Lunar Numbat: Open Source Goes To Space

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http://www.lunarnumbat.org

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What is Lunar Numbat?

- Lunar Numbat is an open-source space technology collaboration which was formed by a group of people from across Australia and New Zealand in 2009, with the intention of developing innovative, low-cost, open-source hardware and software solutions for space technology.
- Lunar Numbat hopes to encourage Australian and international innovation in space science and increase the accessibility of space development.
- The project was initiated in 2009 by Marco Ostini, and a review of Lunar Numbat work was presented at `linux.conf.au` by Jon Oxer in 2010. Since then, however, some significant milestones have been accomplished.

What We Do

- The focus of our research and development at present is in three main areas: rocket engine throttle control avionics, radar altimeters, and media compression.

- Linux, open hardware, open software development, open documentation, open standards, and community-driven collaboration all have an important role in meeting Lunar Numbat's challenging goal of delivering flexible, useful space technologies at a relatively low cost.

- Lunar Numbat is collaborating with the Australian Space Research Institute (ASRI), and with White Label Space, a team competing for the Google Lunar X-Prize.

AUSROC 2.0 / 2.5

Figure: The AUSROC-2 launch vehicle on the launch rail, being loaded with liquid oxygen prior to launch.

Australian Space Research

- We're now completing the development and testing of the CAN-interfaced propellant valve throttle controllers we have developed for AUSROC 2.5, a powerful liquid-fuelled sounding rocket developed as part of ASRI's AUSROC program.

- 7.5 meters tall
- Liquid-fuelled: kerosene and liquid oxygen
- Peak velocity $= 1100\ \mathrm{ms}^{-1}$ (Mach 3.3)
- Apogee at about 33 kilometers (110,000 feet)
- Thrust $= 35$ kN; $\mathrm{I_{sp}} = 240$ seconds.

AUSROC 2.5

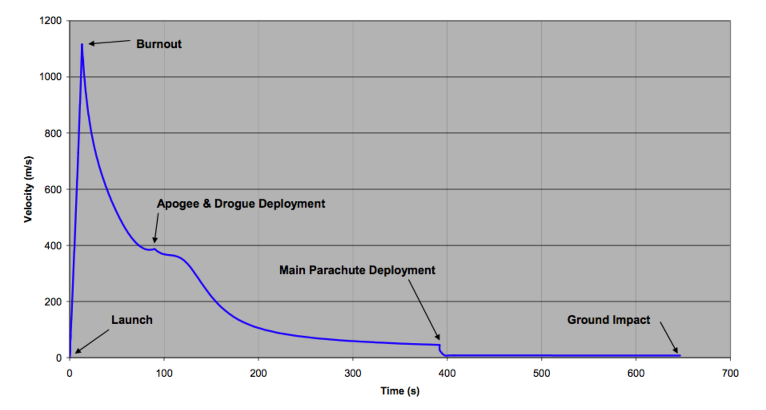


Figure: Simulated velocity profile for AUSROC 2.5 flight.

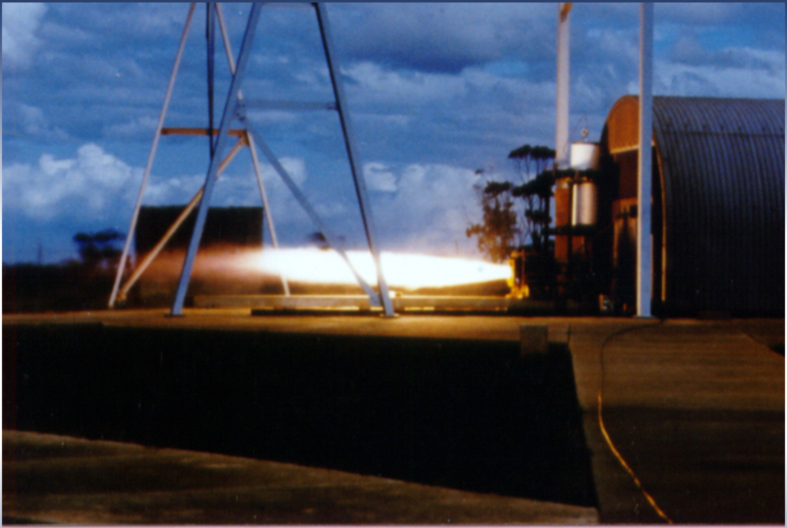


Figure: A static test firing of the AUSROC 2 rocket engine.

ASRI activities

- We are providing ASRI with innovative, low-cost open source solutions to meet the needs of Australia's own in-house space launch vehicle research and development.
- In the process, we're making a positive contribution back to Australian space research, which is greatly in need of Australia's support.

Figure: One of ASRI's solid fuelled Zuni rockets being launched.

Engine throttle controllers

- We are designing and implementing electronic controllers for the valves admitting fuel and oxidiser to the liquid-fuelled rocket engine on AUSROC 2.5.
- This electronic control over the propellant valves allows the flight computer to throttle down, stop and restart the rocket engine, as well as to adjust the fuel-oxidiser ratio on-the-fly.
- These throttle controllers embody a combination of open electronic hardware, open-source embedded software, and some open mechanical design.

Open Software and Open Hardware

Free is good - GNU and TAPR licenses

- TAPR Open Hardware License - `http://www.tapr.org/ohl.html`

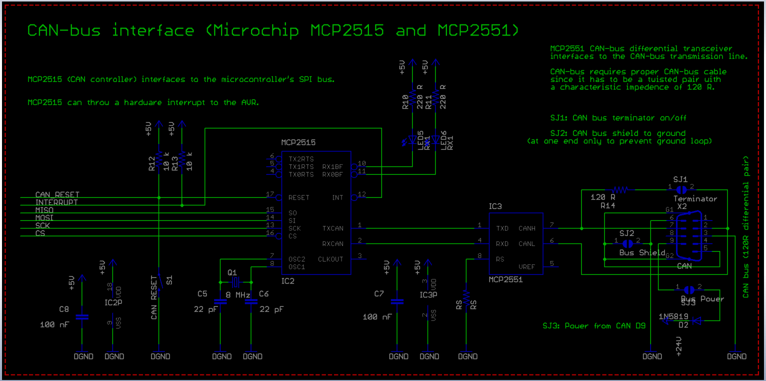


Figure: The CAN interface component of our protoype engine control hardware.

Mechanical Assembly

- A pair of stainless steel ball valves, rated for cryogenic oxygen service, are used for the fuel and oxidiser.
- A pair of powerful DC brush motors and reduction gearheads move the valves, with a pair of position sensors to measure the absolute valve positions.

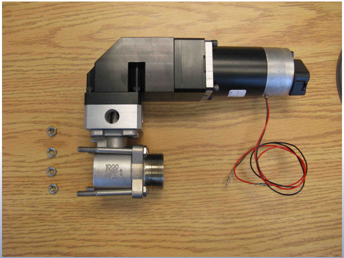


Figure: The liquid oxygen valve assembly for AUSROC 2.5, including the ball valve, reduction gearhead and motor.

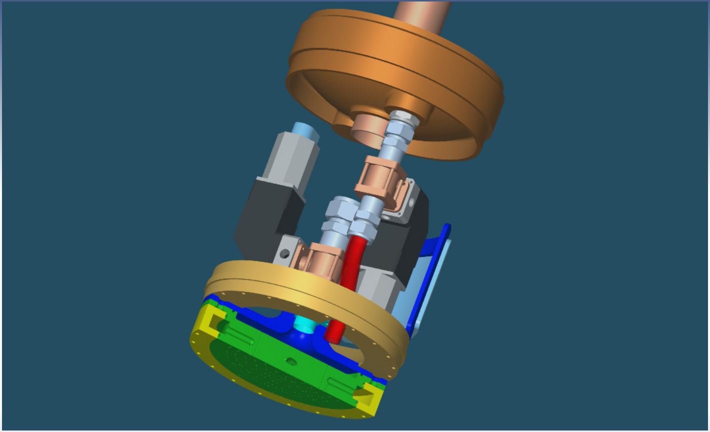


Figure: The overall assembly of the AUSROC 2.5 valve fairing.

Throttle Controller Electronics

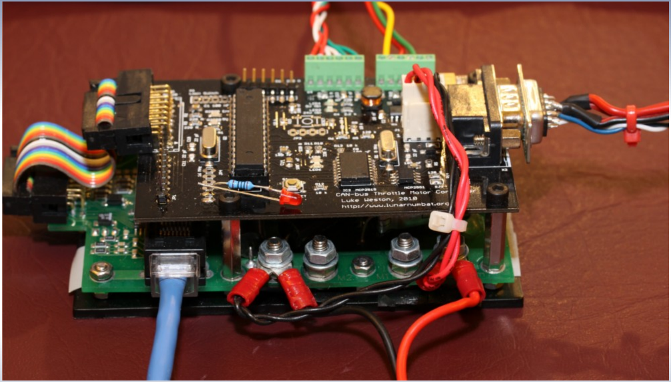
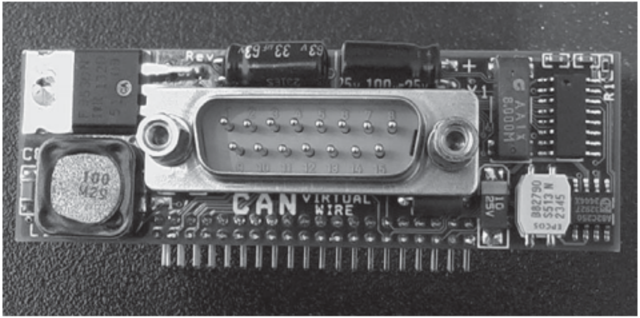


Figure: The first generation valve control electronics for the kerosene valve of AUSROC 2.5.

CAN Interface

- CAN-Do! is a general purpose CAN interface module designed for use on satellites and spacecraft.
- Designed by a group within the AMSAT community, led by Bdale Garbee.
- Based around the Atmel T89C51CC01 (8051 core).
- Already basically space-rated; tested for thermal and ionising radiation tolerance.
- Open source!
- An excellent starting point for White Label Space, perhaps!

CAN Interface



Circuit Board Showing Sub-D Connector

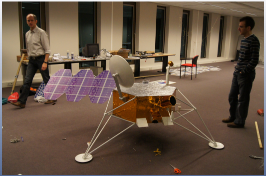
Figure: An example of the CAN-do! hardware.
`http://can-do.moraco.info/Default.htm`

White Label Space

- Such systems will possibly be evolved further and applied on the White Label Space lunar lander. The ability to throttle the descent engine is essential for a controlled lunar landing.

  What is White Label Space?

- One of the teams in the Google Lunar X-Prize.
- The only team with any significant Australian involvement.
- Significant international partners in space technology, including people from ESA and the Swiss Propulsion Laboratory and people from Tohuko University with experience on the Hayabusa mission.



Google Lunar X-Prize

- US$20 million prize for the first non-government mission to land a spacecraft on the surface of the Moon, travel over 500 meters on the lunar surface, and transmit images and data back to Earth.

C-band Radar Altimeter

- We're also in the early stages of developing a radar altimeter for White Label Space. We're working to develop a relatively simple, low-cost radar altimeter, with the altitude range and resolution required to support the landing of an unmanned probe on the lunar surface.
- For a successful landing on the moon, a lander needs to know its altitude above the lunar surface precisely, and the only means to do this is by radar.
- This unique use case requires a radar altimeter with large altitude range and high resolution, and no radar hardware suitable for this application is available off the shelf.

C-band Radar Altimeter

- The radar system we are in the early stages of developing will operate in the C-band, at about 4.3 GHz, and will probably be based around an ARM microcontroller controlling the microwave heterodyne system.
- The microwave component of this system will be constructed using high electron mobility transistors (HEMTs) on a Teflon or similar PCB substrate with good microwave performance, using microstrip technology.
- This radar altimeter designed and built by Matjaž Vidmar and completely open-sourced onto the Web is very similar to the kind of radar system we are aiming to implement - although our system will have a greater range and RF power output.

C-band Radar Altimeter

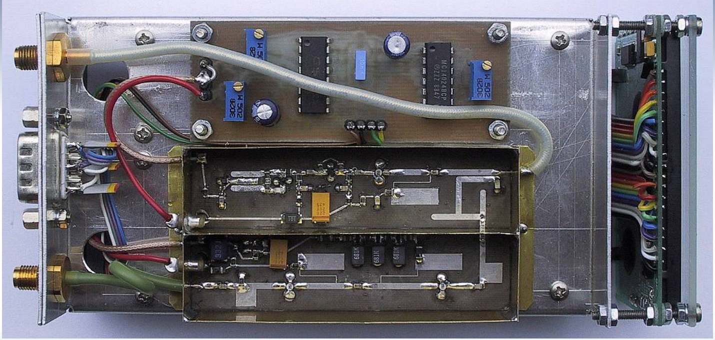


Figure: A microwave radar altimeter designed and built by Matjaž Vidmar for use on a small aircraft.
See `http://lea.hamradio.si/~s53mv/avnr/adesign.html`

HD Video and Still Compression

- We're developing systems for rapid, on-the-fly compression of high-definition video and still images, suitable for the transmission of high-definition images from spacecraft where very limited amounts of communications bandwidth are available.

- This will be important, for example, on lunar rovers participating in the Google Lunar X-Prize, since video and image transmission is a key requirement of the GLXP.

- In particular, we're investigating JPEG2000 and MJPEG2000 (Motion JPEG)-based systems. A proof-of-concept - "JPEG2000 Decimator" - has been experimented with so far.

- This video and image processing will require moderately powerful embedded computers running Linux, and/or FPGAs, which will operate successfully for the mission duration required in the thermal and radiological environment of the lunar surface.

Questions?

Thanks!

Many thanks to:

- Marco Ostini
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- Stuart Young
- Joanna Cheng
- Andy Gelme
- Roy Duncan
- Mark Blair
- Jon Oxer
- Lee Begg

Radiation Hardening

- It is true that you can't just take any system using modern microcontrollers and VLSIs that you've designed for use inside the atmosphere, launch it into space and expect that it will work reliably on an ongoing basis.
- However, it **is** practical to build electronic systems using standard off-the-shelf components which can survive and operate in space, without spending hundreds of thousands of dollars on "real" radiation-hardened embedded CPUs such as the IBM RAD6000 or RAD750.
- When we look at the amateur satellite community, for example, we find a good deal of experience and prior art designing electronics systems for use on satellites, which operate reliably in space for an extended period of time, which are designed and implemented at relatively low costs, using relatively simple electronics.

Radiation Hardening

- There's nothing "magical" about the environment of space. We know what the conditions of temperature and ionising radiation experienced by a spacecraft will be, and we can design space systems to ensure reliability for the mission profile required.
- When Apollo astronauts travelled to the Moon, for example, the ionising radiation doses they received were recorded on their personal dosimeters.
- As transistor integration density becomes higher and higher on modern VLSI chips, the transistors themselves are fabricated smaller and smaller, and therefore, the gate capacitance of the transistors becomes smaller and smaller.

Radiation Hardening

- Since $\mathrm{C} = \frac{\mathrm{Q}}{\mathrm{V}}$, the smaller gate capacitance means that the voltage spike that results when a charged particle (such as an electron or proton) carrying a certain quantum of charge hits the transistor's gate is much larger. This is why VLSI devices are more susceptible to radiation-induced soft errors than older devices with lower integration density.
- Radiation-hardening was actually less of a challenge in the Apollo era than it was today. The higher the transistor density on an IC, the more susceptible to radiation effects it is. The magnetic-core memory and primative integrated circuits used on Apollo were not susceptible to radiation effects, whereas modern microprocessors and memory devices are.
- The simple RTL logic gate ICs used to build the Apollo Guidance Computers contained a whopping 6 transistors on each chip. For comparison, today, an ARM7 chip contains about 600,000.

Smaller-Scale Integration

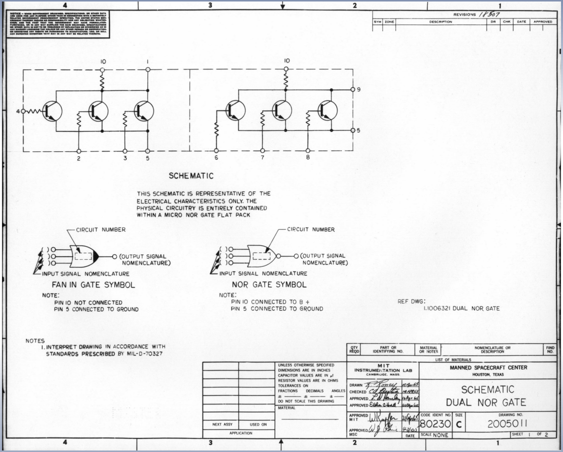

Figure: Six transistors on a single chip!

Radiation Hardening

- FPGAs can be configured with soft cores designed to be radiation tolerant; eg. redundancy to tolerate cosmic-ray bit flips.
- The Cibola satellite developed several years ago at Los Alamos will validate the space use of commercial, off-the-shelf Xilinx FPGAs.
- The Cibola team has been actively testing Xilinx FPGAs since 1999, to evaluate the use of off-the-shelf FPGAs in the space radiation environment.