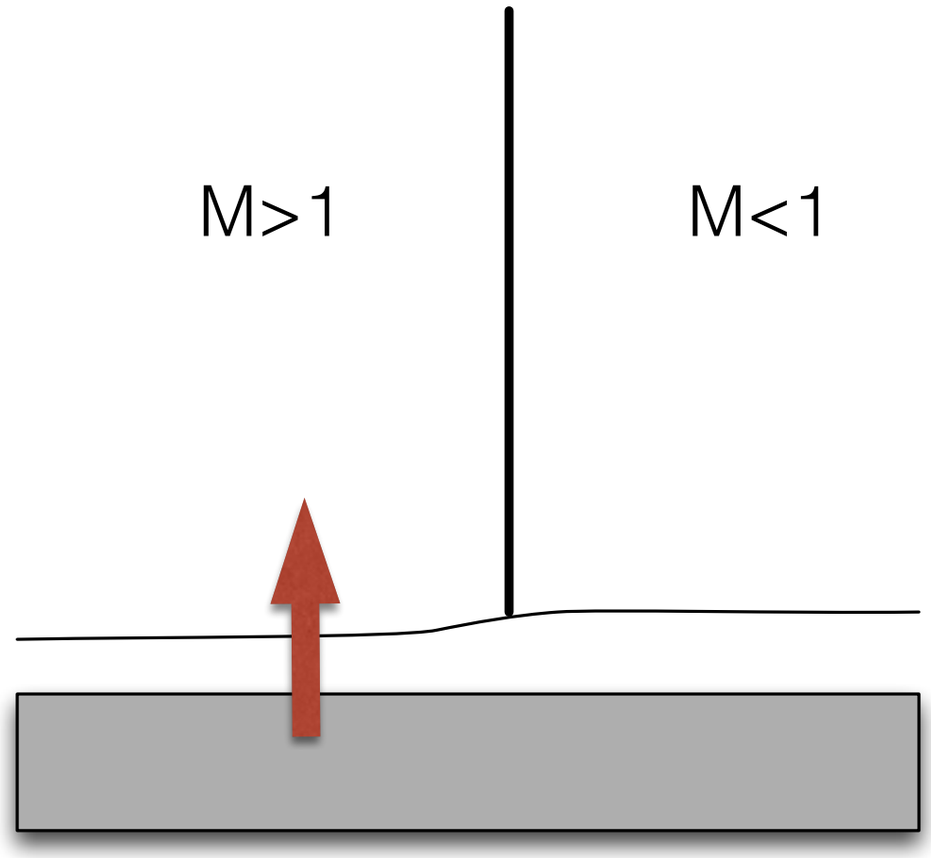
- Make the compression more gentle





what can we do to weaken shocks?

- Make the compression more gentle
- ‘push’ the flow ahead of shock



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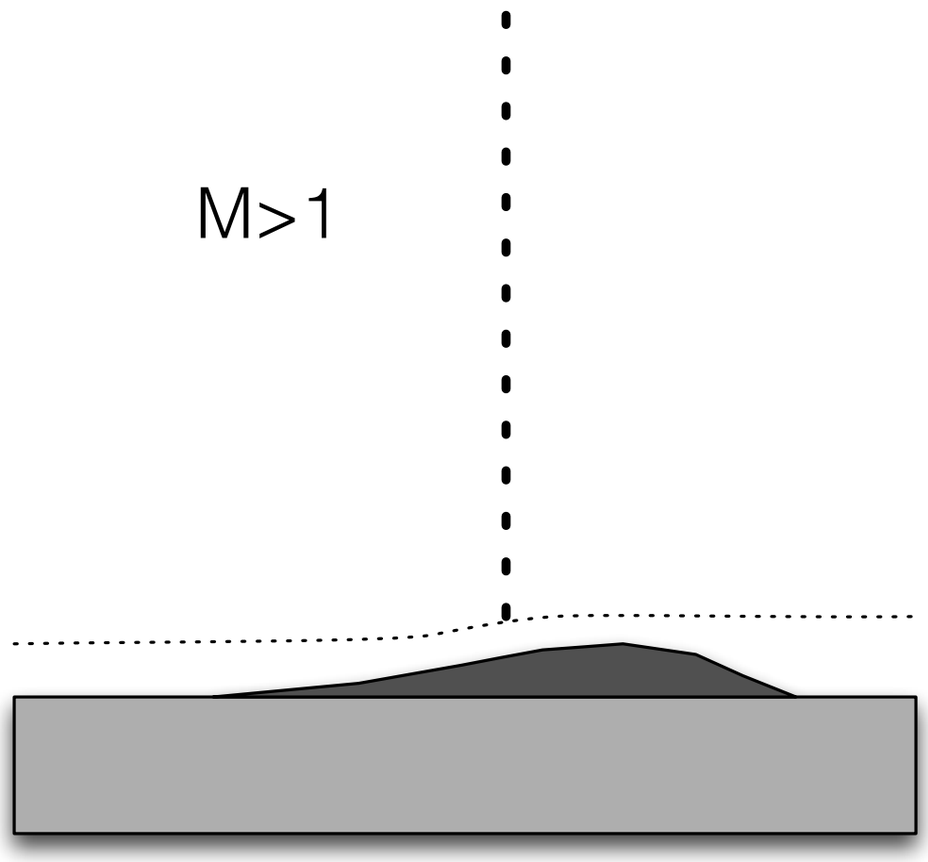

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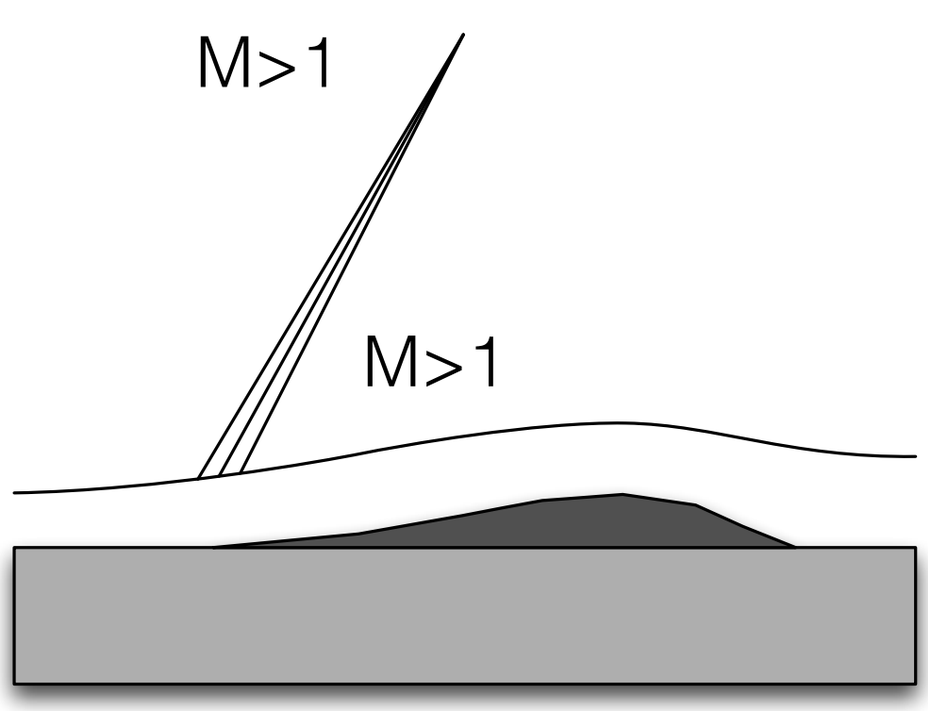

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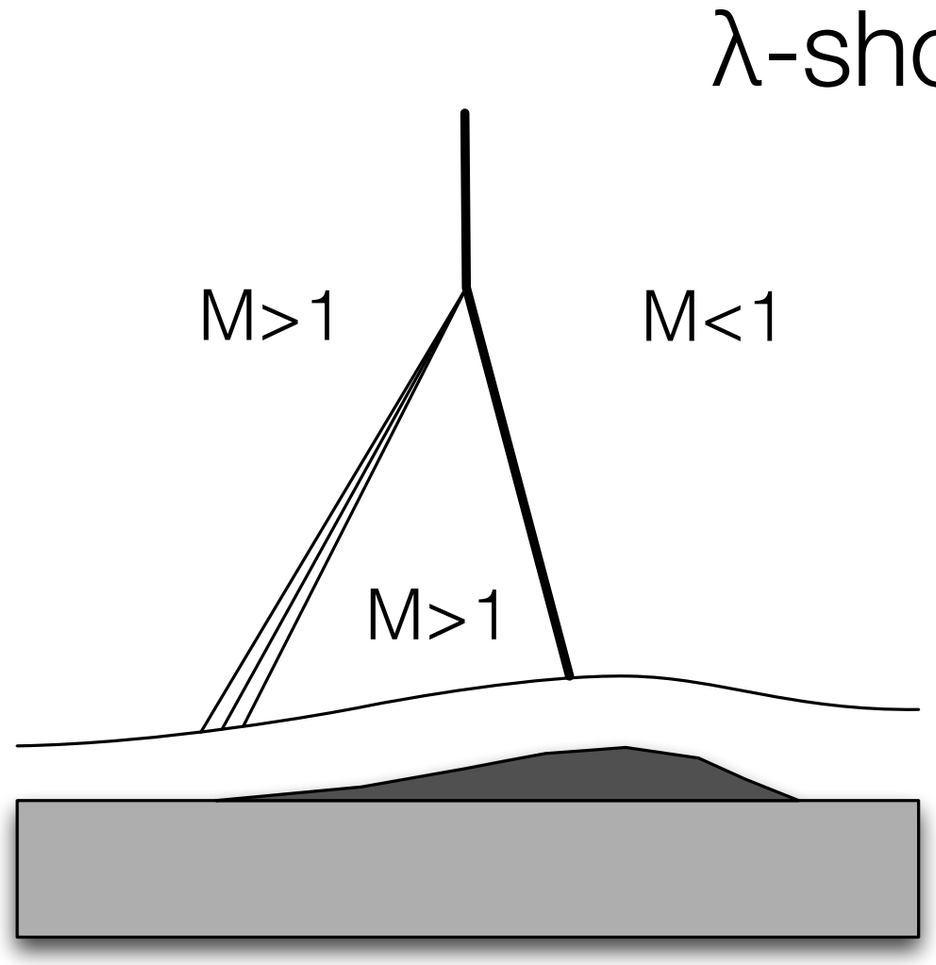
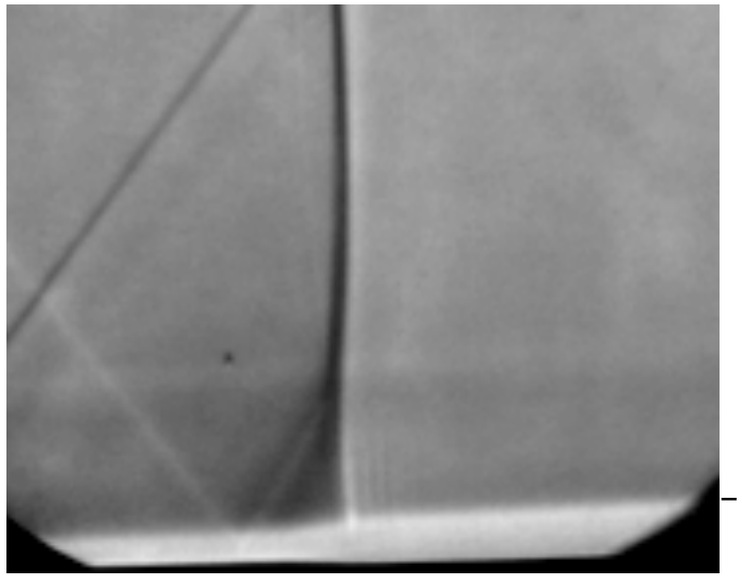
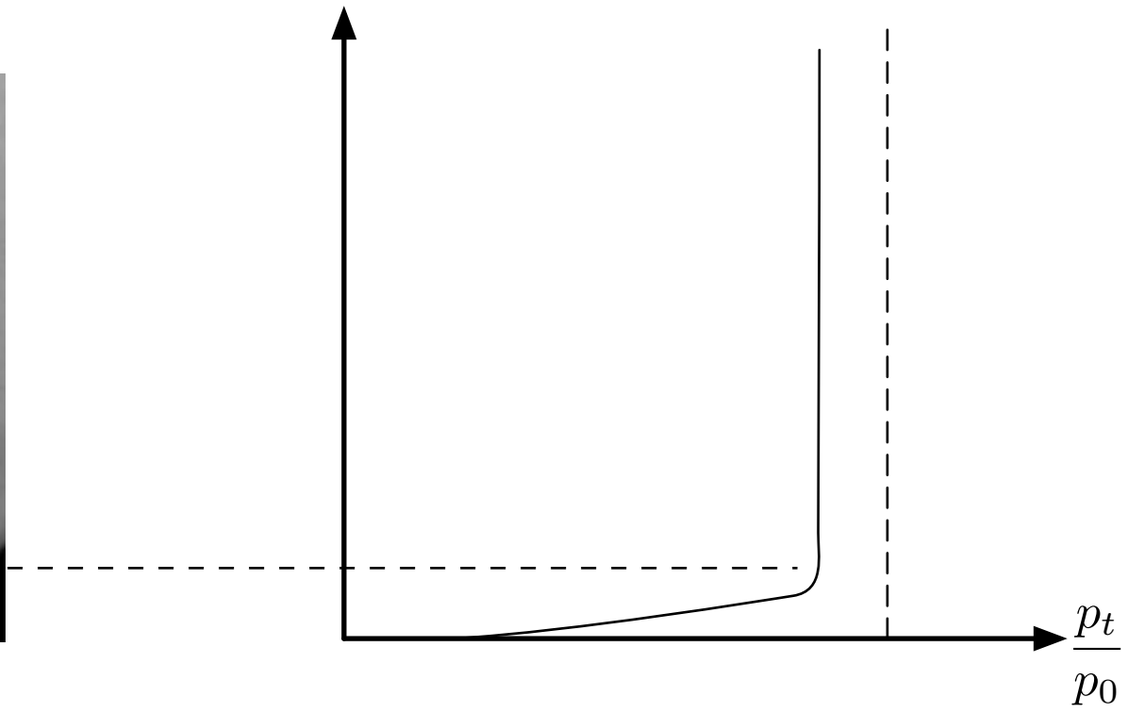
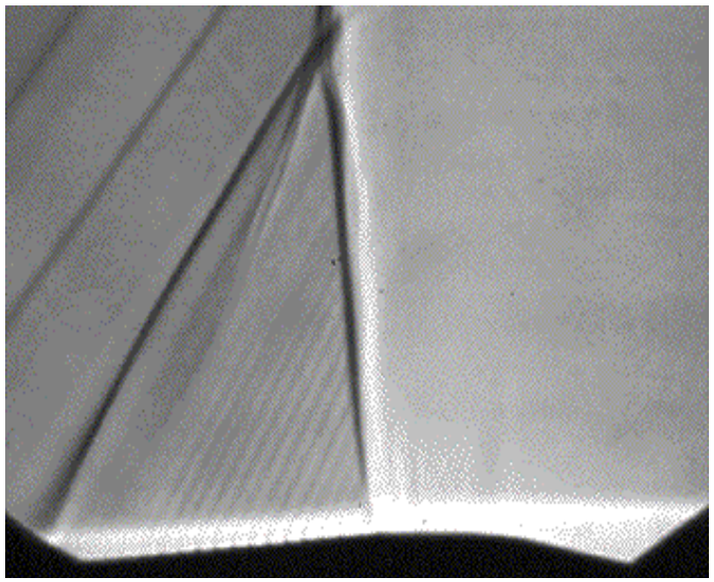
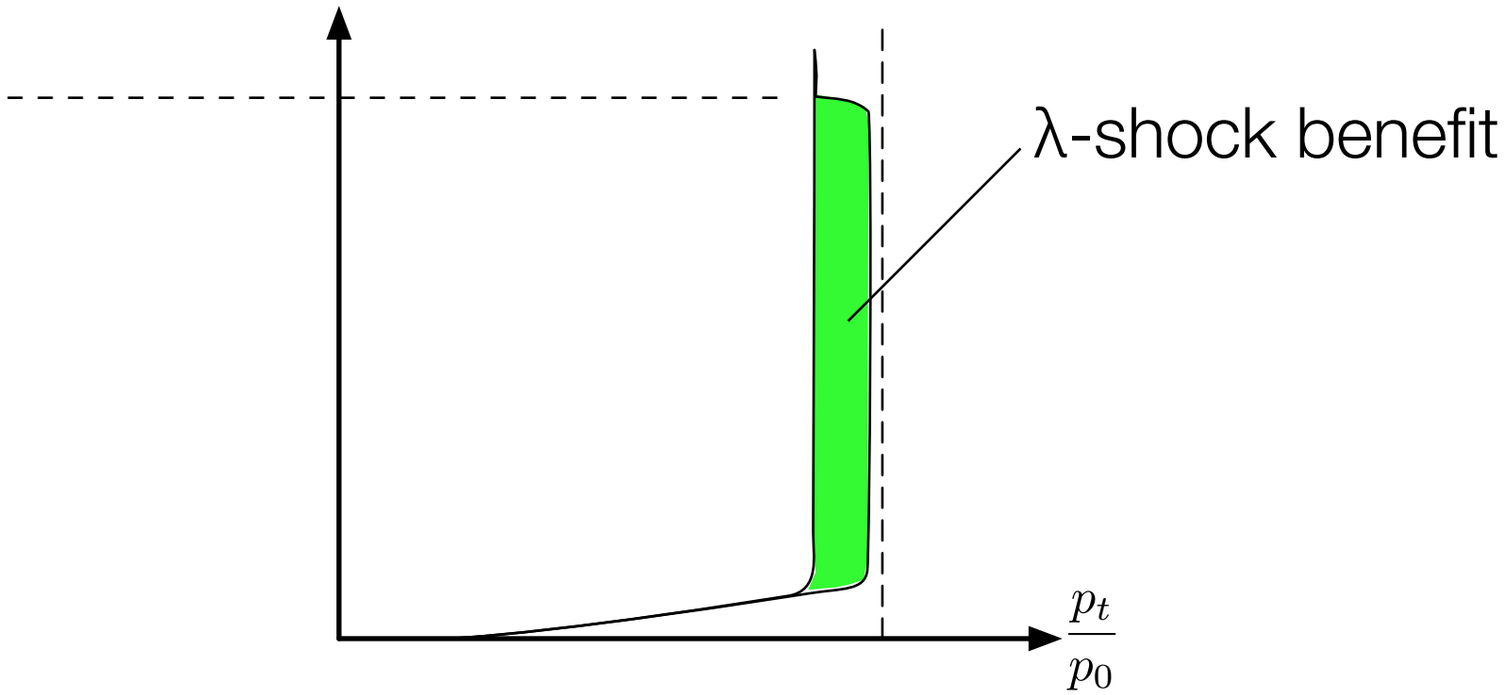


The shock control bump (2D)









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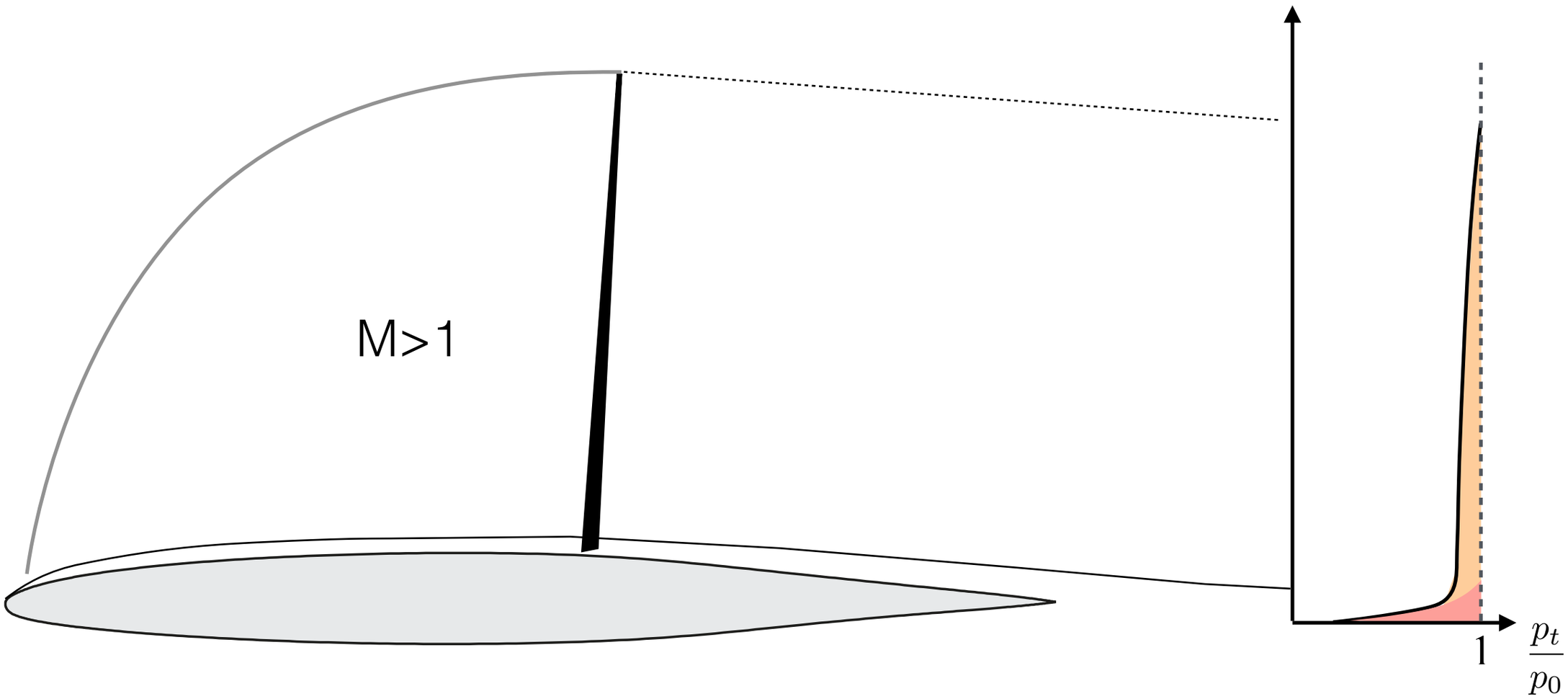

boundary layer loss

shock losses

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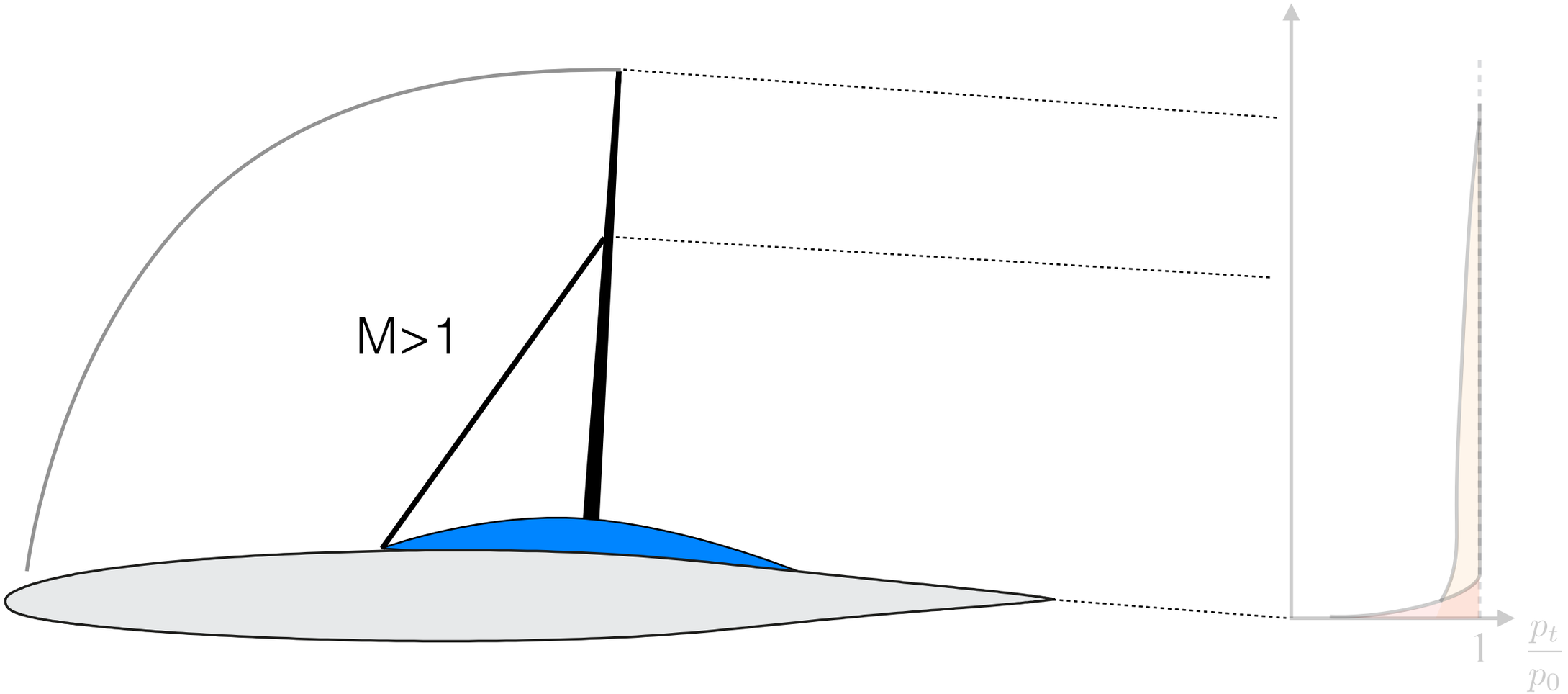

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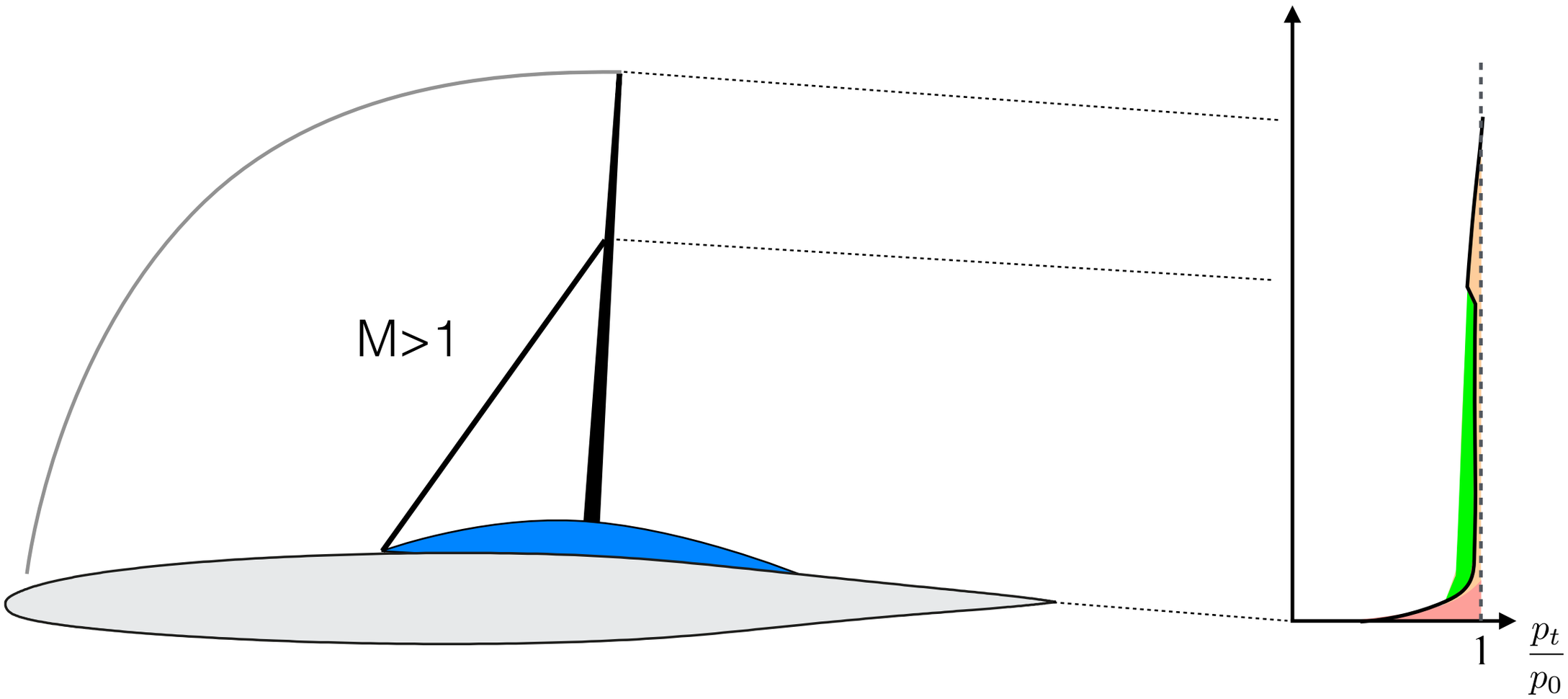


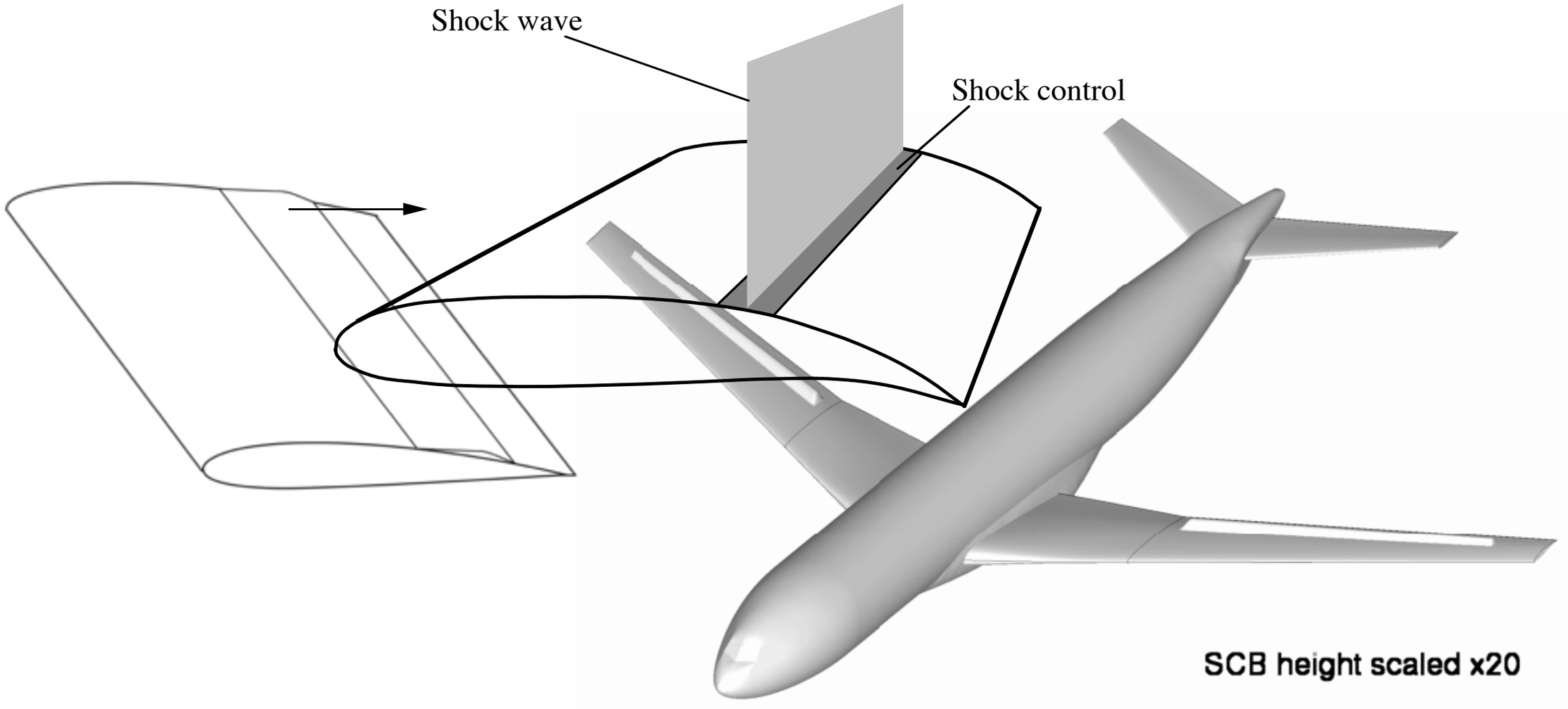
boundary layer loss

bump control gain

shock losses

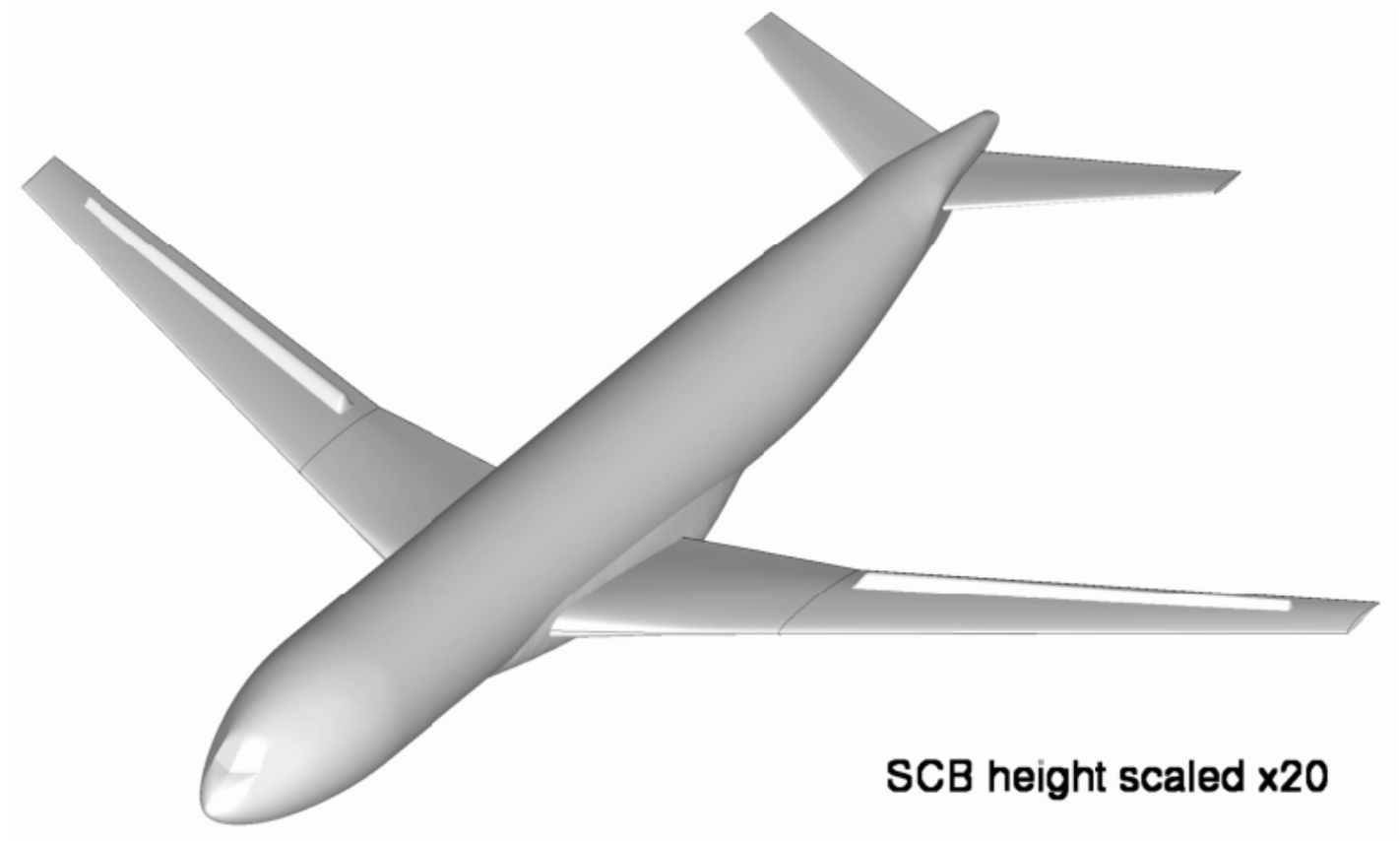
The shock control bump (2D)

- Bump is placed on wing - following the shock footprint



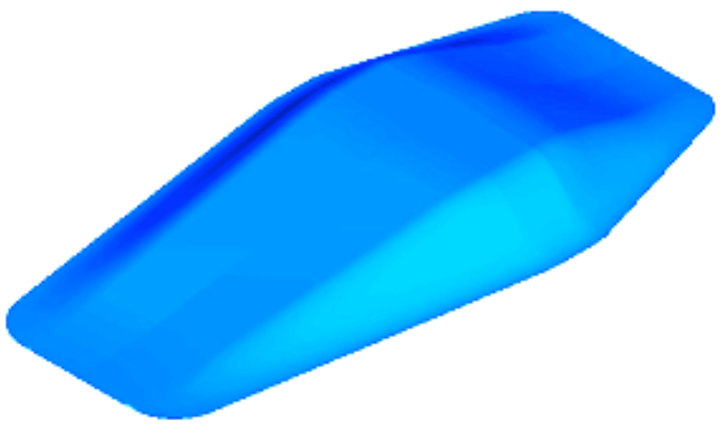
The shock bump - downsides

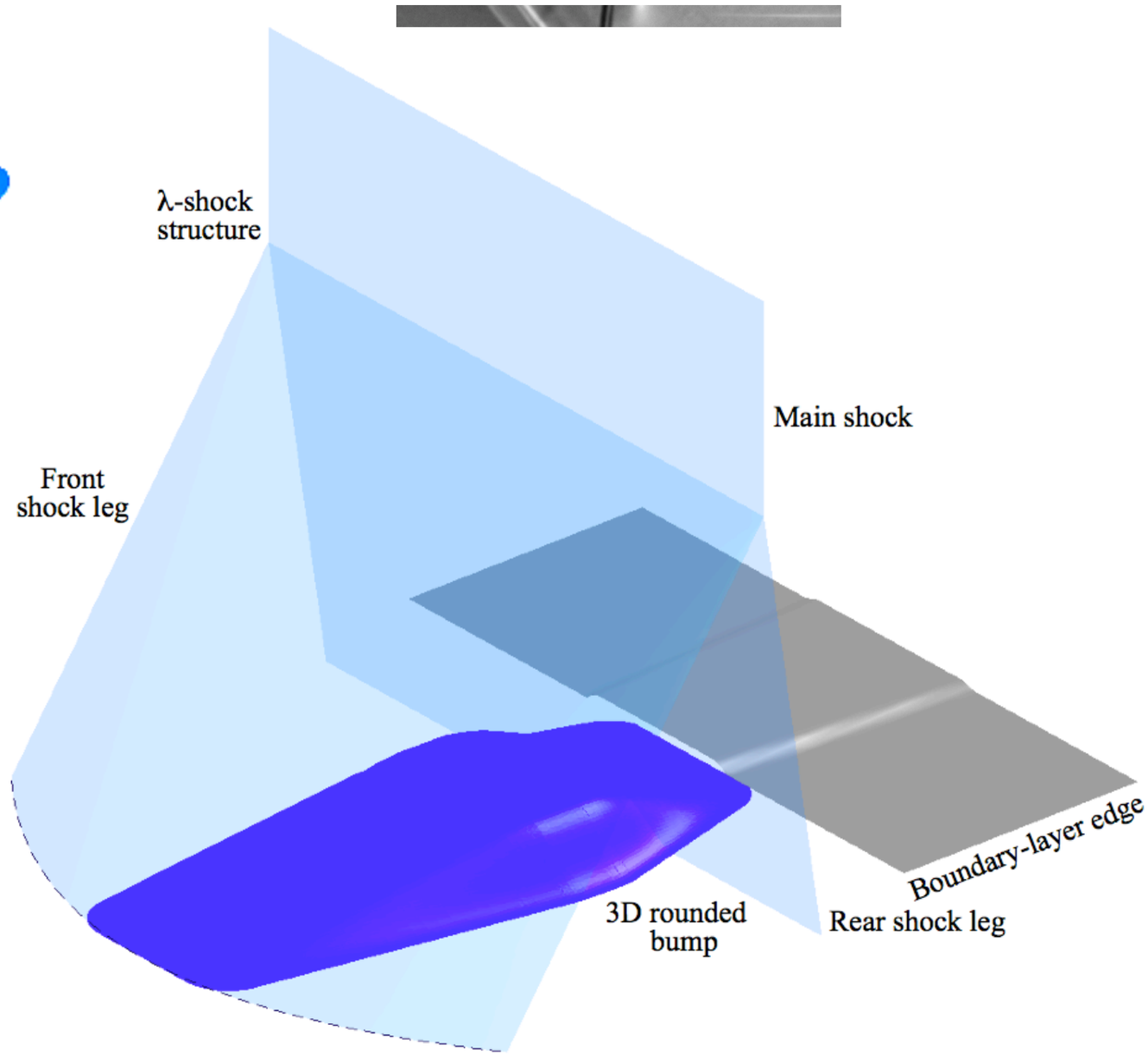
- Needs to be perfectly aligned with the shock
- Not great for the near-surface flow (boundary layer)
- Bad ‘off-design’ behaviour (when the shock is elsewhere)



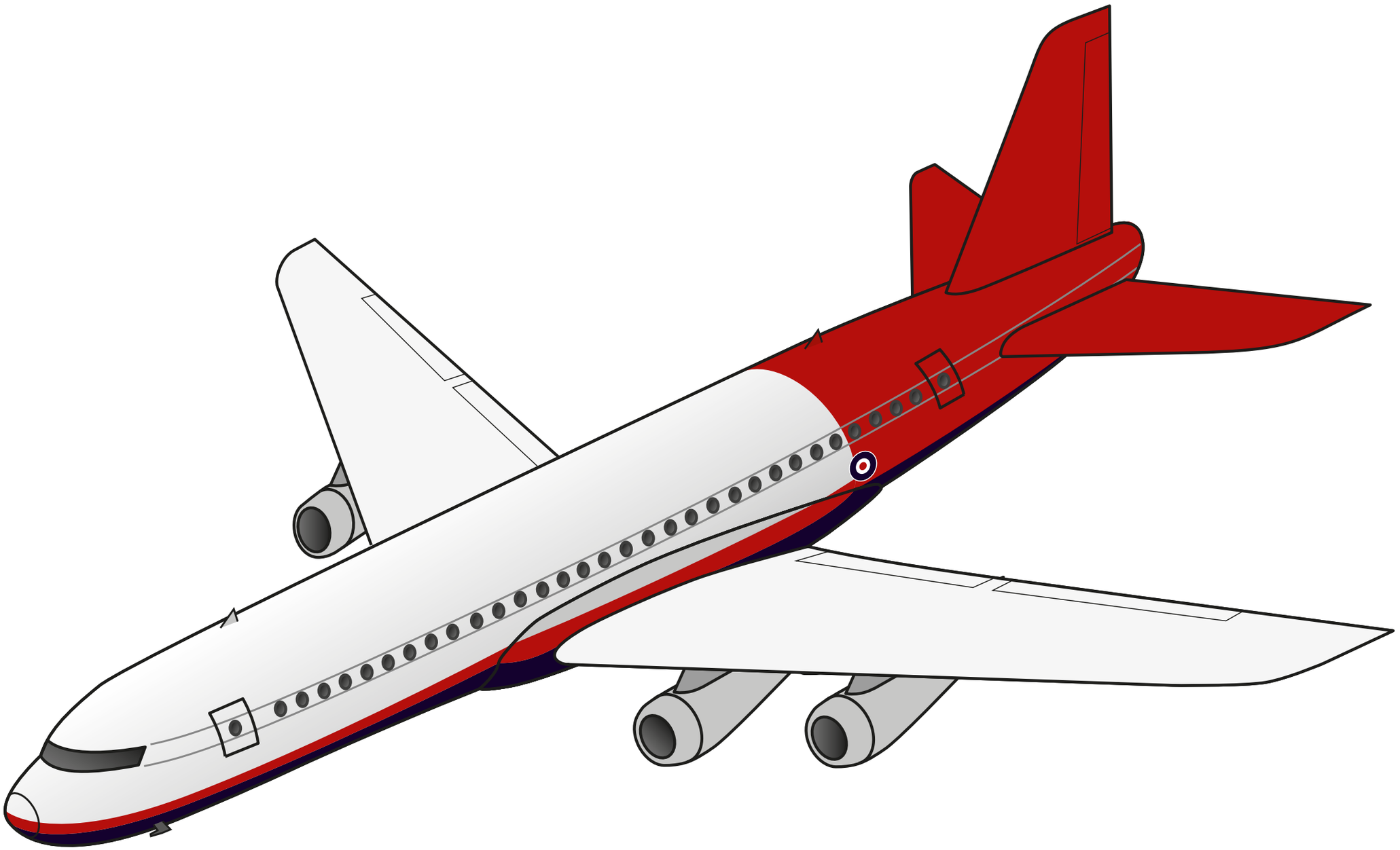
3-D to the rescue

3D to the rescue

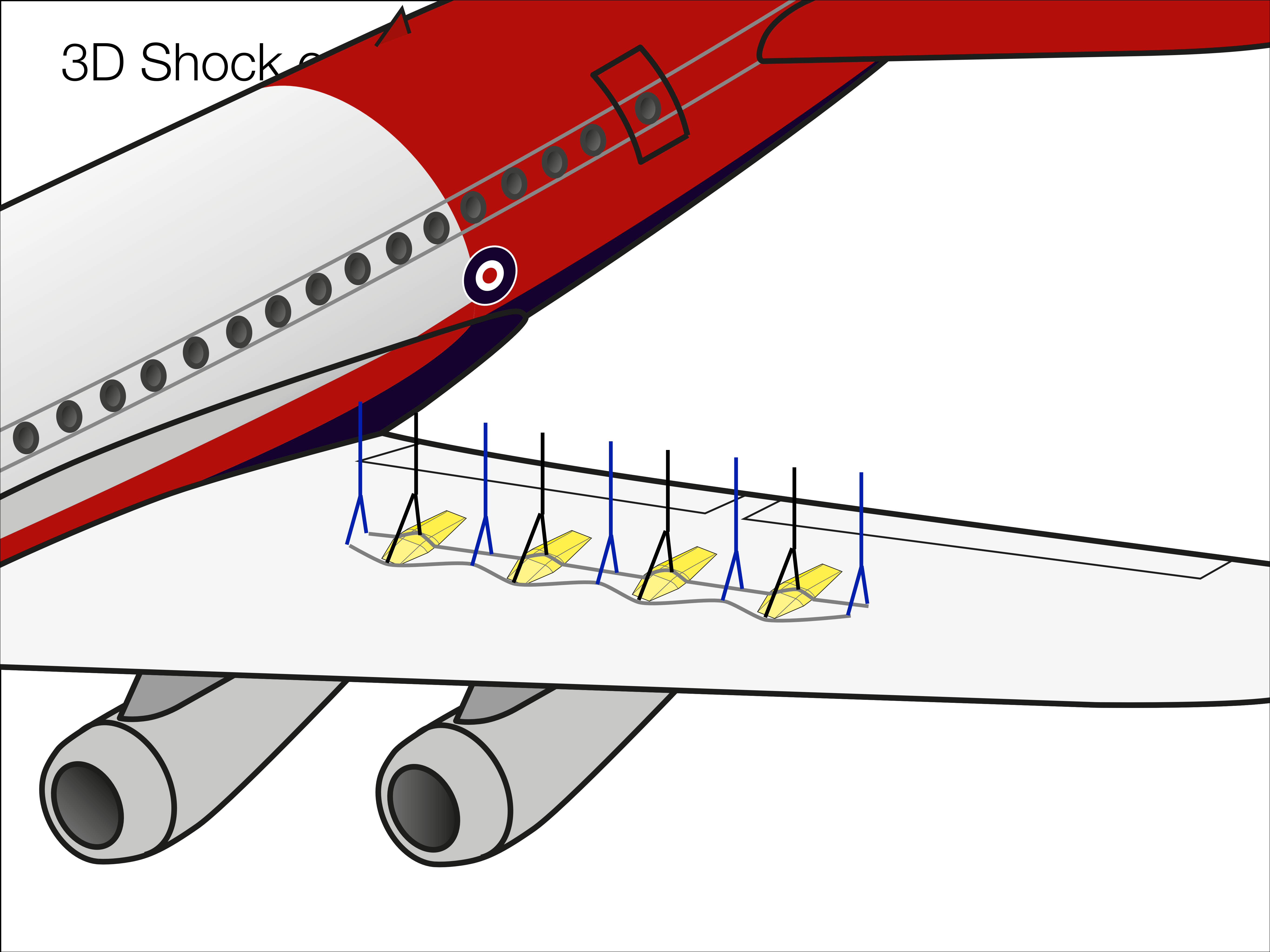




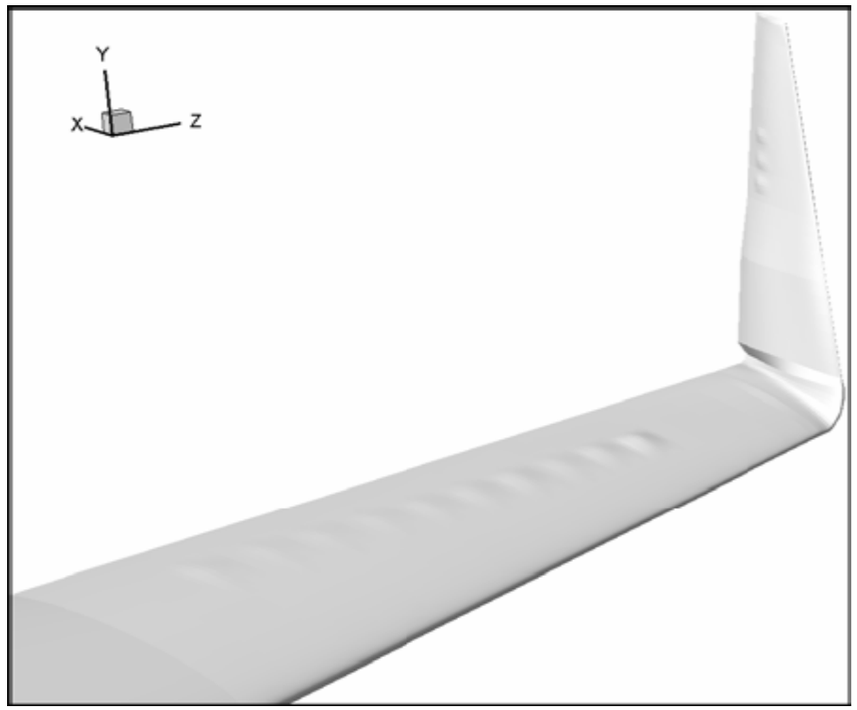
3D shock control bumps



3D Shock c

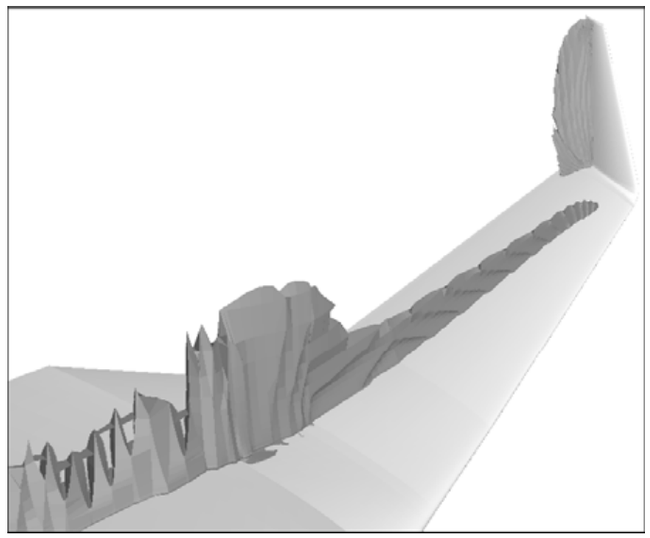


3D to the rescue

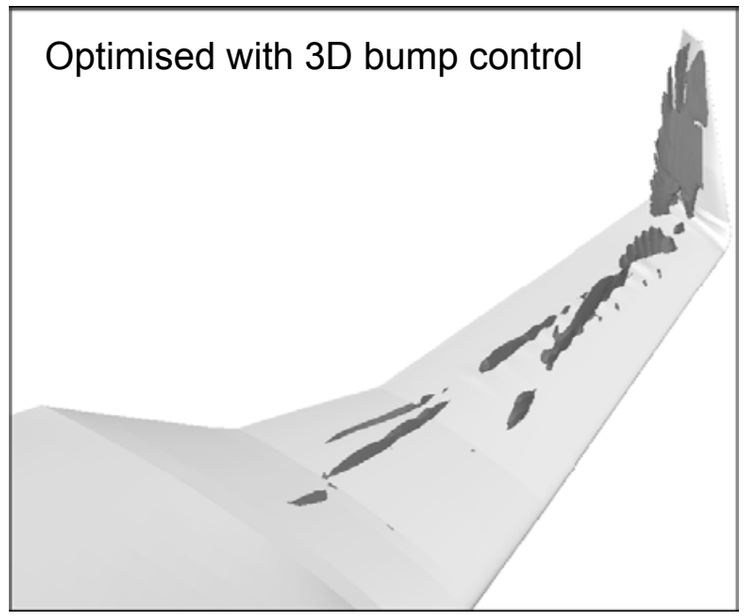


3D bump array on transonic wing
(Wong et al., Univ. of Sheffield)

Baseline (no control)



Optimised with 3D bump control



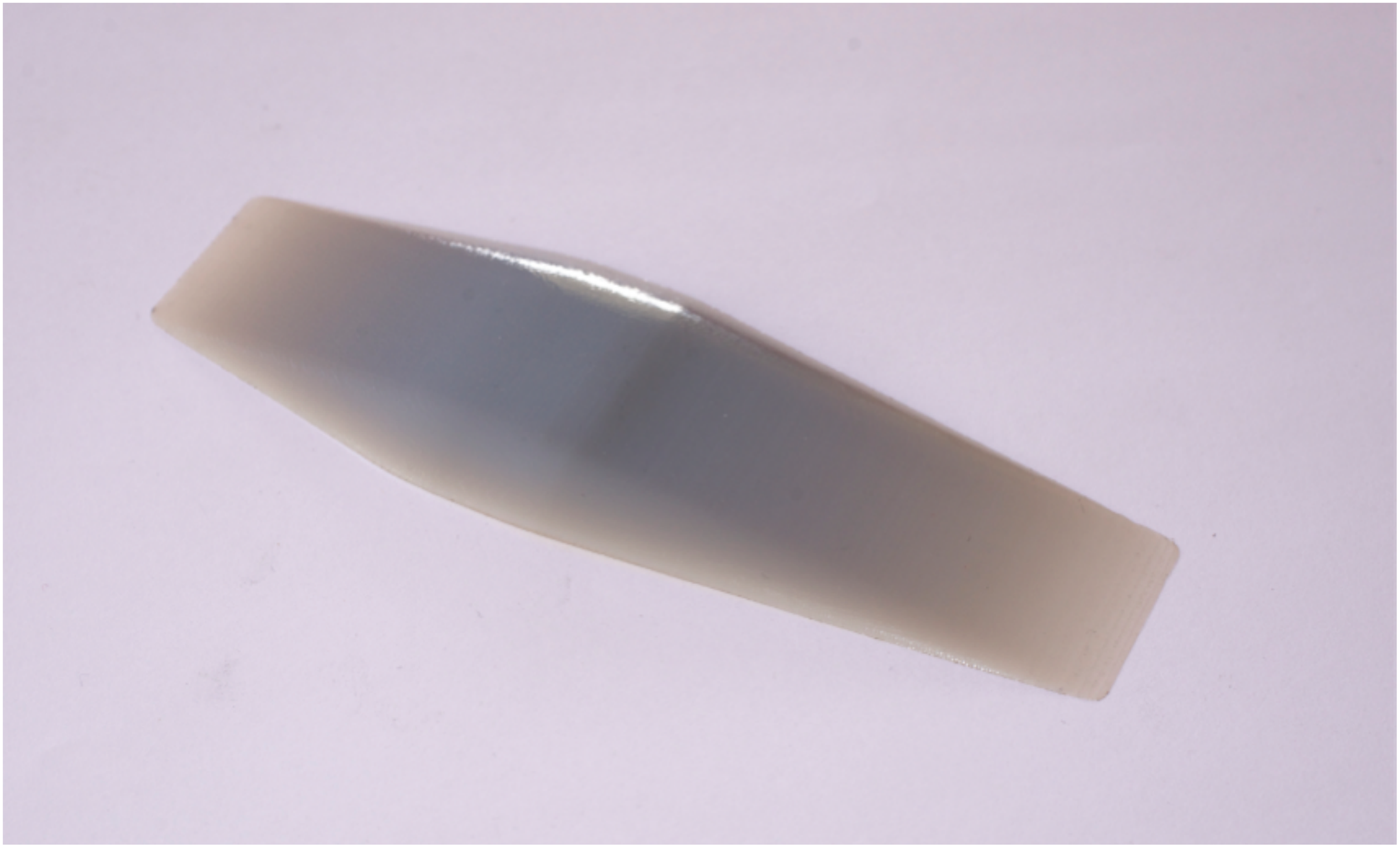
Computed shock wave structure
(Wong et al., Univ. of Sheffield, CFD)

- some early computations (Univ of Sheffield)

Current research

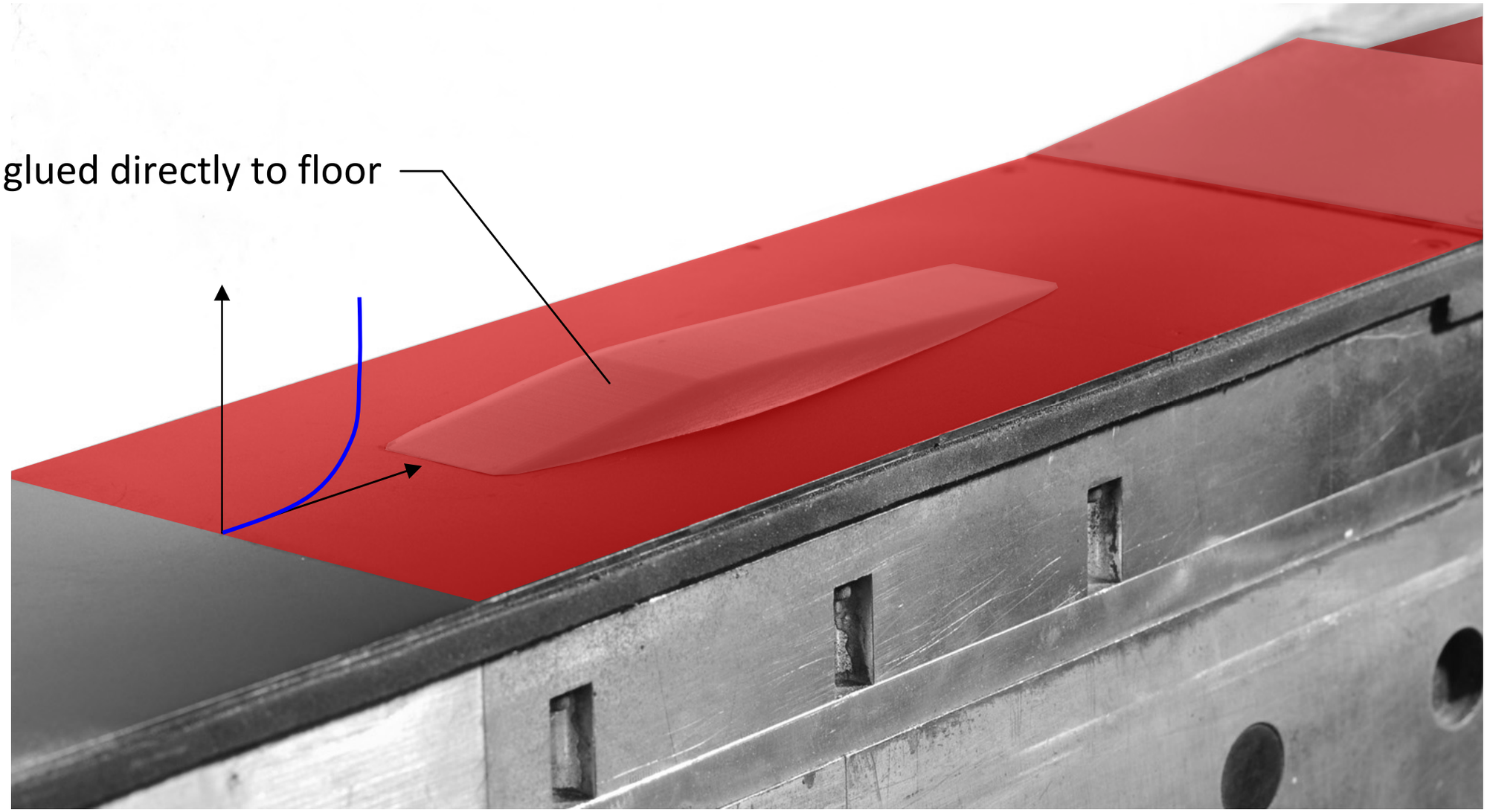
From our early attempts…

to current research

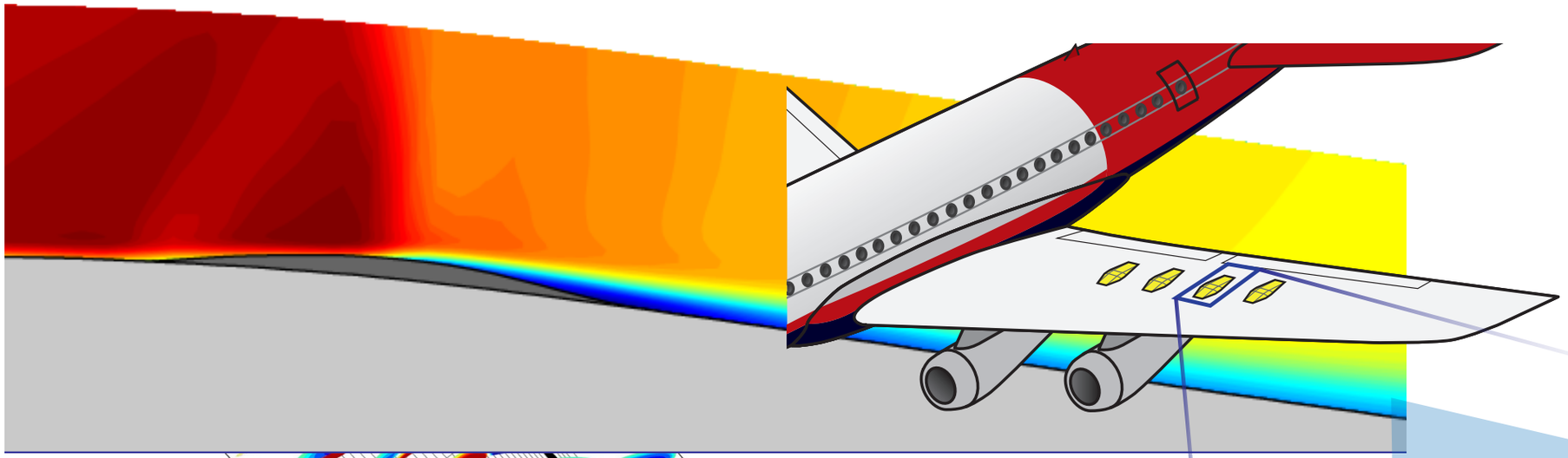


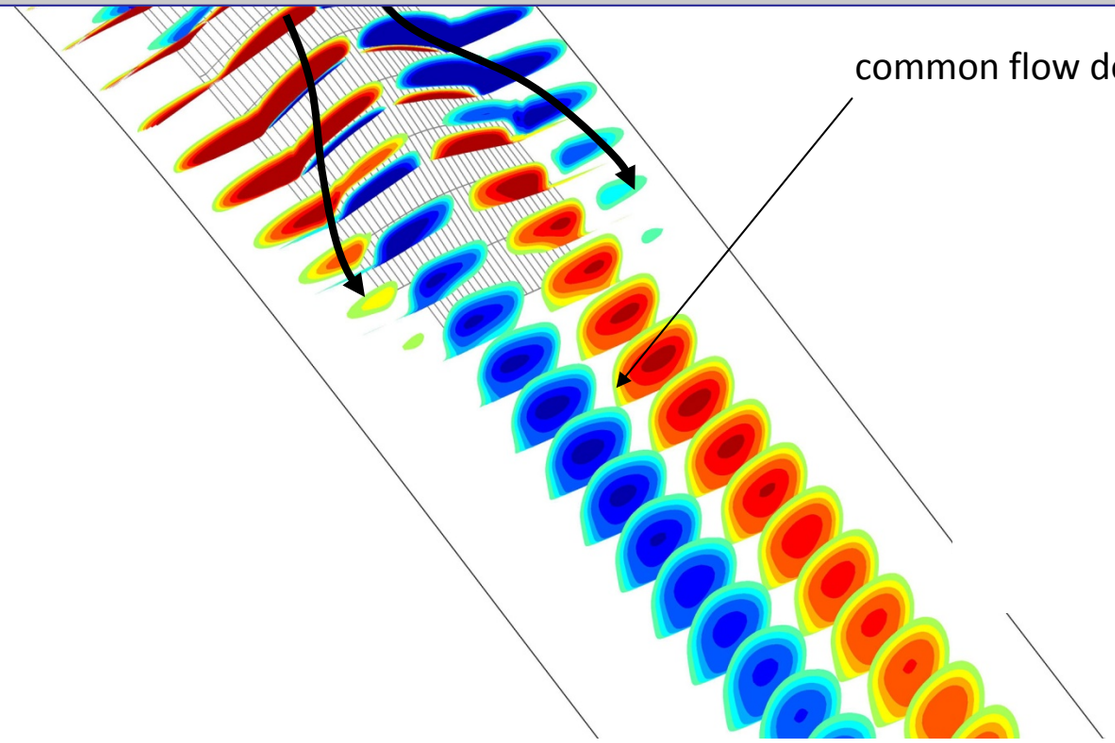
- 3D printing has come at the right time

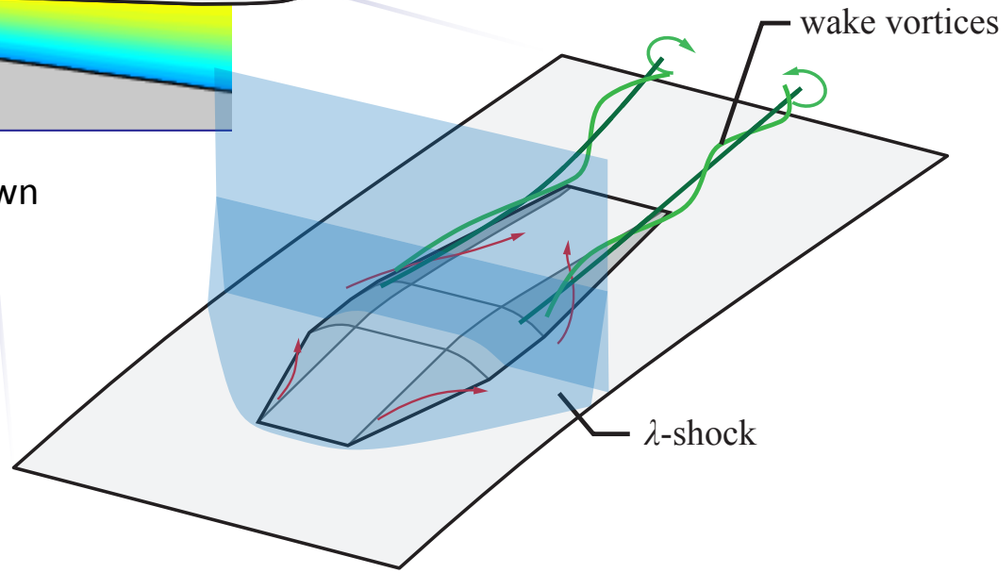
Detailed flow studies



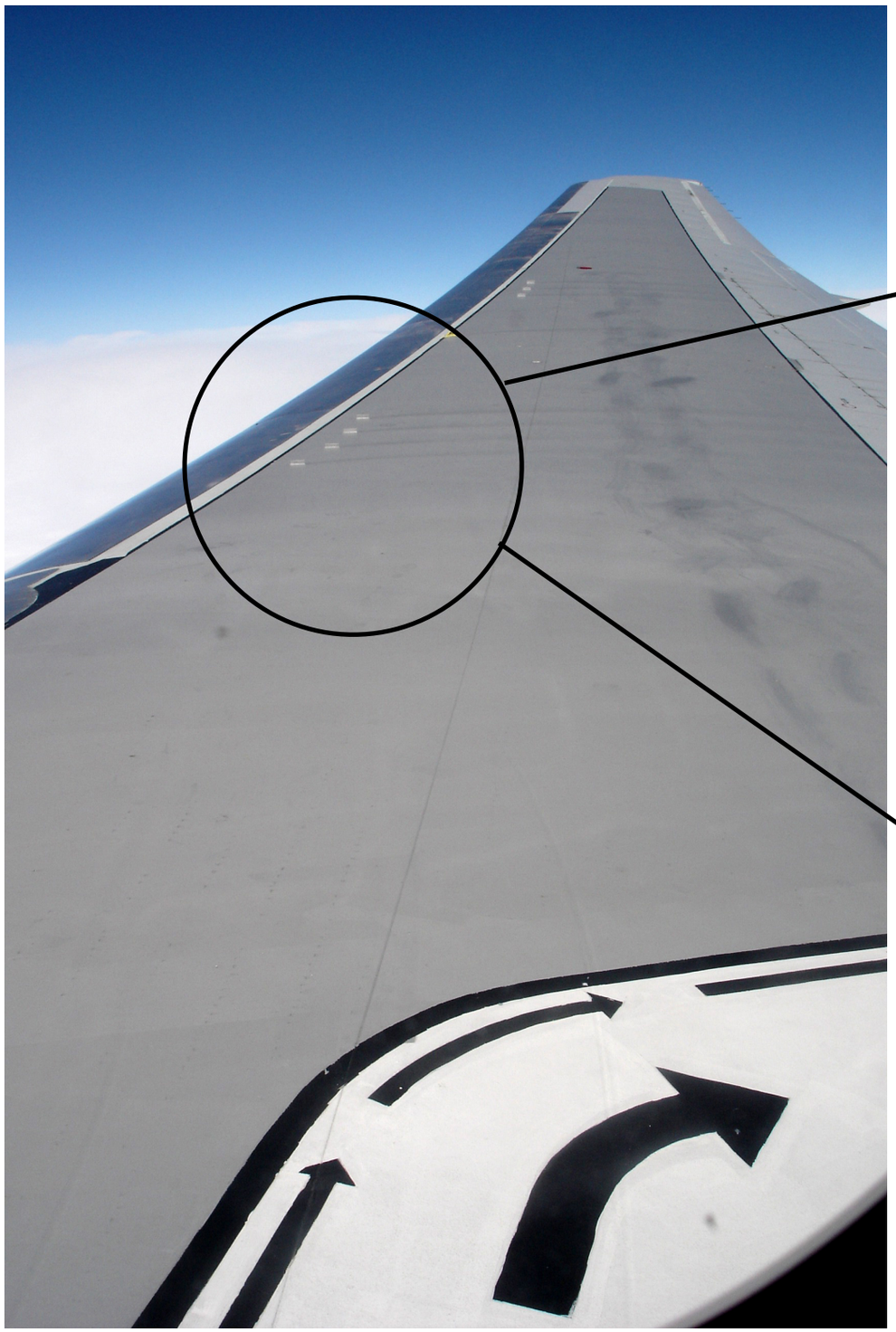
Detailed flow studies







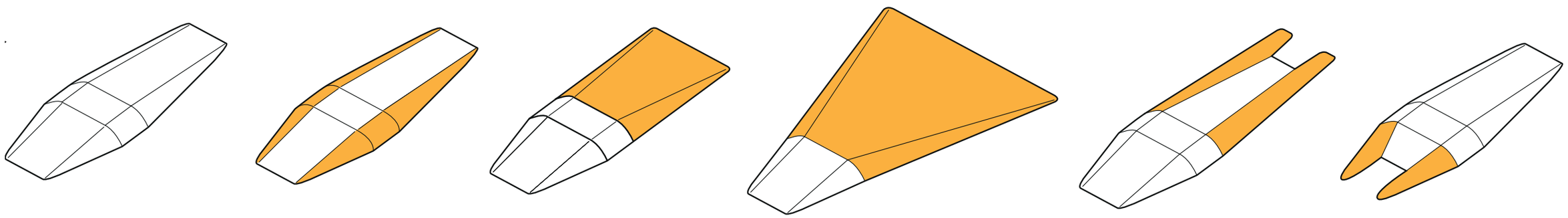
Vortex generators



Commonly used on aircraft (Boeing)

Cause parasite drag

Novel shapes



wedge bump

steep-sided bump

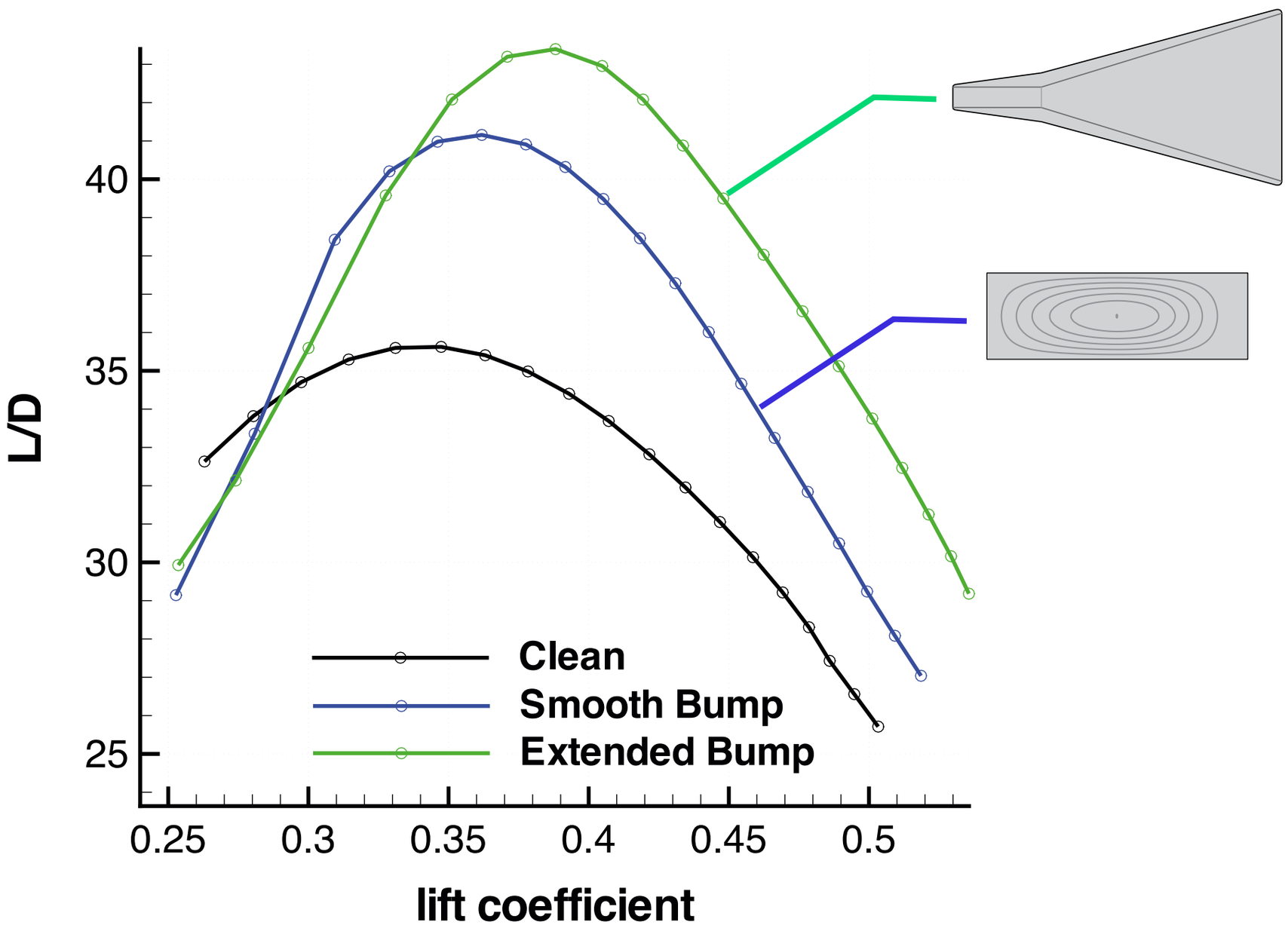
wide-tailed bump

exSCB

F(I)SCB

F(II)SCB

Novel shapes



Summary

Airfoils cause lift through flow curvature

You don’t need Concorde to experience supersonic flow

Transonic aircraft have shock waves on upper wing surface

- wave drag
- limit flight speed

New ‘laminar flow wings’ require stronger shocks

Surface bumps can alleviate wave drag

3-dimensional bumps look particularly promising

with thanks to….

Collaborators

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- Paul Bruce
- Thorsten Lutz - Stuttgart University
- Klemens Nübler - Stuttgart University
- Ning Qin - University of Sheffield

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- EU
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Questions?