

Aeronautics & Mechanics AENG11301

Lecture 13 Cruise



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Outline for today

- Cruise flight performance
- Power vs altitude
- Thrust vs altitude
- Cruise speed vs altitude
- Speed stability

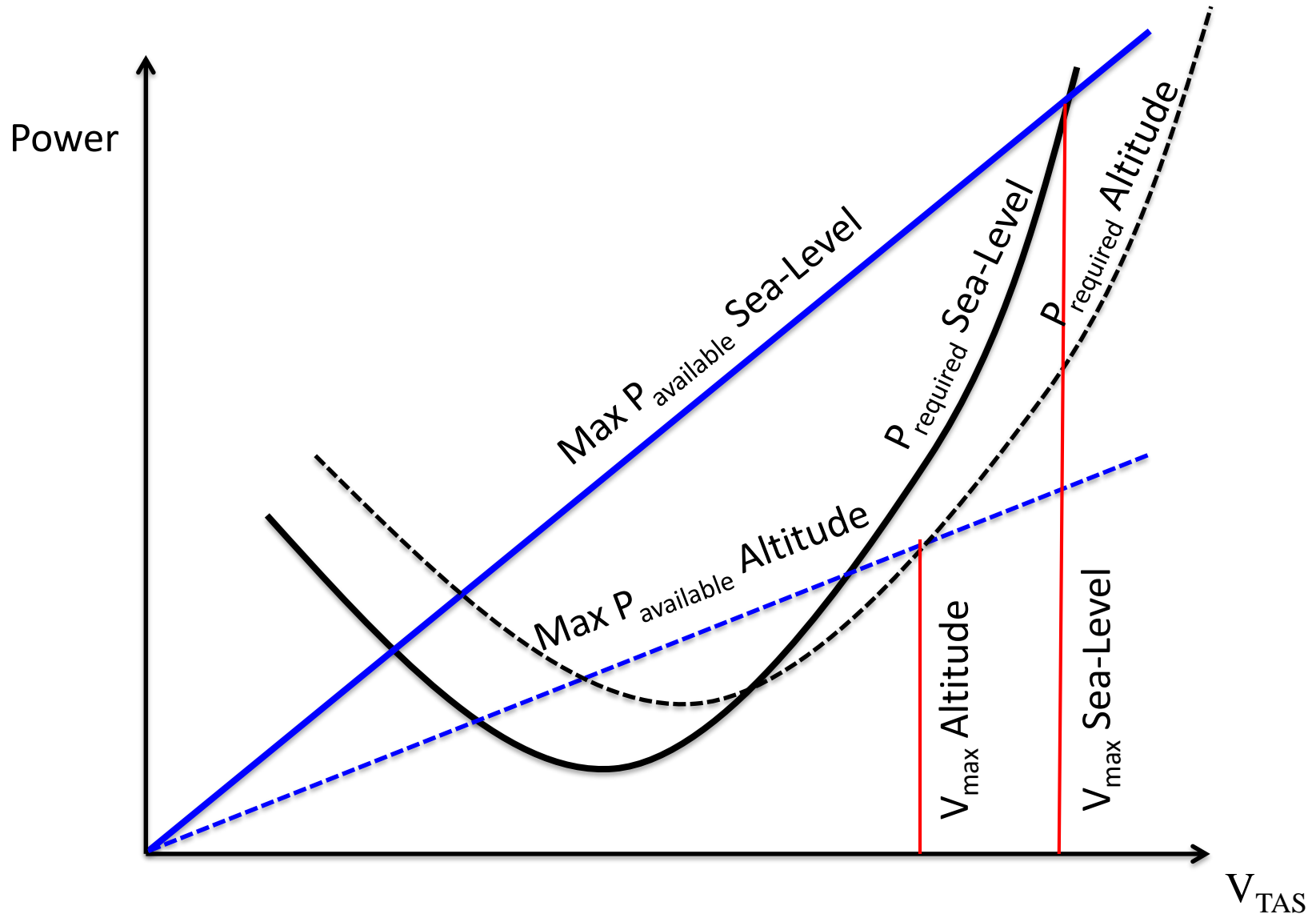
Aims for today

- From thrust/drag and power curves be able to determine:
 - Cruise velocity
 - Absolute ceiling
- Understand how altitude effects thrust available
- Determine speed stability on different portions of a thrust/drag curve
- Be able to define the service ceiling and appreciate why aircraft operate here

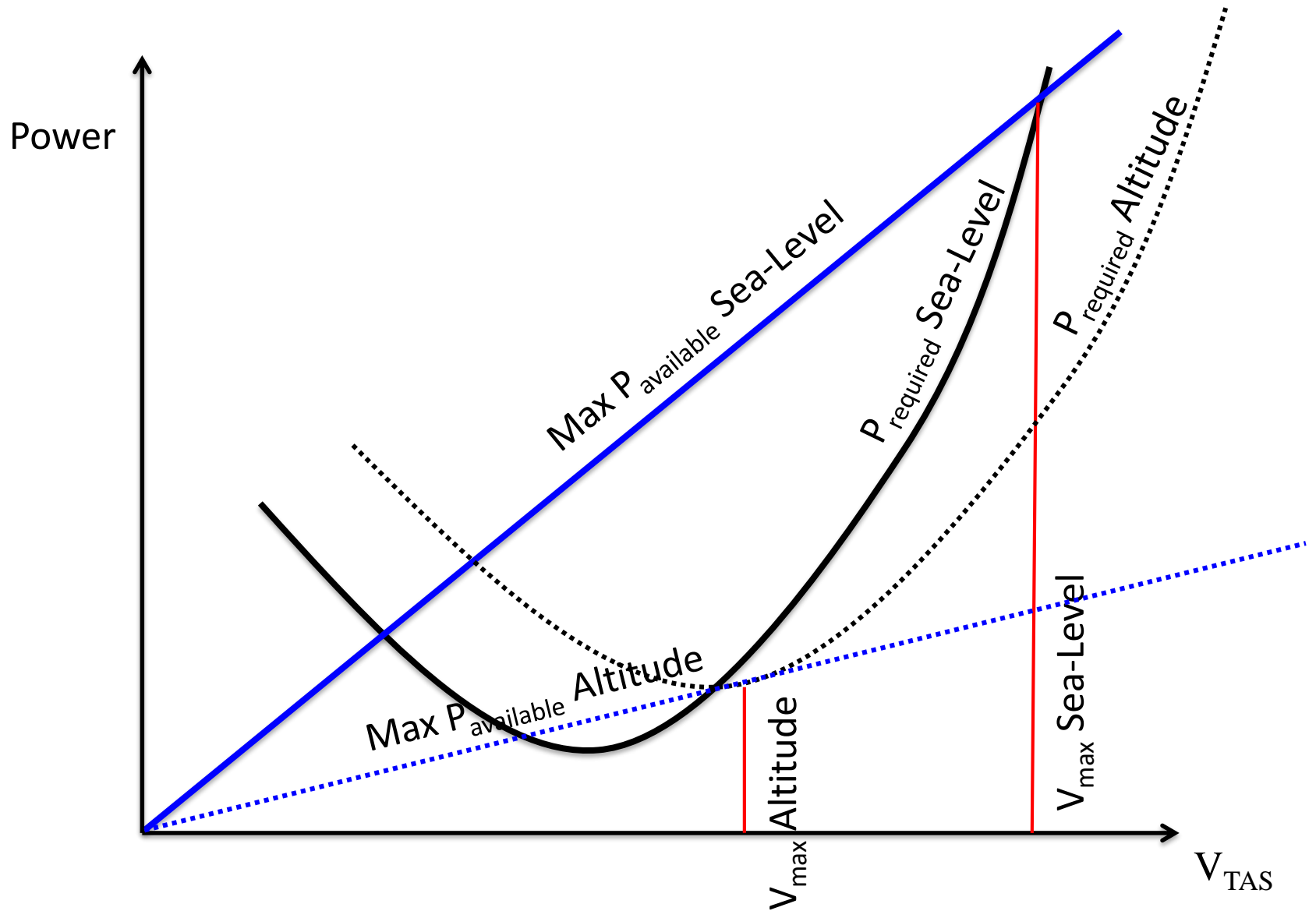
Things to think about

- Density decreases with altitude
 - Lift will also decrease with decreasing density so must speed up to compensate
 - Drag decreases with decreased density, but grows with increased speed required to maintain lift
 - Engine power decreases along with density – limits maximum altitude, but fuel consumption also decreases
- Is there a point where power required = maximum power available (i.e. no excess power)?
- Regardless of optimum speeds for minimum drag or minimum power, operating conditions may dictate flight speeds (pilots fly based on schedules).

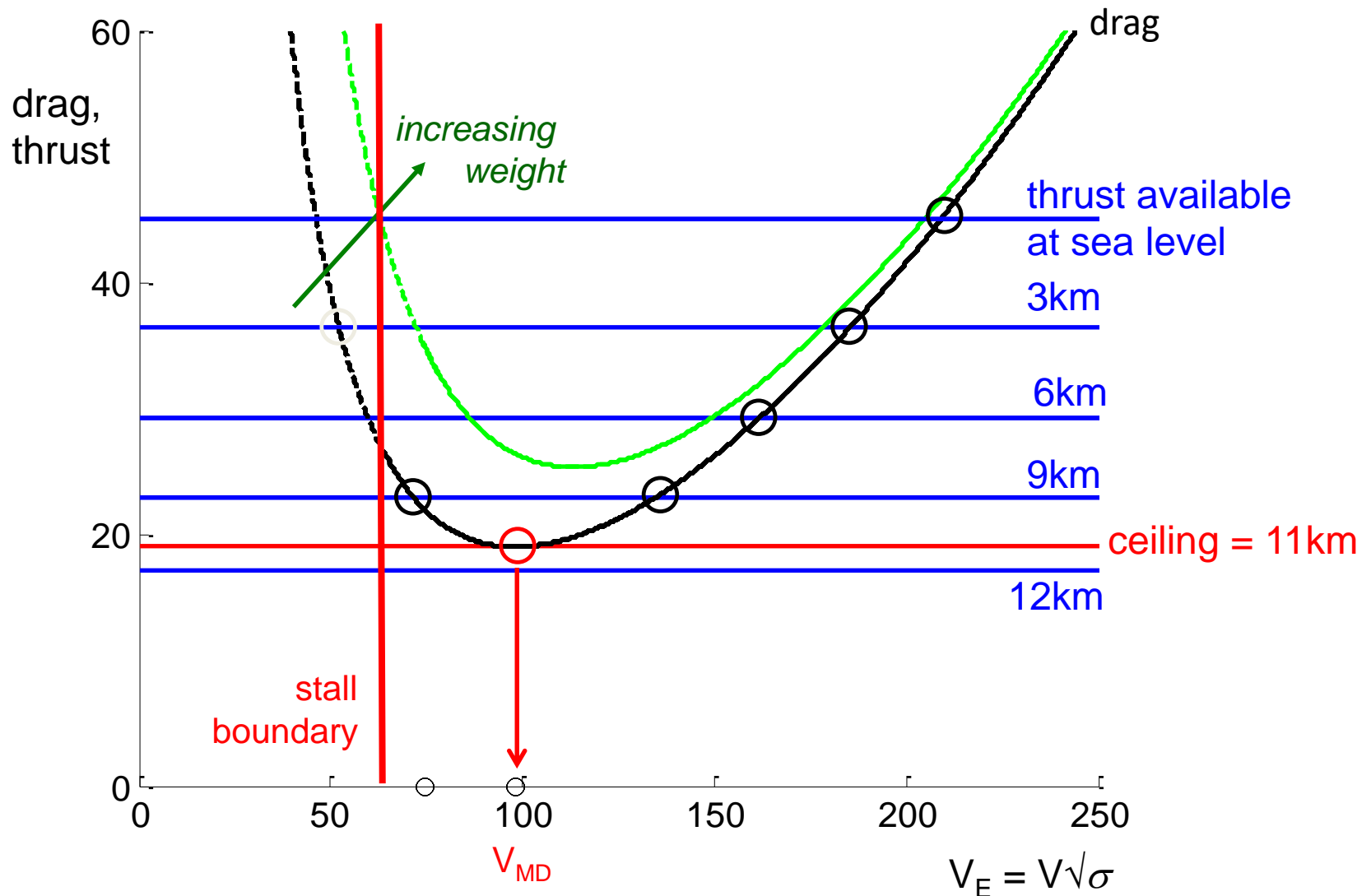
Power at Altitude (for a jet)



Power at Ceiling



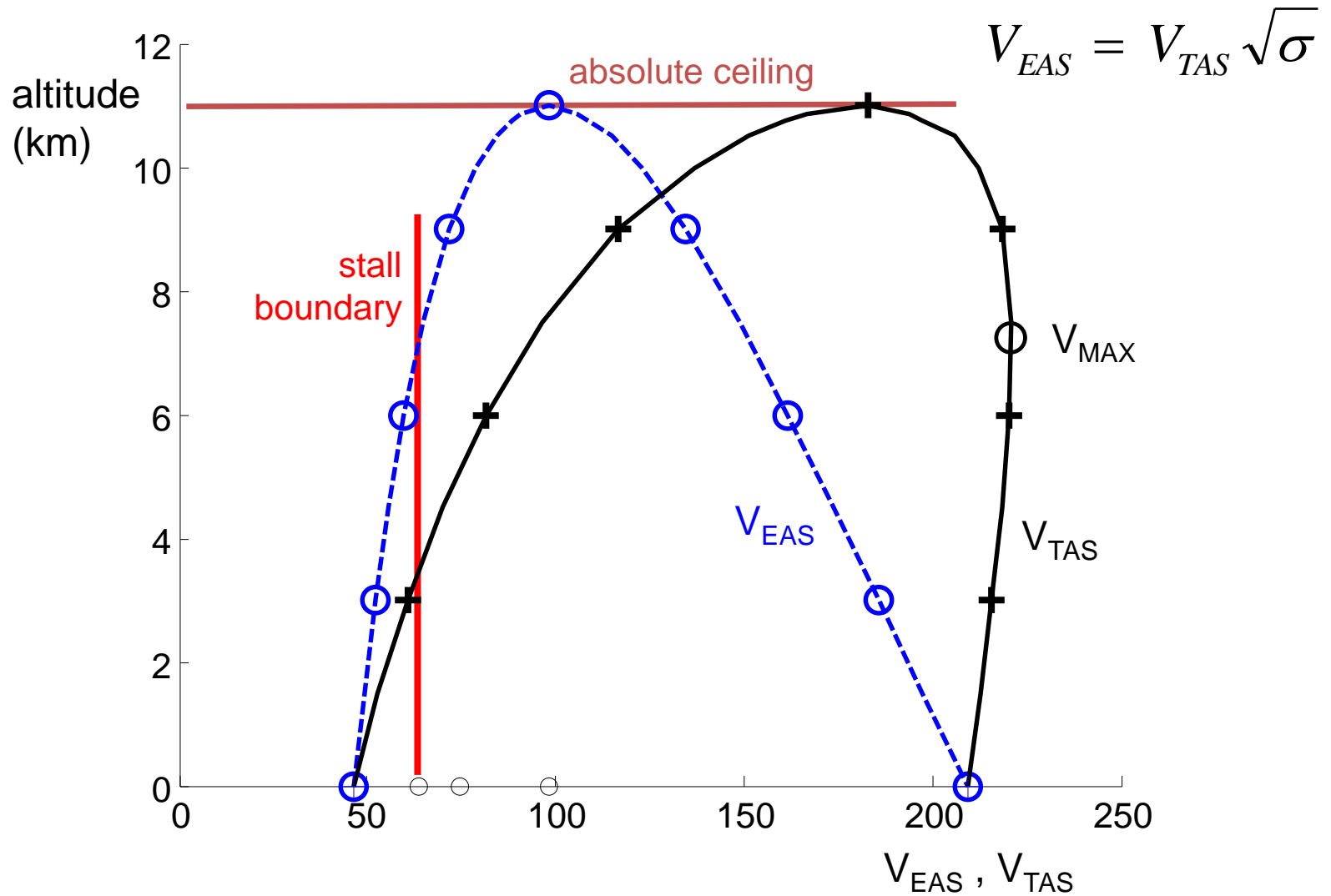
Thrust at Altitude (for a jet)



Features of Thrust at Altitude Diagram

- *simplified* representation of thrust $T = kT_0\sigma^x$
 - **throttle setting** k
 - maximum thrust at sea level T_0 (independent of speed)
 - density ratio σ (trend: \propto power 0.7 below 11km, 1.0 above)
- maximum and minimum speed at each altitude for $T = D$
 - lower speed may be unattainable at low altitude due to stall
 - upper speed is practical **cruise speed**
 - between upper and lower speed aircraft will accelerate or climb unless throttle setting is reduced
- Absolute ceiling is when there is no excess thrust available
 - **absolute ceiling** for the throttle setting used
 - achieved at minimum drag speed
- increasing weight reduces cruise speed and lowers ceiling

Jet Aircraft Cruise Speed



Features of Jet Cruise Speed

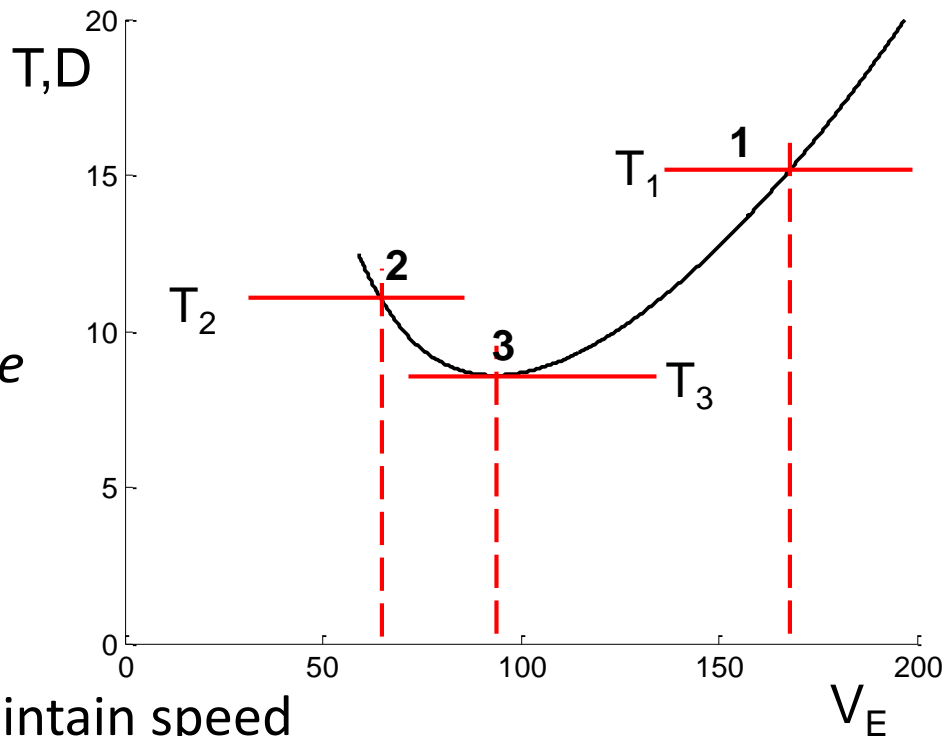
- cruise speed in EAS *reduces* steadily as altitude increases (due to available power reductions)
- maximum cruise speed in TAS *increases* with altitude
 - up to a maximum V_{max} before the absolute ceiling is approached
- demonstrates some advantages of cruise at high altitude
 - maximum cruise speed in TAS (ie ground speed) similar to (or greater than) speed at sea level
 - Thrust (drag) at maximum cruise speed reduces with altitude
 - fuel consumption reduces with altitude (consumption \propto thrust)
- minimum fuel consumption at minimum drag speed (abs ceiling)
 - work done = thrust \times distance
 - in theory should be unaffected by altitude (since D_{min} constant), but at low altitudes engine would need to be throttled back
 - reduced thermodynamic efficiency & hence increased fuel burn

Speed Stability in Cruise

- consider aircraft with throttle adjusted to cruise at points 1, 2 and 3
 - what is effect of *small* fluctuations in velocity (eg due to gusts) ??

1. speed increase
= increase in drag
 - aircraft decelerates = *stable*
2. speed increase
= reduction in drag
 - aircraft accelerates = *unstable*
3. speed increase
= no change in drag
 - aircraft is *neutrally stable*

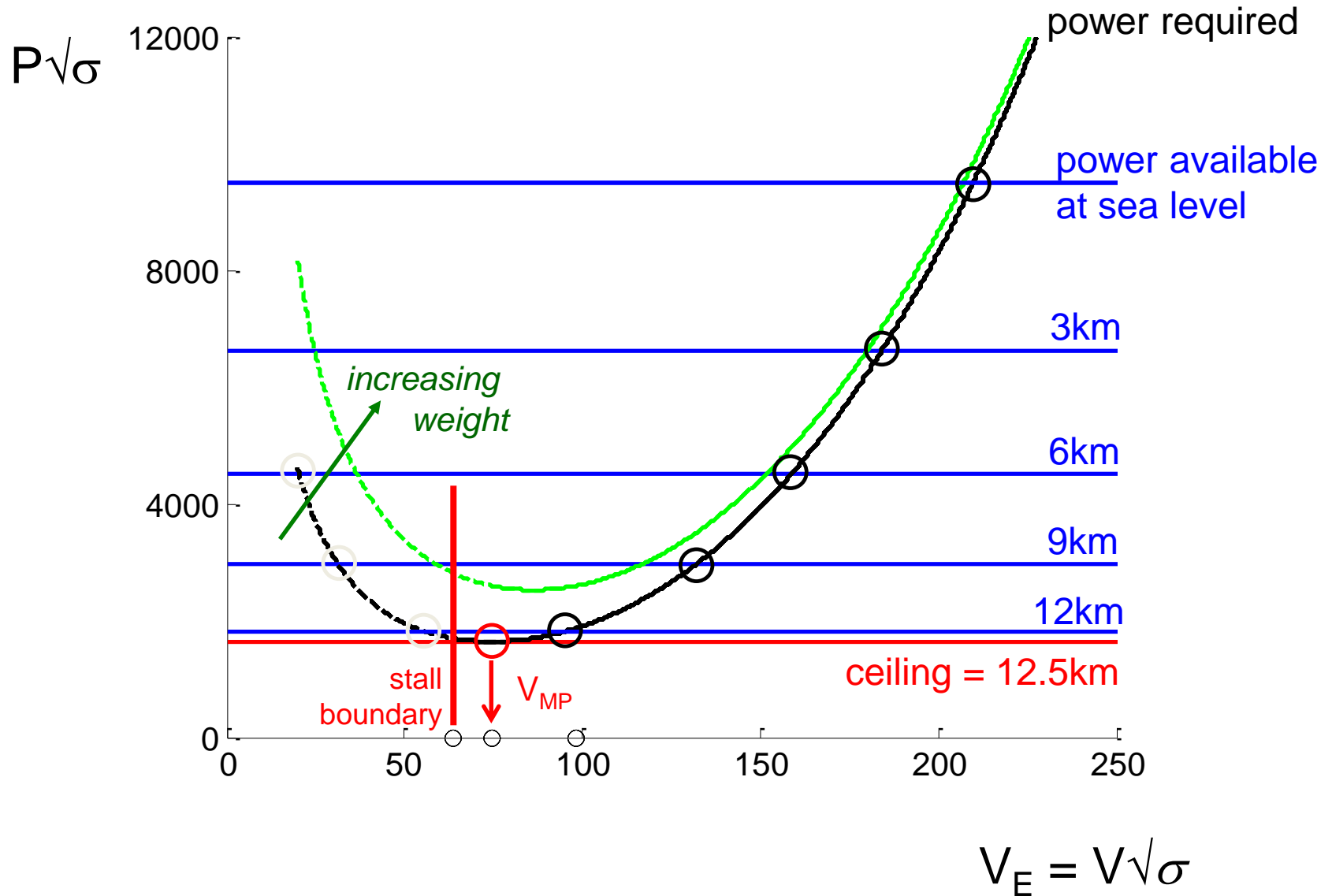
- in case 2 pilot must continually adjust throttle to maintain speed
 - flight on '**backside of drag curve**' – rather unsafe!



Speed Stability at Ceiling

- **absolute ceiling** is an unstable condition to maintain
 - maximum thrust setting at minimum drag speed
 - *any* change in speed will *increase* drag above available thrust and hence cause aircraft to descend
- excess thrust and hence rate of climb drop to zero as ceiling is approached
 - absolute ceiling cannot be established in reasonable time!
- **service ceiling** is a practical alternative definition of maximum operating altitude
 - at the service ceiling the aircraft still has a small specified rate of climb
 - defined as 2.5 m/s for jet aircraft and 0.5 m/s for propeller-driven aircraft

Propeller-Driven Aircraft in Cruise



Summary

- Cruise speed at a given altitude, for a given throttle setting, is where drag curve and thrust available cross, or where power required and power available curves cross
- Absolute ceiling is the altitude where there is no excess thrust available
- Thrust generated by a jet engine is proportional to air density
- To be stable in cruise need to be operating on portion of drag curve with a positive slope
- At the service ceiling an aircraft still has a small specified rate of climb

Follow-up materials

To help with exam:

- Introduction to Flight – 6.7, 6.10