



# 5 SECONDS TO MARS

TOUCHDOWN ON THE RED PLANET

Description, Rules and Procedures v0.3 20210413

## Task Description

The Australian Space Technology Research Organisation (ASTRO) is sponsoring Australia's first manned expedition to Mars. The mission plan will have the spacecraft set down in the *Elysia Planitia* lowlands, at a landing site pre-levelled by a previous autonomous rover mission. Though manned, the spacecraft's descent will be entirely autonomous, with no human intervention except to activate the abort mode. The spacecraft's high weight prohibits relying solely on parachutes or cushions as deceleration systems; one or more thrusters must be used, with or without other systems.

Your task is to build a powered descent-arrest system for the spacecraft's terminal landing phase. The spacecraft is to release from its service module, then descend through the atmosphere under gravity, decelerate and touch down in the centre of a clear, level, flat platform. Given the presence of a human crew, the landing must be as gentle as possible, and ideally as close to the centre of the designated landing zone. The spacecraft shall carry an instrument package to measure barometric pressure, temperature, and acceleration during descent. The spacecraft must also carry a separate (provided) G-sensor to measure and indicate the maximum deceleration detected during landing, and thus determine the health status of the crew.

The spacecraft must stow in a compact configuration for launch, within the volumetric limitations of the launch vehicle fairing. The descent must be slowed with a propulsion system capable of developing less than 1 G of static thrust; the propulsion system may only consist of a ducted fan - open rotors are strictly prohibited. Only ducted fans available commercially as an integrated fan-and-duct unit **or as independent fan/duct parts designed to interoperate** may be used. As a safety precaution, the fan system must never be operated without the duct in place.

A remote off-site 'mission control operator' team member must receive telemetry from the spacecraft, extract and record the measurements and produce a plot of the atmospheric pressure, temperature, acceleration and orientation as a function of time during descent.

All-up system testing will occur during scheduled demonstration sessions in week 13. There will also be incremental demos in weeks 7, 9 and 11, allowing partial functionality to be demonstrated. Be aware that this project specification **will** be updated through the course of the semester, with at least one guaranteed project specification change, requiring your design to be flexible to accommodate changes.

## Testing Procedure

During testing, the spacecraft will be held at a known height of at least 10 m above the landing platform with an unknown offset of <2 m lateral error, affixed to the service module

adaptor. The mission control operator will connect to the spacecraft and instruct it to prepare for landing. The adjudicator may request that the abort modes be demonstrated in situ prior to attempting a landing. When ready, the remote operator will instruct the spacecraft to detach from the service module and begin descending. The spacecraft is to descend entirely autonomously, with no operator intervention or input until the spacecraft has landed. If during descent the adjudicator instructs an abort, the spacecraft must immediately kill its thruster and deploy any other descent-arrest systems. The spacecraft's performance will be evaluated on its accuracy in landing on target, and on the gentleness of touchdown, as well as demonstration of key capability milestones. The spacecraft is considered to have landed when it is at force and energy equilibrium, at zero velocity. Bonus consideration shall be given if the spacecraft is able to land upright, centred on the target, without exceeding 2 G of acceleration.

Each demonstration session will run for 25 minutes, during which students must complete all required setup and make up to three landing attempts. After 25 minutes or three attempts, the students must cease operations and will have 5 minutes to pack down and clear the testing area, ready for the next team. The time-limits and attempt limits will be rigorously enforced. If the adjudicator instructs an abort, the aborted attempt will not count towards the three attempt limit. Build quality may be assessed at any time during the testing slot.

### Scoring

Task performance will be assessed by a points system based on demonstrated performance and build quality. Refer to the separate build quality rubric and guidelines for build quality specifications. Only the performance of the overall system will be considered; no part will be considered separately. All basic functionality must be demonstrated before marks will be awarded for precision or acceleration performance. Systems which do not meet the construction and budget requirements will not be eligible for anything but basic functionality and build quality points.

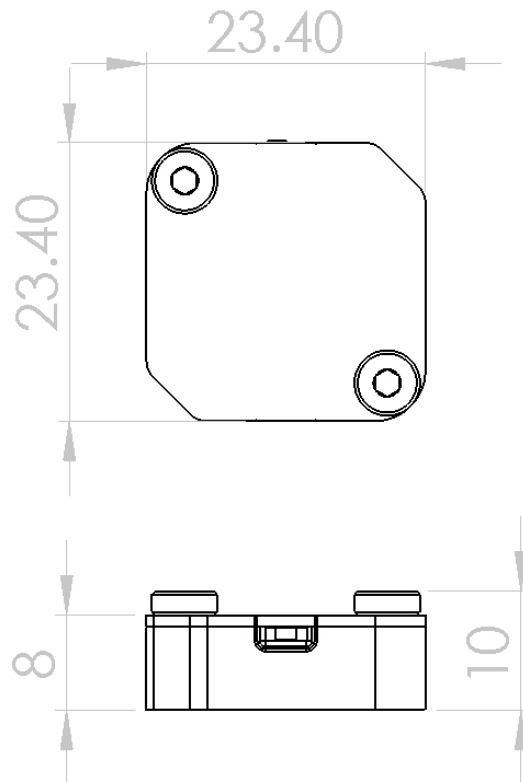
|  |                     |
|--|---------------------|
| <b>Build Quality</b>                                     | <b>10/10 Points</b> |
| <b>Basic Functionality</b>                               | <b>40/40 Points</b> |
| The thruster activates on command                        | 10                  |
| The arrest system deploys                                | 10                  |
| The on-board sensors read meaningful data                | 10                  |
| Telemetry data is received and plotted by ground control | 10                  |
| <b>Landing Precision</b>                                 | <b>30/30 Points</b> |
| Space craft lands upright                                | 4                   |
| Space lands on landing pad                               | 8                   |
| Space lands within 0.66 m of target                      | 4                   |
| Space lands within 0.33 m of target                      | 6                   |
| Space lands on target                                    | 8                   |
| <b>Landing Acceleration</b>                              | <b>20/20 Points</b> |
| Spacecraft does not exceed 16 G                          | 2                   |
| Spacecraft does not exceed 8 G                           | 4                   |
| Spacecraft does not exceed 4 G                           | 6                   |
| Spacecraft does not exceed 2 G                           | 8                   |
| <b>Bonus Functionality</b>                               | <b>10/10 Points</b> |
| Upright, centred, <2 G landing                           | 10                  |

If the adjudicator determines that a spacecraft exceeds the allowable (and legally significant) weight or thrust limits, or is in any way unsafe to operate, they may decline to test the craft and scoring shall be limited to build quality and basic functionality only.

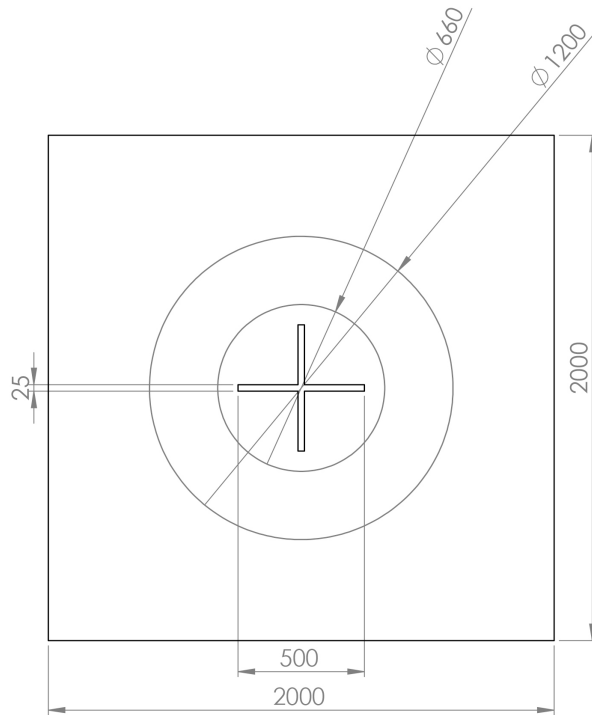
### Apparatus

The provided apparatus consists of three components: the inertial measurement package, a landing pad, and the service module adaptor.

The inertial sensor uses red, amber and green lights to indicate the maximum acceleration it has measured since arming. The inertial sensor will be self-powered and ~~be no larger than 25 x 25 x 10 mm. More details of the inertial measurement package will be made available later in the project.~~ will consist of a 23.4 x 23.4 x 8 mm module, with two screw heads that protrude an additional 2 mm. The mass of the unit will be less than 10 g, excluding Velcro. The top surface of the unit (the surface with the screw heads) will allow light from the internal indicator lights to be displayed in the centre of the unit and must be visible during testing. The unit shall incorporate hooked Velcro fabric on its bottom surface for mating with fuzzy Velcro fabric.

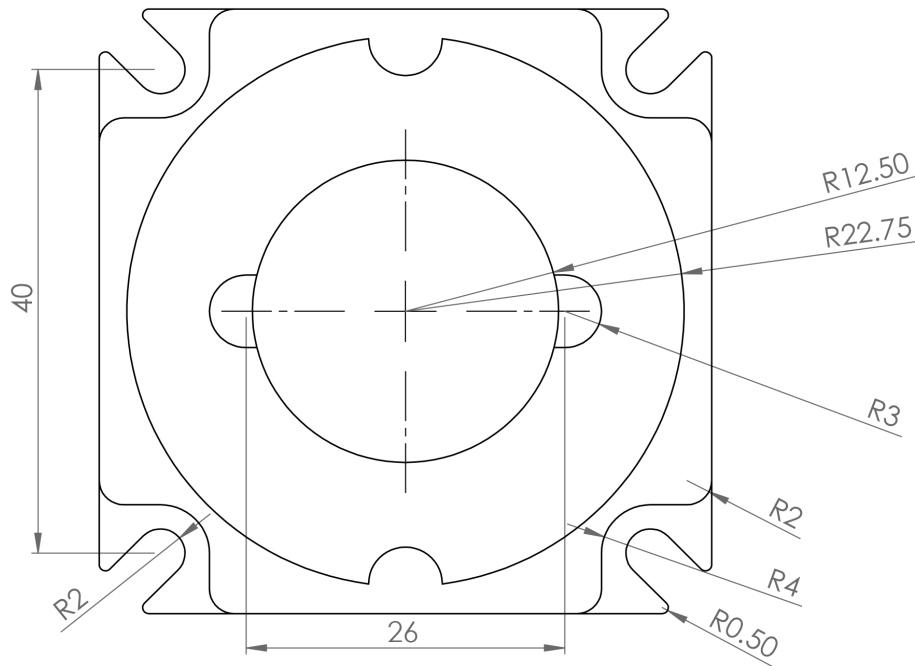


The landing pad is a 2 m x 2 m flat platform constructed from smooth material (eg. particle board, laminate, or plywood), with a high-contrast 0.5 m x 0.5 m reticle in the centre painted with lines no less than 25 mm wide. The colour of the landing surface and reticle are not specified.



Landing platform target geometry (top view)

The service module adaptor is a mechanical structure that spacecraft must be rigidly connected to during the transit to Mars. The spacecraft must disconnect itself from the adaptor in order to commence descent to the surface. During testing, the service module adaptor shall be oriented downward, with the spacecraft slung below it, to facilitate deployment. See the detailed drawing document for full part specifications.



Service Module Docking Adaptor (bottom view)

# System Design Guidelines

Each team must construct a spacecraft descent-arrest landing system using a limited budget. At least one component must be machined from metal, using milling, turning, water-jet cutting or any combination thereof. At least one custom PCB must be produced. The adjudicator shall be the final arbiter of whether any part of the system, or the system as a whole, is legal within the guidelines. Students may provide their own laptops or desktop computers, which do not count towards size or budget limits.

## Modularity and stand-alone testing

The mechanical and electrical interfaces between each subsystem must be fully-specified and documented, with sufficient detail to allow a third-party to design a system to interoperate with them. Each component should be capable of demonstrating functionality in isolation when provided with power and control. The descent system is considered to be hardware used for controlling the velocity and trajectory of the spacecraft in the air, including structures such as aerodynamic devices; the arrest system is considered to be hardware used for bring the spacecraft to a halt, including structures such as landing legs. These need not be separate or distinct systems.

## Construction

### *Dimensions*

The complete spacecraft system must be sized to fit inside a standard box: the entire system, including all support equipment (except laptop/desktop computers), must fit inside a ~~typical shoebox~~ BX3 or BXP3 Australia Post (or other equally-sized) mailing box<sup>1</sup> for final submission. The system may be partly deconstructed to fit in boxes, with the understanding that students must reconstruct it during the strictly time-limited testing slot for the final demo. Students are strongly advised to design their system with the boxing requirement in mind.

The spacecraft's mass may not exceed 250 g, and must be sized to fit within the launch vehicle's payload bay (excluding the service module adaptor). The launch mass limit is a legal CASA limitation and will be absolutely enforced: no flight testing of any sort may be carried out with a non-compliant spacecraft. There must be space to securely mount the instrumentation unit on the exterior of the spacecraft, such that its status LEDs may be easily observed after landing.

The spacecraft is to be labelled with clear markings indicating which orientation of the spacecraft constitutes "up" for the purpose of assessing an upright landing; if none is specified, or if the orientation is insufficiently specified, then the adjudicator may apply such markings as they see fit.

The spacecraft is to be entirely self-contained during flight, and may not be attached to any wires, cables or links connected to ground.

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<sup>1</sup> This was changed due to abuse of the definition of what constitutes "shoebox" by previous students. Suffice it to say, if you have to redefine commonly understood terms of reference to make your design meet the specification, your work is probably not going to pass muster.

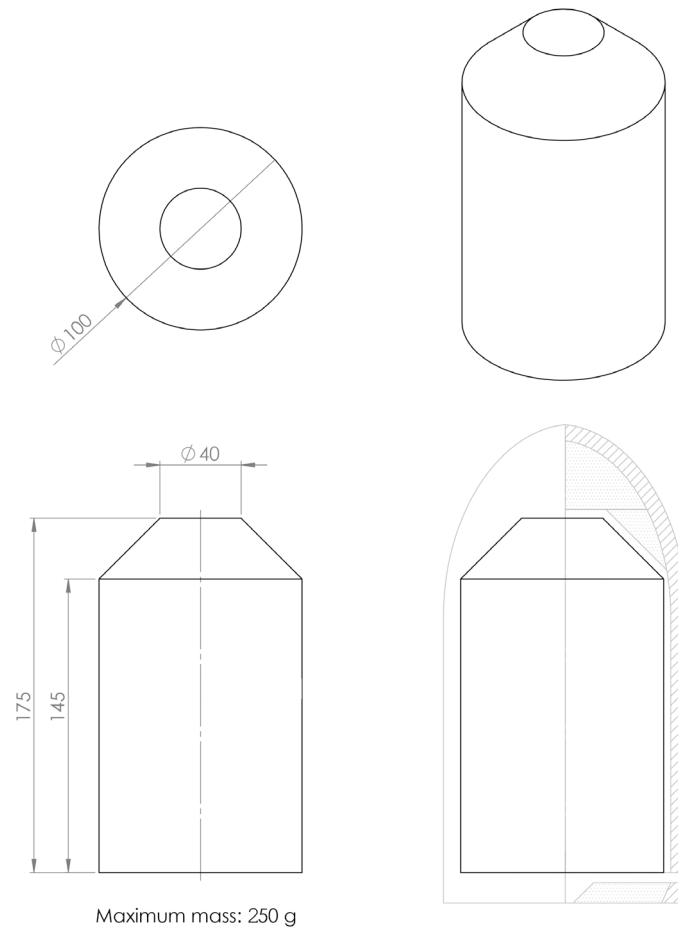


Figure 3: Permissible stowed spacecraft convex hull and COG location

### *Control*

The spacecraft must be autonomous during the descent phase, though it must be capable of receiving and executing an abort command from both the mission control operator and separately by the team on-site. Prior to descent the abort modes, telemetry systems and any deployment functions must be demonstrable to validate operation of the craft. For this reason, deployable systems should be capable of being rapidly reset in preparation for testing. Computer mice and keyboards are considered part of the computer system provision and do not count towards the budget; handheld control interface components such as joysticks, gamepads or space mice are not considered part of the computer, and must be accounted for.

The abort mode must act instantaneously to kill power to the ducted fan and deploy any parachutes or airbags incorporated in the design.

### *Power Sources*

Energy sources for the system are limited to wall plug power packs (for ground systems), or charged electrical devices and stored elastic energy; no stored gravitational, kinetic, nuclear or thermal or other chemical energy systems may be used. Exceptions may be granted by the course coordinator on a case-by-case basis. For safety reasons, any proposed elastic energy storage device must be approved by the adjudicator. **Li-poly batteries may total no more than 15 kJ maximum energy capacity.**

### Processors and programming

Pre-fabricated processor and computer modules may be used. However, due to abuse by previous students, no Atmega 324/328 processors may be used, and Arduino software (IDE, scripts etc) is strictly prohibited. Exceptions may be granted by the course coordinator on a case-by-case basis (for example, a commercial product that incorporates a 328P processor, but which is non-reprogrammable). It is strongly recommended that teams program using C.

The spacecraft flight control system will be exposed to a deep space environment. As such, the mission-critical systems must be controlled by a “management microcontroller” that is available in a space-rated version. The management microcontroller must be able to power cycle the orientation control, telemetry and imaging subsystems on command from the ground station. The specific part used and budgeted does not, itself, have to be an actual space-rated device – but that model of microcontroller must come in a space-rated version with identical performance specs. Other controllers used within the various subsystems do not need to be radiation hardened.

### Budget

The total cost of materials, parts and components incorporated in the product shall be no more than \$400 (excluding laptop/desktop computers). Regardless of actual cost to construct, the team must demonstrate that the product produced *could* be constructed from parts costing less than or equal to \$400. Up to \$400 will be provided for purchase orders through ETSG.

**Reimbursements will *not* be permitted.**

Cost of parts shall be calculated on a per-item basis; parts that are purchased in multiple units may be costed per unit – e.g. a bag of 10 nails for \$10 may be charged at \$1 per nail used. Bulk unit discounts from suppliers may be applied, provided the quantity of items used in the product is sufficient to earn the discount. Items sourced for free (i.e. not paid for) may be costed at half the market purchase price. Circuit boards must be purchased via ETSG in order to be paid out of budget.

~~Each team will be provided with 500 g of 3D printer filament in a specified colour. Once this material has been exhausted, no further filament will be provided or nor may be purchased with the build budget. Only the provided filament may be used in submitted work, where permitted. The cost of provided filament does not count towards the budget total.~~

### Specific Prohibitions

- **No unshielded propellers, rotors or fans**  
**At no point during the semester may any spinning propulsive element be energised outside of a safety duct.** This rule will be *strictly enforced* as part of the lab safety requirements. Failure to abide by this rule will lead to immediate barring from the lab for the remainder of the semester.
- ~~**No internet connection**  
No part of the system may be connected to the Internet. Where WiFi or similar wireless protocols are used to connect between submachine systems or another computer, it must be demonstrated that no computer on its network is connected to the Internet. The instructor may elect to have the connection status of any input device demonstrated prior to testing. The instructor shall be the final arbiter of whether a connection constitutes connection to the Internet.~~

- **No alterations**

No permanent alterations may be made to the landing pad or service module docking adaptor. Spacecraft that cause damage to the pad or service module docking adaptor may be prohibited from operating.

## **The Aim of the Project and the Spirit of the Rules**

Without a doubt, engineering students are extremely creative and talented at finding clever solutions to difficult problems. This project aims to teach you about the practical trade-offs encountered by engineers when facing a multi-faceted challenge with broad scope and many possible solutions. It is recognised that no set of rules could cover every possible edge-case without becoming cumbersome fodder for 'rules lawyers'.

Thus, the two cardinal rules are:

1. The instructor's decision is final.
2. Stay within the spirit of the problem.

If you think what you are attempting might not be in accordance with the spirit of the rules, there is no harm in asking! The instructor will rule whether a particular approach is permissible. Obviously, it is best to ask these sorts of questions early in the semester and before committing to a particular solution!

## Other Miscellanea

By-laws, clarifications and addenda go here. This used to be a short section, but previous years' students have shown that it is *depressingly* necessary to spell-out exactly what you should not be doing. But you're going to be smarter and better dressed than them, *right?* ☺

1. All OH&S inductions and procedures *must* be adhered to. You **WILL** be ejected from the lab if you are unsafe or in violation of footwear requirements. Repeat offenders will be barred from the teaching labs for the remainder of the semester.
2. It is the responsibility of all students to keep the teaching labs in clean, functioning condition. Lab cleanliness will be arbitrated by a warning system, as posted on the class blackboard site and class website. All detritus and debris must be collected and cleared.
  - a. The lab status starts at GREEN.
  - b. If the condition of the labs deteriorates and becomes messy, status will change to YELLOW, indicating that a clean-up is needed.
  - c. If conditions do not improve or deteriorate further, the status will be changed to RED and the labs will be set to fixed-hours, with after-hours access prohibited.
  - d. If conditions still do not improve or deteriorate further, the status will be changed to BLACK and the labs will be locked to students until the next practical session, whereupon the labs must be completely cleaned before any non-cleaning work may resume.
3. The following are specifically prohibited inside the lab:
  - a. Eating or drinking in the lab (including water), or having food or drink outside of a backpack or bag.
  - b. Sleeping in the lab
  - c. Leaving the lab door open (all students have access cards)
  - d. Giving non-enrolled students/non-students access to the lab
  - e. Non-work related activities (e.g. computer games)

Students found to be violating these rules will have lab access revoked.

4. Under no circumstances may project infrastructure, test equipment, tools, supplies, furniture, etc. be removed from the teaching labs. 'Vegas rules' are in effect: what happens in c404 *stays* in c404. Transgressors will be barred from the teaching labs for the remainder of semester.
5. No grade will be awarded until all assigned tools and equipment are returned and accounted for. Students are separately and collectively responsible for their group's tools.