Large and small UAS for trace gas measurements in climate change studies

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High Altitude Long Endurance (HALE) UAS   small Unmanned Aircraft Systems (sUAS)

Figure 1 Collage of UAS platforms used left to right, including NASA Altair during NOAA 2005 Demo, NASA Global Hawk during ATTREX in 2014, SkyWisp (SwRI), and Aero (3DRobotics).

1. Introduction: NOAA and CIRES scientists have used Unmanned Aircraft Systems (UAS) for the measurement of trace gases involved in climate change since 2005, including both high altitude-long endurance (HALE UAS: NASA Altair & Global Hawk) and 1-m wingspan, small UAS (sUAS: SkyWisp, Aero) (***Fig. 1***). These gases include nitrous oxide (N_2O), sulfur hexafluoride (SF_6), methane (CH_4), ozone (O_3), carbon monoxide (CO), hydrogen (H_2), and water vapor (H_2O). In particular, atmospheric N_2O is the third strongest greenhouse gas (326 parts-per-billion, ppb) and is the largest increasing stratospheric ozone depleting gas in terms of future emissions (~4 Tg N_2O-N yr^{-1}), primarily from fertilizer use. Atmospheric SF_6, another potent greenhouse gas, is present globally at 8.2 parts-per-trillion (ppt) and growing at a rate of 0.25 ppt yr^{-1}, and is used primarily in electrical power distribution. It is an excellent indicator of transport timescales (e.g., mean age) in the troposphere and stratosphere, because of its source distribution (~95% emitted in NH), long atmospheric lifetime (~600-3200 yr), and large relative atmospheric growth rate (~3%).

We have developed atmospheric instrumentation for HALE platforms using a two-channel gas chromatograph with an ozone photometer and a water vapor tunable diode laser spectrometer. We are currently investigating a sUAS glider (SkyWisp) for balloon-assisted high altitude flights (30 km) and propeller driven sUAS (Aero) as a test bed for a new autopilot (Pixhawk, 3DRobotics or 3DR). Our motivation for utilizing this autopilot is a low cost, open source autopilot alternative that can be used to return AirCore samples from high altitude balloons for quick laboratory analysis. The goal is a monitoring program to understand transport changes as a result of climate change during different seasons at many locations from a balloon-borne package (Moore et al., *BAMS*, pp. 147-155, Jan. 2014). The glider version of our open source autopilot system is also being considered for a future aerosol and trace gas study, called GOAHEAD (Gao et al., this meeting, Wednesday, May 20, 2015 14:15-14:30 , *A New and Inexpensive Tool for Ozone, Aerosol, and AOD Vertical Profiling*).

2. HALE Global Hawk UAS 2013-2014 (ATTREX-3): The Airborne Tropical Tropopause EXperiment (ATTREX3) offered an opportunity to compare our ozone and carbon monoxide measurements from our Unmanned Aircraft Chromatograph for Atmospheric Trace Species (UCATS) instrument on the Global Hawk. The mission was based over Guam in the eastern Pacific Ocean (***Fig. 2a***). The purpose of the mission was to investigate the transport of trace gases in the Tropical Tropopause Layer from convective systems using three different aircraft (***Fig. 2b***). The Global Hawk UAS flew above the NSF NCAR GulfstreamV (GV) on February 12-13, 2014. The comparison of O_3 and CO was very good and illustrates the usefulness of the Global Hawk to extend field mission measurements to a higher altitude (***Fig. 2c***). Little or no convection was seen above the TTL during ATTREX3 on the Global Hawk. Tropospheric O_3 was extremely low, sometimes as low as 10-20 ppb near the ground. Convection transported the low O3 higher, sometimes into TTL during March. We saw elevated CO concentrations high in the troposphere, where trajectories show that the air mass is coming from continental and ocean areas of East Asia (probably polluted air from fossil fuel combustion (***Fig. 2d***). Nitrous oxide (N_2O) was slightly elevated over the tropopause (***Fig. 2d***). Hear more about this work from E. Hintsa et al., this meeting, Wednesday, May 20, 2015, 11:0011:15, *Low Ozone in the Tropical Tropopause Layer (TTL) Over the Western Pacific.*

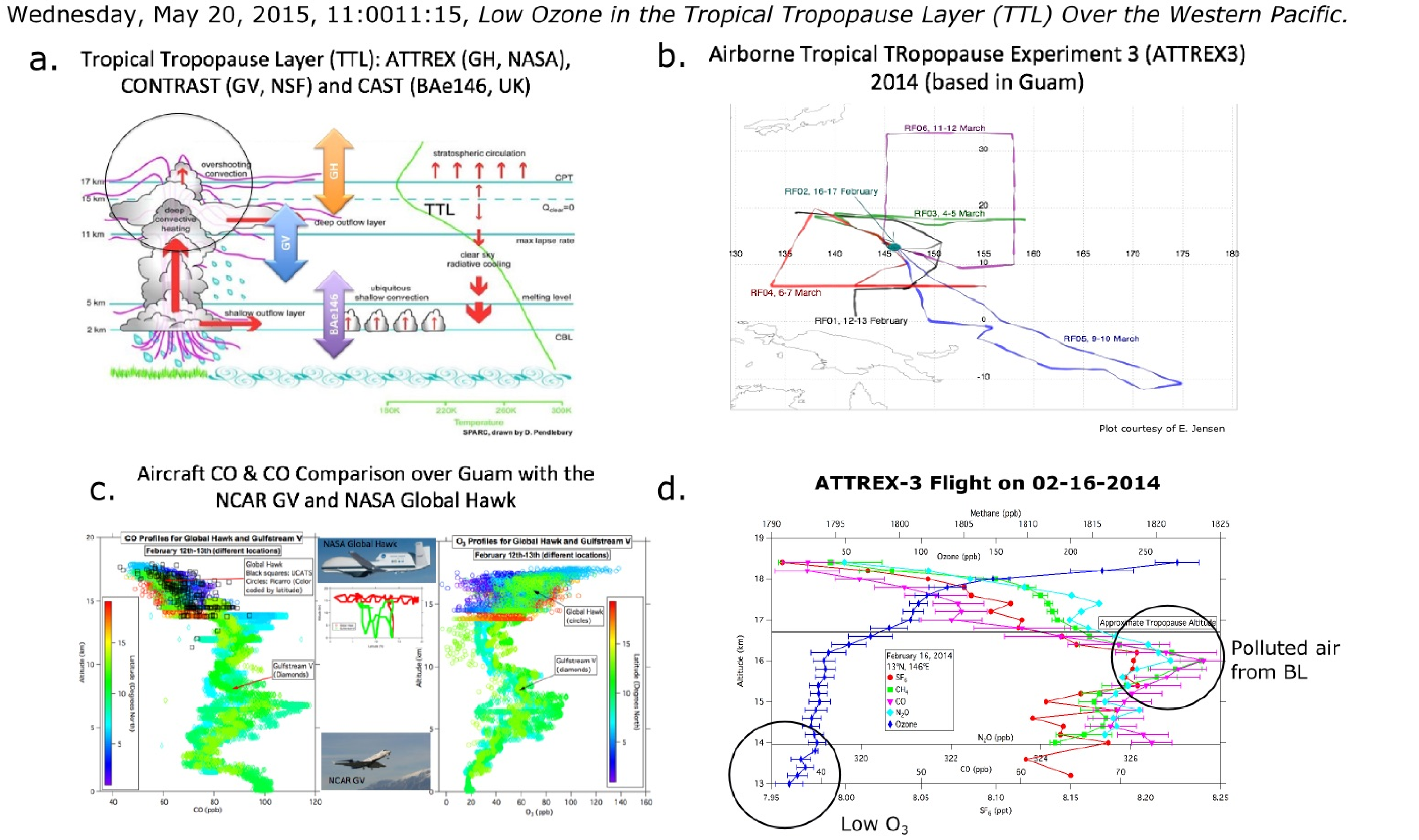

Figure 2 (a). Schematic of convective systems over the tropics; **(b).** Flight paths of the NASA Global Hawk during ATTREX-3 based out of Guam, USA; **(c).** Overflight of the Global Hawk UAS and the NCAR GV; **(d).** Representative flight showing the trace gases of CH_4 (ppb), O_3 (ppb), N_2O (ppb), and SF_6 (ppt) on 02-16-2014.

3. SkyWisp sUAS 2013-2014: Our goals are to develop (1) small sensors to measure ozone, relative humidity, aerosols, and selective meteorology parameters; and (2) to collect an AirCore for trace gases on the platform, retrieve it for laboratory analysis. The goal of a stratospheric AirCore is to retrieve it and to monitor trace gas concentrations over time at many locations worldwide to investigate atmospheric circulation changes that are predicted by Global Climate Models (GCMs). By measuring a number of trace gases with varying local atmospheric lifetimes along with seasonally varying trace gases like CO_2, O_3, and H_2O, it is possible to quantify the changes in atmospheric circulation (***Fig. 3a***). SkyWisp is a standard model airplane glider made of balsa and plywood frame, and Monokoto™ (plastic film). The glider sUAS is lifted by a weather balloon to altitudes as high as 32 km, released at altitude, and glides down to a pre-determined location using an on-board autopilot (***Fig. 3b***). We have developed a version of a radiosonde (P,T, RH%, radio link, and additional RS-232 channel) for sUAS (***Fig. 3c***). The additional serial line is used for data from a modified version of a standard ozonesonde (***Fig. 3d***) An aerosol-sonde is also being developed at NOAA for a sUAS (GOAHEAD).

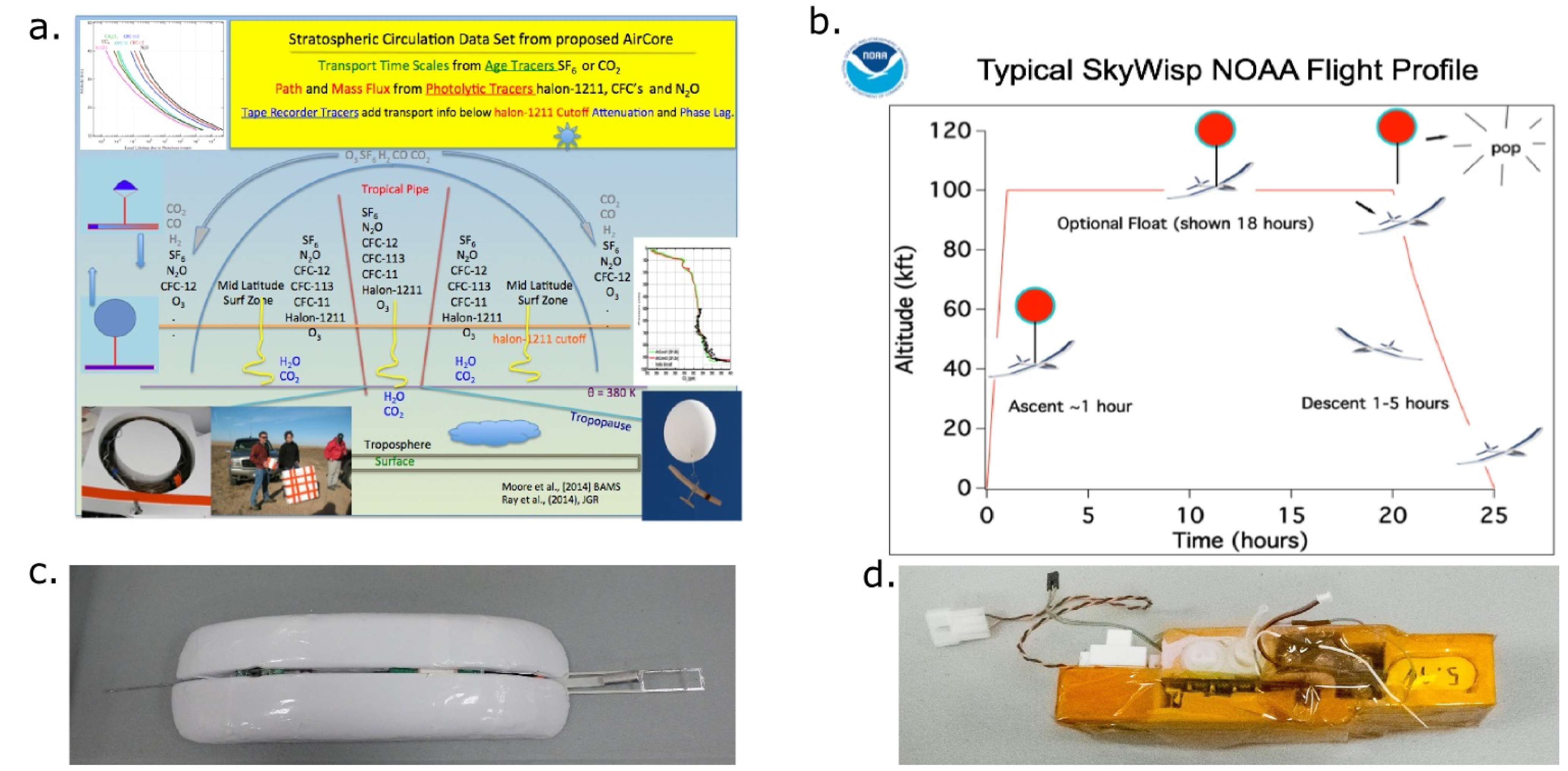

Figure 3 (a) Stratospheric AirCore Monitoring Program Diagram; **(b)** Typical Flight Plan for a glider sUAS lifted by weather balloon; **(c)** NOAA/GMD modified radiosonde for sUAS; **(d)** NOAA/GMD modified ozonesonde for sUAS.

4. Aero sUAS 2014: SkyWisp has very interesting capabilities, but it has a proprietary software and hardware that uses unsupported software (Windows XP). We decided to investigate the "open-source" Aero sUAS by 3DRobotics (***Fig. 4a***). The Aero sUAS includes an "open-source" autopilot called Pixhawk (***Fig. 4b***). The software can be run on Windows, Apple OS, and Linux operating systems. The sUAS has a propeller that can lift the sUAS without a balloon for testing and practicing manual override of the autopilot, and landings. During the summer, we evaluated the platform as part of a NOAA Hollings Student Internship. We flew the plane over a model airfield using its autopilot to propel it to a certain altitude over the ground, fly three times in a oval pattern overhead, and land safely (***Fig. 4c***). The platform has many advantages including a stronger styrofoam airframe with carbon fiber rod supporting the tail section to the fuselage, the abliity to use more than one preprogrammed waypoint, and simpler software to monitor the flight plan (***Fig. 4d***). We are working on converting the software to a non-propeller version for the autopilot to glide the Aero down to selected waypoints.

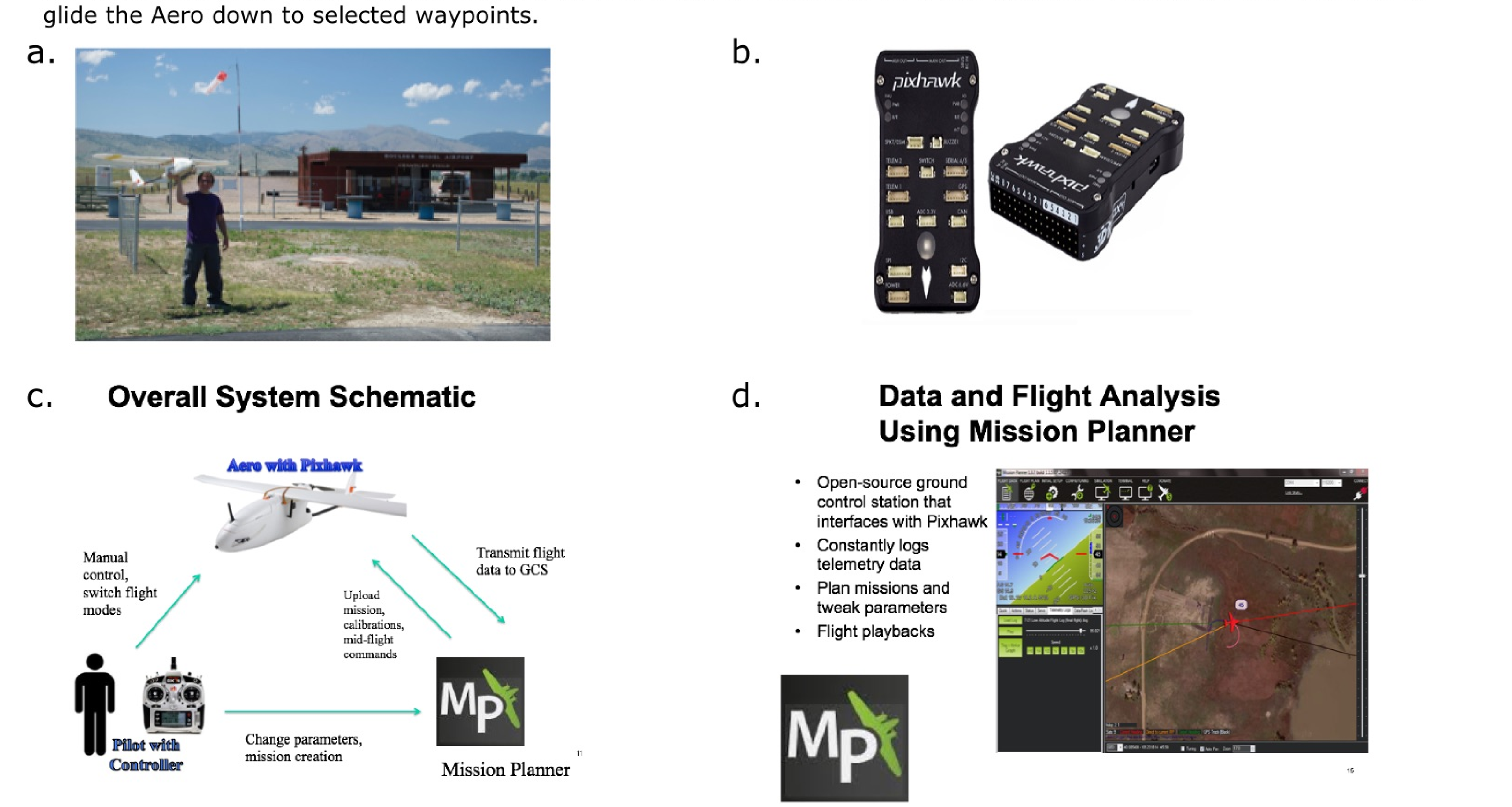

Figure 4 (a) Aero with Hollings Student at Boulder Model Airplane Airport; **(b)** Pixhawk Autopilot; **(c)** Overall system schematic; and **(d)** Mission planner software.