Aeronautics & Mechanics AENG11301

Lecture 13
Cruise

13/3/16

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Outline for today

- Cruise flight performance
- In-class test feedback
  - We'll go through the test together and I'll explain common mistakes

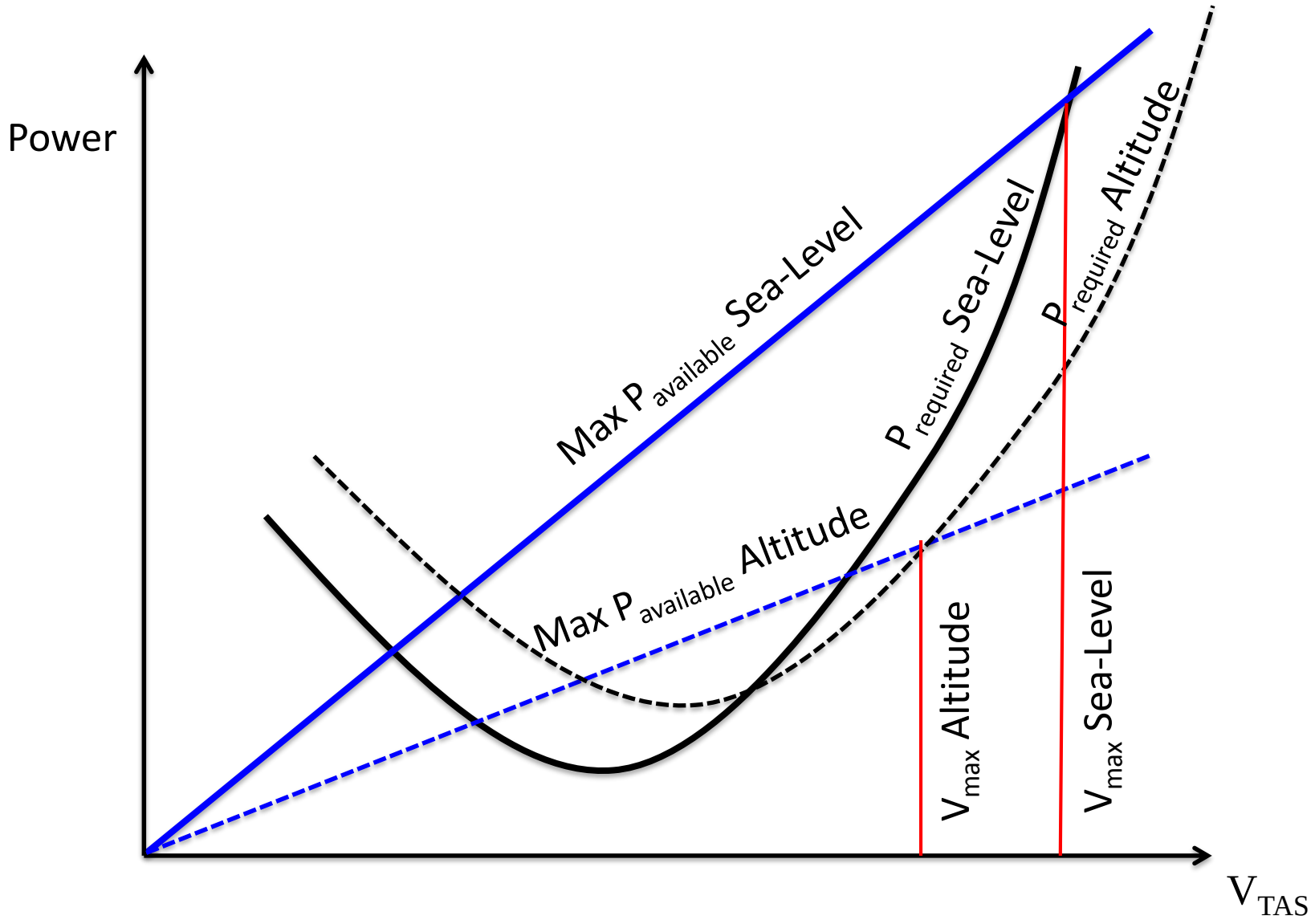
Aims for today

- 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

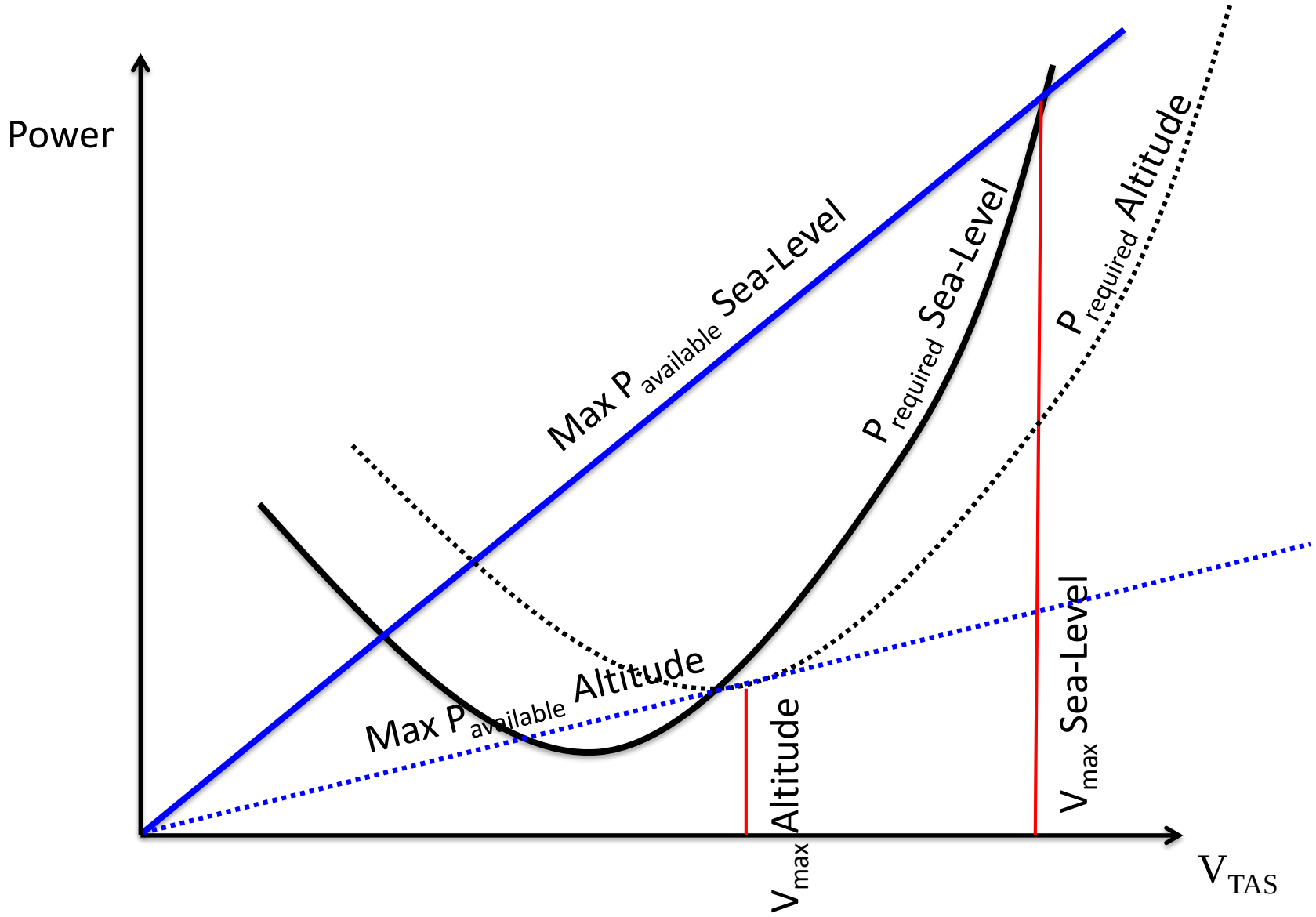
Things to think about

- 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).

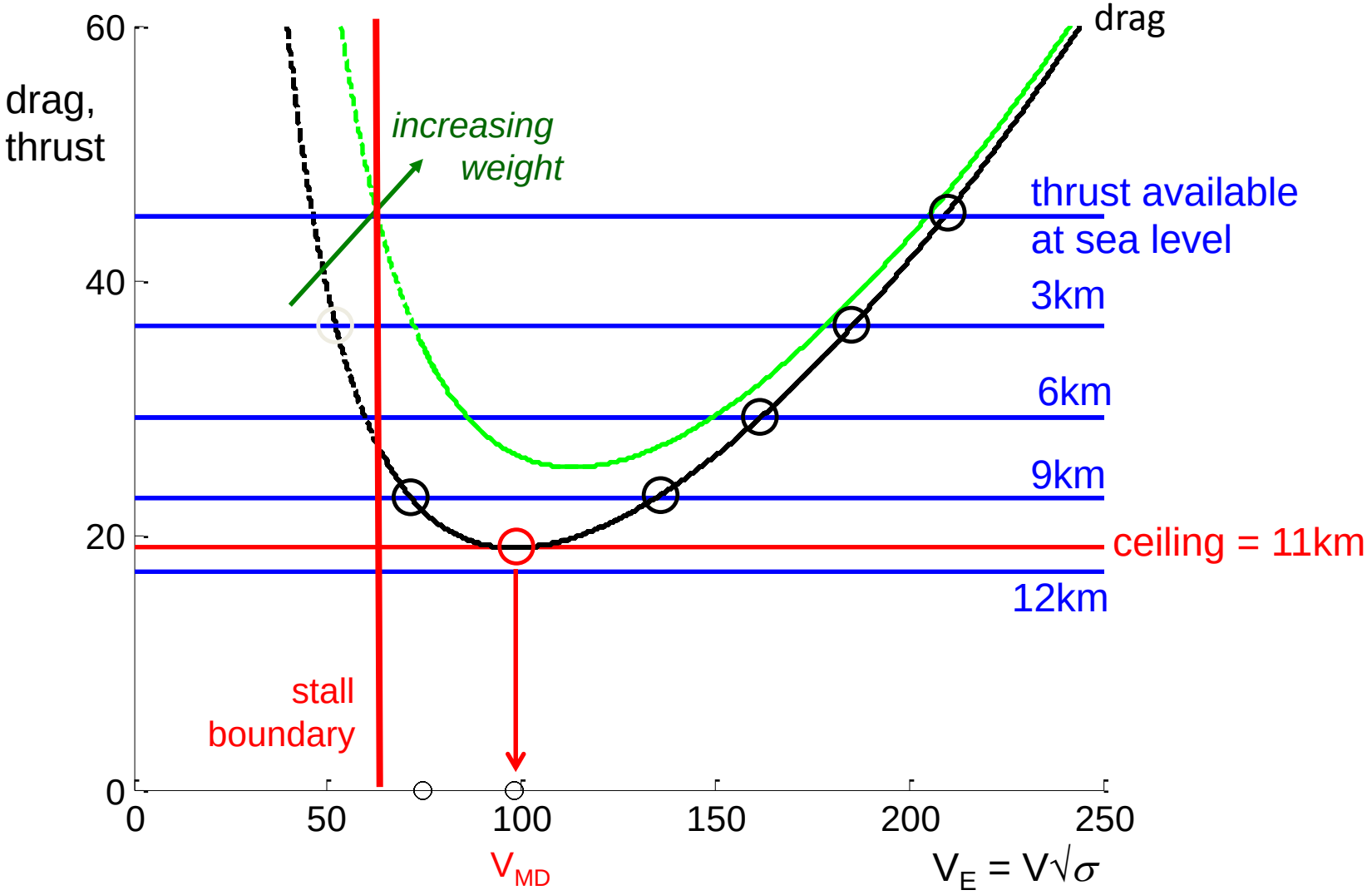
Power at Altitude (for a jet)



Power at Ceiling



Thrust at Altitude (for a jet)



Features of Thrust at Altitude Diagram

- *simplified* representation of thrust
  - **throttle setting** k
  - maximum thrust at sea level T_0 (independent of speed)
  - density ratio σ (trend: *x* power *0.7* below 11km, *1.0* above)

$$T = kT_0\sigma^x$$

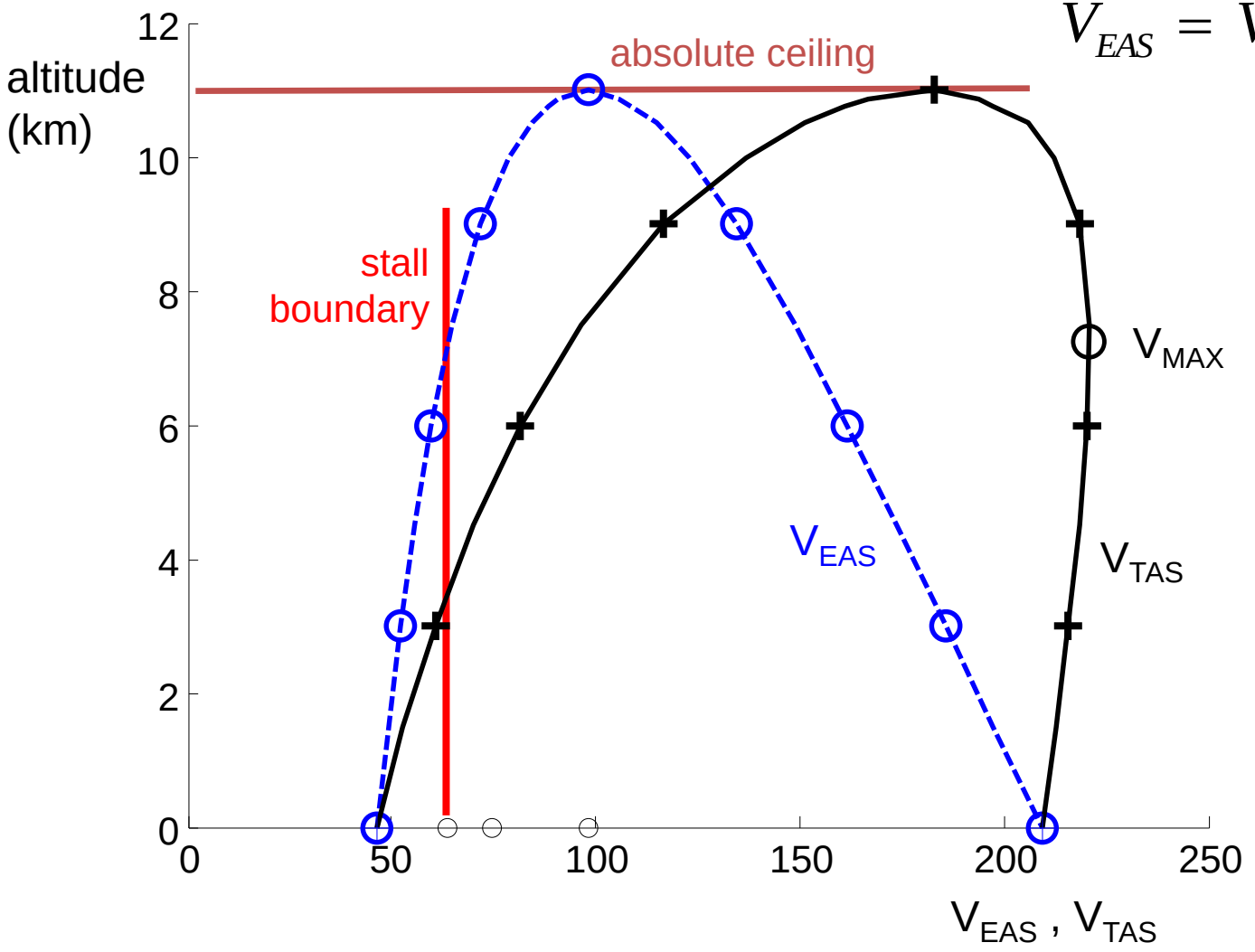
- maximum and minimum speed at each altitude for $T = D$
  - lower speed may be unattainable at low altitude due to stall
  - upper speed is practical **cruise speed**
  - between upper and lower speed aircraft will accelerate or climb unless throttle setting is reduced

- 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

$$V_{EAS} = V_{TAS}\sqrt{\sigma}$$



Features of Jet Cruise Speed

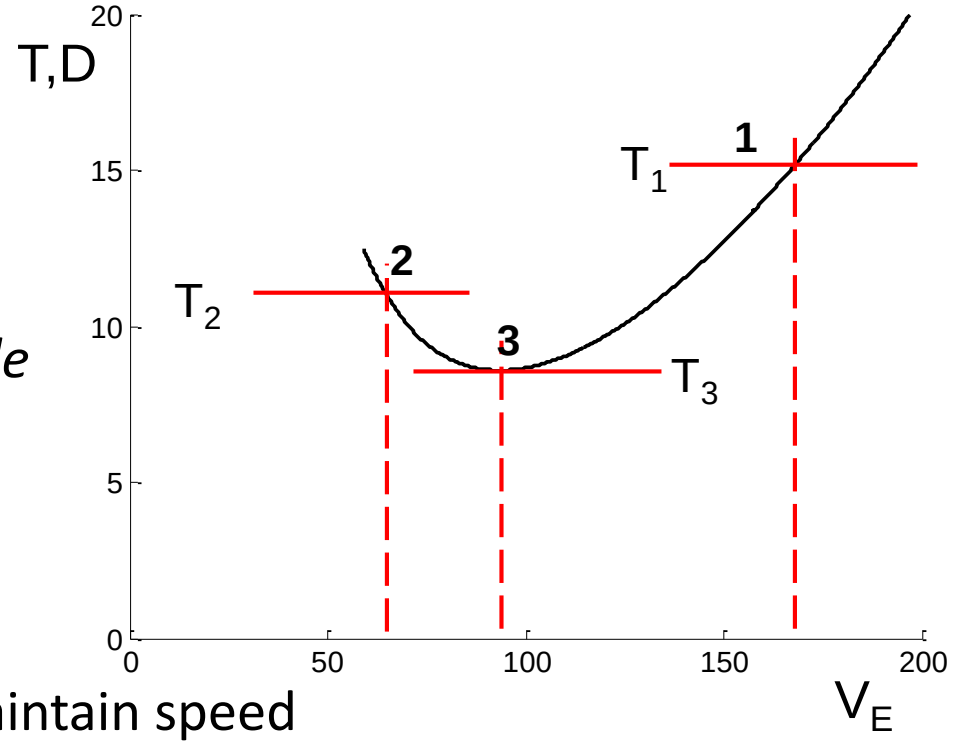
- cruise speed in EAS *reduces* steadily as altitude increases (due to available power reductions)
- maximum cruise speed in TAS *increases* with altitude
  - up to a maximum V_{max} before the absolute ceiling is approached
- demonstrates some advantages of cruise at high altitude
  - maximum cruise speed in TAS (ie ground speed) similar to (or greater than) speed at sea level
  - Thrust (drag) at maximum cruise speed reduces with altitude
    $\rightarrow$ 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

$\rightarrow$ 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*

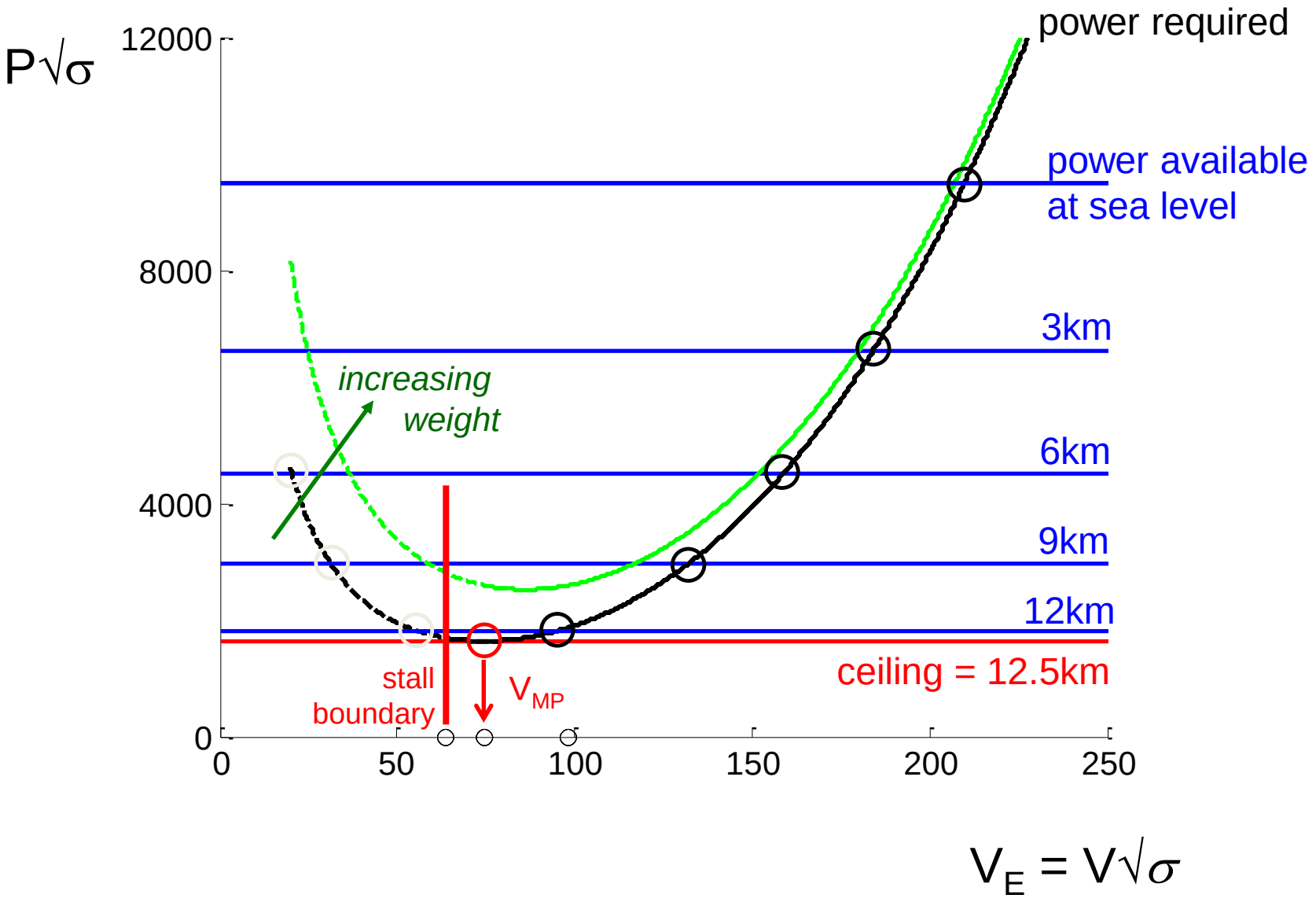


- in case 2 pilot must continually adjust throttle to maintain speed
  - flight on '**backside of drag curve**' – rather unsafe!

Speed Stability at Ceiling

- **absolute ceiling** is an unstable condition to maintain
  - maximum thrust setting at minimum drag speed
    $\rightarrow$ *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