Terminal Velocity of High-Altitude Balloon Payloads: Experiment Versus Theory

Academic High Altitude Conference, June 2011

Paul Seifert, Concordia College
Gordon McIntosh, University of Minnesota, Morris

Outline

- Development of terminal velocity model for payload descending under a parachute to compare real-world experimental data against theoretically modeled data.
  - Derive terminal velocity equation
  - Calculate air density from pressure and temp data
  - Compare theory to experiment

- Final goal is to develop basic physics lab activity to do all of the above.

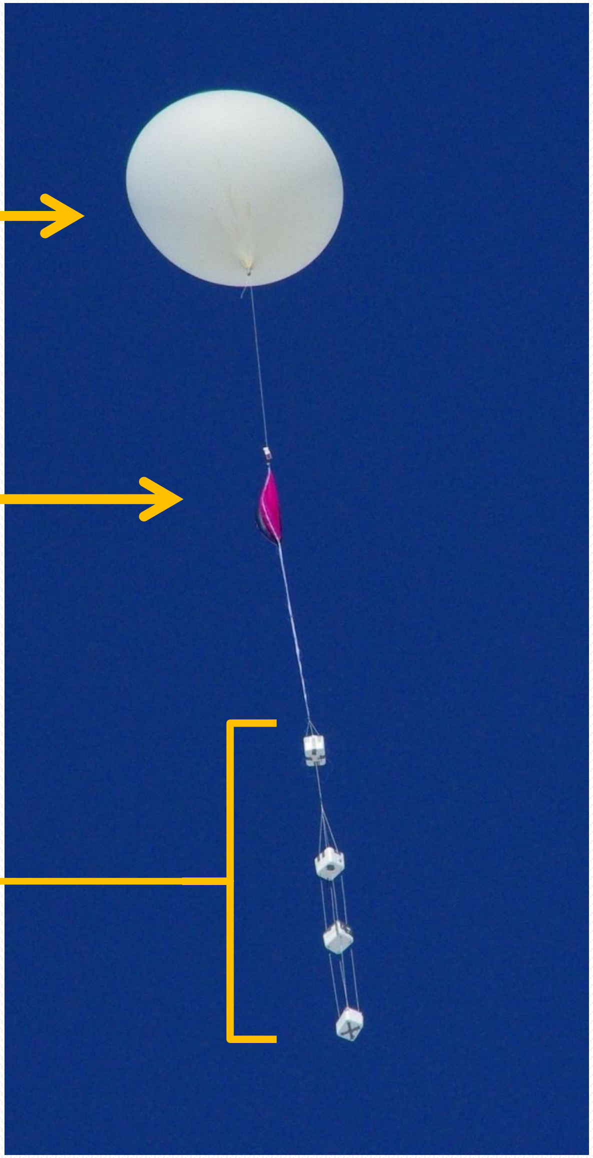
Flight Profile

- Payload is 8-10 pounds (maximum 12 lb.)
- Lofted on large helium-filled balloon
- Flight continues upward until balloon bursts. Up to 100,000+ feet (27,000+ meters)
- Parachute brings payload back to Earth

Balloon

Parachute

Payload boxes

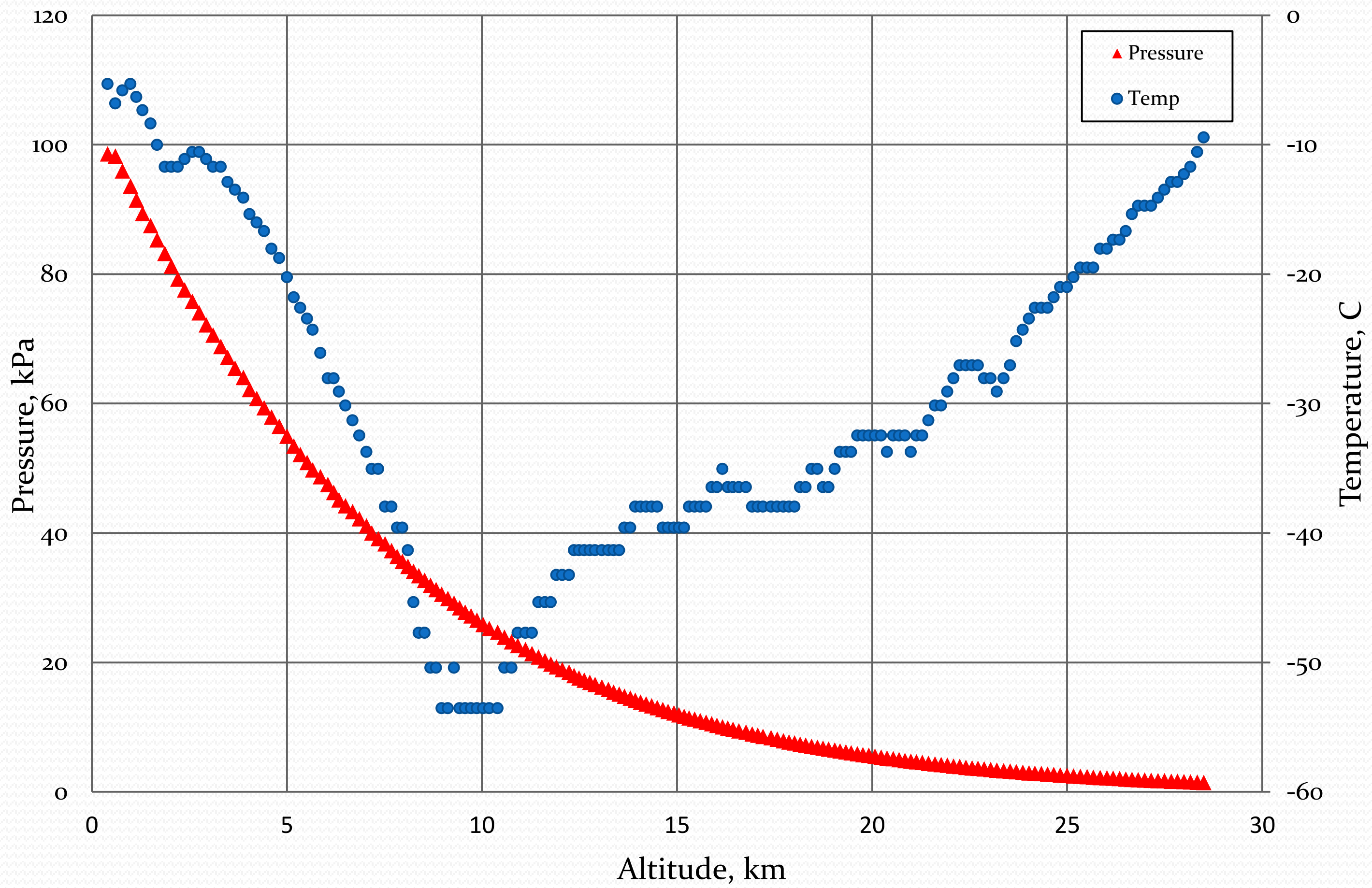


Atmosphere

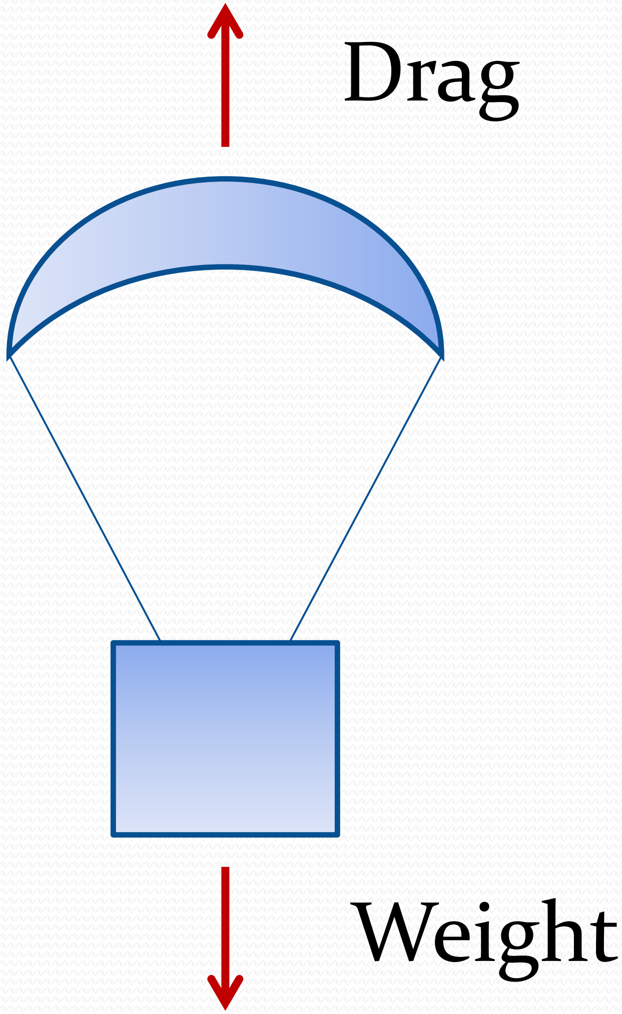
- Payload passes through distinct layers:
  - Troposphere to ~10km
    - Temperature falls
  - Tropopause
    - Constant temperature for 200-300 meters
  - Stratosphere
    - Temperature rises

- Pressure decreases exponentially

Pressure and Temperature



Forces During Descent



The system reaches *terminal velocity* when drag force and weight are equal.

Forces

- Drag modeled using simple Prandtl expression:

$$D = \frac{1}{2} C_d \rho A v^2$$

- Weight:

$$W = mg$$

Terminal Velocity

- Equating drag and weight:

$$\frac{1}{2}\,C_d \rho A v^2 = mg$$

- Solving for *v*:

$$v_t = \sqrt{\frac{2mg}{C_d \rho A}}$$

Density

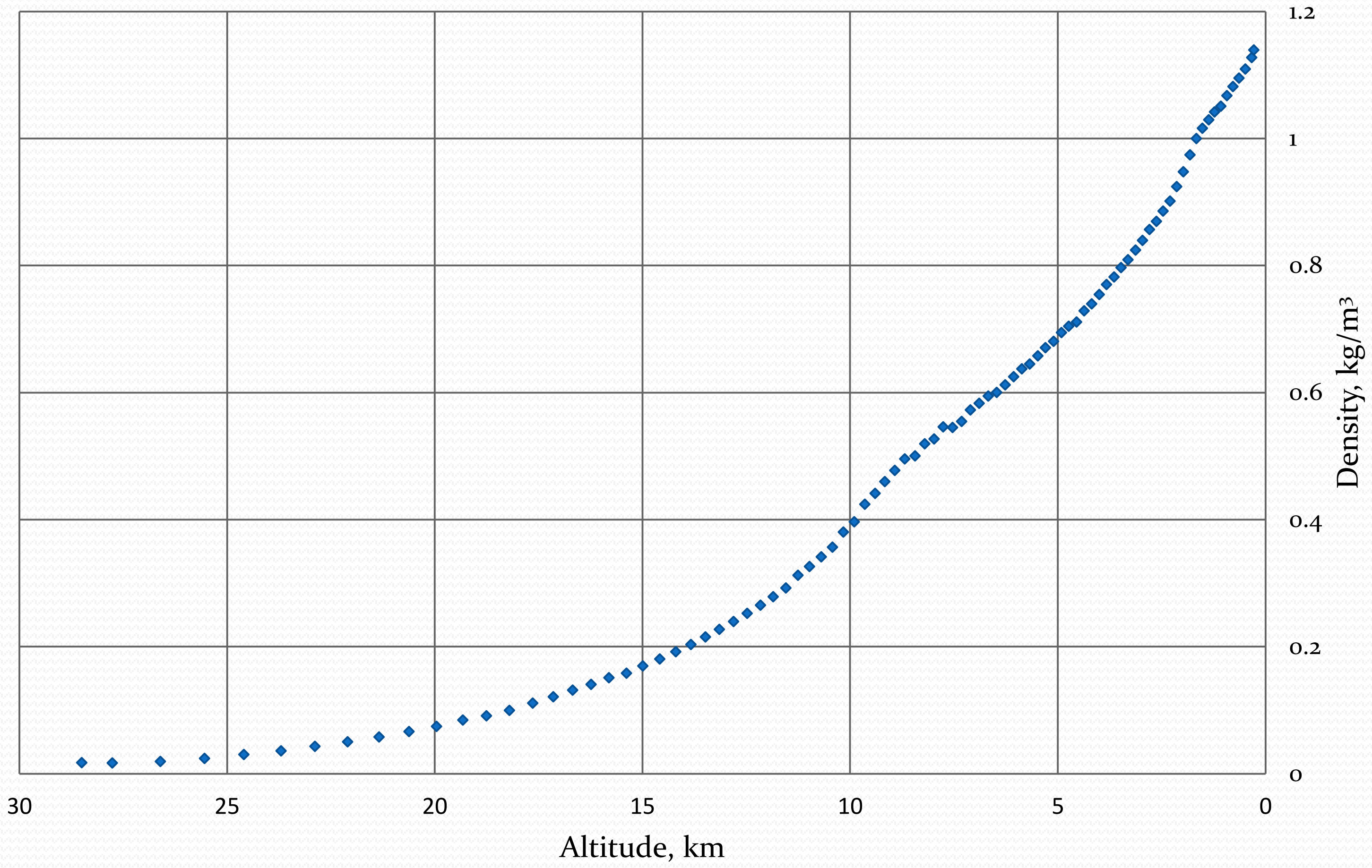
- Use gas-specific form of Ideal Gas Law:

$$PV = mR_{gas}T$$

- Solve for m/V:

$$\frac{m}{V} = \rho = \frac{P}{R_{gas}T}$$

Density



Putting It Together

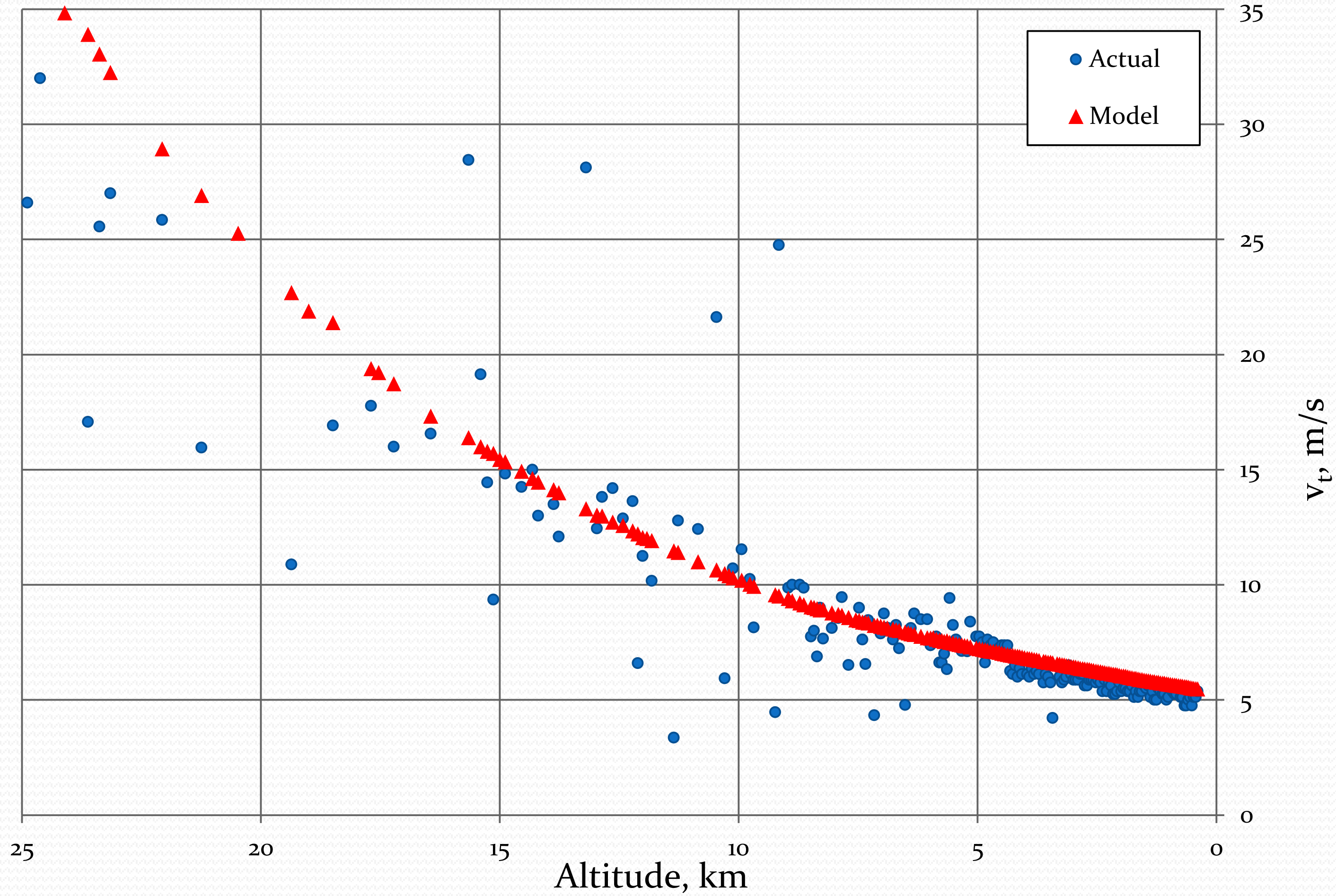
- Final terminal velocity equation:

$$v_t = \sqrt{\frac{2mgR_{gas}T}{PC_dA}}$$

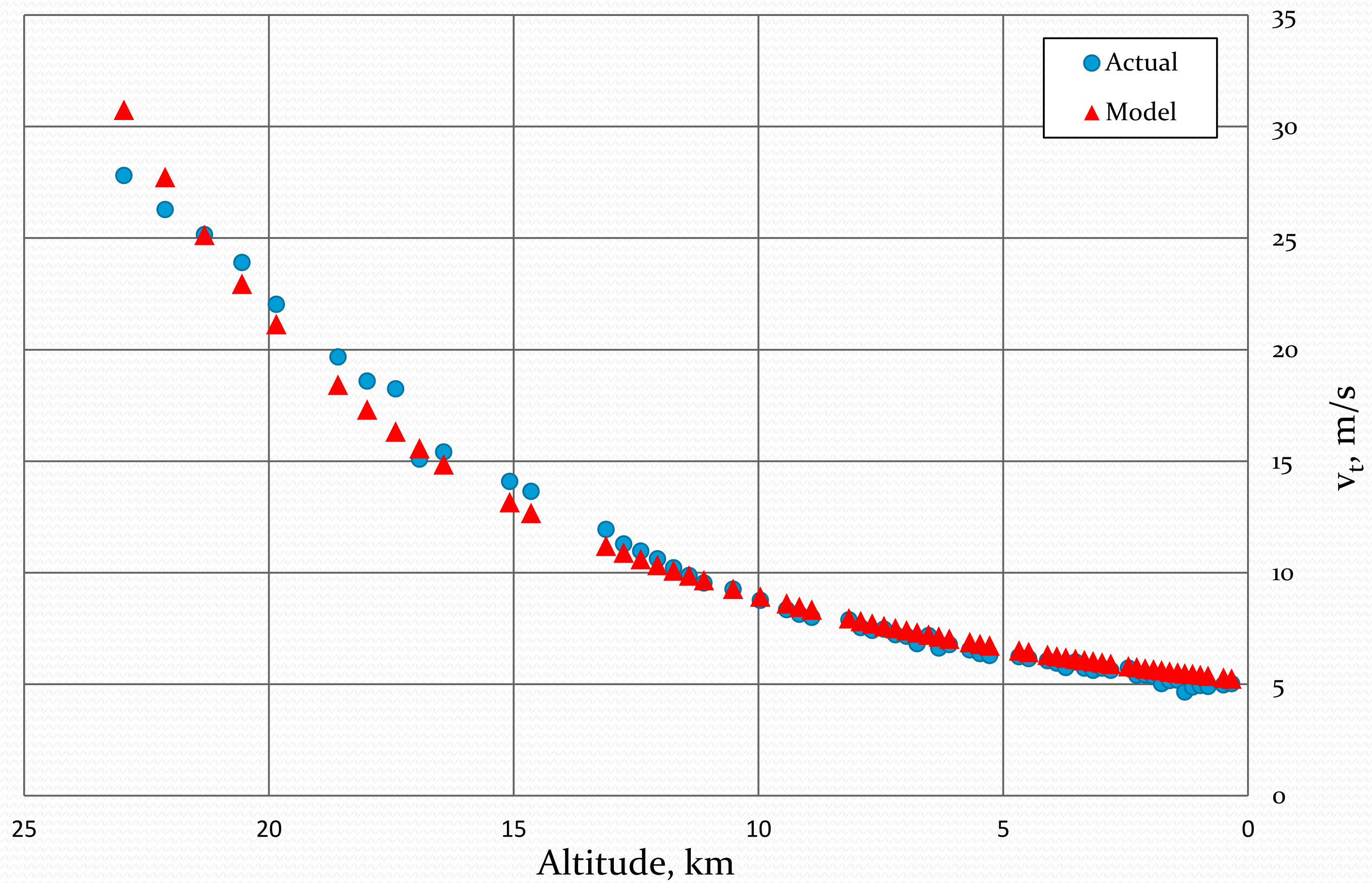
Parachute Aerodynamics

- Cross-sectional area A measured as the total area of fabric.
- Coefficient of drag C_d can be between 0.5 - 0.9 depending on parachute design
- UMM parachute:
  - Hemispheric design, $A = 2.62\ m^2$, $C_d = 0.7$
- ConHAB parachute:
  - Cupped parabolic design, $A = C_d = ?$ (Picked $4.1\ m^2$ and 0.6)

Reality vs. Theory (UMM)



Fitting Theory to Reality (ConHAB)



Lab Discussion

- Fit between theory and model
  - What factors may influence each? Assumptions or simplifications?
  - Effects of payload boxes
- Parachute parameters
  - Comparison of different designs
  - Fitting actual data to determine parameters

- Activity can be tailored to any level.

Conclusions

- Parachute aerodynamics is an extremely complicated subject.
- Nice agreement between theoretical and experimental data.
- Future work:
  - More flights
  - More data on different parachute designs

Acknowledgements

- Brent Perreault, Megan Jacobsen, and Darren Schluter
- Minnesota NASA Space Grant Consortium
- University of Minnesota, Morris