AIAA SciTech Forum
23-27 January 2023, National Harbor, MD & Online
AIAA SCITECH 2023 Forum

10.2514/6.2023-1725

World record duration flight of group 2 unmanned aircraft with VTOL and hybrid propulsion system using solid oxide fuel cell

Dustin E. Gamble
Lockheed Martin Aeronautics, San Luis Obispo, CA, 93401, USA

This is a technical out-brief of a world record endurance flight of the Lockheed Martin Stalker VXE30 aircraft which flew for over 39 hours. The aircraft is a group 2 unmanned aircraft weighing less than 25kg. It also features vertical takeoff and landing. It was powered with a hybrid propane solid oxide fuel cell and lithium battery. The flight featured an external asymmetric propane wing tank which enabled the long endurance. The event was livestreamed and monitored on site by officials over the entire duration.

I. Nomenclature

AMA	=	Academy of Model Aeronautics
FAI	=	Fedration Aeronautique Internationale
FAA	=	Federal Aviation Administration
NIST	=	National Institute of Standards and Technology
SOFC	=	Solid Oxide Fuel Cell
UAS	=	Unmanned Aircraft System
SUAS	=	Small Unmanned Aircraft System, takeoff weight less than 55lb
VTOL	=	Vertical Take Off and Landing
VXE30	=	Stalker VXE30, V=VTOL, XE=SOFC support, 30, Block 30
W	=	Electrical power in watts

II. Introduction

On the 16th of February 2022 at 5:20 PM PST the unmanned aircraft, Stalker VXE30, launched vertically from an airfield in Santa Margarita, California, USA. The system featured a fixed wing aircraft to cruise at low power with a vertical take-off and landing multirotor system. The electric propulsion system was powered by a hybrid battery and propane solid oxide fuel cell. The flight concluded with a vertical landing on the 18th of February 2022 at 8:37 AM PST after 39 hours 17 minutes 7 seconds of flight.

Figure 1: Pictures from flight event

III. Stalker History

Over time the Stalker system has evolved to meet customers' evolving missions and to leverage the latest technologies. Early Stalker versions were hand launched with deep stall landing and could stay aloft for 2 hours. In 2011, a solid oxide fuel cell was integrated which formed the Stalker XE variant. The fuel cell consumed propane and allowed the aircraft to stay aloft for 8 hours. This version used a hand released bungee launch system and flaps for precision landing. The latest version, Stalker VXE30, incorporated vertical take-off and landing with improved fuels, communications, and avionics.

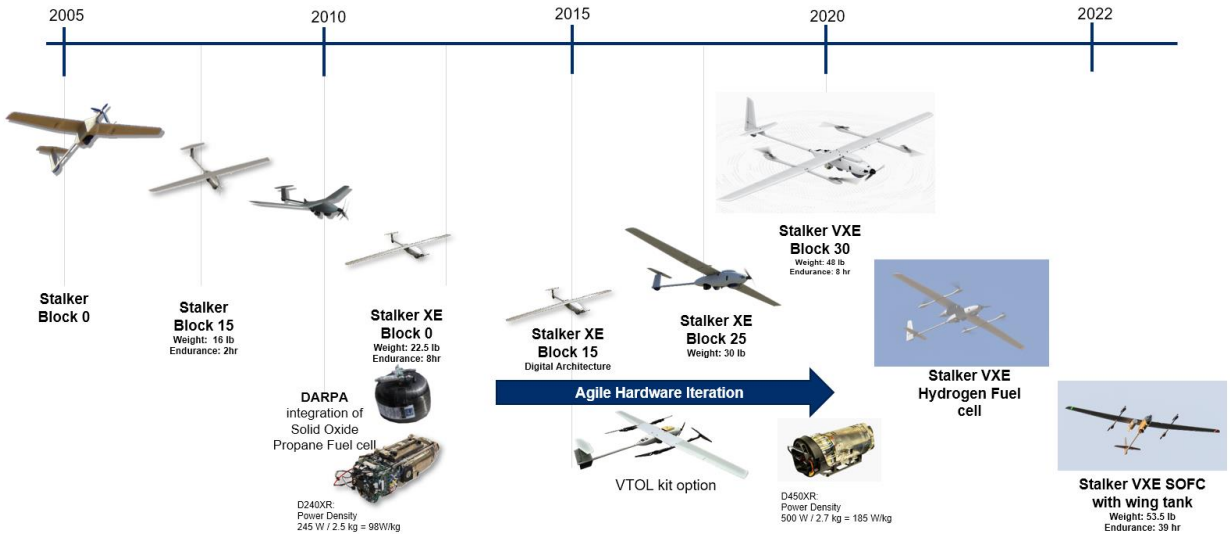
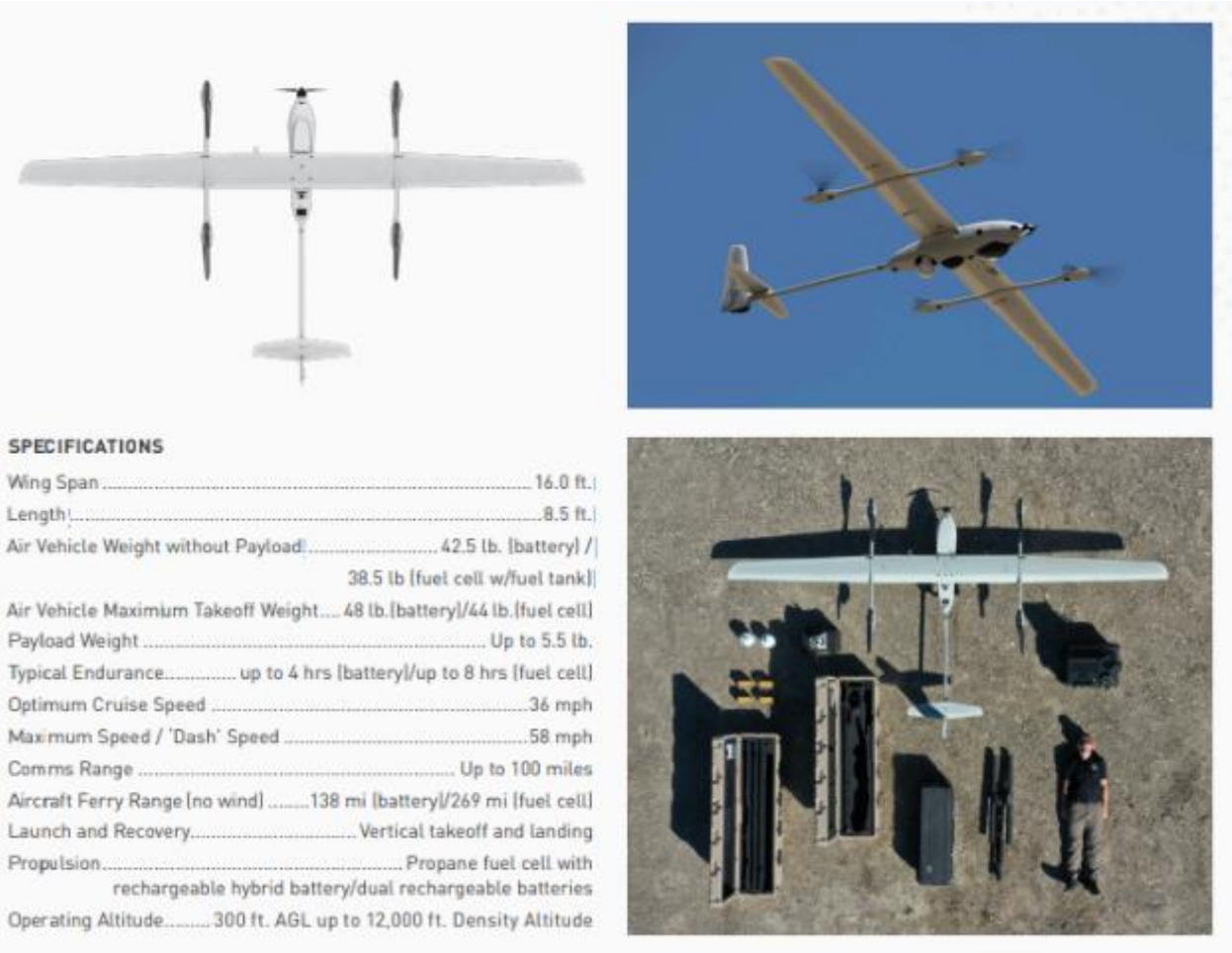


Figure 2: Stalker Timeline

IV. Stalker VXE30 Baseline Aircraft

Stalker VXE30 is a next-generation vertical take-off and landing (VTOL) small unmanned aerial system (SUAS) with unmatched robustness and flexibility. VXE30 builds off the success of the operationally proven Stalker extended endurance SUAS by combining the flexibility of a portable system with class exceeding endurance and payload performance. The system allows for a wider range of launch and landing with precise touchdown accuracy. The system is built to address the practicalities of diverse mission types and extended service life with more payload weight and configuration options without sacrificing endurance or compatibility.



SPECIFICATIONS

Wing Span	16.0 ft.
Length	8.5 ft.
Air Vehicle Weight without Payload	42.5 lb. (battery) / 38.5 lb (fuel cell w/fuel tank)
Air Vehicle Maximum Takeoff Weight	48 lb.(battery)/44 lb.(fuel cell)
Payload Weight	Up to 5.5 lb.
Typical Endurance	up to 4 hrs (battery)/up to 8 hrs (fuel cell)
Optimum Cruise Speed	36 mph
Maximum Speed / 'Dash' Speed	58 mph
Comms Range	Up to 100 miles
Aircraft Ferry Range (no wind)	138 mi (battery)/269 mi (fuel cell)
Launch and Recovery	Vertical takeoff and landing
Propulsion	Propane fuel cell with rechargeable hybrid battery/dual rechargeable batteries
Operating Altitude	300 ft. AGL up to 12,000 ft. Density Altitude

Figure 3: Stalker VXE30 Product sheet

The aircraft can be powered by a propane solid oxide fuel cell. The fuel cell converts fuel into electrical power. This unit internally reforms propane gas to extract hydrogen electrons to generate electricity. The reformation of propane requires the core temperature of the fuel cell to be 800C.

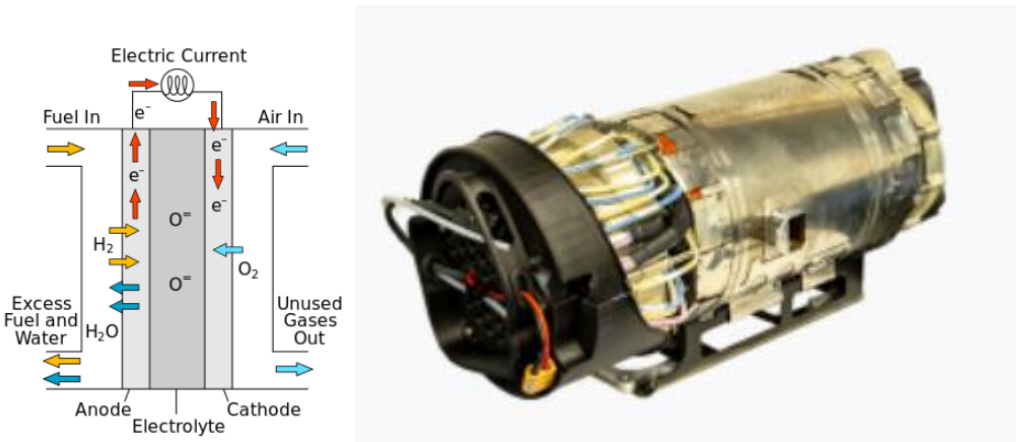


Figure 4: Solid oxide fuel cell scheme and actual unit

V. Modifications

A. Weight

The maximum gross takeoff weight of the aircraft is 48lb. At that weight the aircraft can vertically climb to 300ft above ground level and then transition to a fixed wing aircraft with forward flight. It can do this at a density altitude of up to 12,000 ft. To accomplish this record, the aircraft was required to support a takeoff weight of 53.5lb. At that weight the aircraft could carry the external wing tank with the fuel needed to set the record. To achieve this weight there were changes to the baseline configuration. The autopilot airspeed set point was increased by 10% to support the fixed wing flight. The VTOL system was also stressed with the extra weight. To address this the vertical climb rate was reduced by 30% and the transition altitude was reduced from 300 ft to 150ft. These changes allowed the baseline lift system to carry the extra weight. This reduction in performance restricts the launch site location to be clear of obstacles and at low density altitude.

B. Performance

In flight, the aircraft's typical cruise power utilizes 60% of the fuel cell's maximum power. The addition of the external tank had a minor impact on the aerodynamic drag but had a strong impact on the wing lift drag. The in-flight power with a full external tank utilized 80% of the fuel cell's maximum power. It was critical that the sustained propulsion power be less than the fuel cell power for the flight to sustain long endurance. The propulsion system is hybridized with a small lithium polymer battery. On launch the aircraft climbs at 10 times the cruise power for 25 seconds which consumes 30% of the hybrid battery. After transition the power is reduced to cruise power. The excess power from fuel cell is used to charge the battery back to 100%.

Low flying, slow aircraft are threatened by rising air from thermal convection. Even on a calm day afternoon air can create turbulence which will push the aircraft down and require it to use climb power to maintain altitude as the air mass is descending around it. To minimize the impact of afternoon thermals when the aircraft was heavy at takeoff, it was launched in the evening. This allowed the aircraft to consume 20 hours of propane and be lighter when the afternoon thermal convection began. At 400W the fuel cell propane consumption is 130 grams per hour. Launching at 5:20 PM allowed the aircraft to consume 2.6 kg or 5.7lb of propane loosing 10% of the vehicle weight before afternoon the next day. The 10% reduction in aircraft weight from fuel burn reduced the inflight power required.

C. Wing Tank

To extend the endurance the aircraft required more on-board propane. To reduce the changes to the aircraft an external wing tank was used. The tank is a liner-less composite propane tank weighing 2.2 lb/1 kg and 8.6 liters in size. The tank used anti-slosh foam to prevent any pitch issues with the aircraft in flight. A single wing tank was used instead of two wing tanks. One larger volume tank was nearly 2 lb lighter than 2 smaller tanks. This was due to minimum wall thickness of the composite tanks, reduction of number of pylon mounts and fuel manifolds.

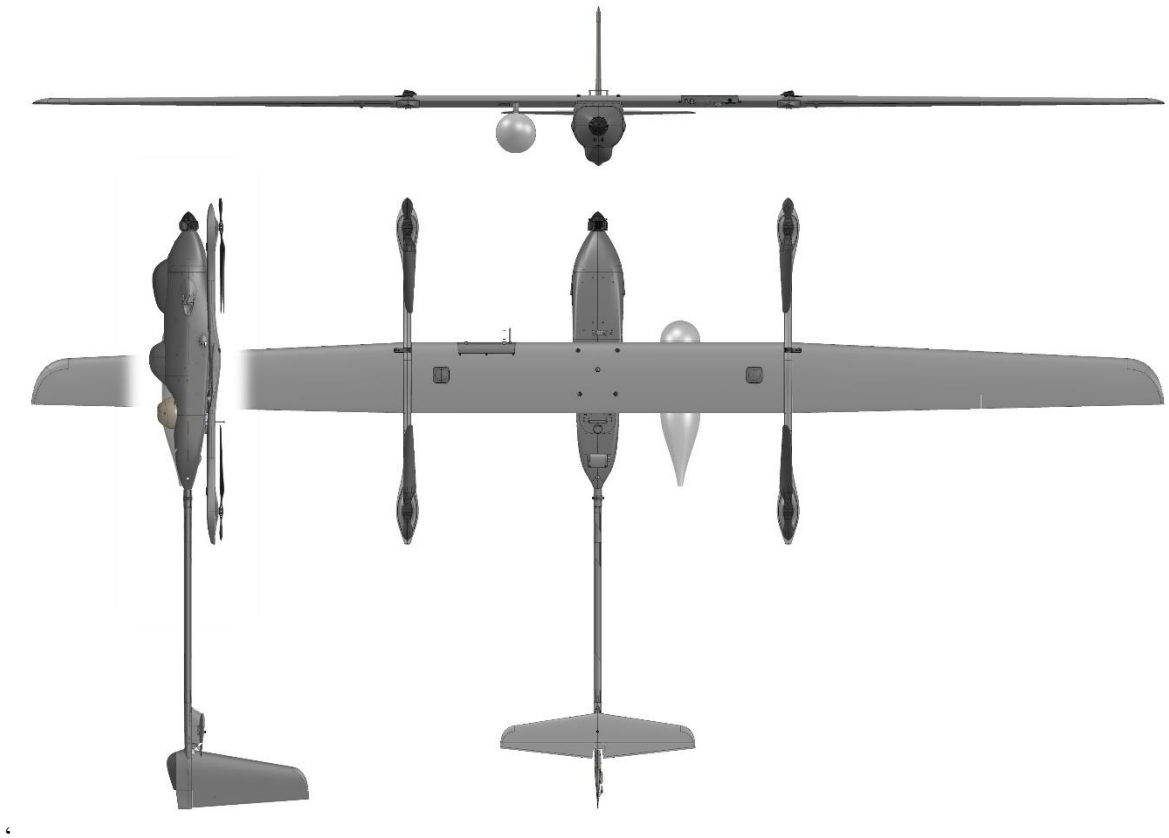


Figure 5: 3 View of aircraft with external propane tank

Figure 6: External wing tank in flight

D. Fuel Vaporizer

The baseline system used a single 2.2L tank inside the fuselage. The tank was oriented so that the pickup point is at the top. In the pressure vessel propane condenses and becomes a liquid. At the top of the tank is a manifold where

there is a regulator. Propane gas pressure depends on the temperature. This can range from 15 psi to 250 psi. A regulator steps down the propane pressure to 15 psi for consumption by the fuel cell.

Figure 7: Propane tanks swapped out in Stalker fuselage

With the introduction of a large wing tank, we need to tie in the fuel lines from both tanks. The lightweight propane wing tank has a pickup on the end. When the tank is on its side that pickup point is submerged. This will feed liquid propane through the line. If liquid propane is introduced to a regulator without heating, the regulator will freeze and malfunction.

To resolve this issue a fuel vaporizer was used. The vaporizer used heat from the fuel cell to convert liquid propane to gas and then tie it into the fuel system. This created a vapor barrier and prevented liquid injection into the regulator. The wing tank system had to be connected after the fuel cell had warmed up to its operating temperature.

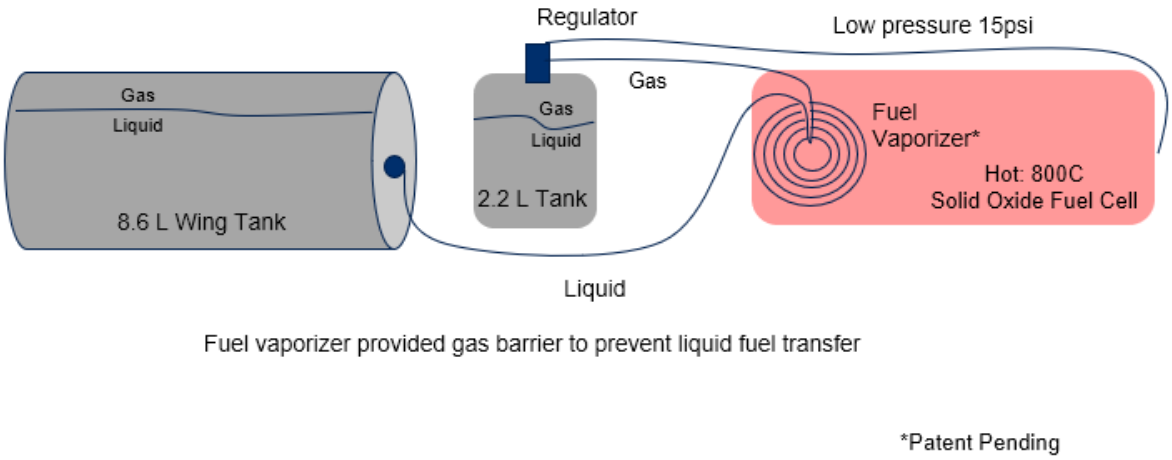


Figure 8: Fuel Vaporizer

VI. Record setting logistics

The aircraft weight is in the unmanned aircraft weight range from 5kg to 25kg. To set a record in this class the AMA organization uses contest directors with FAI sporting licenses. The AMA reports to the NAA who reports those results to the FAI. To capture this record, a contest director would need to monitor the flight for the entire duration. Given the long duration of the flight a livestream system was set up for remote team members and official observers to monitor the event. The livestream used a camera tracking system to view the aircraft from the ground. The live feed also shows a camera from on board the aircraft. The baseline aircraft features a wing camera for real time pilot awareness. Another livestream view showed telemetry flight on gauges. These included the estimated endurance remaining, elapsed time, estimated land time, airspeed, altitude, and power.

In the end the livestream was not officially needed for the record because three contest directors were able to monitor the event in person.

Figure 9: Automatic inflight camera tracking system

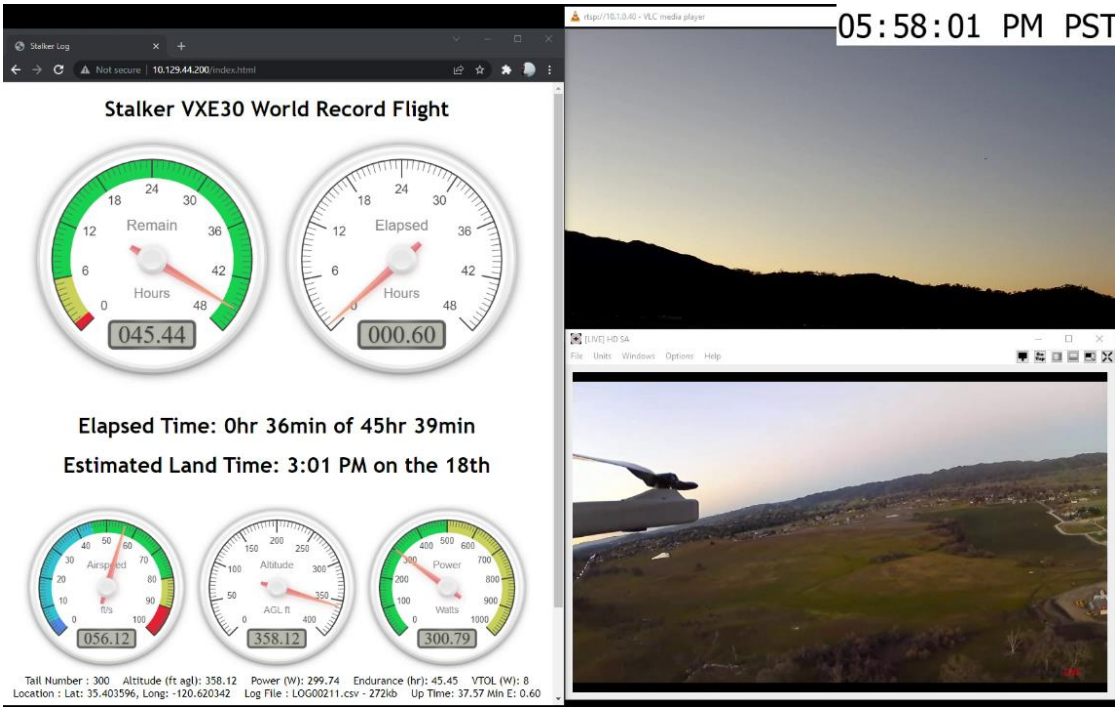


Figure 10: Live stream view

The official requirement for a duration record is to use two NIST time devices. We equipped three contest directors with two timers each for a total of six timers.

Figure 11: NIST Timer used for measuring duration

Timer	Instrument Identification	Serial Number	NIST Traceable Reference	Cal Date	Cal Due Date
1	5008,94461-23	210777561	1000468745	10-Sep-21	10-Sep-23
2	5008,94461-23	211108299	1000467077	30-Dec-21	30-Dec-22
3	5008,94461-23	211108377	1000467077	30-Dec-21	30-Dec-23
4	5008,94461-23	211108376	1000467077	30-Dec-21	30-Dec-23
5	5008,94461-23	210777586	1000468745	10-Sep-21	10-Sep-23
6	5008,94461-23	210777560	1000468745	10-Sep-21	10-Sep-23

Figure 12: Time with NIST Certification information

The flight was conducted at Santa Margarita Ranch, California, USA. 35.400216, -120.616479. A UAS NOTAM was issued for the area to notify local air traffic. The aircraft was flown in uncontrolled airspace under FAA drone regulations.

Figure 13: Drone NOTAM UAS during flight, Small UAS certification

For the night flights the aircraft was equipped with wing tip lights in following with the FAA Part 107 light regulations.

Figure 14: Wing tip lights

VII. Flight event

On the 16th of February 2022 at 5:20 PM the unmanned aircraft, Stalker, launched vertically from an airfield in Santa Margarita, California, USA. The contest directors' team of three, split their time, so they always had at least one person observing the flight. The aircraft was programmed to fly in an orbit within 1 km of the pilot ground control station. The altitude was set at 350 ft above ground level.

Figure 15: Ground control station setup

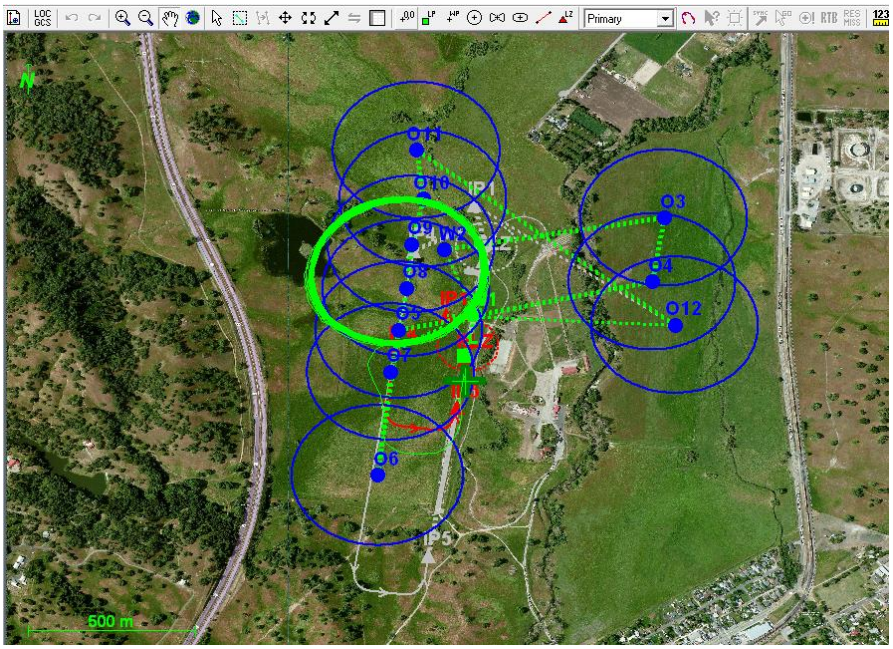


Figure 16: Ground Control Station Mission plan

The flight required three shifts of at least three pilots each. Below was the schedule used by the crew to operate the aircraft:

		Pilot 1	Pilot 2	Support Staff	Hours on	Elapsed time
Wednesday	4:00 PM				0	0
Wednesday	6:00 PM				2	2
Wednesday	8:00 PM				4	4
Wednesday	10:00 PM				6	6
Wednesday	12:00 AM				0	8
Wednesday	2:00 AM				2	10
Thursday	4:00 AM				4	12
Thursday	6:00 AM				6	14
Thursday	8:00 AM				0	16
Thursday	10:00 AM				2	18
Thursday	12:00 PM				4	20
Thursday	2:00 PM				6	22
Thursday	4:00 PM				8	24
Thursday	6:00 PM				0	26
Thursday	8:00 PM				2	28
Thursday	10:00 PM				4	30
Thursday	12:00 AM				6	32
Thursday	2:00 AM				0	34
Friday	4:00 AM				2	36
Friday	6:00 AM				4	38
Friday	8:00 AM				6	40

Figure 17: Crew shifts

The autopilot logged the entire flight and was provided to the officials in a data package.

The date column shows the date at the Universal Time Coordinated (UTC) from the on-board GPS. The event occurred in California, Pacific Standard Time (PST), 7 hours behind UTC. The Msl column shows the GPS altitude above mean sea level. The ground elevation was about 985ft. The aircraft remains 300ft above ground elevation for the full 39.29 hour flight. The height above ground level shows proof of flight for the entire duration. There are 424 columns of data collected.

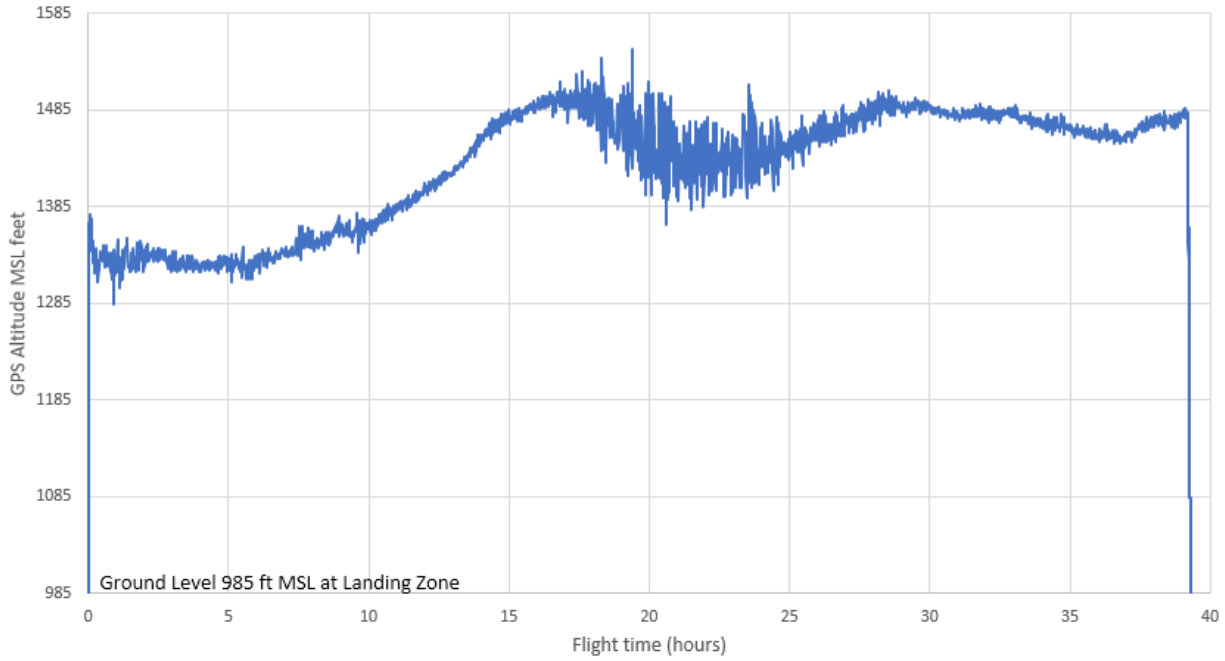
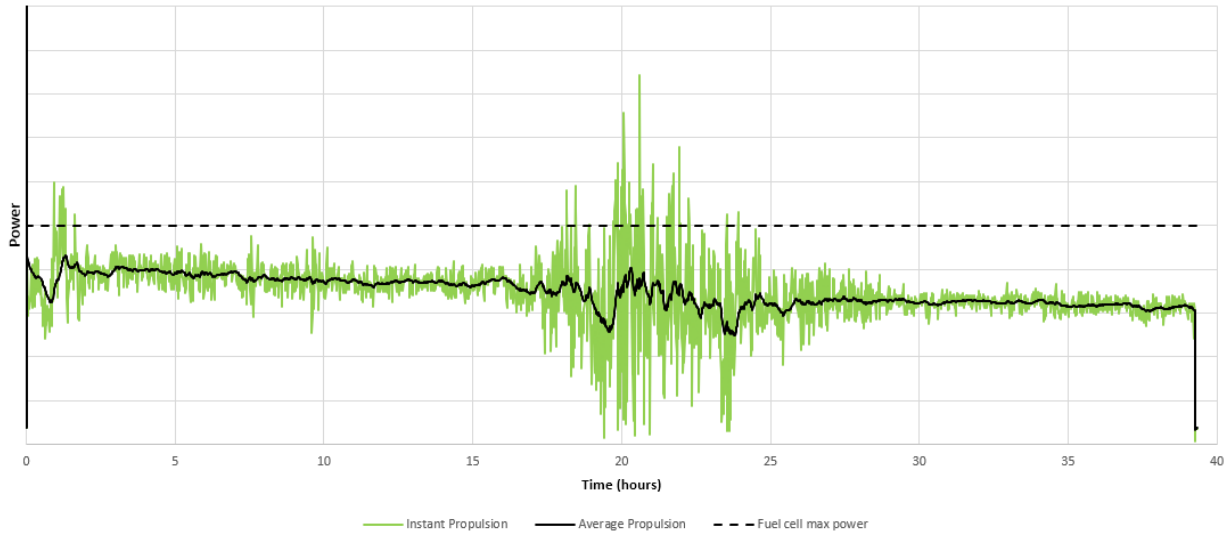


Figure 18: Flight data log, GPS altitude vs time

The average power decreased from the beginning of the flight to the end of the flight. This was due to the fuel burn which reduced the weight of the aircraft from 53.5lb to 43.5lb over the flight.



The flight concluded with a vertical landing on the 18th of February 2022 at 8:37 AM after 39 hours 17 minutes 7 seconds. At landing all contest directors stopped each of their stopwatches. A picture of those stopwatches is below.

Figure 19: NIST Stopwatches with average reading 39 hours 17 minutes 7 seconds

That same day the preliminary notification was sent to the AMA Director, the NAA, and the FAI record organization.

Figure 20: Landing photo with team

VIII. Conclusion

A small, unmanned aircraft using vertical takeoff and landing was able to use hybrid propulsion to set a new duration record. That aircraft utilized propane solid oxide fuel cell technology to provide a high enough energy density for the endurance. The aircraft featured vertical takeoff and landing and an imagery camera payload. An external fuel

tank changed the baseline of the aircraft to support the extra fuel for the long flight. The world record has been ratified by the FAI World Air Sports Federation.

Acknowledgments

Flight test team: Theo Coetzee, Matt Curran, Gordon Jennings, Chris Hofheins, Curtis Keenon, Sam Miller, Carson Buckley, Enoch Nicholson.

Organizations:

- Lockheed Martin Aeronautics as lead integrator of the systems
- Edge Autonomy as a developer and original equipment manufacturer of high-performance unmanned systems, including the Stalker VXE aircraft
- Adaptive Energy to develop cutting-edge fuel cell technology, investing in advanced power sources and testing innovative implementation techniques for field operations
- Composite Technology Development Inc. to build a light-weight external wing tank
- Precision Integrated Programs to provide flight operations support
- Clovis Area Modelers to provide FAI official contest directors to continuously monitor and adjudicate the world record flight for ratification

References

https://en.wikipedia.org/wiki/Solid_oxide_fuel_cell

FAI Record Status site: https://fai.org/record/19634

Lockheed Martin News release:
https://news.lockheedmartin.com/2022-04-11-Lockheed-Martin-Stalker-VXE-UAS-Completes-World-Record-39-Hour-Flight

Lockheed Martin Stalker information site:
https://www.lockheedmartin.com/en-us/products/stalker.html

Stalker VXE30 product card:
https://www.lockheedmartin.com/content/dam/lockheed-martin/aero/documents/Stalker/StalkerVXE30ProductCard.pdf