High-altitude Inflatable Kites and Their Role in Atmospheric Boundary Layer Research

Michael J. Irvin

1 Essential Content, Principal
Longmont, CO 80504  USA
michael.irvin@zoho.com

© 2021 American Meteorological Society
Abstract

*High-altitude Inflatable Kites and Their Role in Atmospheric Boundary Layer Research*

Kites have been used as weather sensing solutions for over 250 years. The fact that they are simpler to operate and train on than alternative aerial systems, their ability to keep station at a fixed point for a long term, simplified altitude control, and the ease of retrieving their payload attribute to their growing appeal in atmospheric research. NASA, Toyota, and the School of Mechanical and Aerospace Engineering Oklahoma State University are active in developing and deploying high-altitude inflatable kite systems for atmospheric boundary layer (ABL) research—crucial to advancing the accuracy of weather forecasting. Improvements in kite design, as well as instrumentation and supporting infrastructure, are key to further accelerating the use of kites in atmospheric research. The work underway by these researchers is intended to be a deliberate step in the evolutionary development of these beneficial systems.
Who would have thought that the song, “Let’s Go Fly a Kite” by David Tomlinson, and made popular in the 1964 Disney movie, Mary Poppins, would have been such a predictor for the use of kites in atmospheric research?

Actually, kites have been used as weather sensing solutions for over 250 years. During the first half of the 1900’s, kites served as the principal tool for conducting atmospheric profiling advancing both meteorology and operational forecasting. While other forms of atmospheric vehicles like balloons and small unmanned aircraft systems (UAS) are also used to conduct atmospheric research, kites offer some compelling reasons for their continued enthusiasm: the fact that they are simpler to operate and train on than alternative aerial systems, their ability to keep station at a fixed point, simplified altitude control, and the ease of retrieving their payload.

Research conducted in the atmospheric boundary layer (ABL) or lower troposphere is crucial to advancing the accuracy of weather forecasting. It is precisely in this region where researchers at Oklahoma State University Unmanned System Research Institute and Toyota have dedicated tremendous time and technology studying kite development and operations for high altitude
deployments. Their goal is to develop an inflatable kite capable of reaching high altitudes (up to 10,000 m or 32,808 ft) for precise local weather predictions, wind energy harvesting, and enhanced telecommunication technology.

Kathleen McNamara, Research Engineer, at Oklahoma State University (OSU), has been involved in kite research since 2017. When asked about the use of kites as research platforms she said, “The primary objective in using kites is to provide airborne platforms for energy harvesting, weather data sensing, and advancement in communications. These high-altitude tethered kite platforms would fly at altitudes around 30,000 ft, in the jetstream, and remain there long-term. This is an idea that came from Toyota Motor Corporation Japan. OSU started working with Toyota to help improve the technology for high-altitude kite systems, particularly those built with inflatable structures. Incorporating inflatable structures into the large platforms, instead of typical rigid kite structures like carbon fiber, can improve the weight efficiency.”

To that end, Oklahoma State University and Toyota have successfully designed and deployed kites that incorporate lightweight inflatable structures capable of handling wind gusts and high-altitude conditions. The OSU/Toyota 8th Generation Inflatable Kite (Figure 1), has performed up to 2,755 m (9,039 ft) AGL. By suspending sensors below the kite, it is possible to provide continuous sensing in an easily deployable, cost-effective platform. The use of kite-based profile systems with distributed or mobile sensors to collect data on the lower troposphere is
predicated on the fact that is the region of the atmosphere where the majority of damaging
weather occurs.

OSU is currently utilizing several kite-based solutions in their research: RAVEN (Repositionable Aerial Vane Environmental Network), a distributed sensing solution which uses aerodynamically stabilized data acquisition units to concurrently collect data from a number of altitudes, an approach pioneered by NASA’s Geoff Bland, which he called AEROKATS (Advancing Earth Research Observations with Kites and Tethered/Atmospheric Sensors); and SWIFT (Sliding Weather Instrument Fixed to Tether, an OSU innovation), a lightweight alternative to RAVEN for smaller systems at the cost of concurrent data collection from multiple sensors.

RAVEN is a set of independent data acquisition units. Each unit is composed of an aerodynamically stabilized body with sensors for temperature, pressure, humidity, wind speed, wind direction, and position. RAVEN’s design places sensors, controllers, radio and batteries on the nose, and an aerodynamic tail on the back, similar in design to that of NASA’s AeroPod¹ (Figure 2).

SWIFT on the other hand uses a radio-controlled sail designed to slide up and down along the tether line from the ground to the kite (Figure 3). Wind-driven instrumentation platforms have demonstrated their effectiveness in prior kite-borne research (Balsley et al., 1998), yet

¹ AeroPod is protected by U.S. Patent 8,196,853 and is available for licensing. More information available at: https://technology.nasa.gov/patent/GSC-TOPS-10

Accepted for publication in Bulletin of the American Meteorological Society. DOI 10.1175/BAMS-D-20-0242.1.
advances in miniaturized sensor technology are proving to be pivotal in expanding their functionality and usage.

Basic operation for weather research kites is fairly straightforward: you launch the kite, attach your data acquisition units as the kite climbs, and then stop when the target altitude is reached. OSU’s RAVEN system transmits data to the ground station as the kite is in flight providing real-time data profiling of the atmosphere for immediate analysis while the kite continues to fly. When you have captured the desired data, the kite is retrieved.

Expanding flight envelopes for kites and operating in the National Airspace Systems (NAS) remain challenging. Typically, flight in the NAS follows compliance with 14CRF Part 101, including notifications to airports and the FAA as necessary, or arranging for restricted airspace. “Automated position reporting is a fairly straight forward systems requirement,” states Jamey Jacob, PhD, Director, Unmanned Systems Research Institute, School of Mechanical and Aerospace Engineering, Oklahoma State University. “Current Part 101 FARs limit tethered operations to a small range of scenarios, precluding wide-spread use. However, as Remote ID requirements under Part 107 regulations start to take effect, it is expected that this will also increase the availability of other autonomous systems as autonomous detect and avoid capabilities come online, potentially replacing requirements for direct ATC authorization. However, this will largely depend upon improved safety cases and for the time being will still require approval on a case-by-case basis.”

https://www.ecfr.gov/cgi-bin/text-idx?rgn=div5&node=14:2.0.1.3.15

Accepted for publication in Bulletin of the American Meteorological Society. DOI 10.1175/BAMS-D-20-0242.1.
Dr. Jacob adds, “While current kite systems are limited to a small range of atmospheric conditions, as control systems are improved these enhancements will allow a larger range of operation conditions, particularly winds.”

Research has demonstrated that smart winches can launch kites with little to no wind controlling the ascent profile. Additionally, feedback on winds aloft can allow the kite to change angle of attach through active control via the bridle or onboard effectors, increasing the upper limit of maximum winds. Both of these concepts have been tested on OSU’s high attitude kite demonstrator.

“Kites are not intended to be a replacement for other unmanned technology,” says Geoff Bland, a research engineer in the Earth Science Field Support Office at NASA’s Goddard Space Flight Center’s Wallops Flight Facility. “Kites are an alternative unmanned aircraft system that can augment and bring a threshold for utilization that requires less training, and because it’s on a string, some inherent safety features associated with it.”

While kites are used predominantly in the lower troposphere, advanced aerodynamics and structural design of both kites and associated advancements in line handling systems, are enabling flight into higher altitudes and higher winds. Bland is quick to point out that his sights are set well beyond the atmospheric boundary layer. “My goal is ultimately the stratosphere, but we’ve got a long way to go before we get to do that.”
In order to ultimately achieve stratospheric altitudes, work continues to make sensors, probes, and related componentry smaller, lighter, and less expensive. One firm on the forefront of these initiatives is Black Swift Technologies out of Boulder, CO. “NASA has partnered with Black Swift Technologies as part of our Small Business Innovation Research (SBIR) Awards beginning in 2012,” Bland states. “The most important result of the company’s work with NASA is a fully integrated set of miniaturized instrumentation that delivers usable data under extreme conditions.”

SwiftFlow™, a 3D wind dynamics probe (Figure 4) that Black Swift Technologies (BST) developed as part of NASA’s SBIR award work, addressed the need for a highly accurate atmospheric measurement device capable of being deployed on a small UAS or UAV, like a kite. “What sets this probe apart, in my mind, was that it was developed by a company that really understands the scientific requirements for this type of product,” emphasizes Bland.

Black Swift Technologies SwiftFlow, a multi-hole wind probe, is engineered to be a tightly integrated wind vector measurement device able to accurately record air speed, altitude, angle-of-attack, side-slip, ambient temperature and relative humidity.

“BST’s 3D wind probe allows us to look at the three-dimensional wind field as it changes in the atmosphere,” Bland states. “I see it as the ‘go-to’ or destination instrument package for those...”
using kites to make these types of atmospheric measurements and employ them in a research field.”

Bland goes on to say, “What we're after is really where is the wind coming from relative to the earth, which means you also have to have the information of where is your instrument relative to the earth, and where is it pointing? And that's what Black Swift does in a very nice package. They provide all of that information: the attitude, the position, and the wind vector, all in a package that outputs the data such that we can get that wind vector, which is otherwise a very difficult measurement to obtain, especially if you want the vertical component. The beauty is that this is a device that you can take in a backpack somewhere and get that measurement.”

NASA and OSU are not alone in their focus on atmospheric research. The International Society for Atmospheric Research Using Remote Aircraft (ISARRA) represents a broad spectrum of the atmospheric research community that is focused on the vertical aspect of atmospheric research, especially as it relates to the movement and presence of gases, such as methane and carbon dioxide in our atmosphere. By capturing the vertical component of those gases, as well as water vapor, serves as a crucial step in better understanding the dynamics impacting our atmosphere and weather patterns.

While vertical profiles have traditionally been conducted using towers, this approach results in a fixed-point source as opposed to being able to make it portable and go to a particular site, take those measurements, or in the case of an unmanned aircraft flying a transect. Vertical
profiling in the boundary layer can be done through remote sensing (lidar, radar, microwave profiling, sodar, etc.), yet key to kite-centric research is the ability to sample sites on-demand as a result of its easy portability.

With the continued work of institutions like Oklahoma State University, Toyota, NASA, ISSARA, and companies like Black Swift Technologies, the sky’s the limit for the potential kite research holds. So, as the lyricist said, “Let’s go fly a kite.”
Figure 1: Oklahoma State University’s 8th generation inflatable beam design is clearly visible, providing lightweight, practical structure for high altitude flights. (© Photo by Mike Simons, Tulsa World Media Company)
Figure 2: Oklahoma State University’s RAVEN (above left) and NASA’s AeroPod (above right).

Figure 3: SWIFT's servos actuate the opening and closing of the foldable frame that holds the sail fabric to enable upward or downward movement of the sensor suite.
Figure 4: The Black Swift SwiftFlow™ 3D wind probe captures not only pressure measurements, but its magnetometer and inertial measurement unit coupled with fusion algorithms provide a full wind vector solution.