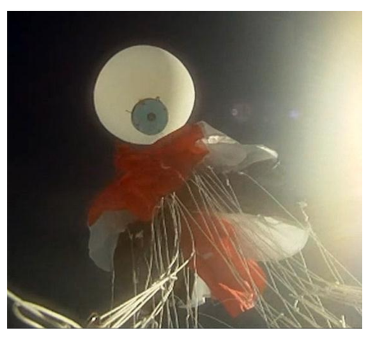
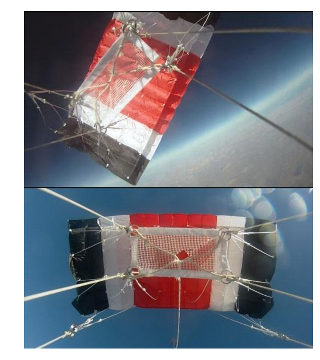
9th International Planetary Probe Workshop, Toulouse, France, 16th-22nd June 2012

Development of Precision Parafoil Flight at High Altitude For Sample Return Applications





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Context:

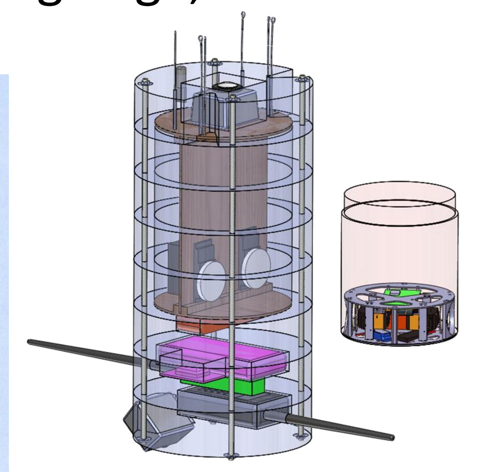
*S*mall *P*ayload *Q*uick-*R*eturn (SPQR), Final Descent Phase

Concept currently under development at NASA Ames Research Center

- Intended to deliver payloads on-demand from International Space Station (ISS)
- Accommodates a 3U payload volume (10 x 10 x 30 cm) in a pressure and temperature-controlled canister
- Self-contained; complete deorbit, reentry, and landing system
- Minor reentry positional error correction and final landing target precision enabled by autonomous parafoil control

Autonomous Parafoil Control System Evolution

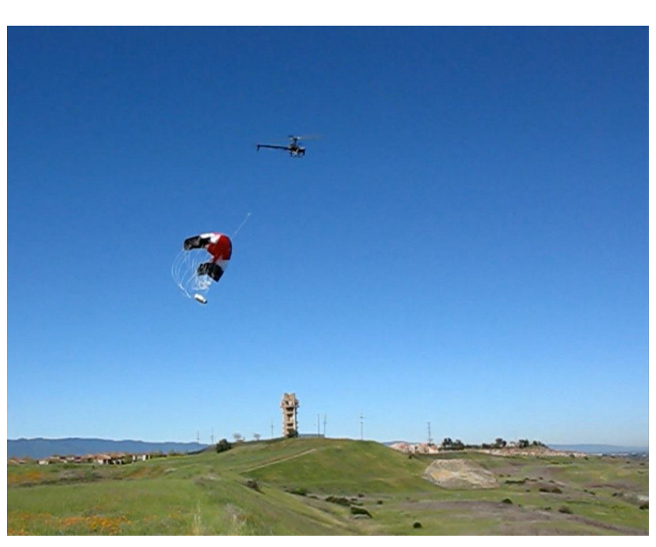
- Based on original research by Naval Postgraduate School (NPS) and their "Snowflake" parafoil system
- New control system designed specific to SPQR payload canister: miniaturized, simplified, ruggedized
- Autopilot board maintains control via GPS and an integrated IMU, with uplink capability for real-time wind data
- Control facilitated by winch servos and deflection of parafoil trailing edge, with 10 Hz closed-loop feedback



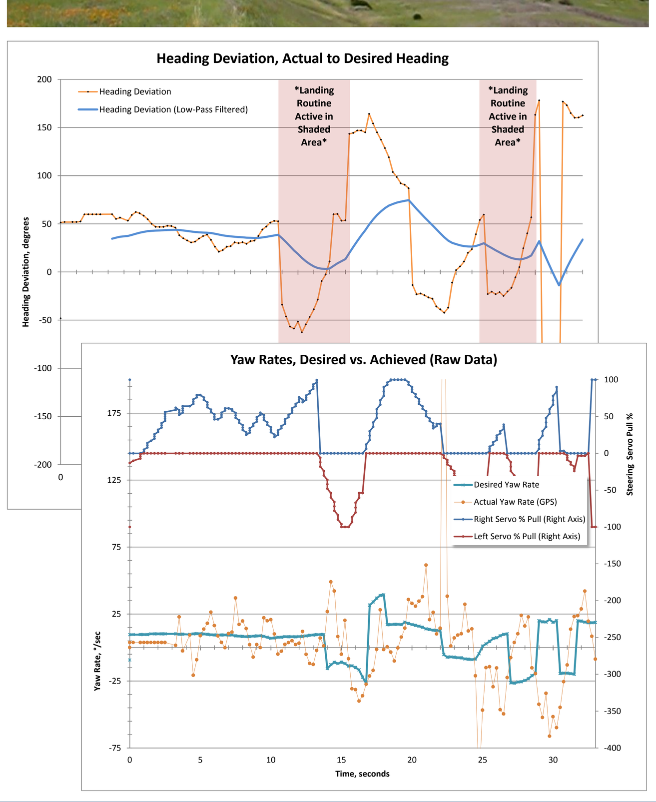
Development and Testing

Computer Simulation and Low-Altitude Drop Tests for Control Algorithm Development

- Updated flight algorithms written for revised control system, requiring only target latitude, longitude, and altitude as inputs
- Basic control response debugged and verified via computer simulation.
- Flight control verification performed by low-altitude drop-testing from a remotely piloted R/C helicopter



R/C helicopter drop-tests conducted from San Jose, CA foothills to verify control system performance at sea level conditions.



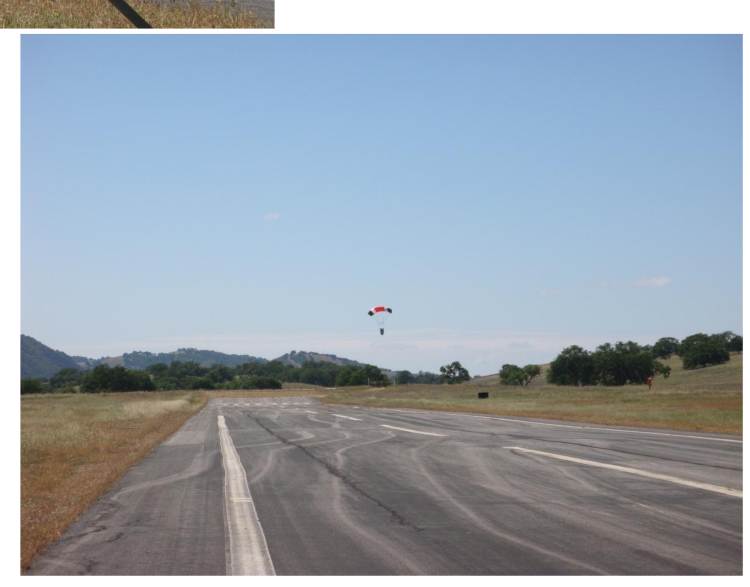
Key flight parameters recorded by on-board data logging during testing, and used to refine flight control algorithms and verify simulation results (sample data shown).

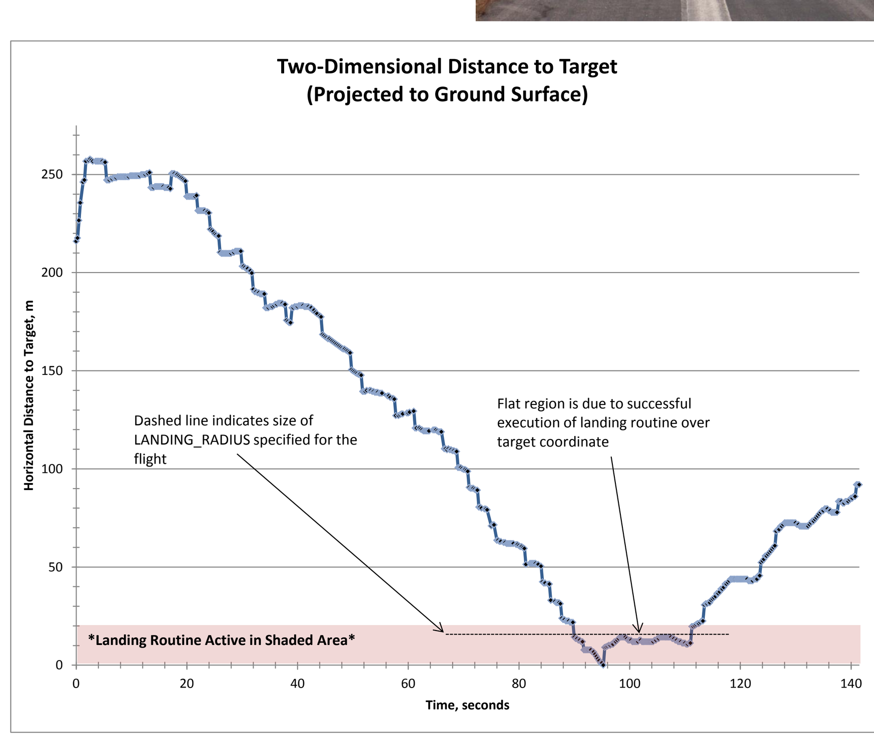
UAV Drop Tests from Increased Altitude in High Winds for Control Algorithm Validation

- Unmanned autonomous UAV used to further refine control system performance at higher altitude over greater descent duration

Parafoil systems mounted in wing pods on carrier UAV prior to flight. Drop tests conducted up to 2,000 ft. AGL in high winds for validation of control performance at near-sea level atmospheric density.

Parafoil system returns to target coordinates on center stripe of runway following release and deployment of parafoil at 2,000 ft. AGL.

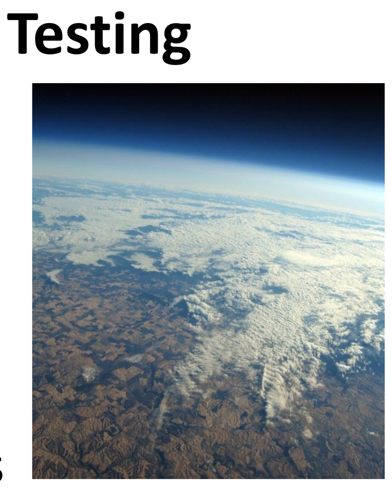




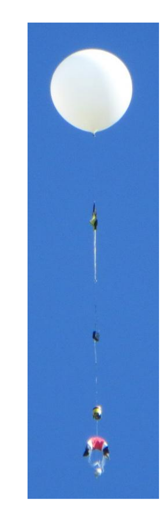
Sample plot of distance to target coordinates vs. time for a drop test in high winds. When the curve intersects the X-axis, the parafoil system is directly overhead the desired target, and a circular landing approach routine commences.

High-altitude Balloon Testing

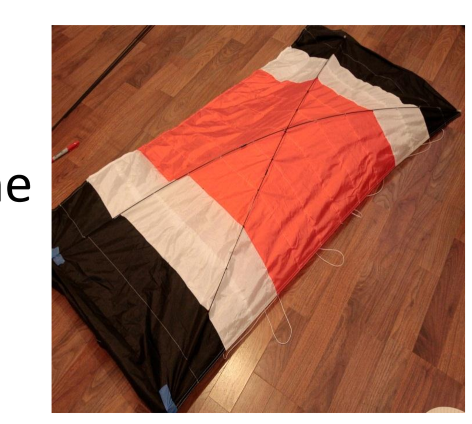
- To maximize targeting correction ability following reentry, establishing control and stable flight at very high altitude is advantageous

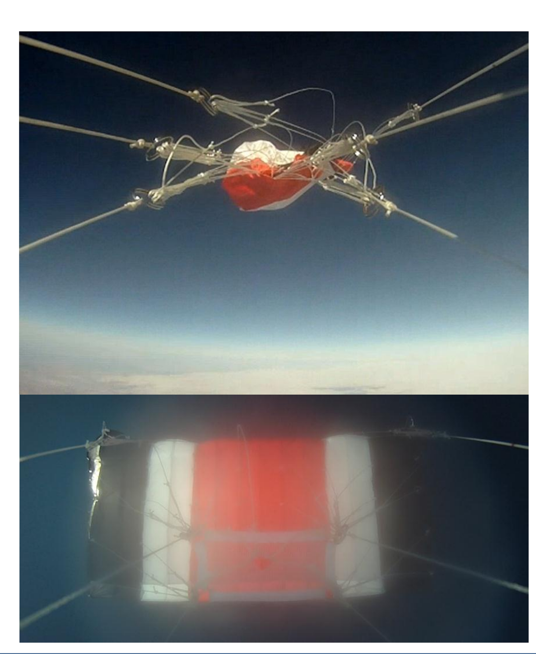


- To date, five balloon tests have been performed, releasing the parafoil system near 50,000 ft. (15.2 km) altitude. Early tests resulted in parafoil inflation failures caused by low dynamic pressure



- A solution was achieved by fitting a lightweight, "semi-rigid" structure to the parafoil, assisting in parafoil deployment without impairing flight characteristics





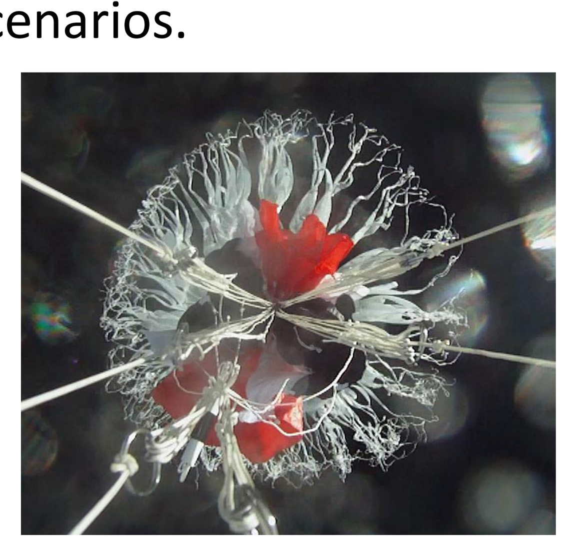
Top: Failed inflation due to low dynamic pressure and gentle release from host balloon at 15.25 km altitude. A high-energy spin developed and severe tangling occurred. *Bottom*: Successful inflation and stable flight achieved at 15.25 km, using parafoil rigidization system.

Conclusion

- Successful parafoil inflation and stable flight demonstrated at 50,000 ft. altitude; near-future tests to go higher.
- Parafoil "rigidizer" creates hybrid parafoil/wing device; retains weight and stowage advantages inherent to standard parafoils while enabling usage at greatly increased altitudes.
- Control algorithm maintains required heading in presence of crosswinds or headwinds for precision delivery of sample payload.

Future Work

- Further balloon tests planned for 2012 to demonstrate inflation and precision control at increased altitude.
- Implementation of improved altitude management algorithms for modulation of descent rate in high-wind scenarios.
- "Full-up" system test using engineering model of SPQR payload canister and parafoil deployment system.



Other Applications

- Precision micro-probe delivery for Martian applications, *e.g.* multi-point weather network probes or small, mechanically-simple science probes to highly-specific locations without requiring roving capability.
- Scalable return of sub-orbital sounding rocket payloads for improved data collection capability via on-board logging of large data volumes.
- Return of high-altitude balloon payloads for growing community of amateur and professional balloon scientists.