ARLISS Xtreme: An Amateur Educational Sounding Rocket to the Edge of Space

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Photo Courtesy Ken Adams

ARLISS Xtreme is an amateur sounding rocket program sponsored by AeroPac to take CanSat[1] sized payloads to the edge of space. It is based on the philosophies of the very successful 15 year old ARLISS (A Rocket Launch for International Student Satellites) program[2,3] – a unique partnership between highly skilled amateur AeroPac rocketeers that fly ingenious student robot experiments as experimental rocket payloads. Classic ARLISS flights typically go to 3.3 km, carry a 1 Kg student robotic sub-orbital satellite, have an outstanding reliability record of 99.6% success in payload deployment (over the 600+ flights since 1999) and are based a highly reusable airframe design with over 20 flights on an airframe being typical. ARLISS is a non-profit, all volunteer program, in which ARLISS team members build airframes on their own and fly student payloads for the cost of the propellant.

ARLISS Xtreme takes the next big step and tackles the challenge of suborbital flights with a CanSat or PocketQube[4] to the 30-70 km range. Balloons do very well in the lower and middle of the stratosphere up to about 30 km. ARLISS Xtreme reaches above balloons to explore the complete stratosphere and large parts of the mesosphere on the edge of space. It fills the gap between balloons and small LEO CubeSats and PocketQubes.

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1 http://en.wikipedia.org/wiki/CanSat

2 www.arliss.org

3 Biba, Ken,"ARLISS 2013", *Sport Rocketry*, National Association of Rocketry, Jan/Feb 2014, 6, print.

4 http://en.wikipedia.org/wiki/PocketQube

And it is a lot of fun.

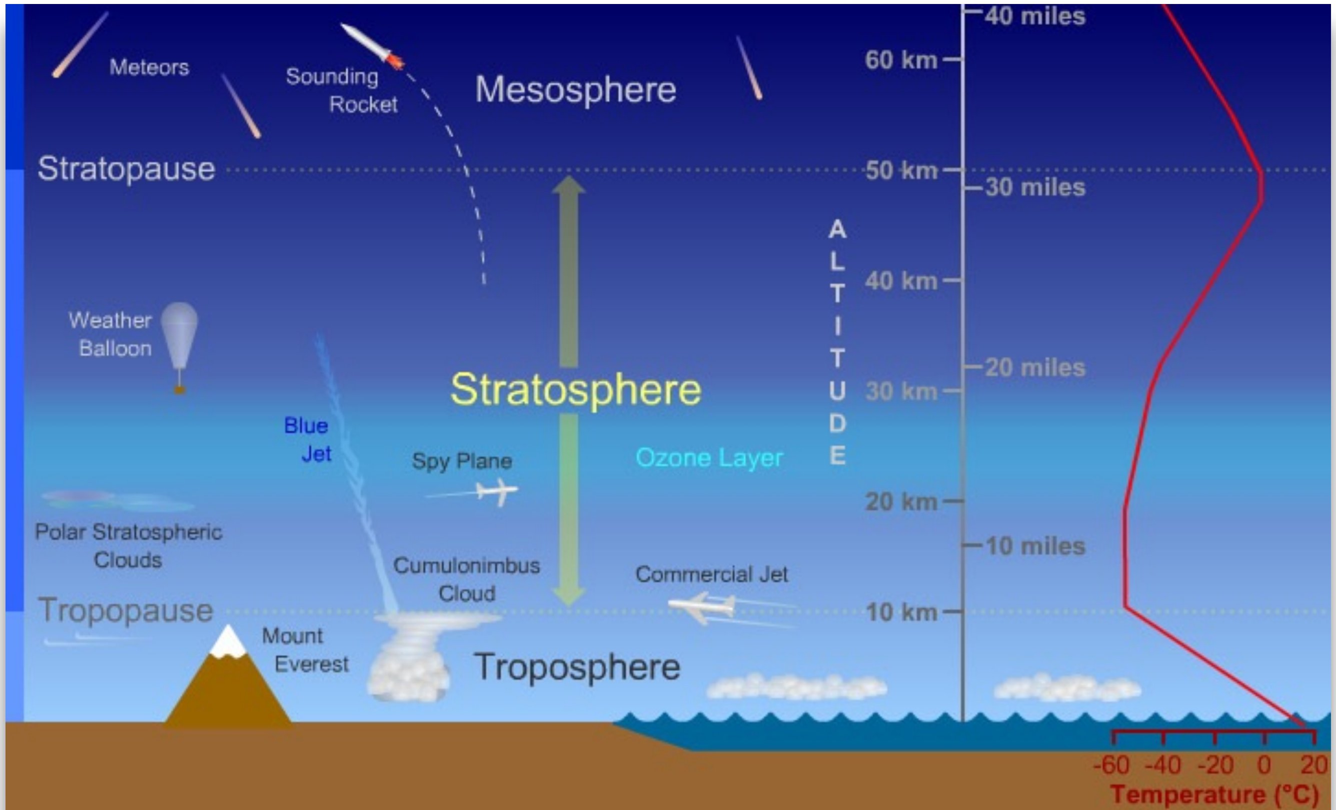


Image courtesy of Windows to the Universe (www.windows2universe.org)

Like ARLISS, ARLISS Xtreme airframes are open source, made with commonly available amateur rocketry composite components and assembly techniques . Capital cost per airframe (including avionics) is under $2k and about $1-$1.5k in per flight propellant and expendables. Flight duration above 30 km is a few minutes. Airframe design is open source.

ARLISS Xtreme is very efficient, matching the efficiency of post WW II commercial sounding rockets with airframes typically flying Mach 3-4 on 20 to 30k Nsec of commercially available solid propellant.

A Bit of History

ARLISS Xtreme comes from a two AeroPac/LUNAR group projects on high altitude amateur airframes from the 2005-7 time frame: to100K and 99k. While neither project succeeded in their common goal of exceeding 100k' AGL at their Black Rock, NV range, both taught valuable lessons about airframe design, flight profile and avionics that led to the AeroPac 100k project of 2012. That project won the

Carmack Prize – created by John Carmack to recognize the first amateur rocketry team to exceed 100k' AGL, document the altitude with GPS and publish a complete analysis of the project and the system. That flight was in September 2012 to 104k' AGL – but one of a series that the team flew with this airframe – characterizing its performance.

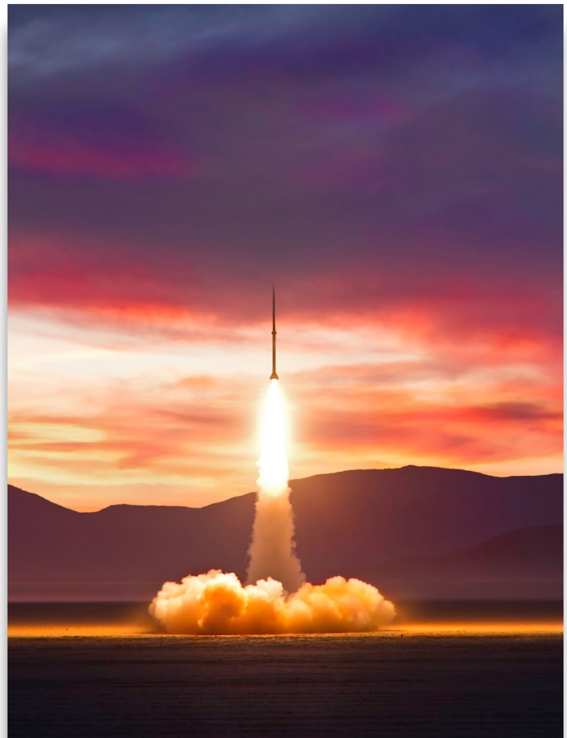


Photo courtesy of Tom Rouse

That project, and more importantly the team[5], created a high performance sounding rocket system:

- that is highly efficient in its use of propellant, dramatically decreasing flight cost to high altitude;
- can be constructed from common HPR materials and techniques;
- that is explicitly designed to carry an educational student payload, as does ARLISS Classic;
- that is highly reliable, reusable and precise on recovery;
- that can explore the limits of the atmosphere using commercial motors of less than 40k Nsec of total impulse.

The ARLISS Xtreme system is the result. It consists of a proven, flight characterized airframe, a mission profile that optimizes recovery, launch system and telemetry system designed to deliver .3 Kg, soda can sized (550 cm^3) payloads to 30-70 km in altitude and recover them.

And fly again the next day with a new payload.

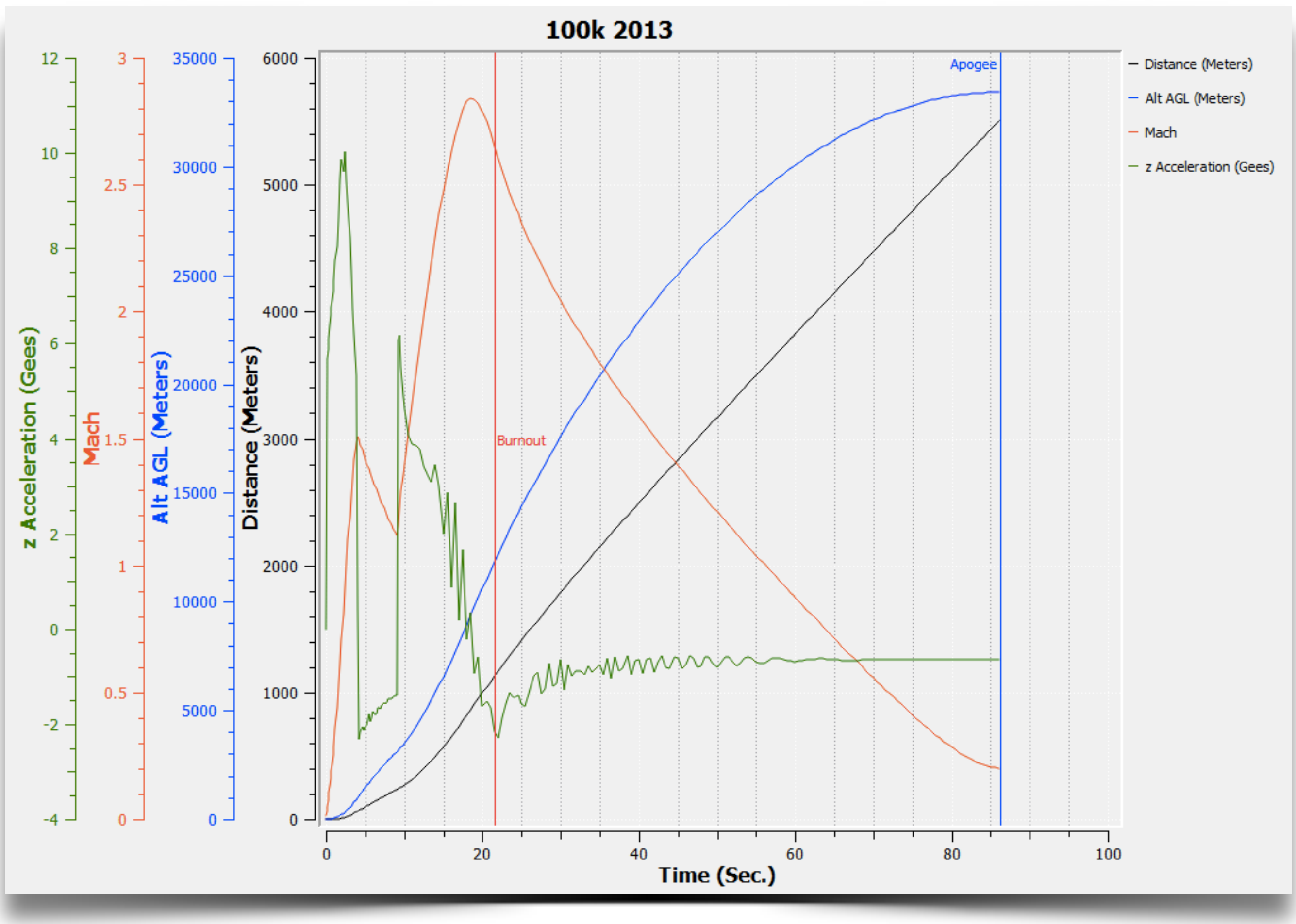
<u>Mission Profile</u>

The ARLISS Xtreme airframe is a two stage (4" booster to 3" sustainer) rocket. It can be configured with a range of commercial solid fuel motor configurations in booster (98mm) and sustainer (75mm) totaling between 20-30k Nsec of propellant.

[5] Ken Biba, Casey Barker, Erik Ebert, Becky Green, Jim Green, David Raimondi, Tom Rouse and Steve Wigfield

ARLISS Xtreme is launched from a 30' pointable rail that can be adjusted in azimuth and elevation to compensate for upper atmosphere winds to increase the precision of recovery. Standard procedure is to fly a small pilot weather balloon with a GPS tracker prior to flight to characterize the local high altitude wind column. Data from the wind column is used in Monte Carlo simulations to determine the best launcher attitude.

Both sustainer and booster have 70cm GPS beacons based on the HAM standard APRS protocol for tracking and recovery. Both sustainer and booster have HD cameras for recording the flight.



Staging occurs at between 3k and 7k meters AGL depending on the booster motor selected. Booster motor selection is focused on getting sufficient velocity off the launch rail to ensure accurate flight while not being too energetic to waste too much energy in friction in the lower atmosphere. Staging is either passive drag separation or an active piston is used to push out the sustainer from the interstage to ensure staging.

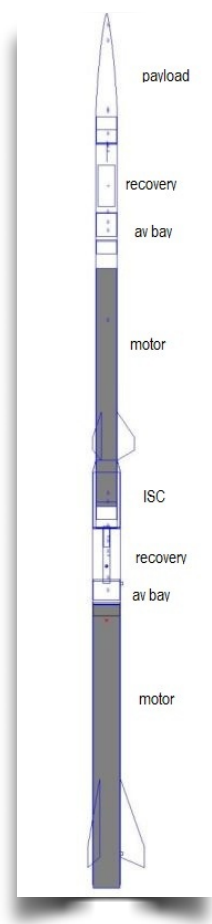
The booster avionics barometrically determine apogee and deploy a drogue at booster apogee to slow and orient recovery of the booster. At about 1k meters AGL, the booster avionics deploy the main booster parachute.

Sustainer avionics light the sustainer motor shortly after stage separation. There is a short staging delay before sustainer ignition with sustainer avionics overriding sustainer ignition if the airframe is not in a sufficiently vertical profile for effective recovery. Sustainer motor selection is biased towards longer burn motors to optimize altitude and minimize energy lost to drag. Sustainer avionics are redundant and are primarily based on accelerometer apogee detection above 30 km about 80-90 seconds into the flight.

The sustainer (and payload) spends about 60-100 seconds above 30km during the flight.

A drogue chute is deployed at sustainer apogee to align and to minimize tangling of the recovery harness. At about 1k meters AGL, the sustainer avionics will deploy a main sustainer parachute. Total flight time from launch to recovery is on the order of 5 minutes.

AeroPac provides four critical components of infrastructure to enable these sounding rocket missions: a standard, well characterized, proven airframe, a mission profile to maximize recovery near the launch site, a highly capable launcher and the Virtual Classroom for sharing these missions throughout the Internet.



<u>Airframe</u>

The 2014 airframe is the third ARLISS Xtreme airframe constructed, the first two having been retired - still flight capable. Airframe A, the Carmack Prize winner, has been promised a long term home at the Boeing/Seattle Museum of Flight's amateur rocketry exhibit currently under construction. Airframe A had four flights. Airframe B had 1 flight.

Airframe C incorporates minor updates in design from the first two - reflecting the experience of the 2012 flight program. C has changes in avionics, recovery, interstage, motor selection and payload organization. It also, sadly, remains unpainted!

<u>Airframe</u>. Airframe C retains the same basic planform and structure as its predecessors … and thus inherits its well characterized drag and stability profile. The exterior profile is the same.

Airframe C moves the Beeline GPS telemetry from the avionics bay to the nosecone. The nosecone has two bays … an upper bay with the main sustainer Beeline GPS telemetry and a lower payload bay. The new payload bay occupies space formerly used by the CO2 recovery system in airframes A and B.

Avionics. The booster avionics remain the same, dual Featherweight Ravens for recovery deployment and staging, a GoPro Hero camera and a Beeline 70cm GPS for tracking and telemetry.

The sustainer avionics have been upgraded. The RDAS Tiny[6] remains but the Featherweight Raven has been replaced with an Altus Metrum TeleMega[7], the GoPro camera has been upgraded to the new, smaller Hero3 model and the Beeline GPS tracker has been moved to the tip of the nosecone above the payload bay.

The TeleMega, while a very new product, offers two new capabilities. First, the integrated IMU offers measurement of airframe attitude potentially allowing control of sustainer ignition based on airframe attitude, minimizing dispersion and maximizing altitude Second, it includes a second, 70cm telemetry and tracking system … as a backup to the primary Beeline GPS. Spectrum analysis of the two operating 70 cm transmitters shows that with the movement of the Beeline to the nosecone, there is sufficient separation that the two trackers will have only minimal, if any, interference.

Interstage. Airframes A and B used a milled Delrin interstage – the thinking being to minimize friction with the extended part of the sustainer motor and encourage drag separation. The difference in expansion coefficients between Delrin and aluminum (while not significant on paper) seemed to matter a lot (and required much hand sanding before launch) in practice at the hot Black Rock launch site. Airframe C moves to an interstage based on a custom fitted fiberglass tube set in a milled aluminum frame. The combination of passive separation from drag separation and active separation with a BP activated piston remains.

Motor selection. The off vertical 2012 results spurred the team to cover every base to ensure vertical flight. The new launch system is a core piece of that complemented by an updated motor selection. A higher initial impulse, but shorter burn motor, has been chosen for the baseline booster motor. This higher impulse motor, combined with the longer, stiffer launch rail should ensure a 2x higher full stack velocity when leaving the rail.

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[6] http://www.aedelectronics.nl/rdas/index.htm

[7] http://altusmetrum.org/TeleMega/

We retain using long burn motors in the sustainer.

Payload. Airframe C formally establishes a well defined nosecone payload bay that is CanSat sized – 6.6 cm by 15 cm cylinder designed for 350 gram payload. It sits at the based of the nosecone assembly with the Beeline GPS tracker mounted directly forward. A small hole is provided at the base of the nosecone shoulder for the payload to have direct contact with the outside world either for a camera or other sensor.

Recovery

Both sustainer and booster retain two phase recovery, with a drogue deployed at apogee and a main parachute deployed at ~1km AGL. We have a continuing team internal debate about the value of the sustainer drogue and for the moment the drogue remains.

We learned that surgical tubing wrapped BP charges worked well at over 100k' MSL and that our CO2 recovery system, while it worked, was prone to failure modes with its increased complexity. We decided to remove the CO2 system and rely entirely on the BP charges for recovery deployment.

Payload Profile

ARLISS Xtreme flies small payloads … but those payloads today can be as complex as orbiting satellites. ARLISS Xtreme has the volume and weight constraints of roughly classic CanSats and of 1 and 2p PocketQubes.

What missions can we do? The most interesting missions explore the Earth's stratosphere and mesosphere. While balloons can do a great job of doing science in the stratosphere, much less is known about the mesosphere, since only sounding rocket – like ARLISS Xtreme – are well prepared to do missions at that altitude.

A bit about the science in the stratosphere from Windows to the Universe (Windows to the Universe (www.windows2universe.org).

> The stratosphere is a layer of Earth's atmosphere. The stratosphere is the second layer, as one moves upward from Earth's surface, of the atmosphere. The stratosphere is above the tropospheream and below the mesosphere.
>
> The top of the stratosphere occurs at 50 km (31 miles) altitude. The boundary between the stratosphere and the mesosphere above is called the stratopause. The altitude of the bottom of the stratosphere varies with latitude and with the seasons, occurring between about 8 and 16 km (5 and 10 miles, or 26,000 to 53,000 feet). The bottom of the stratosphere is around 16 km (10 miles or 53,000 feet) above Earth's surface near the equator, around 10 km (6 miles) at mid-latitudes, and around 8 km (5 miles) near the poles. It is slightly lower in winter at mid- and high-

latitudes, and slightly higher in the summer. The boundary between the stratosphere and the troposphere below is called the tropopause.

Ozone, an unusual type of oxygen molecule that is relatively abundant in the stratosphere, heats this layer as it absorbs energy from incoming ultraviolet radiationfrom the Sun. Temperatures rise as one moves upward through the stratosphere. This is exactly the opposite of the behavior in the troposphere in which we live, where temperatures drop with increasing altitude. Because of this temperature stratification, there is little convection and mixing in the stratosphere, so the layers of air there are quite stable. Commercial jet aircraft fly in the lower stratosphere to avoid the turbulence which is common in the troposphere below.

The stratosphere is very dry; air there contains little water vapor. Because of this, few clouds are found in this layer; almost all clouds occur in the lower, more humid troposphere. Polar stratospheric clouds (PSCs) are the exception. PSCs appear in the lower stratosphere near the poles in winter. They are found at altitudes of 15 to 25 km (9.3 to 15.5 miles) and form only when temperatures at those heights dip below -78° C. They appear to help cause the formation of the infamous holes in the ozone layer by "encouraging" certain chemical reactions that destroy ozone. PSCs are also called nacreous clouds.

Air is roughly a thousand times thinner at the top of the stratosphere than it is at sea level. Because of this, jet aircraft and weather balloons reach their maximum operational altitudes within the stratosphere.

Due to the lack of vertical convection in the stratosphere, materials that get into the stratosphere can stay there for long times. Such is the case for the ozone-destroying chemicals called CFCs (chlorofluorocarbons). Large volcanic eruptions and major meteorite impacts can fling aerosol particles up into the stratosphere where they may linger for months or years, sometimes altering Earth's global climate. Rocket launches inject exhaust gases into the stratosphere, producing uncertain consequences.

Various types of waves and tides in the atmosphere influence the stratosphere. Some of these waves and tides carry energy from the troposphere upward into the stratosphere; others convey energy from the stratosphere up into the mesosphere. The waves and tides influence the flows of air in the stratosphere and can also cause regional heating of this layer of the atmosphere.

A rare type of electrical discharge, somewhat akin to lightning, occurs in the stratosphere. These "blue jets" appear above thunderstorms, and extend from the bottom of the stratosphere up to altitudes of 40 or 50 km (25 to 31 miles).

A bit about the mesosphere from the same source.

The mesosphere is a layer of Earth's atmosphere. It starts about 50 km (31 miles) above the ground and goes all the way up to 85 km (53 miles) high. The layer below it is called the stratosphere. The layer above it is the thermosphere. The border between the mesosphere and the thermosphere is called the mesopause. Most meteors burn up in the mesosphere. A type of lightning called sprites sometimes appears in the mesosphere above thunderstorms. Strange, high-altitude clouds called noctilucent clouds sometimes form in this layer near the North and South Poles. It is not easy to study the mesosphere directly. Weather balloons can't fly high enough and satellites can't orbit low enough. Scientists use sounding rockets to study the mesosphere. The top of the mesosphere is the coldest part of the atmosphere. It can get down to -90° C (-130° F) there! As you go higher in the mesosphere, the air gets colder. The top of the mesosphere is the coldest part of Earth's atmosphere. The temperature there is around -90° C (-130° F)!

The boundaries between layers in the atmosphere have special names. The mesopause is the boundary between the mesosphere and the thermosphere above it. The stratopause is the boundary between the mesosphere and the stratosphere below it.

Scientists know less about the mesosphere than about other layers of the atmosphere. The mesosphere is hard to study. Weather balloons and jet planes cannot fly high enough to reach the mesosphere. The orbits of satellites are above the mesosphere. There are not many ways other than sounding rockets to get scientific instruments to the mesosphere to take measurements there. Sounding rockets make short flights that don't go into orbit. Overall, there's a lot that is unknown about the mesosphere because it is hard to measure and study.

What is known about the mesosphere? Most meteors from space burn up in this layer. A special type of clouds, called "noctilucent clouds", sometimes forms in the mesosphere near the North and South Poles. These clouds are strange because they form much, much higher up than any other type of cloud. There are also odd types of lightning in the mesosphere. These types of lightning, called "sprites" and "ELVES", appear dozens of miles above thunderclouds in the troposphere below.

In the mesosphere and below, different kinds of gasesare all mixed together in the air. Above the mesosphere, the air is so thin that atoms and molecules of gases hardly ever run into each other. The gases get separated some, depending on the kinds of elements (like nitrogen or oxygen) that are in them.

There are waves of air in the atmosphere. Some of these waves start in the lower atmosphere, the troposphere and stratosphere, and move upward into the mesosphere. The waves carry energy to the mesosphere. Most of the movement of air in the mesosphere is caused by these waves.

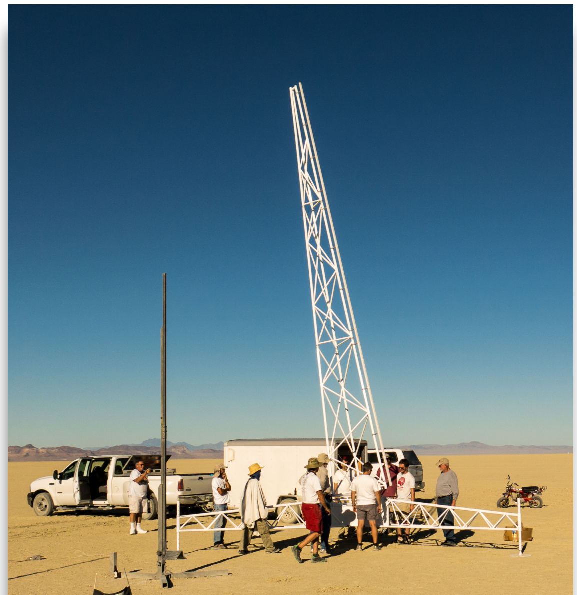
Launch System

The launcher is as an important part of the ARLISS Xtreme system as the airframe and that was a core lesson learned from the 2012 flight program. Stability and rigidity of the launcher is key and the launch system used for the first program left something to be desired.

Secondly, the actions of upper atmosphere winds have a dramatic effect on both the ascent and descent of the sustainer. A test weather balloon launch at 2013 ARLISS suggested that local upper atmosphere winds at Black Rock were not well predicted by NOAA radiosonde measurements at Reno or Lovelock - the closest radiosonde locations.

Extensive Monte Carlo flight simulations suggested that good knowledge of the current wind column would allow pointing a well characterized airframe at launch to compensate for the wind column and allow launch and recovery of the airframe close to launch location. To do this required three parts: accurate wind column knowledge, a method to reverse simulate from the wind column to determine proper launcher attitude, and a launcher rigid enough and paintable enough. We had the methodology … now we needed the tools. The ARLISS Xtreme 2014 program will test this methodology.

The 2013 balloon experiment strongly suggested that local balloons flown at the launch site close in time to the proposed launch were important.   But classic weather balloons are unwieldy and require large crews.   Smaller 1m pilot balloons with miniaturized 70cm APRS GPS trackers were the solution. Fillable with small quantities of helium, they will give a good track through the troposphere to the tropopause where the most important wind effects are located.



ARLISS 2013 saw the introduction of the new “UberRail”, a 30’ modular, chrome-moly 1515 tower that is pointable.   The tower is brought horizontal with a motor and winch, the airframe is loaded onto the rail, and then the tower is erected to vertical via motorized winch.   The tower can then be adjusted small amounts in azimuth and altitude via computerized stepper motors to point to the attitude the current wind data plus flight simulations indicate will result in minimizing landing distance of the sustainer from the launcher.

Virtual Classroom

AeroPac’s Virtual Classroom is a state-of-the-art communications infrastructure for remote rocketry at such sites as Black Rock where there is effectively none. It is based in a converted remote TV reporting van. The VC provides five critical services for high altitude rocketry:

1. Radio telemetry downlink and uplink capability with good antennas to radio packages in the airframe.   Radios are currently available for several different protocols at the 70cm and 2m HAM bands, at 900 MHz, 2.4 GHz and 5 GHz.
2. Internet backbone access via either satellite Internet or 4G cellular

connection.
3. WiFi 802.11n hotspot service over a wide area (a few km^2) surrounding the VC van.
4. HAM radio capability for voice and APRS at 2m and 70cm.
5. Mapping capabilities uniting the tracking capabilities of the radio telemetry with the mapping capabilities of the Internet.
6. Streaming video from multiple VC cameras to uStream.

Each ARLISS Xtreme flight is tracked by the VC in real time and can (optionally) be forwarded to real time maps on the Internet.

Program Plans for 2014

ARLISS Xtreme plans three flights in 2014 to further move the system from development into full deployment. The major goal of the 2014 flight program is to move the system from a one time event to a consistent reliable ARLISS quality payload flier with consistent, reliable flight and recovery performance.

The first flight in June 2014 will be a low powered flight with about 15k Nsec of propellant and targets an apogee of about 20 km AGL at Black Rock (1.2 km MSL launch site). It will be carrying an AeroPac experimental payload.

The second flight is scheduled for August 2014 at AeroPac's Aeronaut launch. It increases the motor total impulse to 20k Nsec with a target apogee of 35 km. It will be carrying an AeroPac experimental payload.

The third flight is scheduled during ARLISS 2014 in September 2014. It increases motor total impulse to about 28k Nsec with a target apogee of 50 km. A noted Japanese university has a student team building a payload for this flight.

If these flights go well ARLISS Xtreme will likely be a mainstream event in 2015 at ARLISS and we will be soliciting other student payloads for the ARLISS 2015 event and other fliers to build more airframes Our simulations say that the airframe can be further upmotored to fly to 70 km with about 30k Nsec of commercial motors. While all multi-stage airframes have higher dispersion than single stage, getting to this altitude with only two stages increases the reliability (and lowers the cost!) of the system over solutions with more stages.

Opportunities

ARLISS Xtreme is an opportunity for AeroPac volunteers to help with prep and launch and to learn about very high performance systems. The team will likely be building additional airframes for the 2015 season. Now is a great time to learn about high performance airframes, stagings, telemetry and all the tools necessary to fly to the edge of space.

And interested student teams, particularly for the 2015 season interested in building payloads to explore - now is the time to think about the science that can be done at the edge of space.

<u>Contact</u>

Contact a member of the ARLISS team for more information.

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