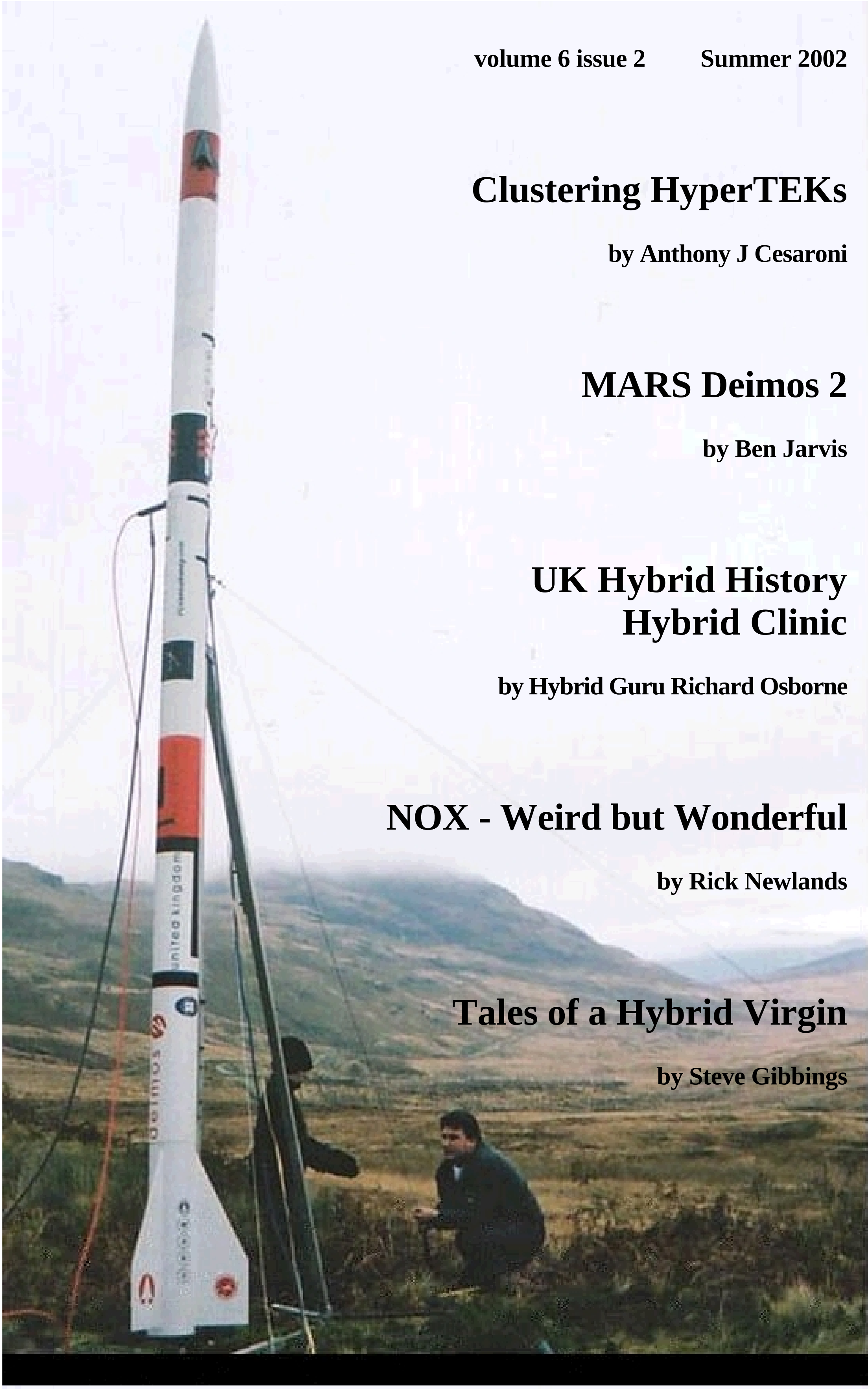
10...9...8...

the voice of UKRA

volume 6 issue 2 Summer 2002



Clustering HyperTEKs

by Anthony J Cesaroni

MARS Deimos 2

by Ben Jarvis

UK Hybrid History
Hybrid Clinic

by Hybrid Guru Richard Osborne

NOX - Weird but Wonderful

by Rick Newlands

Tales of a Hybrid Virgin

by Steve Gibbings

+++ Special Hybrid Issue +++

Editorial

More Hybrids...

Welcome to this special Hybrid issue of 10...9...8... Although hybrids have been flown for quite a long time in the UK, the recent shortage of AP has meant that many are investigating their possibilities for the first time. Given this increase in interest it seemed a good time to try and find material which may help those investigations. There was so much material out there that we decided to produce this special, biggest ever, issue. We hope you enjoy it.

In order to fit everything into this issue, we had to omit the regular rocketry groups contacts pages. Rest assured they will return in future issues.

Apologies

You may have spotted an error in the last issue. When the issue was almost complete, we realised it was a page over size. Over size? Well it has to be a multiple of four pages to be made up into booklet form. So, it was either drop a page or add three. It was too late to prepare content for three more pages, and so we had to drop the Space Modelling 2002 article by Stuart Lodge. That's bad enough but I forgot to remove it from the cover and the contents page. Many apologies to Stuart Lodge for the resulting confusion. The article appears in this issue.

Disclaimer

Due to the technical nature of some of the articles in this issue, we must point out that UKRA can take no responsibility for the accuracy of the information they contain, nor the uses to which that information is put.

The Editor

Contents

Editorial Team

Editor | Darren J Longhorn

Newsletter Contacts

Submissions | newsletter@ukra.org.uk
Competitions | competition@ukra.org.uk

UKRA Contacts

Membership enquiries | membership@ukra.org.uk
General enquiries | enquiries@ukra.org.uk
Media enquiries | media@ukra.org.uk
Safety & Technical | sat@ukra.org.uk
Postal address | P.O. Box 1561, Sheffield, S11 7XA

Cover Photo: Members of the MARS team prep Deimos 2 *(Photo courtesy of MARS)*

UKRA 2002
7th / 8th / 9th June

Sponsors

Southview Farm, Heckington, Lincolnshire

	Weekend Pass	Day Pass
Adult Flyer	£15.00	£10.00
Junior Flyer	£10.00	£7.00
Non-Flyer	£5.00/£3.00	£2.50/£1.50
Temporary Membership		£9.00
Prep Benches (Subject to availability)		£5.00
Card Wallet		£0.50
Raffle Tickets		£1.00
Vendors fee		£35.00

More information:
http://www.ukra.org.uk/ukra2002/

Cesaroni Technology Incorporated www.cesaroni.net

Pete's **Rockets**
The UK High Power and Model Rocket Specialist

Want sponsored certification? ukra2002@ukra.org.uk

MicroMax to M
Ceiling 10000ft*
Sheltered prep area
Vendors welcome
*by prior arrangement

UKRA cert' flights
L2 & RSO exams
Do a hybrid cert' get sponsored (limited availability)

Prize raffle
On-site food
On-site camping
Accommodation available locally

Comfort Friendly Inn
(approximately 7 miles)
Special B&B rate:
£30.00 single
£22.50/person double
(mention rocket w/end)
Tel: 01205 820118

Three's a Crowd

Clustering HyperTEK Hybrids

---

by Anthony J. Cesaroni

With the growing popularity of the HyperTEK hybrid motor system, it's surprising that there have been only a few attempts at clustering these motors in high power rockets. Hybrid motors are sometimes perceived to be more complicated than traditional HPR solid motors. They also require different ground support systems but many clubs now provide HyperTEK ground support in addition to solid motor launch systems. The low cost per flight associated with these motors make them attractive for cluster projects.

Three 54mm HyperTEK J's Integrated in a King Viper ready to launch

There is one fundamental requirement with any clustered motor scheme regardless if it's hybrid, solid or liquid. Ignition has to be predictable, simultaneous and reliable. With a solid motor this can be generally be accomplished with a properly matched igniter / initiator system and by selecting a propellant and motor combination that will come up to operation condition as quickly as possible. Hybrid and liquid motors are a little more challenging in this regard. This is mostly due to fact that a number of prerequisite events must occur during the start sequence before the motor or engine can operate at design pressure. High performance liquid engines such as those used on the shuttle are one extreme example.

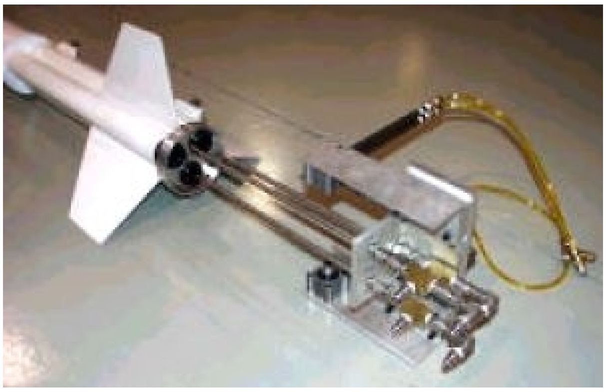
These engines are started at T minus 6 seconds while being monitored and controlled by computers. There are so many variables to control during the start sequence that computers must be employed as no human could respond fast enough given the overwhelming task and the number of decisions that have to be made in such a short period. Only if all parameters have been met by T minus one second are the solids ignited and the hold down clamps released, otherwise the main engines are shut down and the launch is aborted.

Small hybrids that employ self-pressurizing oxidizers such as nitrous oxide are obviously far simpler to start but none the less employ a start sequence. In the case of HyperTEK propulsion systems, there are two main events that occur prior to the engine reaching full operating pressure. When the launch switch is activated on the ground support panel, gaseous oxygen (GOX) starts to flow inside the motor and an arc is simultaneously produced on the end of the igniter lead inside the polymer motor grain. The polymer begins to burn rapidly in the pure oxygen environment and the resulting flame exits the nozzle. Two nylon tie wraps that pass through the very base of the nozzle restrain the motor and rocket. The flame quickly melts these hold downs and the pressure of the nitrous oxide lifts the motor and rocket a fraction of an inch off of the nitrous fill stem allowing nitrous oxide to flow freely into the combustion chamber. The motor instantly comes up to full pressure and the rocket launches.

Some of those who have attempted to fly hybrid clusters have had difficulty for a number of reasons. The most common is having only partial ignition of the cluster. Other problems include melted fill stems or incomplete ignition (warm starts) of the remaining motors. The clustered example described in this article attempts to address these problems by identifying the cause and suggesting solutions that have been used successfully in other hybrid applications.

The first and most commonly overlooked detail is a falling fill stem. Most of you who have experience with the small J class motors probably aren't familiar with that term. Those of you who fly L and M Hypertek motors are. The standard J class motors have a fixed fill stem as mentioned previously. When the hold downs melt away, the nitrous pressure lifts the motor and rocket off of the fill stem. This allows nitrous oxide to flow freely into the combustion chamber. The amount of this force is a function of the sectional hydraulic area of the fill stem versus the tank pressure of the nitrous oxide. Think of it like a small piston in a pressurized cylinder. This works well. When flying a rocket with an L or M or a cluster, the total weight of the tanked rocket may exceed the lift capability of the pressure generated on the fill stem. In a situation such as this the hold-downs will melt away but the nitrous oxide will not flow and the rocket will just sit there burning GOX until the operator aborts. What happens is that the inexperienced operator is not aware of the problem and continues firing the GOX. This exposes the fill stem to very high temperatures for an extended period. The fill stem eventually melts and the rocket launches leaving a melted fill stem in its wake.

The fix for this is simple. Instead of bolting the fill stem to the rail we attach launch lugs or a slider to the fill stem plate so it can actually slide on the rail.



Three stems mounted on the drop sled. Note the pneumatic cylinders on the sled and the motor retainer / hold-down ring on the rocket

The rocket is placed on the rail and lowered to a lug stop. The fill stem is raised into the motor injector and the hold-downs are installed.

It is very important that the distance that the fill stem be allowed to drop is kept as short as possible. It only has to fall enough to allow the tip to clear the injector bell. If you provide too much distance, the stem / slider assembly can gain excessive momentum and shear the lugs off. A rubber bumper or mechanical cushion on the assembly or slide stop is also a good idea.

The next area of attention is the igniter leads. If one or more of the motors is slow in coming up on GOX ignition, the flame from the adjacent motor may melt its igniter lead prematurely and the motor may warm start or not start at all. To prevent this from happening, take some silicone rubber fuel tubing and sheath the igniter lead from the base of the motor nozzle to a point away from the blast deflector. Silicone tubing ablates at high temperatures and will protect the igniter wire from the heat of the adjacent motor until it's had a chance to start. Silicone fuel tubing is available at most hobby stores that handle R/C.

Now if you are determined to have the ultimate in reliability and safety, the following is the best insurance policy. You will have to do a bit of work however. This example employs everything we have discussed so far but instead of being dependant on nylon tie wraps as a hold down system, this launcher uses manually activated, pneumatic hold down clamps not unlike real hybrid and liquid rockets. This design example uses two opposing short stroke, medium diameter pneumatic cylinders to restrain the rocket on the rail and the fill stem(s) in the injector. You will also require an electro-mechanical pneumatic valve to actuate them. A release button to activate the valve is integrated or used in conjunction with the ground support control. The operation of the system is identical to the standard system but with one important advantage. The operator has full authority and releases the rocket only when all the motors are fully initiated on GOX. The operator can also abort anytime during startup if there is a problem.

Fill stem, hold-downs and drop sled used on the Hyperion sounding rocket. Note the swing-away load cell used to weigh the rocket on the pad during tanking

For those who enjoy rocket science and like to tinker, a clustered hybrid rocket can be a very worthwhile and fun project.

A Note about ignition

The only thing I don't go into too much in the article is the igniter set up. I didn't have much luck trying to run three leads off one transformer but there are a couple of ways around this. The unit in the article has a custom box I made with one 12V input and three output transformers and leads. It's tidy but you still have to make some bits. I also use a plastic steel wool substitute (SOS brand) taped at the top of the lead to boost the start-up. Because it's plastic it won't short the lead.

Now the other trick that I use is electric matches with fine real steel wool instead of the high voltage lead. Arrange the wool loosely around the match and down the port for 2 inches or so. Fill as normal, hit the GOX and the matches and off you go.

Good luck!

Anthony.
www.cesaronitech.com

A range of Hypertek motors

Hybrid Rocket History in the UK

by Richard Osborne

Hybrid rocket motors offer a very low cost and safe means of rocket propulsion. Hybrid rockets are very straightforward to launch, and with practice, it takes less time to prepare a hybrid propelled rocket for launch than a solid propelled rocket. Hybrid rockets lack the high thrust of a solid rocket motor, and are less impressive for show launches, however, their longer burns and much cheaper operating costs bring attractions of their own to rocketeers.

HPR Hybrid Rocketry

High Power Rocketry hybrid rocket motors are gaining in popularity in the U.K., and have been seen at all 3 of the major High Power Rocketry events in the U.K. (*The International Rocket Week in Scotland, the UKRA Annual launch event and K-Lob*), as well as local launch events such as EARS launch events. The attractions of not requiring an explosives licence, the much cheaper launch costs over a solid rocket motor, as well as the unique sound they produce, make them very tempting.

In the U.K., High Power Rocketry hybrid rocket motors are available by the following manufacturers; R.A.T.T.Works (H-class, I-class and K-class), and Hypertek (I-class, J-class, K-class, L-class and M-class). Both manufacturers are stocked by Pete's Rockets.

All of the commercially available hybrid rocket motors for the High Power Rocketry community use liquid Nitrous Oxide (NOx) as the oxidizer. Nitrous Oxide has the chemical formula N_2O. Nitrous Oxide is self-pressurising and in terms of handling precautions and general behaviour, it is similar to Carbon Dioxide. Nitrous Oxide and HTPB / Polythene / Polyester / ABS propellant combinations result in a motor with a regressive thrust profile, since as the liquid Nitrous Oxide flows into the combustion chamber, the oxidizer tank temperature drops due to evaporative cooling, this in turn, reduces the chamber pressure.

NOx is available from sources such as custom car engine modification shops, where it is used for injection into car and motorbike engines for extra power. NOx is not expensive, and to fill an I-class (320 - 640 Newton second total impulse) hybrid rocket motor takes about £2.00 of NOx.

In order to supply the oxidizer tank in the hybrid rocket motor with NOx, a pressurised cylinder of NOx is required on the ground. This needs to have a solenoid valve fitted to it, and a fill line that runs to the oxidizer tank of the hybrid rocket. The fill line allows the NOx to flow from the pressurised cylinder on the ground to the oxidizer tank in the hybrid rocket motor. The solenoid valve is switched on to allow NOx to flow to the oxidizer tank, and off to shut off the supply of NOx to the tank. Normally, the solenoid valve will be controlled from a secondary 12 volt output from a launch controller.

The advantage of the currently available HPR hybrid rocket motors, is that they are fitted with a vent - this means that the hybrid oxidizer tanks are not pressure vessels, which adds to the general safe nature of these motors.

The first commercially available hybrid flown in the U.K. was flown at the Scottish Rocket Weekend in Largs in August 1996, by Scott Bartel - Owner of Black Sky Research, and one of the Tripoli Directors. The hybrid motor was a Hypertek 54mm diameter J-class hybrid motor, and the rocket was a Black Sky Research Optimal 65 rocket, using a Black Sky Research ALTACC recording Altimeter/Accelerometer for recovery system deployment. The rocket was launched twice, by Bobby Wark of STAAR Research.

Scott Bartel returned to the U.K. the following year, to launch another Hypertek J-class hybrid at the UKRA '97 launch event near Edingale in Staffordshire, in

June 1997. The launch vehicle specs and the motor specs were the same as the previous year.

Subsequent to that, and up to the summer of 2001, the only other personal hybrids flown were demonstration flights of R.A.T.T.Works hybrid rocket motors by Pete Davy and myself, with Pete using a Blacksky Research ALTACC for recovery system deployment, and me using a combination of an ALTACC, G-Wiz LC Deluxe and an R-DAS flight computer for recovery system deployment.

By the Autumn of 2001 however, there was a blossoming of interest in hybrid rockets, and with the fire at Aerotech, and the unavailability of solid propellant, many rocketeers were attracted to hybrids as an alternative means of rocket propulsion. As of the summer of 2002, several people now have High Power Rocketry commercial hybrid rocket motors, and groups such EARS, MARS and NSRG, as well as Pete's Rockets, have a full set of Hypertek Ground Support Equipment. Hypertek hybrids have again started to be launched in the U.K. again, and hopefully a lot more hybrids will be seen taking to the skies!

Amateur Hybrid Rocketry

Amateur rocketry by its nature, is an area in which much of the pioneering development occurs. With this being the case, the information below is more a list of firsts in amateur hybrid rocketry.

The first amateur (and possibly professional) hybrid to be launched in the U.K. was a hybrid rocket powered by NOx / Polythene, and constructed and launched by MARS in Lincolnshire in September 1998. The rocket used a Cambridge Instruments IAX-96 Recording Altimeter/Accelerometer for recovery system deployment and data logging, and NOx flow was controlled by an onboard 12 volt solenoid valve. The hybrid motor had previously been successfully static tested in April 1998. The launch vehicle was a 2.6 inch diameter rocket called Deimos-1, with a single stage recovery system triggered by the IAX-96.

The first amateur hybrid rocket motor known to have been static tested in the U.K. was quite a few years before this though, with a static test by the Orbital Rocketry Society in 1993. Other static tests may pre-date the ORS static tests too, given that work had been underway in the University of Bristol at the same time.

The first cryogenic amateur hybrid to be static tested in the U.K., was the H20 Liquid Oxygen / Polyethylene hybrid motor built by AspireSpace, and static tested in 1998. Subsequent to this, AspireSpace has also undertaken 3 launches of a much smaller, amateur hybrid rocket motor powered by Nitrous Oxide and Polyethylene, with 2 launches on a 2.6 inch diameter rocket called the Flare, and 1 launch on a 4 inch diameter rocket called ADV-2 in the Autumn of 2001. The hybrid development in AspireSpace actually started in 1993, when a number of students became involved, and brought with them their expertise on small static test hybrid motor research that had been carried out at the University of Bristol.

Not to be left out of the action, more recently, HPR group Starchaser has also initiated development of a small static test hybrid rocket motor.

The first amateur or professional composite cased hybrid rocket motor known to have been flown in the U.K. was a hybrid rocket motor flown in the fibreglass Deimos PTV-1 rocket, built by Ben Jarvis of MARS. The rocket was launched in Lincolnshire in September 2001, to an altitude in excess of 6000 feet, and had both a fibreglass combustion chamber and a fibreglass oxidizer tank. Development of this composite motor saw the flight of a larger diameter version in March 2002 from Lincolnshire as the MARS Deimos PTV-2 rocket. As this article goes to press, the data is still to be analysed from this flight.

The largest amateur hybrid rocket motor flown in the U.K. (and quite possibly the largest hybrid rocket motor flown in the U.K. full stop), was the B4 hybrid motor built by MARS and flown in the MARS Deimos-2 rocket in November 2001. Because of the UK launch location, the vehicle was flown with one of its smaller oxidizer tanks fitted, to ensure it did not go too high. The 18,000 Newton second total impulse motor propelled the 16 foot tall Deimos-2 rocket to an altitude of around 6800 feet from a Scottish launch site. The rocket used twin R-DAS's for flight data logging, as well as a G-Wiz LC Deluxe. It also carried a number of RF tracking beacons, 2 onboard video cameras, and 2 onboard stills cameras. Following recovery, the B4 motor is being refurbished for re-use. The hybrid motor was intended to have a total impulse of around 21-22,000 Newton seconds, but the low ambient launch temperature, coupled with tank chill down, resulted in a low tank pressure. Work is currently underway on a small fleet of similar vehicles.

The largest amateur hybrid rocket motor to be static tested in the U.K. was a hybrid motor designed for the Project FARISpace Space Shot, by Richard Brown, and using Hydrogen Peroxide / Polyethylene as the propellant. Richard Brown had previously used similar motors to set the World Land Speed Record for a 2 wheeled vehicle when he rode the rocket propelled motorbike in the U.S. The FARISpace hybrid motors have now been integrated into a launch vehicle for future attempts at a space launch, using a 2-stage rocket - with both stages employing hybrid propulsion.

Professional Rocketry

Professionally, by far the most successful hybrid propulsion development in the UK has been undertaken by Surrey Satellite Technology Limited (SSTL), with their Hydrogen Peroxide/Polyethylene hybrid rocket motors. The development work, which has been underway since the early 1990s has included static test firings of conventional and novel hybrid geometries at the former Royal Ordnance Liquid Motors Site at Westcott.

The SSTL developments are designed to lead on to upper stage hybrid motors for micro satellites (*including one concept for a Lunar mission*), as well as a micro-satellite orbital launcher. After the excellent developments of SSTL's hybrid rocket motors, and by then the steady hybrid progress in the amateur community, Royal Ordnance Rocket Motors also decided to develop a hybrid rocket motor, however, the hybrid rocket motor they tested was unsuccessful.

The Future

Given the upsurge in interest in hybrid rocket motors, it is likely that they will become a much more noticeable feature at UK launches. This will also add to the general avionics experience of the rocketry community, since hybrid rockets always require electronically initiated recovery systems, so an altimeter or a timer is "de rigueur" for these types of rockets. Already, with the dearth of availability of HPR solid propellant rocket motors after the Aerotech fire, there has been a considerable surge in the number of launches of rockets propelled by HPR hybrid rocket motors.

It would seem that the future is certainly looking good for hybrids in the UK.

References

- Rocket Propulsion Elements - Sutton
- Spacecraft Propulsion Analysis and Design - Humble, Henry and Larson
- Hypertek Hybrid Motor Users Manual - Hypertek

+++ Stop Press +++

Pete's Rockets and Cesaroni Technology Inc have announced that they will be supporting UKRA Level I, II and III high power rocket certification attempts at UKRA 2002. They will be supplying GSE, loaner motor hardware and free standard fuel reload kits for three attempts in each level each day (Level III, 1 attempt per day). Nitrous Oxide will be available at cost. You must apply before the event, and be qualified to attempt the certification. For more information, see: http://www.ukra.org.uk/news/2002/pr1.shtml

+++ Free Reloads +++

Deimos 2

by Ben Jarvis

"All stations confirm we are go for launch..."

The radio cracked... silence...

"Ok, if everyone's ready we will go with a fifteen second terminal count on my mark.."

The 17ft tall rocket stood majestically at the foot of the mountain, the cloud of vented Nitrous Oxide hung in the cold damp air, the umbilical lines blowing gently in the light breeze, the faint sound of multiple electronic devices gently beeping out their readiness was all that could be heard.

"Ok, we are going for launch in T- 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, ignition, 2, 1, 0..."

In a split second the result of three years of hard work would come to fruition. Nothing can describe the tension we all felt as the cloud of smoke from the ignition of the motor erupted from the nozzle of the B4 hybrid rocket motor on that cold morning in the highlands of Scotland last November.

The journey that had brought this team of men and women together that day to witness the most advanced amateur rocket ever built in the UK take to the sky had started

10...9...8...

back in 1996 with two young lads who suddenly decided that building rocket engines probably wasn't as hard as everyone made out it was.

Ben Jarvis and Kenneth Lau, members of the MARS Advanced Rocketry Society based in London had been inspired to build a home made nitrous oxide based hybrid rocket engine. With Ken doing the maths and Ben doing the engineering the 40mm diameter 'BK Flamer' rocket motor was built by the end of 1996. With a little help from the Aspire Space group the motor was later static fired in 1997 and, although no data was acquired from the seven second test firing, a clean tear drop shaped flame and a healthy roar from the straining rocket engine had indicated that the boys had got it right.

The Deimos 2 team

By 1998 the MARS team realised that though other groups, Aspire included, had built amateur hybrid rocket motors, no one had ever actually flown one in the UK. The team decided to try and build a rocket to fly on the BK Flamer motor. The 'Deimos' project was born.

Deimos 1 was a simple rocket made using HPR components and an IAX 96 altimeter for recovery. Using a small 'Sodastream' Co2 cylinder filled with NOx as the flight oxidizer tank the rocket was predicted to give about 400Ns of total power, a mid range 'I' motor in HPR terms. Average thrust was predicted at 140N.

October 1998, Pete's farm in Lincolnshire... with little fuss the 6ft rocket is prepped, loaded on the launch pad and after a short countdown it is fired. The ignition system lights, the NOx valve is remotely opened using internal power and the rocket roared off the pad. Now I had felt excitement before flying big, complex HPR rockets... rockets FAR more complex and more powerful than Deimos 1... but the excitement I felt when a rocket that was not only built by me, but that was powered by a rocket motor I'd helped design and build lifted off and disappeared in to the sky I was absolutely ecstatic. The IAX data showed the motor had given 135N of thrust for three seconds, almost spot on the predictions.

With this humble success under our belts MARS set their sights on space. After a few calculations it became obvious that using hybrid motors of a size we could build at home would be capable of lifting a small payload to an altitude greater than 100km, the internationally recognised boundary of space.

Skipping the 'one small step' and going straight for the 'one giant leap' approach we began work on a four inch diameter, quarter ton thrust hybrid rocket engine. This motor was planned to be the basis of the first stage of our eventual space launcher.

At first we made the combustion chamber out of stainless steel having been warned about the dangers of 'weedy' aluminium motors and how they can burn through. We had a combustion chamber machined out of stainless tube that had its ends threaded for screw-in end closures. No sooner had we built this massive, heavy piece of metal than we realised that it was flawed. It was the wrong length for optimum thrust, we also realised that it simply wasn't necessary to make it out of steel, almost all other amateur groups and professional manufacturers use aluminium or composite combustion chambers so why shouldn't we?

With the construction of a new larger aluminium combustion chamber the project was finally given a name... project B.F.O.R.E. or 'B4' for short, the 'B' stands for big and the 'RE' stands for Rocket Engine, I'll let you work the rest out yourselves.

By early 1999 the new B4 motor was installed in to the first version of 'Deimos 2' a 6" diameter test rocket that would be used to tweak the performance of the motor. Early on we had looked in to the possibilities of static testing such a motor and compared that complexity and cost with the issues associated with building an airframe round the motor and realised that launching it was far cheaper and far easier than firing it on the ground. If we knew the weight of the rocket at launch and flew an accelerometer on board we'd still get performance data from the motor... and we'd get the massive kudos of an amateur launch as well.

Summer 1999 and we exhibited the almost completed Deimos 2 along with a full size model of the proposed Deimos 3 space rocket at the 'Tomorrows World Live' exhibition in Earls Court, London. The public seemed really fired up by seeing a group of amateurs working towards the goal of putting our little island nation back in the space race from their garden sheds and garages and we gained a lot of new members and supporters.

In it's initial configuration Deimos 2 was to run the motor at about 60% thrust using a small 2litre composite tank to hold the Nitrous Oxide giving only a three or four second burn time at most and lifting the big heavy rocket to about 2500ft. As the rocket progressed and it's weight increased it became increasingly obvious that it was unlikely a 2 litre tank would be enough to fly this mammoth engine.

With several rival bids for the UK altitude record and many team members being distracted by personal HPR projects, Deimos 2 sat mothballed for the following two years. Little work progressed on it until, in summer 2001, fate intervened and brought the project back from the dead.

Following the success of the Phobos EAV boosted dart in 2000 MARS had planned to launch a far bigger solid fuel altitude attempt from Black Rock in 2001. Original plans had been for us to build a payload and fin can to mate to a 'Q9000' that would be made for us by Kosdon East in the US, allowing us to launch from the BALLS event in September 2001 to an altitude of at least 75,000ft. This awesomely scary project wouldn't however come cheap... we had been assured sponsorship from a large company for this attempt that then fell through early summer after the rocket motor had already been ordered. Luckily little work had been done on it and so, with heavy hearts, we cancelled the order and scrubbed the 'Phobos Odyssey' project.

We had planned to try and launch the B4 motor from BALLS at the same time as a sub-project, probably not in a 6" airframe as originally planned for Deimos 2 but as a minimum diameter vehicle with a home made 4" nitrous oxide tank bolted straight to the top of the motor making it far higher performance. This now became our primary project instead of the solid fuel rocket.

Over the summer months we toyed with the idea of making the long Nitrous oxide tank from carbon fibre tube instead but sanity got the better of us and in the short time left for the project we accepted the extra weight and manufactured a tank from aluminium tubing.

This thing was going to be huge.

The combustion chamber of the B4 motor that contains the polyethylene fuel grain was almost a meter and a half long (five feet or so). This was mated with a large machined aluminium coupler bulkhead (that incorporated the injector head, which feeds the Nitrous in to the combustion chamber below) which in turn was mated in to the bottom of a three meter long piece of 4" diameter aluminium tube which would form the Nitrous Oxide tank. The 'Deimos Odyssey' project was now in full swing and simulations were predicting that despite the increase in weight this vehicle should still be capable of reaching over 50,000ft in altitude... assuming that massive rocket motor actually worked!

By early September things were almost all in place for the launch four weeks later. The rocket was all but completed, and man was it big! With a length-to-diameter ratio longer than the old Estes 'Mean Machine' rocket this thing was very skinny. Standing over 20ft tall and only 4" wide it looked like a massive polished metal arrow with big carbon fibre fins at the back. We had secured a 60ft launch tower for use in the USA and had ordered 250lbs of Nitrous Oxide to be delivered to the desert in five massive tanks to fuel the rocket for it's record setting attempt.

September the 11th 2001, the day we were to book our flights for the team of ten to fly out to the desert just two short weeks later and that the shipping company were due to collect the now crated up 3m oxidizer tank and ship it out to America. Unfortunately a group of terrorists had other ideas. We were lucky in that we managed to cancel the shipping of the tank and hadn't yet paid for the flights when the terrible events in New York began to unfold on the TV. We clung on to the hope that maybe things would sort themselves out in time for a few days but by the end of that week it was obvious that we would have to scrub the project. There were way too many logistical and ethical problems with us trying to get a 20ft rocket through US customs at that time, coupled with the fact that the FAA withdrew the waiver from the launch meaning no rockets could be launched anyway.

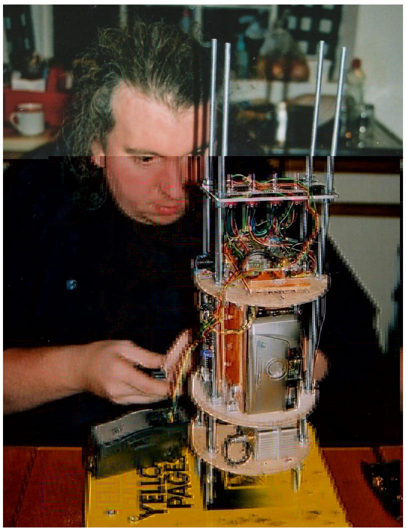
It took us a few weeks to re-group and consider our options. The B4 motor was now ready to test, we had received enough sponsorship from our long term benefactors 'Mission Communications' to cover the US launch costs, we didn't want to wait until the following year when the weather improved to head back out to the US to fly the rocket so making a lower altitude test in the UK seemed our best, if not only option.

Launching the rocket in it's minimum diameter configuration was not going to be possible as it was simply too high performance, no UK launch sites would be suitable for that kind of altitude. We decided we had to keep the test to below 'Flight level 245' or 24,500ft AMSL to keep the CAA happy. After running lots of simulations it was decided that the best bet was to resurrect the Deimos 2 project, put the motor with a shorter 1.5 meter tank instead of the full 3 meter tank inside a 6" rocket to increase the drag and reduce it's performance. Initial simulations put this configuration at a potential altitude of about 15,000ft... that would be perfect.

We knew that wherever we were to test this vehicle it would have to be remote, the chances of a successful flight given just how massive and powerful this thing was were small. Andy Norrie, a recent convert to the MARS cause had previously offered us use of the 'Comer' site up near Loch Lomond in Scotland and, although none of us had been there, and by all accounts it was the hardest launch site to get to in the World... we decided this was our best bet.

The earliest weekend that the site was free was the 18th and 19th of November. We spent the following weeks working to install the now shorter B4 motor in to a 6" airframe. We used the original Deimos 2 fin section and some of it's airframe but also had to use parts from several other 6" rockets to make the lower airframe long enough to house the massive 9ft length of the rocket motor and it's tank.

When completed the new Deimos 2 rocket was a truly impressive vehicle. Standing seventeen feet tall, of which the lower ten feet were the motor bay, and weighing a hefty 110lbs, or 52kg without propellant it was no small rocket, in fact, it was the largest and heaviest rocket MARS have ever flown and, as far as we know, the largest and heaviest true amateur (using home made motor/s) rocket ever to be flown in the UK. Chris Eilbeck, Jim MacFarlane and Dave Warman... gods of electronics, put together a comprehensive payload package to sit on top of this beast and record the trip. Three independent colour video cameras, one looking down the side of the vehicle and two looking sideways out of the vehicle would link to three independent video transmitters to send live video back to three ground stations. Two stills cameras would trigger from an electronic circuit and would take a roll of film each during the flight. Three separate altimeter/accelerometers would record data of the flight and act as recovery units to deploy the rocket's two parachutes.



Chris prep's the payload

Steve Woolhead had worked long and hard to develop a remote disconnect system that allows us to disconnect the high pressure fill line from the side of the rocket remotely, far better than having to go back to the fully fuelled rocket and disconnect it by hand!

All in all the whole team had really pulled together to make this the most stunningly audacious amateur rocket attempt the UK had ever seen. It was a hell of a lot to risk on the propulsion system... but then again, the third MARS motto is: "If you're gonna screw-up... screw-up in style!"

Thursday evening and the team began assembling at the car park in the small village of Aberfoyle about an hour away from the launch site. Andy Norrie met us all there and as the darkness closed in around us we all headed off on the road to Comer. The launch site is unique in that it is so remote it can only be accessed by Landrover. We drove as far as we could through the hills and dense woodland with the van and cars then parked by the side of the road and transferred personnel and sleeping materials to the three Landrovers we had at our disposal and headed for the small cottage down to the other side of the range where we'd be staying for the next four days.

The cottage was spacious enough that the ten of us had no problems sleeping there though us townies found the novelty of no central heating, limited electricity from a small generator and log fires soon wore off. The Friday morning dawned clear and calm, it was prep-day. Several team members head off in the Landrovers to collect the equipment and the rocket from the vehicles left up in the woods. By late morning they were back and everyone was busy getting their part of the rocket and support equipment ready.

The B4 rocket motor was loaded fully for the first time with it's massive plastic fuel grain, phenolic liner tube and custom made graphite nozzle - the igniter system used to initiate the combustion process (based on the ignition systems used in professional rockets) to start NOx decomposition was to be fitted at a later point. The electronics team worked upstairs on the launch control system and the video cameras and transmitters, whilst the rest of us worked on preparing the recovery rigging and other systems in the living room, the only room big enough to fit the huge booster in.

We all worked late in to the night prepping parts of the rocket but by the small hours of Saturday morning even the die-hards decided they'd need some sleep before the big day tomorrow.

Saturday again dawned calm with broken clouds and blue skies. The booster of the rocket was already laying waiting to head to the launch site while the electronics team continued work on the launch control systems. The first team headed up to the launch site mid morning to begin setting up the launch pad. The rest of us waited at the cottage for things to be completed.

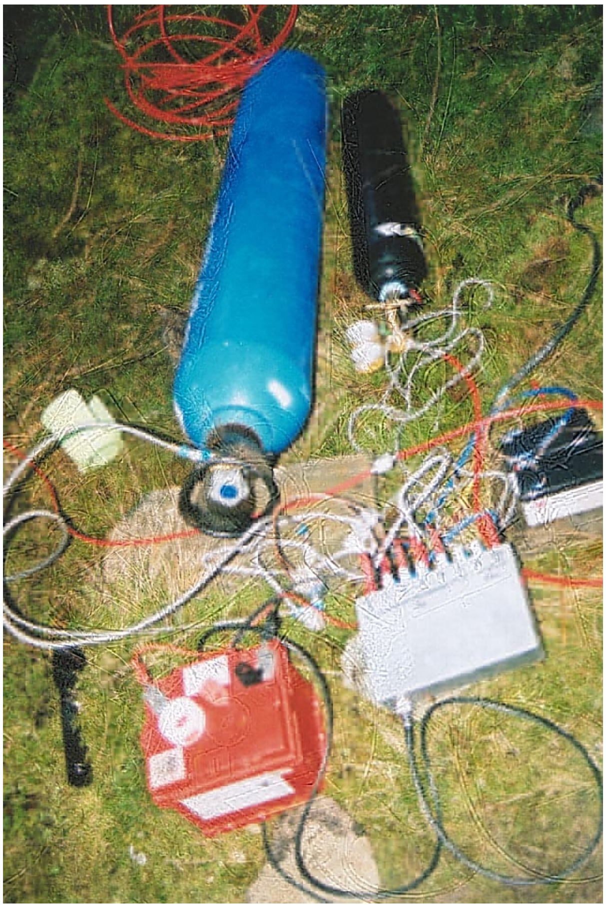
Finally by late morning we seemed ready to go. We lashed the massive booster to the top of the roof rack on Andy's Landrover with several meters of Kevlar 'donkey-tape' and packed the launch equipment in to the back of the vehicles. We began the long winding climb back up the steep mountainside towards the launch point. Half an hour or so later we arrived. It was now nearly lunch time... the clear calm weather of the morning was disappearing, mist was moving in, it was getting cold and damp.

After final preparations, we made a final test of the rocket's valves before erecting it on the launch pad. The vent valve wasn't working. This was not good. We disassembled the front of the booster to get at the malfunctioning valve. A trapped wire beginning to short against a piece of studding appeared to be the problem, it was fixed and the rocket reassembled. The massive heavy rocket was erected on the launch pad with much heaving, sweating and no small number of four letter words. The steel guy-lines were tightened and for the first time we could all stand back and see what we had created. Even in the thickening mist and drizzle the sight of something that is, for all intents and purposes a real sounding rocket standing almost 18ft tall in the middle of this vast desolate place is mightily impressive.

As the weather closed in and time was running out tempers began to fray. Some team members wanted to launch now before the weather deteriorated further, not being able to guarantee that we'd get a launch window the next day. Others felt it was already too bad to launch and that taking the rocket down and trying again early the next morning was the best bet. In the end we all decided we had little choice than to postpone to the Sunday and with heavy hearts we took the massive rocket down off the launch pad and safed all of it's electronic systems and pyrotechnic systems.

Cath Bashford, our official 'launch b*stard' was in charge of motivation to prevent a similar lazy morning on the Sunday. At 6:00am sharp she ran through the cottage shouting, pushing and threatening people out of bed. By 7:00am the entire team was up, washed and had eaten and before dawn had even broken the ground support team were on their way up the hill in Jim's Landrover to begin set-up of the GSE. The rocket team were close behind and by about 8:30 everyone was at the launch pad working smoothly and coherently to get the rocket launched.

The early morning mist was still hanging on the mountains as the rocket was once again erected on the launch pad, it's multiple umbilical lines hanging down it's sides. The ground support equipment including a brand new eight channel launch controller were assembled and tested, all valves were working, all systems were go. The video was checked, all three cameras were working well. We all huddled round the monitors to gasp at the view from the down-looking camera as the ground support crew worked at the base of the rocket looking like dwarfs at the bottom of some huge NASA-esqe behemoth. Finally at about 9:30 we all agreed we were ready to launch. Andy called the local air traffic control and a one hour window was agreed starting at 10:00am. We set up our cam-corders on tripods at different locations around the launch site, Steve's now famous 'brown-trouser-cam' was left on a rock just fifteen feet from the base of the rocket to record the ignition sequence.



Ground support equipment

At ten minutes to ten we all evacuated the area and retired to launch positions. All team members were in radio contact. The telemetry base-station was set up in the back of Jim's Landrover about 800yards up the track. Kevin Cave was sitting half way up the mountain with his cam-corder to record long-distance tracking shots of the launch, Andy Norrie was about 800 yards the other way on the bend in the track where he was able to get mobile phone reception to stay in touch with ATC. The rest of us were with the launch controller on the hillside to the west of Kevin's position, about 500-600ft from the rocket sitting down in the valley.

10:00 arrived and I radioed the team to let them know we were about to begin filling the NOx tank. The home-made on-board tank had not been pressure tested since it had a remotely controlled vent valve. It was rated to have a 200% safety margin according to our calculations, but no one knew for sure.

10...9...8...

I gave a five second count down then Jim pushed the button to open the fill solenoid. The massive 30ft fill line twitched and a distant hissing could be heard, it seemed to be ok. Jim tapped the vent solenoid to check we were in fact pressurising the tank, a plume of gaseous NOx hissed loudly from the vent outlet half way up the rocket, things were looking good.

Jim continued the fill, pausing every 30 seconds or so to prevent the solenoid valve from getting too hot. We also continued bursting the vent valve open to allow any gas out and ensure it was filled with liquid NOx rather than gaseous NOx. We had originally estimated it could take fifteen minutes to fill the tank. We would know that the tank was full only when we saw a plume of white liquid NOx coming from the vent valve. Fifteen minutes passed, the NOx was still hissing in to the flight tank. Twenty minutes, we began getting a little concerned. Twenty five minutes came, by now we were very nervous that something was wrong, then, suddenly, the plume changed from faint wisps to a brilliant white plume. Jim hit the vent again, more wisps... he carried on filling, a few more seconds then another burst on the vent, a white plume roared out of the side of the rocket, the tank was full.

I radioed all stations, "Standby, we are going for disconnect"

The team waited... Jim hit the button to fire Steve's disconnect line, with a burst of liquid NOx the umbilical shot away from the side of the rocket and snaked on the floor for a few seconds as the NOx emptied from the line.

"We confirm we DEFINITELY have disconnect!"

Steve grinned.

"Ok, can we have a final confirmation from all stations that you are go for launch"

Ground station confirmed readiness, Andy confirmed readiness and that the airspace was ours, Kevin confirmed readiness. I turned to Jim..

"Jim, if you're ready we will go with a fifteen second terminal count on my mark". Jim nodded.

"Ok, we are going for launch in T-15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, ignition" Jim hit the ignition button, we had passed launch commit, Deimos 2 was on it's own now, smoke erupted from the base of the rocket, "3, 2, 1, "

The radio crackled to silence, the sound of the deep rumble of the ignition system pressurising the combustion chamber was all that could be heard, the flames licked around the base of the rocket as the tail section disappeared behind a veil of thick smoke. Then, at T+2 seconds, the burst disk actuated. The Nitrous exploded in to the combustion chamber. The footage from Steve's brown trouser cam showed the start-up beautifully. The burst disk fires with a crack followed by a screaming whine that rapidly increases pitch, half a second later a column of brilliant orange flame erupts from the nozzle and Deimos 2 lifted off the ground. A seven foot pillar of flame punctuated with seven Mach diamonds is clearly visible on all three of the close-up video cameras as the rocket climbs the rail.

The 120lbs of rocket roars majestically in to the sky crackling like a Saturn V. It gently arcs above us towards the mountains and powers in to the sky until it disappears from sight and just the eerie sound of the huge rocket engine roaring away from us can be heard. Fifteen seconds after lift of the motor runs out of liquid Nitrous oxide and goes in to blow-down mode.

The sound of the motor can be heard to change on the video going from a deep roar to a faint whine.

T+21 seconds, main engine cut-off.

"All stations we confirm MECO" crackles over the radio in an almost hysterical voice.

The team on the hillside erupts in to insane jubilation, four grown men in tears begin leaping around the hill in a group hug. About that time Kevin radios that he heard an echo off the hills. What he actually heard, and if you turn the volume up on the video what is clearly audible, is the sound of the parachute opening on the booster about 15 seconds after burn out.

Due to the cold weather at launch the NOx in the tank was at far lower pressure than planned. This meant the thrust of the motor was also lower than planned, proven by the increase in burn time from the predicted 9 seconds to over 14 seconds. The rocket arced in flight and was still travelling quickly when the parachutes were ejected. The main parachute on the 100lb booster blew out a few panels when it opened, causing the distant thud that Kevin heard. The booster landed quite hard in the next valley, the payload section, which we had the foresight to recover on it's own parachute, touched down safely on the other side of the mountains.

The entire rocket was recovered by sunset and the team retired to the cottage for champagne and post-flight analysis. The altimeter data proved very interesting. The low pressure had caused the motor to oscillate in it's burn more than expected and had, as suspected, caused the motor to give lower thrust than predicted for a longer time. That aside the total impulse of the motor was only 5% lower than expected still making it a border-line 'O' motor. Given the low pressure this is very encouraging and means that at normal pressure we should get very, very good performance from this motor.

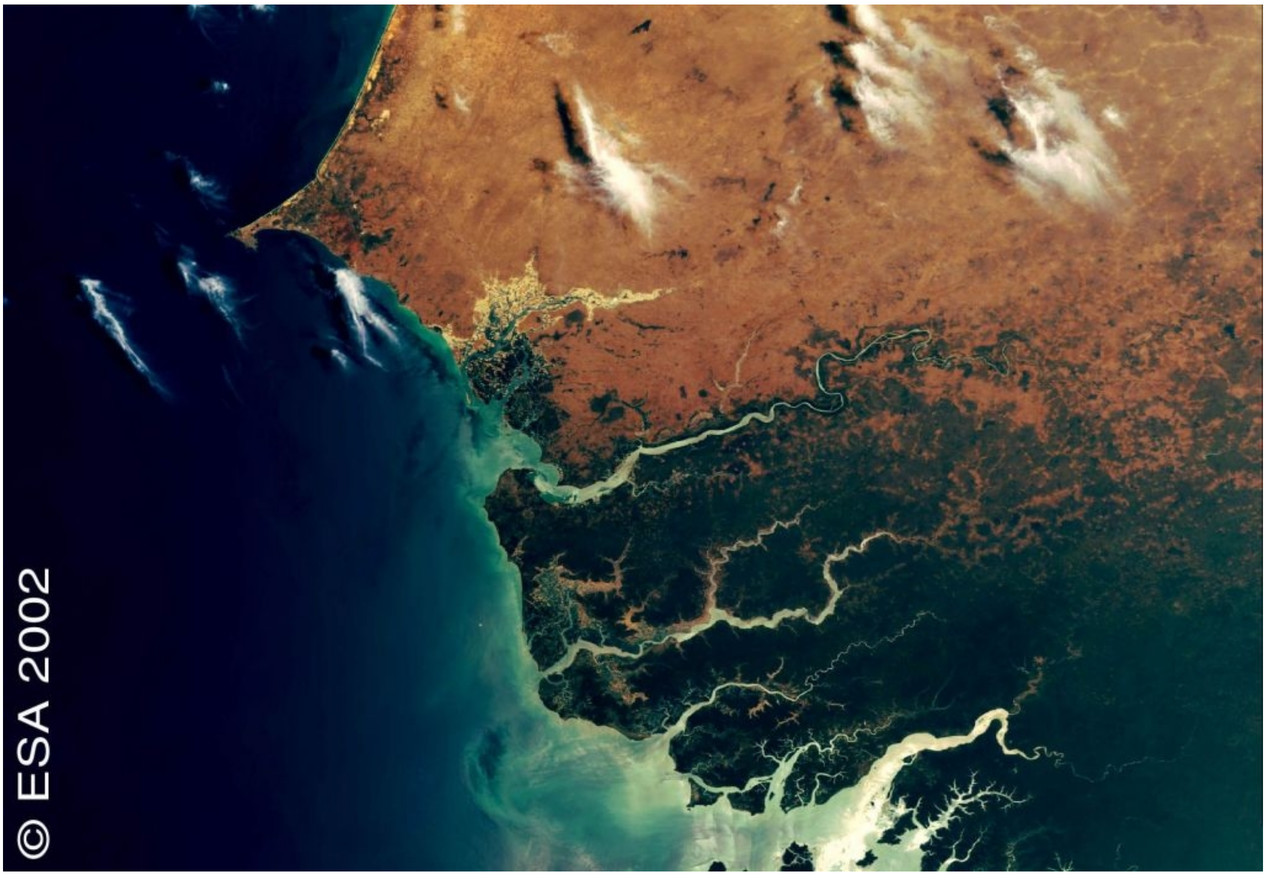
The team headed back Home the next morning content with the stunning success they had achieved. We are still analysing all we can from the Deimos 2 launch but have learnt so many things from it that we are confident that the next flight will be a complete success.

For many members of the team this was the first true amateur rocket that they had ever been involved with and, if we all learnt nothing else from this project, we certainly learnt that the buzz you get from flying a vehicle you've built yourself on a rocket motor you've built yourself beats even the coolest HPR flight any day. We also learnt the true value of teamwork and have become closer and more productive as a result.

"The higher the stakes, the bigger the thrill" as they say, and D2 was certainly one hell of a thrill!

MARS Deimos 2 lifts off from the Comer site

Two views of West Africa taken by different Envisat instruments



MERIS image of the Casamance river system

Topological view of the same area derived from MERIS image with data from ERS-2 altimeter

Postcard from Kourou - the sequel

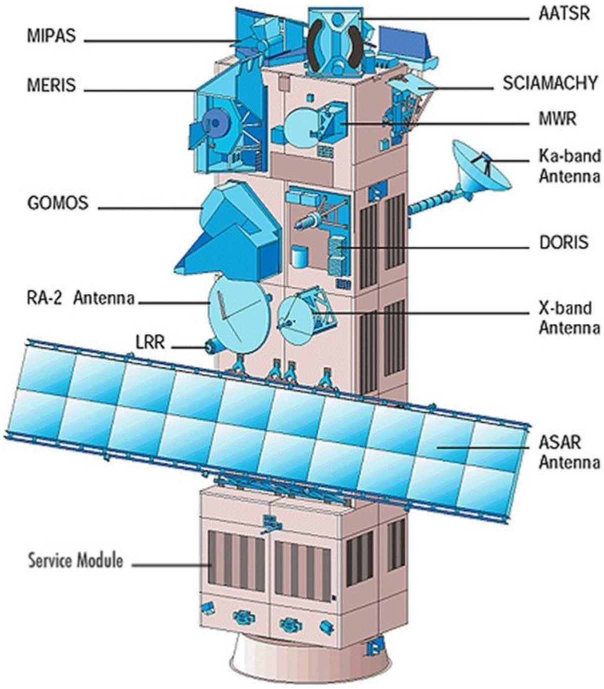
by Andy Moore

If you remember back to the middle of last year, I wrote a rather long postcard from the European Spaceport in Kourou, French Guiana. Well at long last, it is time for the second installment. In May last year a large number of us went to French Guiana for the first part of the Envisat Launch campaign and were due to return in September for the actual launch. A major fault in another Ariane 5 launch only days after we returned to Europe meant the Envisat launch had to be delayed.

Arianespace found the problem to be related to pre-ignition in the final EPS stage (Fr: Etage de Propulsion Secondaire). During the Summer/Autumn Arianespace performed a lot of testing, with a number of test firings of the Aestus engine to validate the fix to the final stage, and demonstrate to ESA and the Insurers that the modifications would work.

Finally, in Early 2002 a number of engineers from Astrium and ESA returned to Kourou for the final preparations of Envisat with a launch date 1st March. Unfortunately, I had managed to end up on another project which was just entering a critical testing phase at ESA in the Netherlands, so had to suffer the miserable Dutch weather instead of the tropical sunshine! So instead of a nice easy time sitting by the pool sipping cocktails I ended up working 12 hour shifts supporting a thermal vacuum test on Rosetta, a probe due to intercept, orbit and land on Comet Wirtanen some time in 2007.

On February 2nd, the upper stage engine arrived at Cayenne after a transatlantic flight from Bremen aboard an Antonov An-124. A few days later Envisat was prepared for fuelling.



ENVISAT layout

It would take a few days to fuel the four tanks with 314kg of Hydrazine monopropellant. This fuel is extremely hazardous and carcinogenic and fuelling has to be performed in a dedicated clean room with very stringent safety regulations, and all the operators have to wear space suits with externally fed air supply. This fuel would be used for manoeuvring the satellite into its orbit after separation from the launcher, and to fuel the attitude and orbit control thrusters during its five-year lifetime.

February 16th, Envisat is mated with the Ariane 5 adapter ring, the first contact with the rocket that would propel it to space in 12 days time.

February 20th, Envisat is moved from the Assembly and Integration Hall to the Ariane 5 Assembly building. This is around 6km drive along the only road through the launch site, and the road is closed to all traffic for the slow journey. Two days later, the satellite is finally lifted onto the rocket. So many people had been waiting for this day for quite literally years. When I joined the project, this day should have been in October 1999.

February 25th, goodbye forever as the 17-metre long payload fairing is lowered over the satellite. The satellite would never be seen again, as the Ariane complete with payload is finally complete. The following day is declared "go for launch", and roll out of the Ariane begins on 27th February.

Then disaster! A problem develops in the umbilical connection which provides clean air ventilation of the payload bay. During the night the launcher is rolled back into the assembly building for inspection. Apparently the wind had caused the umbilical quick-release to activate, and the hose had dropped away! Fortunately, the problem is rectified and final roll out begins again the following morning with the complete rocket and integrated launch table/tower towed at 4km/h.

Finally the day we had been waiting for. I guess you could say a lot of people were a bit emotional, and most had no fingernails left. Some people had worked 15 years, and I had worked over 5 years testing the instruments. And now it was sitting on top of a rocket which had failed on the previous launch, and had failed two or three times before. It was also the first Ariane 5 launch into a polar orbit, the first with the extended payload bay, the first with a modified final stage and the first after a failure. And with GBP 1.4 Billion sitting on top of a very big firework, I think people had a good enough reason to be nervous!

From about midnight CET about 500 people started arriving at the Space Expo, the museum next to the ESA facility in Noordwijk. This was the only building where they could fit that number of people, with space for multiple big screens, jazz band and TV camera crews. Video screens everywhere had the Arianespace TV link fed into them, and even the 1:1 scale Columbus Space Station module made a good screen for one video projector. At 01:00 UTC the video links from Kourou were showing the control room and all indicators were green. The Meteo one is renowned for being red in Kourou, but the Spaceport Weather Centre declared that conditions were favourable.

Then at 01:07 UTC the final seconds of the countdown and there is near silence, only people's hearts pounding, and every pair of eyes glued to a the nearest visible screen. "Dix" in the countdown sequence always seems to last forever, maybe due to the fact that once the countdown proceeds past that point then the automatic launch sequence is initiated. "Neuf"..."Huit"... at last, so that's go for launch. A few seconds later and the main cryogenic engine if fired up... and then "Deux", "Un", and the solid boosters light and then suddenly the whole thing is let go. The rocket lifts slowly at first and then appears to shoot off the pad. Then your mind just starts racing!

Firstly it's a flashback to the first Ariane 5 launch which was arguably one of the most spectacular CATOs, and then you're thinking "5 years of my working life are on top of that flame", and then "what a spectacular sight of the clouds lighting up and the silhouettes of the palm trees"!

Big relief number one is the booster separation at T+2:24, and then separation of the main cryogenic stage at T+9:33. So a repeat of A501 can't happen, but a repeat of A510 still could! There's still a long time before separation yet! And then the clapping starts from the control centre in Kourou signalling that Envisat has been successfully released into orbit at around T+26:35. PARTY TIME!!!! Out comes the champagne for 500 people.

But there's still a number of hurdles yet. The screens then switch to Darmstadt where ESOC, the European Space Operations Centre is based. A camera was trained on the graphical display of the battery and power status and also the pyro and thruster status. Everybody eagerly waits for 45 minutes for the solar array to deploy and then appear over the horizon so that the solar array sees its first rays of sunlight.

Big relief number two is that solar array deployed successfully and the automatic sequence fired all of the pyros and thrusters to manoeuvre the spacecraft into the correct orientation.

The following morning everyone is a bit hung over. I think a few people, including me, didn't go into work until lunchtime. That was when things started to sink in. That beast that we'd worked with for five years wasn't here any more, but was circling overhead once every 100 minutes. We had succeeded in getting the largest European satellite, with the largest solar array in the world into space. The 10 instruments that I had worked with, testing day-in day-out for

5 years were finally "up there" somewhere! And the icing on the cake was that Ariane had delivered Envisat to a near perfect orbit.

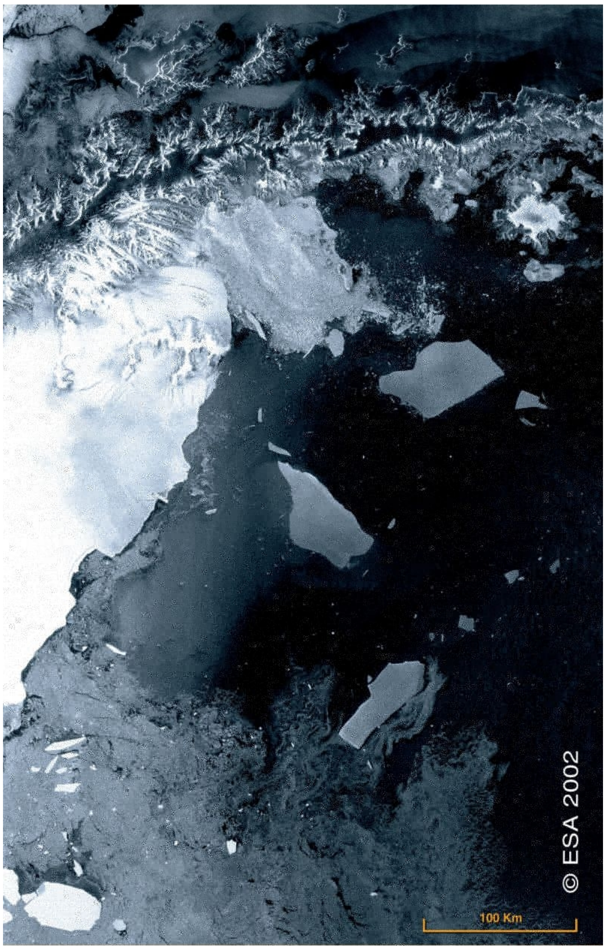
Over the next few days, the commissioning phase started. Firstly Envisat is raised 35km for 33 days, which would use 10kg of fuel. Then the SAR antenna array (the biggest, most complex and most import instrument) is deployed successfully, followed by the antenna which points to Artemis (the satellite which was on the previous Ariane launch failure!).

The ASAR (Advanced Synthetic Aperture Radar) and RA-2 (Radar Altimeter) were the two instruments that I worked with most closely over the last five years. On March 8th, the ASAR calibration and functional checkout was performed, followed by RA-2 three days later. Over the following two days both instruments were in real operational modes for functional verification, calibration and tuning. But to see REAL data from an instrument that I'd worked with so closely was the one thing that really did it for me!

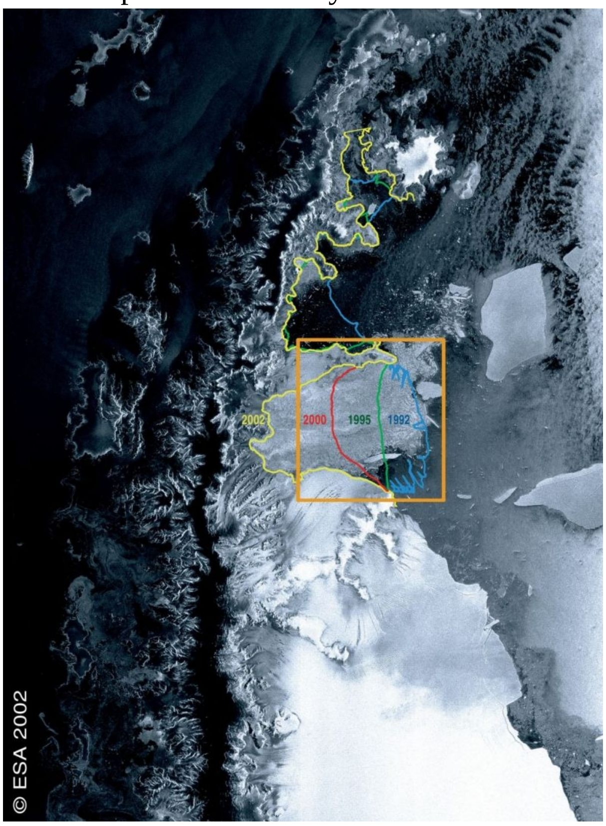
So what does it feel like knowing that your work is in space, orbiting Earth and working? Don't ask me... I can't explain it in words, but it is a good feeling!

Well now I'm working on Rosetta, a space probe that whose final destination is the Comet Wirtanen. The probe will orbit the comet taking various measurements, and also build up a stereoscopic image of the comet. Eventually it will release a lander, a highly ambitious project to land on the comet for even more accurate measurements. This will be launched from Kourou on an Ariane 5 with some new features early next year, so there may well be another installment, this time from the launch site.

If you missed the launch, then you missed a good one. But if you have a good internet connection, then checkout the Arianespace website where you can see the streamed video. If you're interested in the Envisat mission, then check out the ESA web site:
http://www.arianespace.com
http://envisat.esa.int



View of the collapse of the Larsen B ice shelf in the Antarctic peninsula taken by Envistat's ASAR



Closer view, annotated to show the progress of the collapse since 1992

Space Modelling

Contest Calendar 2002

by Stuart Lodge

Updated from the list in the last Interspace issue of 2001 – we've lost the Lleida-Barcelona (ESP) event in June, Stip & Prilep (MKD) Cups in May & August and the Victory Cup (TUR) in September. But rediscovered another – the Carl Neubronner Cup in Germany! Here is the FAI:CIAM Space Modelling Contest Calendar for 2002.

Stuart Lodge, Vasil Pavljuk & Mikilás Szabo with S7 models, Ljubljana Cup, 1997

Tone Sijauee, Joze Cudan & Tomaz Kogej from Slovenia at World Champs in Slovakia, 2000

KEY - FAI contest class definitions:

S1*x*	Altitude
S3*x*	Parachute Duration
S4*x*	Boost Glider
S5*x*	Scale Altitude
S6*x*	Streamer Duration
S7*x*	Scale
S8*x*	Radio Controlled Rocket Glider
S9*x*	Gyrocopter Duration

Where x indicates motor impulse

Date	Event	Location	Description
19-22 Apr	Korolev Cup	Stupina-RUS	S4B-S6B-S8E/P-S9B-World Cup
26-28 Apr	RAK 2002	Oberkulm-SUI	S4B-S6B-S8E/P-World Cup+non-FAI
3-5 May	Bratislava Cup	Bratislava-SVK	S6B-S7-S8E/P-S9B-World Cup
18-19 May	Krupka Cup	Krupka-Teplice-CZE	S6B-S8E/P-World Cup
23-26 May	Bucharest Cup	Bucarest-ROM	S4B-S6B-S7-S8E/P-S9B-World Cup+S9D
14-16 Jun	Sirmium Cup	Sr.Mitrovica-YUG	S4B-S6B-S7-S8E/P-S9B-World Cup
5-7 Jul	Yangel Cup	Dniepropetrovsk-UKR	S4B-S6B-S7-S8E/P-S9B-World Cup
13-14 Jul	Carl Neubronner Cup	Roggden-GER	S1F,S8D non-World Cup event
12-14 Jul	Plock Cup	Plock-POL	S6B-S7-S8E/P-World Cup+Show & Expt'l classes
26-28 Jul	Liepaja Cup	Liepaja-LAT	S6B-S7-S8E/P-S9B-World Cup
2-4 Aug	Texas Two Step Cup	Windom-USA	S4B-S6B-S9B-World Cup+S1B
2-4 Aug	3rd Canterbury Cup	Stalisfield UK	S6B-S8E/P-S9B-World Cup+S4A
11-12 Aug	Texas Cup	McGregor-USA	S6B-S8E/P-S9B-World Cup+S1B
24-25 Aug	Rybnik Cup	Rybnik-POL	S6B-S7-S8E/P-World Cup
7-8 Sep	Kosice Cup	Kosice-SVK	S6B-S7-S8E/P-S9B-World Cup
14-15 Sep	Oradea Cup	Oradea-ROM	S4B-S6B-S7-S8E/P-S9B-World Cup+S9D
21-22 Sep	Shostka Cup	Shostka-UKR	S4B-S6B-S8E/P-World Cup
28-29 Sep	Pegaz Cup	Ruma-YUG	S4B-S6B-S7-S8E/P-S9B-World Cup+S9D
5-6 Oct	Ljubljana Cup	Kamnik-SLO	S4B-S6B-S7-S8E/P-S9B-World Cup+S3A, S5C & Show
13-20 Oct	14th World Space Modelling Championships	Sazena-CZE	S1-S4-S5-S6-S7-S8-S9..Junior & Senior categories and World Cup event also

HPR Hybrid Clinic

by Hybrid Guru, Richard Osborne

1. What type of valves do I need? The standard type of valves used with hybrid rocket fill systems are high pressure, NOx safe solenoid valves such as the solenoid valves manufactured by NOx (brand names are names such as Powershot). These solenoid valves require 12 volts to operate, and are available with 1/4 inch NPT and 1/2 inch NPT threaded connections. Normally, 1/4 inch NPT is the standard connection thread used with High Power and Amateur hybrid rockets, for no reason other than it seems to be the size people have standardised on. Note that the solenoid valves used for hybrid rocket launch systems should be high pressure solenoid valves, since lower pressure valves will not be capable of handling the pressures involved with pressurised Nitrous Oxide. low pressure valves could stick, or not open, and in extreme cases, could rupture or blow apart. It is also possible to use high pressure ball valves coupled to an electric motor (*either directly, or through a gearing assembly*). This is a lower cost alternative to using solenoid valves, but requires some careful design and mechanical construction. Additionally, there needs to be a means of reversing the motor, to ensure the ball valve can be both opened and closed.

2. Where can I get solenoid valves? In the U.K. performance car or bike shops tend to sell the solenoid valves suitable for High Power and Amateur rockets, since they are designed for use with Nitrous Oxide injection systems for car and motorbike engines. In London, shops such as Customville in Goodmayes, Romford, sell the NOx valves.

3. Where can I get ball valves? In the U.K. high pressure ball valves able to be used with hybrid rocket motor fill systems are available from suppliers such as Swagelok (*through distributors such as North London Valve and Fitting Company*), RS and Farnell. **N.B.** Appropriate ball valves need to be high pressure ball valves, and have either PTFE, NBR or Nylon threads, or the ability to fit PTFE, NBR or Nylon threads.

4. What types of threads, greases or seals are needed? Appropriate threads are generally PTFE, NBR or Nylon. PTFE tape can be used for sealing. Krytox grease is the recommended Nitrous safe grease - it is not cheap, but it is safe. Petroleum Jelly (*Vaseline*) is not recommended as a grease.

5. What does NPT, BSP etc mean?

- NPT stands for National Pipe Taper, and is the most common U.S. standard for pipe fittings. NPT fittings are measured on the internal diameter of the fitting.
- AN fittings were designed originally for the U.S. Military (The "A" standing for Army, and the "N" standing for Navy). AN fitting numbers refer to the outside diameter of fittings in 1/16 inch increments, thus an AN 4 fitting would have an external diameter of approximately 4/16", or 1/4", and an AN 6 fitting would have an external diameter of approximately 6/16" or 3/8". The approximately is important, since the AN external diameter is not a direct fit with an equivalent NPT thread, and the table below, should provide some guidance.
- Dash or - fittings are interchangeable names for AN fittings, thus a Dash 8 fitting would be the same as an AN 8 fitting.
- BSP stands for British Standard Pipe and is the U.K. standard for pipe fittings.

NPT Size	*Nearest AN Size*	*Nearest Dash (-) Size*
1/8"	4	4
1/4"	6	6
3/8"	8	8
1/2"	10	10
3/4"	12	12
1"	16	16
1 1/4"	20	20
1 1/2"	24	24

6. What fittings do I need for my hybrid GSE? The fittings used mainly in Hypertek and R.A.T.T.Works hybrid motor fill systems tend to be 1/4 inch NPT fittings for connections to the solenoid valves, with Dash-4 fill hose fittings.

7. What is the dump valve for? A dump valve is used to rapidly release Nitrous Oxide from the hybrid motor's oxidizer tank in the event of a pre-launch abort. A dump valve is only really necessary or desirable on hybrid motors without a vent line, and on hybrid motors of J-class total impulse and above. For smaller hybrid motors with vent lines, such as the R.A.T.T.Works H-70H and I-80H hybrids, the amount of Nitrous Oxide contained in the hybrid motor oxidizer tank is sufficiently small that it will be released through the vent line relatively quickly, and generally sufficiently quickly to negate the need for a dump valve. If building a Nitrous Oxide oxidizer fill system, there is no requirement for the dump valve to be a solenoid valve either (*or the fill valve too* *for that matter*). A ball valve with a spring release system controlled remotely is quite adequate, as long as the ball valve is rated as a high pressure ball valve.

8. Where can I get NOx in the UK? As with the solenoid valves, the best source of Nitrous Oxide is likely to be performance car or bike shops. Again, since the Nitrous Oxide is used in engine injection systems, the Nitrous Oxide tends to be available from these types of shop. In London, shops such as Customville in Goodmayes, Romford, supply Nitrous Oxide and Nitrous Oxide tanks. Pete's Rockets are also able to source Nitrous Oxide for hybrid rocket motors. For the micro-hybrid rocket motors, Nitrous Oxide sparklet bulbs are used. These are small pressurised cylinders containing Nitrous Oxide, and used in the catering industry for whipped cream.
N.B. The larger suppliers of gases frequently claim that people are unable to get Nitrous Oxide "across the counter". This is wrong, and because of the frequently erroneous information supplied, it is probably better to approach the smaller suppliers, such as performance car and bike shops, from the start. The following is a list of Nitrous Oxide sources in the U.K. with a web presence:
http://www.highpower.freeserve.co.uk/
http://www.customville.co.uk/

9. What type of tank do I need for NOx? Nitrous Oxide is stored as a gas over liquid (*750 psi at room temperature*), and either commercially available tanks designed specifically for Nitrous Oxide, or high pressure tanks (such as a SCUBA diving tank or a CO2 fire extinguisher tank) are required for its storage. The tank has to be capable of withstanding the pressure of the Nitrous Oxide with a significant safety margin - hence the requirement for high pressure tanks. At room temperature, pressurised Nitrous Oxide is generally stored at around 54 bar pressure. A SCUBA diving tank is rated to approximately 300 bar pressure, and a CO2 tank is rated to approximately 350 bar pressure. In both cases, these are more than capable of holding Nitrous Oxide. A Nitrous Oxide supplier will be able to advise on the most appropriate tank. A dip tube fitted to the tank is also often used, since this stops the need to tip the tank upside down to get the last bit of liquid Nitrous Oxide out of the tank. The actual pressure hose is enclosed within the braided stainless steel, so it can be used on its own, or with the braided stainless steel covering. To protect the pressure hose, it is preferable to get a pressure hose with stainless steel braiding, but if cost is an issue, the stainless steel braiding is not essential.

10. How do I get NOx from the tank to the rocket fill fitting? The most common means of supplying the Nitrous Oxide to the rocket fill fitting is via a braided stainless steel hose. Fittings at each end of the hose will depend on the fittings required for the Nitrous Oxide valves and tank fittings.

11. Is NOx storage regulated? There are no restrictions on storing Nitrous Oxide in the U.K., as long as it is stored in a suitable high pressure tank. In terms of rules and regulations, the only rules and regulations apply to the containers used to store the Nitrous Oxide, and these are Health and Safety Executive (HSE) rules and regulations for the storage of gases under high pressure in suitable containers. In the case of hybrid rocket motors, this applies to the tanks used to store and supply the Nitrous Oxide to the hybrid rocket motor.

The manufacturers of the tanks used (whether Nitrous Oxide specific, SCUBA or CO2) will already have to have met the standards laid down by the HSE, not the end user.

12. Why use NOx in hybrid motors? Nitrous Oxide (N2O), also known as Dinitrogen Monoxide, NOx or Laughing Gas, is used as the oxidizer in commercial HPR hybrid rocket motors because it is probably the easiest oxidizer to handle, easiest Oxidizer to store and most readily available oxidizer. Liquid Oxygen is cryogenic, and requires another level of safety in terms of cleanliness of equipment, cryogenic capable flow lines, etc. Hydrogen Peroxide is far harder to obtain in useful concentrations, and is a more reactive oxidizer capable of causing some nasty damage to organic material such as people.

13. What is the boiling point of NOx? The boiling point of Nitrous Oxide is 97 degrees Fahrenheit.

14. What is the density of NOx? The density of liquid Nitrous Oxide is 1.22 g/cm3.

15. What pressure is the NOx held at? At room temperature, the pressure of the Nitrous Oxide in a pressurised oxidizer tank is around 750 psi or 54 bar. The pressure in the tank will increase in warmer temperatures, and the tank pressure will decrease in colder temperatures. The result of this, is that in warmer temperatures, a hybrid motor will burn for a shorter amount of time at a higher level of thrust, and in colder temperatures, a hybrid rocket motor will burn for a longer amount of time at a lower amount of thrust. The following table provides an approximate guideline:

Vapour Pressure (psi)	***Temperature (Degrees C)***
460	0
520	5
600	10
680	15
760	21
860	27

16. Are hybrid motors dangerous? Hybrid rocket motors are very safe. Certainly far safer than solid rocket motors. There was a report conducted by the USAF that gave hybrid motors a TNT rating of zero. This basically means that they are non-explosive. Even with a mis-ignition where the oxidizer is released, but there is no oxidizer ignition, a hybrid rocket will fail safely, since the oxidizer will just blow out of the nozzle like any other pressurised gas that has been released. To really try and break a hybrid rocket motor, a nozzle blockage (*caused by igniter grain fragments jamming in the nozzle throat*) would be needed, since this would cause a pressure buildup, and an overpressure in the motor. Generally, in an instance such as this, the hybrid rocket motor will be designed to fail axially (*as with a solid rocket motor*), so that any catastrophic failure and resultant debris would be directed in one direction.

17. Is a pressure gauge necessary? Not strictly, no. A pressure gauge is a nice optional extra. In order to determine how much Nitrous Oxide is in a tank, the other way of measuring it (*somewhat cheaper*), is to weigh the tank when it is empty, then weigh it again when it has been filled with Nitrous Oxide. Each time Nitrous Oxide is used, then weigh the tank for an approximate measure of how much Nitrous Oxide has been used.

18. Does it take longer to prep a hybrid? Yes and no. It takes longer to set up the ground support equipment for a hybrid rocket motor, simply because there is no separate oxidizer involved with a solid rocket motor (*a solid rocket motor contains both the fuel and the oxidizer bound into the solid propellant*). If all the equipment is already available and is largely pre-assembled, then initial hybrid motor ground support setup can take as little as 5 minutes. To prep a typical Hypertek or R.A.T.T Works hybrid rocket motor takes less time than an equivalent solid rocket motor, simply because there is less to prep. However, hybrid rocket motors do not have ejection charges like solid rocket motors do, so time needs to be allowed to prep an ejection charge fired from an electronic recovery deployment system such as an altimeter, accelerometer, altimeter/accelerometer or timer. So, to summarise, with practice, prepping a hybrid rocket motor can take less time than a solid rocket motor, but more often than not, it will take at least the same amount of time, if not more time, to prep a hybrid motor than a solid motor.

19. Does a hybrid motor differ from a solid motor during flight? As the oxidizer in the oxidizer tank is used up, there is a loss of mass that acts axially along the length of the rocket. This differs from a standard core burning solid rocket motor, where the mass loss occurs radially. The result of the axial mass loss with a hybrid rocket, is that the Centre of Gravity moves backward, causing the vehicle to become more unstable. This frequently results in weather cocking, or a tendency for the vehicle to fly into the wind. The more unstable the vehicle becomes, the more it weathercocks, and the more its trajectory becomes less vertical. This is why passive, fin stabilised hybrid rockets (*i.e. most HPR and amateur rockets*), tend to arc over, especially towards the end of their motor burn.

20. Does a hybrid powered rocket have to be built differently? Yes. Generally, a rocket built to accommodate a hybrid rocket motor will need to have a longer motor section, sometimes 2-3 times the length of a comparable solid motor section. Additionally, hybrid rocket motors tend to be lower thrust, longer burn motors than equivalent solid rocket motors. This necessitate building rocket airframes lighter and with careful thought to payload and recovery system placement to account for the shift of mass during flight as the oxidizer in the oxidizer tank is used up.

+++Stop Press+++

Pete Davy of Pete's Rockets reports that he expects to receive new shipments of both Pro38 & Aerotech 38mm Blue Thunder reloads in time for UKRA 2002.

+++Reload availability+++

Tales of a hybrid virgin

by Steve Gibbings

Well after having the equipment for a month or so I final made use of it and lost my hybrid virginity!

As I didn't have an airframe that could take the HyperTek 54mm J 835cc motor I built a standard three fins and a nose cone design using PML Quantum Tubing. The rocket ended up 75" tall and 2.6" diameter. It features a tiny drogue section and a 16” main chute section. Without motor it weighs 2.2kg. It ended up with a five calibre static margin so I won’t be flying it in too much wind. I opted to go for the J330 motor which was simulated to 6580ft.

To ensure the venting NOX can easily be seen I drilled an 8mm hole in the side 11" up so the vent on the bell housing lined up with it. A piece of tubing or straw can be pushed over the vent to ensure the NOX vents out of the airframe.

I tried the Slim line motor retention from Giant Leap for the first time secured with JB Weld. Very neat but a bugger to get the clip inside one handed!

For anyone that hasn't handled a HyperTek motor I can honestly say that they are very nice bits of kit. They are well engineered in my opinion and worth every penny especially when you consider the cost of a J Grain. You can make two I flights on the same J grain (with a smaller tank) for £15 a flight. That’s got to be good news.

The flight was made in February at the SWARM club site in South Devon near Okehampton [SWARM is a relatively new club, find out more about them here - mysite.freeserve.com/swarm]. Thanks to Jim, Felix and the rest of the members for allowing me to use their cracking site. I travelled down with Pete Davy who was RSO for a couple of SWARM level 1 certification flights. Jim, Roy and Adrian all passed on Saturday so congratulations to them. The cloud closed in before we could make a flight on Saturday so we delayed until Sunday. We awoke to some fog but it soon cleared and showed us a clear sky with no wind. Perfect!

The motor was easy to prepare. You choose which orifice you want, assuming yours is user adjustable, and screw it in hand tight. You then grease two o-rings, the small one drops into the Kline valve to sit on the orifice you just screwed in and the second goes around the outer edge of the injector assemble. The latter creates a gas seal against the grain. You just screw the grain in hand tight and that’s it.

There were a few model flights as Pete and I set-up his ground support equipment. Thanks to Pete for the use of his GSE. This was also my first close inspection of the GSE and it looks good too. Easy to set-up and Pete had it done within 20 minutes. One thing Pete explained worth noting was the benefit of purging the NOX and GOX fill lines. This ensures that the lines have no air left in them and will supply NOX and GOX as soon as you activate the supply. This can be done by switching to "Fill" and activating without a rocket sitting on the fill stem. The NOX is easy to see venting out the end of the fill stem. For the GOX you switch to "Fire" (make sure you don’t have the electrical system connected up) and activate again.

With this all done Pete showed me how to prepare the igniter wire and tape it to the fuel stem. The HyperTek instructions are quite clear about this. Pete was flying first so he set the fill stem plate for 54mm diameter and lowered his rocket down. I was interested in seeing how positive the fill stem mated to the Kline value. You can easily feel the end of the stem push past the inner o-ring. Pete then set the stand off and raised the drop stem plate so it was in contact with the bottom of the grain. A single cable tie is used to pull the grain down onto the drop stem plate.

All that was left was to connect up the igniter to the electrical system and leg it back to the launch controller. Pete made a superb flight to something like 2500ft on an I motor.

After an easy recovery we went back to the pad and reset the GSE for my 2.6" rocket. Pete showed me that you could reuse the igniter wire by simply cutting off the burnt section that was used previously. It is a good reason then to cut your fresh igniter wire on the long side otherwise you'll end up throwing away perfectly good but short lengths. I was using an R-DAS for deployment that can get foxed if you rely on the g-switch for launch detection. I had a break wire fitted using a jumper style socket bonded to the airframe and a jumper plug on a length of Kevlar thread. We tied the thread to the pad so it will be pulled out as the rocket takes off. I also had a safe/arm key switch which Pete very kindly reminded me to set! This all done we returned to the controller.

The on-lookers were a bit close for a J

motor so Pete asked them to move back further. I then started the fill. This took a little while but the time went quite quickly. We soon saw the NOX venting and I started the count down. Pete had advised me to keep the fill activated until I reached 2 then release, switch to fire and at the end of the countdown I activated.

You can hear the GOX as it rushes into the combustion chamber and is ignited by the 7500volt arc. You get a yellow orange flame out the back as the grain starts to burn in the oxygen and after a second the flame burns the cable tie and the fill stem drops down. The NOX then enters the combustion chamber and the rocket was away. The difference in noise and volume these motors make over solid fuels is fantastic. OK you may not get the flame and smoke but I'm definitely hooked.

The rocket was soon out of sight and we all lost track of it. We did hear the drogue charge go off but it wasn't until we heard the rape alarm going after the main had come out at 600ft that Pete spotted the rocket. It was recovered perfectly intact about 2000ft away. Next time I will see if I can get the courage to drop it drogue-less as Pete had done on his flight.

The R-DAS was beeping out 6091ft, which was a little disappointing given the perfect conditions. However when I downloaded the data to my laptop it showed an apogee at 6550ft. The simulation was just 30ft out, not bad at all.

To sum up, these are fantastic motors and I can't wait to fit the 0.125 orifice and fly this rocket to 9500ft on a K240.

Nitrous Oxide

Weird but wonderful

---

by Rick Newlands

Most amateur groups choose Nitrous Oxide (often referred to as either 'nitrous' or 'nox' but *not* 'nitro' (which is nitromethane) as the oxidizer for their hybrids as it's human-friendly unless you inhale it. It is a powerful anaesthetic: you might never wake up again. NOx's chemical formula (N2 O) shows a predominance of Nitrogen, which doesn't help at all with burning; it's just dead-weight that has to be carried aloft. Still, tweaked for performance, NOx hybrids will outperform any solid, so the following are some of the points to consider when designing and/or using a nitrous hybrid. Notable properties of NOx are:

1) The simple gas bottles NOx has to be stored in are a lot cheaper to buy or rent than, say, liquid oxygen or hydrogen peroxide containers, so at the small quantities most amateur groups use, NOx systems work out cheaper, even though the NOx itself is quite expensive per litre. NOx is readily available from many sources, such as hotrod car shops. You can carry bottles of NOx in the back of vans, but not in cars; there should be a barrier between driver and bottle incase of a leak as NOx is a powerful anaesthetic.

2) A large oxidizer to fuel ratio is required when burning NOx in the combustion chamber (around 7:1 by mass) which results in a requirement for vast quantities of nitrous, and so a big heavy tank onboard. This high ratio isn't all bad news, because as the oxygen within is a low fraction of the total NOx, you can be quite sloppy with the 7:1 *NOx* to fuel ratio without altering the actual *oxygen* to fuel ratio within much. This means that a graph of Specific Impulse plotted against NOx-to-fuel ratio doesn't have a sharp peak at best ('stociometric') mix that drops off sharply on either side. So you'll still get plenty of thrust even if your mixture ratio of NOx to fuel is way off 7:1, which is good if your test rig can't give you accurate figures to let you tune up the motor: the first few flights will still be good ones provided the motor doesn't melt.

3) Like bottled C02, NOx is **subcritical** at room temperature meaning that both a liquid and a gas phase can coexist within a *closed* tank. I'll elaborate on this in a moment, but the gist of it is that the moderately dense liquid phase of NOx can therefore be stored in a compact tank on the pad in the British climate.

4) As an added bonus, the pressure of the nitrous gas phase (termed the 'vapour pressure') is seriously high at room temperature, at around 55 Bar (800 PSI). The gas phase can therefore be used aquajet-style to squirt the liquid phase into the combustion chamber at very high pressure. This means you can tweak the combustion-chamber to be at almost this high a pressure and the nitrous will still run downstream (in a pressure sense) into the chamber. The higher the chamber pressure, the higher the Specific Impulse of the motor: the AspireSpace hybrids run at about 30 Bar chamber pressure, which is about as high as you can get whilst still having enough of a pressure drop between tank and chamber to prevent a screaming motor.

5) NOx has to be raised to a moderately high temperature before it will decompose and release its oxygen. This is very good from a safety point of view, but it does mean that a lot of heat has to be pumped into the nitrous from some other source at ignition, or the hybrid simply won't light-up. Once the plastic fuel is burning though, the temperature in the combustion-chamber is high enough to decompose the rest of the NOx as it feeds-in from the tank during the burn.

NOx tanks

Any old container that can safely withstand the vapour-pressure without bursting will do for a tank, though give it a damn good clean, preferably with chloroform, or failing that, plain water without any soaps or detergents. Stand next to a vessel pressurised full of nitrous however, and your delicate bits are right next to a potential grenade; it's the shrapnel of the exploding casing of a grenade that does the ripping through everything bit. Currently, UKRA quite rightly regards standing anywhere near a hastily knocked-up flight-weight cylinder under nitrous pressure as too hazardous to allow: so for hybrids only remote-controlled filling of the thin-walled flight tanks is permitted. Obviously, you *can* safely be close to the massively over strengthened tanks used to transport nitrous from the suppliers; they're properly engineered and manufactured to allow you to move nitrous around the country after all, and they're tough unless you drop them on their necks and break the valve off. Then you get a rocket alright. Such a commercial container is safe enough to handle (though not idiot-proof) but is far too heavy to fly.

Filling the run tank

I tend to call the beefy container supplied with the nitrous the **fill-tank**, whereas the lightweight tank inside your rocket-vehicle that it fills I call the **run-tank**. (the term 'fuel tank' is just plain wrong; the fuel is the plastic in the combustion chamber.)

Now you could fill the run-tank completely full of the liquid nitrous phase simply by turning it upside down then connecting it to a fill tank at a higher level. Gravity will then fill the run-tank with the denser liquid phase, while the gas phase bubbles back into the fill tank. **This, however, is dodgy**. Pick up any fresh bottle of camping-gas or CO2 and give it a gentle shake; the sound of waves sloshing inside reveals that the bottle hasn't been completely filled with liquid, there's obviously a small amount of gas in there as well. This small 'head space' of gas is in there for a purpose, because after filling, the liquid's density will change with any future changes in temperature. In fact just-subcritical fluids like NOx, CO2, or butane can change density rather a lot with temperature if they're around room temperature. The danger is that if the temperature increases, and as I'll explain later this usually happens after filling the run-tank, the liquid density will drop. If the tank was completely full of liquid, then the tank's fixed volume now won't be enough to contain the mass of liquid as it expands, increasing its volume. If the tank is stoppered, the liquid will then self-pressurise. Liquids don't compress easily, so the ensuing hydraulic self-pressure can often be enough to burst the tank, or any closed-off plumbing downstream of the tank.

To prevent such an accidental hydraulic overpressure, then just as in nature's design of the egg, a small percentage of the tank volume is deliberately left free of liquid to allow for expansion with temperature.

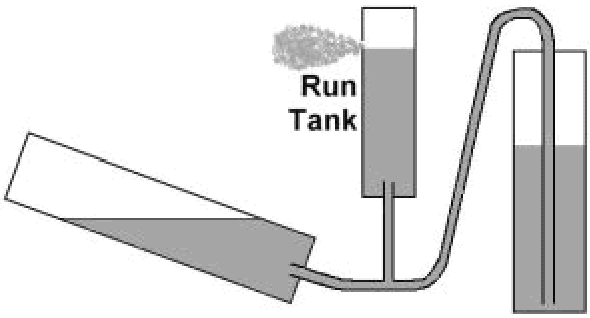
This gas pocket can then compress to absorb reasonable volume changes without over pressuring the tank.

It's up to you to design a way of creating this 'head space' of gas. 15% of the tank volume is a typical head space size, as this also provides a good reservoir of gas to pump the liquid out.

Vents

On many hybrid systems, the head-space is achieved by a vent-hole or vent-pipe with an inlet situated slightly below the top of the tank, the outlet is open to the atmosphere outside. It works exactly like the overflow outlet on a bathtub in that the liquid never fills higher than the vent. (provided that you fill it slowly.) The outlet of the vent-pipe can be higher than the vent inlet if required, because the massive pressure difference between inside the tank and outside will happily carry the nitrous several metres 'uphill'.

As soon as the nitrous reaches the level of the vent, you'll see the plume issuing from the vent thicken and whiten appreciably, and that's the time to stop filling. If your hybrid design allows, now's also the time to remotely close the vent hole to stop the loss. Most commercial nitrous hybrid systems keep the vent open permanently. Although a small enough vent diameter will keep the tank pressure high for some time, liquid nitrous is continuously being lost. This progressively lowers the tank vapour-pressure over time, so such a design has to be launched *immediately* after filling. Faff around on the pad for too long, and significant thrust is lost.



In this diagram, the fill-tank on the left has to be tilted-up to get liquid phase out, whereas the fill-tank on the right has a 'dip-tube' running down inside it so that it can be sat upright. When you buy your nitrous, remember to ask whether the fill tank has a dip tube fitted or not.

Subcriticality and Supercriticality

The apparent simplicity of nitrous hybrids comes at a price. The nitrous is typically at a temperature where its physics is anything *but* simple, but as in every other branch of rocketry, do thy homework to get thy max performance. Most substances, below a Critical temperature (each substance has its own T_{crit}), can exist as more than one phase simultaneously; they are then termed subcritical. For example any combination of two of the solid phase, liquid phase, or gas phase, can exist together in a tank in 'phase equilibrium', or even all three at the same time. Nitrous oxide sitting inside a closed container at room temperature is subcritical: partly liquid, and partly gas which being less dense collects at the top of the container.

Nitrous properties

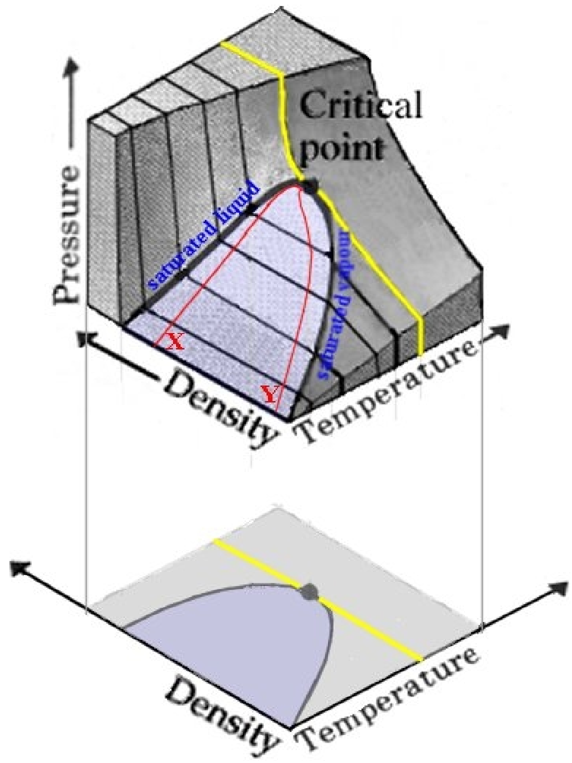
Firstly, a definition: The word 'vapour' is usually used to refer to a gas when it's below its Critical temperature, and so is existing alongside some other phase. It's purely a matter of context: there's no physical difference between a vapour and a gas, they're exactly the same thing.

Here's a table of nitrous properties reproduced from ESDU 91022. ? is the symbol for density. Note how the vapour pressure and vapour density increase with increasing temperature, whilst the liquid density decreases with temperature.

Temperature °C	***Vapour Pressure Bar Abs***	***?liquid kg/m³***	***?vapour kg/m³***
-20	18.01	995.4	46.82
-15	20.83	975.2	54.47
-10	23.97	953.9	63.21
-5	27.44	931.4	73.26
0	31.27	907.4	84.86
5	35.47	881.6	98.41
10	40.07	853.5	114.5
15	45.10	822.2	133.9
20	50.60	786.6	158.1
25	56.60	743.9	190.0
30	63.15	688.0	236.7
35	70.33	589.4	330.4
T_{crit} 36.42	**72.51**	**452.0**	**452.0**

Living at the bottom of Earth's atmosphere as we do, all of our experience of phase changes, usually of water, occur with a constant pressure of 1 atmosphere around us, which usually swamps the results of our experiments. If the atmosphere wasn't there, water would behave quite differently from our usual experience. To start with, water's subcritical below 374°C so there are always at least two phases present below this Critical temperature. One phase may well be much less obvious than the other though, in fact it's only when the temperature has climbed to 100°C that the pressure of water's vapour phase gets as high as the atmosphere around it. What we call boiling is when bubbles of water vapour can exist without getting squashed flat by the pressure of the Atmosphere. So though we're used to thinking that only liquid exists below 100°;C, and only gas above 100°C, this is actually a high school physics simplification. This is Britain after all; we do get the odd cloud.

Nitrous goes supercritical at plus 36°C, so it's very easy to overheat it into supercriticality: In the heat of the desert launching campaigns in the 'States, the nitrous in several hybrids went supercritical. Supercritical nitrous is a strange beast that requires special injector design, so almost all thrust was lost using the standard injectors. Here's a 3-D graphical representation (not to scale) known as a phase diagram, of the physical properties of nitrous oxide in the range of pressures and temperatures we'll use in rocketry.



The slopes of this chunk of 'mount nitrous' represent the values that nitrous physically can exist as; pressure being shown as height. The coloured section is where a subcritical mixture of liquid and vapour occurs, and describes what's happening in your tanks. The density graph below shows the view from above.

On our planet, nitrous' vapour pressure is well above the pressure of the Atmosphere at the temperatures we'll play with it: Boiling point for nitrous is one or two hundred degrees below 0°C. So any air trapped in our nitrous tanks that doesn't immediately get squirted out the vent hole by nitrous' high room-temperature vapour pressure might as well not be there, the tank behaves as if it contained only pure nitrous.

When heated, the liquid phase of nitrous follows the saturated liquid line on the graph whereas the vapour phase follows the saturated vapour line. The series of parallel lines crossing lines X and Y are known as 'tie-lines', and it's a *convention* to represent how much mass of each phase there is (as a fraction of the total mass in the tank) by the position on the tie-line. So by this *convention* (each phase *actually* follows its respective saturation line), the exact path up the coloured section depends upon what fraction of the mass of the substance was in the form of each phase when you started heating it: For example, path X would be a tank of nitrous mostly filled with liquid, whereas path Y would be a tank of nitrous with little liquid in it. By this *convention*, the liquid saturation line is therefore the path of a tank completely full of liquid that is warming up, whereas the vapour saturation line is the path of a tank completely full of vapour.

Notice that as the temperature increases, the density of the liquid saturation line decreases while the density of the vapour saturation line increases. This phase diagram is based on real data: at the Critical point, the densities do become the same; the two phases merge into one single phase, so paths X and Y both pass through the Critical point. Supercritical nitrous can therefore be regarded as either a super-dense gas, or a very low density liquid.

Looking at the density versus temperature diagram, you can also see that the change in density of both phases of nitrous per degree change in temperature is largest just before the Critical point. It turns out that the change in vapour pressure per degree Centigrade is also largest just before the Critical point. For nitrous, even the Scottish climate is still rather close to it's Critical point of 36°C, so sadly, you suffer *big* changes in pressure and density with *small* changes in temperature. A whopping two Bar decrease in vapour-pressure per degree decrease in temperature is typical in Britain, so if your nitrous gets too chilly, you'll get a lot less pressure in the tank, so a lot less thrust than you expected.

This close to the Critical temperature, the nitrous vapour phase is actually moderately dense and can't be ignored; it has a sizable mass inside the run tank. (and inside the combustion-chamber eventually.) Conversely, the liquid phase isn't terribly dense: heat it too much before filling the run tank and you won't get as much mass of liquid in there, (but chill it too much and you loose a lot of vapour-pressure, pick your own favourite temperature.) It is the subcritical liquid phase that we use in the combustion-chamber. The gas phase will cause extra thrust after the liquid runs out, but its lower density means the burning is way fuel-rich, so the extra thrust it gives is small.

Going back to the diagram, look closely at the tie-lines, recalling what they represent, and you'll notice something odd about the paths X and Y. *The ratio of liquid to vapour within the tank changes with temperature*. This means that the amount of liquid nitrous that you *think* is in your run-tank will change over time if you don't take care to keep its temperature constant between the time that you *start* filling and the time that you launch! So while it may at first seem a good idea to pre-chill the run-tank to get a good fill of dense liquid phase in there, after a couple of minutes of faffing on the pad the nitrous has warmed up and so everything's changed.

The nitrous is contained inside the fixed volume of the closed tank, and so it's mass can't change. So it's forced to self-adjust so that it can physically fit inside the tank as the densities of the two phases change with temperature. The way it physically alters the volumes of the liquid and vapour phases is that a rise in temperature causes some of the liquid to vapourise into vapour, whilst a drop in temperature causes some of the vapour to condense into liquid. This all occurs within your closed run tank and so you can't see it happening. Worse still, the total mass of nitrous in the bottle remains the same of course, so weighing scales won't pick up any changes in the proportion of liquid to vapour. Also, because pressure, temperature, and density are connected, if we cause big changes in *pressure* within our run-tank, either during filling, or when we empty its contents into the combustion-chamber, temperature changes will occur. And as we've seen, temperature changes cause the ratio of liquid mass to vapour mass in the run tank to change.

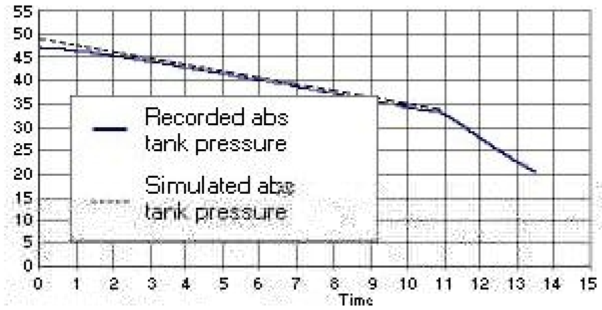
Several examples of this occur during hybrid operation: Firstly, the vent-hole works because the vapour-pressure inside the run tank is higher than the atmosphere outside, and so an outflow is established. The vent should either be of tiny diameter, or be a pipe with a restriction of tiny diameter somewhere along it. (0.3mm diameter is typical.) A wide vent is bad because it provides little resistance to the flow out of it, so the drop in pressure between tank and outside occurs more within the tank than within the vent hole. (electronics bods call this a Potential Divider). The nitrous responds to this low tank pressure by vaporizing its liquid away big-time. Moreover, the flow rate of nitrous leaving via the vent-pipe is much higher, so it'll all disappear after a short time. Also, a vent produces gas thrust like any rocket, so you want this small if it's venting sideways!

Similarly, when the run valve opens, (what I call the valve between tank and combustion chamber) the gas phase forces the liquid out of the tank aquajet-style, because the combustion-chamber connected below the tank is also at lower pressure. (unless you've made the nozzle throat too small!) As the tank empties, the liquid level obviously drops, so the volume available to the vapour phase above the liquid increases, so the vapour expands. And like any gas, it's pressure drops as it expands.

Whatever caused the vapour-phase's pressure to drop, venting or emptying, the pressure is now lower than it aught to be (it aught to be at it's vapour-pressure) and this drop in pressure is 'felt' by the liquid phase below it.

Some of the liquid phase will then vaporize in an attempt to create more vapour to raise the tank pressure back up to vapour pressure: the lower the pressure, the higher the vaporization rate.

Now the process of vaporizing liquid into vapour requires energy (called the latent heat of vaporization), and this energy has to come from somewhere. The heat energy required is drained from the nearest available source, which in this case is the remaining liquid nitrous itself, which therefore gets cooled. Oddly enough, my experiments and simulations show that the metal wall of a nitrous tank doesn't give up heat that quickly into the liquid even though you'd expect it to: the tank may be a conductor, but the liquid isn't. So the metal of the tank can be ignored as a heat-source for pressure changes, *provided* that they occur in a short time, say the 5 seconds or less that are typical of a hybrid firing. This cooling of the remaining liquid (and therefore any future gas to be vaporized from it's surface as the emptying progresses) means that the vapour-pressure (the tank pressure) will slowly drop over the burn time: burnout was at 11 seconds here, when the liquid phase ran out:



The lower the pressure drops below vapour-pressure, the more vapour is required to raise the pressure back up, and the more chilled the liquid-phase becomes as it provides this vapour. This is why leaks show up in any pipe-joints carrying the liquid phase of nitrous oxide as regions covered in ice; the nitrous sucks heat out of the atmosphere as it leaks out to atmospheric pressure and vaporizes, freezing the water-vapour in the air around the leak. It'll freeze your hands or face too if they're near a leak: **wear goggles and gloves when you work with nitrous**. So if you crank open the vent-valve (to the atmosphere outside) to huge diameter to do a quick fill, you'll lower the tank pressure way below vapour pressure, and so the nitrous will vapourise big-time, chilling itself seriously cold in the process as it drains heat from itself.

If the leak is plugged, for example by shutting a valve on the vent-line, or by shutting the run valve mid-burn, liquid will continue to vaporize inside until the vapour-pressure is restored. (albeit the lower vapour-pressure you get at a colder nitrous temperature.) Then as heat from outside *slowly* trickles back into the liquid through the tank walls (this takes a long time, so the tank *does* count), the vapour-pressure will slowly rise again until the liquid is back at ambient temperature, then no more heat can flow in. This can take a good 15 minutes for even small run-tanks though. If the nitrous was originally very chilled (from too fast a fill) an awful lot of it will vaporize during this time, so what started out as a run tank nearly full of liquid might well now be mostly vapour!

On the pad

Well, a quick recap of what all this esoteric physics means to us on the launchpad:

Hybrid Motors Taking off in 2002

1. If you plug the vent-hole after filling to get a higher tank pressure and so better performance, your tank better have a head-space or your innocent-looking run-tank may hydraulically overpressure (it go boom) several minutes after filling.
2. It is the liquid phase that we use in the combustion-chamber, so we want to preserve as much of this as possible. Though the gas phase will cause extra thrust after the liquid runs out, its thrust is very small.
3. Use a **small** vent-hole so that the run-tank fills **slowly**, or a lot of the liquid you put in there will have vaporized by the time you fire it, if it hasn't all leaked away out the vent.
4. If you fill the tank too quickly by cranking open the vent-hole, you'll over-chill the nitrous, so if you fire it straight away, you've got naff-all tank pressure which will reduce combustion-chamber pressure and so kill most of the thrust.
5. If you quick-fill and then wait several minutes before firing, then (assuming you've plugged the vent) there will be much less liquid in there than there was 5 minutes ago; it'll have vaporized into vapour form in the tank.
6. It may seem cool (sic) to pre-chill the tank to increase the density of the liquid phase to get a lot in there, but you'll get all the problems due to over-chilling mentioned in 3) 4) and 5).
7. If it's cold outside, warm the run-tank (remotely!).
8. If it's too hot outside, chill the run-tank to keep the liquid density reasonable, or even to prevent the nitrous going supercritical.

In UK rocketry terms, 2002 started off in style with a Hypertek J-class hybrid rocket launch by Pete Davy of Pete's Rockets, at Pete's Rockets in Heckington, Lincolnshire. The launch, on January the 1st, of a 54mm diameter, fibreglassed, PML Nimbus rocket kit on a Hypertek J-115 hybrid motor, blasted the rocket to over 5000 feet, before safely recovering (*using a Blacksky Research ALTACC altimeter / accelerometer*) via its 2-stage CPR system.

Pete Davy was at it again the following month, February, with a hybrid launch at the SWARM rocketry club at Folly Gate in North Devon, when he launched his PML Nimbus rocket again, this time on one of the new Hypertek 54mm diameter, I-class hybrid rocket motors, once again, using a Blacksky Research ALTACC altimeter/accelerometer, for 2-stage recovery. At the same launch event, Steve Gibbings of EARS blasted his modified PML kit, the NEO rocket, skywards on one of the new Hypertek J-330 hybrid motors with an extended oxidizer tank. This motor propelled the 2.6 inch diameter rocket to over 6500 feet! With a recovery using an AED Compact R-DAS flight computer.

March 2002 saw Pete Davy making yet another hybrid launch, once again, it was on his PML Nimbus using a Blacksky Research ALTACC altimeter/accelerometer for a 2-stage recovery, and again, on a Hypertek I-class motor. Also during March, Helen Green and Steve Gibbings of EARS each launched high power hybrid rockets, with Helen making 2 launches on RATTWorks hybrids, using a Blacksky Research ALTACC for recovery, and Steve making 1 launch on a Hypertek J-class hybrid, using an AED Compact R-DAS for recovery.

The EARS launch event in April 2002 was the venue for another 3 Hypertek hybrid launches, with launches of Hypertek J-class rockets by Chris Eilbeck of MARS (using 2 AED Compact R-DAS's for a flight of a 3 inch diameter rocket, with 2-stage recovery) and Steve Gibbings (using an AED Compact R-DAS for a flight of a 2.6 inch diameter rocket, with 2-stage recovery), and Helen Green of EARS (using a Blacksky Research ALTACC for recovery of a 54mm PML Nimbus).

Increasing the total number of hybrid rocket launches in the UK this year to 14 so far, was Richard Osborne, with 4 launches of his Scratch built, 4 inch diameter, Hades rocket, all 4 launches on a Hypertek J-250 hybrid motor, and all using an AED Compact R-DAS for recovery, 2 of the flights with single stage recovery, and 2 of the flights with 2-stage recovery.

It would seem that with the continued dearth of high power solid rocket motors in the UK, and numerous hybrid rocket launches planned, 2002 is shaping up to be the year of high power hybrid rocket motors

UKRA News

Launch Sites

---

by Charles Simpson

We all know how difficult it is to find a decent launch site. Many people have smaller sites but with the ever increasing number of us who wish to launch rockets at the larger end of the spectrum, the need for larger and more versatile launch sites becomes more and more pressing. There are many possible launch site sources to consider, some of which may not have occurred to some people. To aid with your investigations I have listed some suggestions below :-

1. Military / MOD (See below)
2. Local land owners (This will usually be the local farmer, but could however be a management group or consortium, depending on what part of the country you're from)
3. Old airfields (Usually in private ownership)
4. Beaches (You'll have to make your own enquiries on this one)
5. Government owned land

For the largest sites, the first and most immediate thought is to look to the military (MOD), and its is for that reason that I continue this article.

UKRA has a role to promote rocketry in its many forms within the UK. To this end, we would like to take this opportunity to ask all our members to inform the Safety and Technical Committee (sat@ukra.org.uk) if any members approach the MOD for the purposes of obtaining flying permission on any military range. This might sound at first reading as very authoritarian, however, all we're asking for, is for you to drop us a quick email or letter letting us know briefly what you're doing. The purpose of this is to keep UKRA informed so that in our own dealings with the MOD we are aware of

other groups activities. Also by acting as a hub for all information, the progress made by a few can be disseminated to all interested parties, benefiting everyone.

We have no interest in taking over unless UKRA's assistance is requested. In that case we are more than happy to offer any assistance we are able to give.

Council Meeting 24/02/02

Location

Cherry Willingham Community School, Lincoln

Attendees

Charles Simpson (CS - Chair), Mike Crewe (MC), Darren Longhorn (DL - Secretary), Liz Perman (LP), Cath Bashford (CB), Richard Osborne (RO), Pete Davy (PD), Steve Randall (SR) Hugh Gemmell (HG).

Agenda

- Apologies
- Minutes of previous meeting
- Mailing list
- European space festival
- Pete's permanent premises proposal
- UKRA 2002
- Insurance
  - UKRA insurance above M
  - Workshop insurance for UKRA members running these at Fete's etc.
- Big EARS
  - RSO Help?
  - What Kit can be borrowed?
- Certification on Clusters
- AOB
- DVNM

Apologies

Apologies were received from Ben Jarvis and Bob Arnott.

Minutes of previous meeting

The minutes of the previous meeting were read and approved. The list of action points was worked through, and progress noted.

Mailing list

CB suggested that we create mailing lists for various UKRA uses. CB stated that previously encountered problems could be avoided, if the same server was used as that which hosts the UKRA web site. It was agreed that we would try it again.

European space festival

DL reported that a French organisation had contacted UKRA about the possibility of attending a European Space Festival. It was agreed to maintain contact with the group and monitor developments.

Pete's permanent premises proposal

PD reported that the cost would be £100/month renewable on an annual basis. A vote was taken as to whether or not we should go ahead with the rental of the building. The result was - In favour 7, against 0, abstain 0. PD declined to take part in the vote. PD reported that work had begun, and that he would keep us informed as to progress.

UKRA 2002

PD reported that there was a good likelihood of Cesaroni sponsoring Hybrid and Pro38 motors for certification flights at UKRA 2002. It was suggested that other vendors may like to contact their suppliers to see if other sponsorships or raffle prizes could be provided. It was agreed that at least 30 benches would be required in the hut for UKRA 2002. PD proposed that fixed benches could be built around the walls, and other benches hired for the middle. PD reported that he had additional accommodation details for the event.

Insurance

UKRA insurance above M The current situation is that flights above M class may be insured by prior arrangement with our insurers. Members should approach S&T if this is required.

Workshop insurance Members seeking insurance for "rocket building workshops" should seek approval from the BMFA. They have been supportive of this in the past.

Big EARS

RSO Help? SR asked if UKRA could ask RSOs to consider helping out at the Big EARS event. This was agreed.

What Kit could be borrowed? It was agreed that Stakes, disclaimer posters and Radios could be loaned.

Certification on Clusters

SR had been asked by a member for the rationale behind the current limitations on clusters for certification flights. It was stated that there were two reasons. The first was to keep our certification procedure as close to TRA & NAR as possible in order to pursue UKRA/TRA cross certification. The second was for simplicity and safety.

AOB

Promotional materials

CB reported on a range of promotional materials. It was agreed that T-shirts were the most saleable, and that we should look more closely at these. It was agreed that the T-shirts should feature the UKRA name and logo in the new style, and would feature three colours (red/blue/white) on black or grey background.

PMR radio equipment

It was agreed that we were in need of approx. 8 radios and head sets to replace those previously loaned to UKRA by members.

DVNM

It was agreed that the next meeting would be held at Cheery Willingham School, Lincolnshire, on 06/04/02.

Meeting closed