STUDENT ASSESSMENT IN TEAM PROJECT-BASED LEARNING: CHALLENGES AND EXPERIENCES

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Abstract

The final year of the Bachelor of Aerospace Engineering degree at RMIT University includes a capstone aerospace design project involving student teams working together to develop a concept solution to a given requirement. Project-based learning (PBL) is an important part of engineering education where student teams work together to achieve a common objective and acquire a deeper knowledge through active exploration of real-world challenges and problems. In industry, engineering projects are a collaborative effort of a team of professional engineers, managers, regulators, finance officers, etc. and by replicating this environment in education students learn how to work with fellow students, who have different skills, abilities, motivation, enthusiasm, work ethics and drive, to solve a real-world problem. Although it is generally accepted that this experience is very valuable in preparing students for the workplace, the challenge from a course coordinator's perspective is how to manage these groups and how to determine a transparent and fair assessment scheme. This paper introduces some of the challenges of individual student assessment in group projects and will give an overview of some of the techniques applied in tertiary education, supported by the experiences at RMIT University with the capstone aircraft design project.

Keywords: Project-Based Learning, problem solving, aerospace design project, assessment.

1 INTRODUCTION

Engineering design projects are complex in nature. A typical aircraft design project takes about 5 years or more and will involve engineers, scientists and managers from a wide range of disciplines. For the design team to develop a competitive product, a clear and well-managed process is critical. As part of their education, aerospace engineering students learn about all disciplines that are relevant to the design, development and operation of aircraft. However, this does not necessarily make them good problem solvers or excellent team players. When they join the workforce, they will eventually be given a problem-solving task, where domain knowledge is essential but not sufficient. Engineers need to be able to manage problems, usually as an effective member of a team. They must be able to think critically and creatively, share thoughts and opinions, use good judgment, and make decisions.

Although expert problem-solvers come through experience, graduate engineers need to be aware that real-world engineering is problem solving and what typical processes are followed.

An essential topic is the five steps CPS approach:

1. Customer requirements: What are the customer requirements? Who are the stakeholders? What are the objectives and constraints?
2. System requirements: How do the customer requirements translate into technical requirements?
3. Conceptual design: Generate several concept solutions, including creative and innovative ones, and downselect based on feasibility, affordability (life-cycle cost), support, competitiveness, etc.
4. Detail design: Progress a small number of concepts to detail design.
5. Verification: Select the final solution. Does it meet the system requirements?

A complex engineering project is generally conducted by a team of engineers, scientists and managers. Multi-disciplinary teams provide domain knowledge in various technical disciplines, such as aerodynamics, loads, structures and materials, systems, propulsion, performance, etc. The graduate engineer will be a participant in a larger team, which introduces the requirements for communication skills and being effective team player.

Are graduates ready to address real-world problem solving? Are they able to ask the right questions? Are they able to formulate system requirements? Do they understand the context, i.e. regulations, safety, reliability, cost?
Project-Based Learning (PBL) is an important part of engineering education where student teams work together to achieve a common objective and acquire a deeper knowledge through active exploration of real-world challenges and problems. PBL is an activity in which students work together to solve a realistic, engaging and complex question, problem or challenge. The student gains knowledge and skills by “doing” and include Essential Project Design Elements:

- **Key Knowledge, Understanding, and Success Skills** - The project is focused on student learning goals, including standards-based content and skills such as critical thinking/problem solving, communication, collaboration, and self-management.

- **Challenging and Authentic Problem or Question** - The project is framed by a meaningful problem to solve or a question to answer, at the appropriate level of challenge. The project features real-world context, tasks and tools, quality standards, or impact – or speaks to students’ personal concerns, interests, and issues in their lives.

- **Sustained Inquiry** - Students engage in a rigorous, extended process of asking questions, finding resources, and applying information.

- **Decision Making** - Students make some decisions about the project, including how they work and what they create.

- **Reflection** - Students and teachers reflect on learning, the effectiveness of their inquiry and project activities, the quality of student work, obstacles and how to overcome them.

- **Critical Review and Improvement** – Students reflect on their work and processes. They receive and use feedback to improve their process and products.

- **Presentation** - Students make their project work public by explaining, displaying and/or presenting it to people beyond the classroom.

The final year of the Bachelor of Aerospace Engineering degree at RMIT University includes a capstone aerospace design project involving student teams working together to develop a concept solution to a given requirement. In industry, engineering projects are a collaborative effort of a team of professional engineers, managers, regulators, finance officers, etc. and by replicating this environment in education students learn how to work with fellow students, who have different skills, abilities, motivation, enthusiasm, work ethics and drive, to solve a real-world problem. Although it is generally accepted that this experience is very valuable in preparing students for the workplace, the challenge from a course coordinator’s perspective is how to manage student groups and how to determine a transparent and fair assessment scheme.

## 2 CAPSTONE AEROSPACE DESIGN PROJECT

The capstone aerospace design project in the final year is preceded by a formal design course where students learn what design is, the steps in a typical design process, available resources, multi-disciplinary design, etc. This course includes assignments involving research of a design related topic, estimating initial aircraft weight and aircraft sizing. The capstone aerospace design project runs during the first semester of the final year of study (12 weeks). The associated workload is about 144 hours, which is includes 2 hours per week face-to-face lectures/tutorials and about 10 hours per week student-directed learning through project meetings.

### 2.1 Group selection

Group selection may look like a simple task, but it is a sensitive process as far as students are concerned. There are several ways groups can be formed, each with their own pros and cons. The course coordinator can form groups randomly, which would reflect the situation in the workplace where you have to work with your colleagues. There are two disadvantages to this approach:

1. Groups will include students of varying skill level. High performing students do not like their grade being affected by less performing students. Although this could be managed through individual assessment, as discussed in section 4, the perception remains that the groups will not do as well or the project will not be as satisfying with students of similar skill level.

2. Groups need to choice their design project, which will be more difficult to get a group consensus if students are selected randomly. This could be managed by having all students declare their design topic preference in advance and take this into consideration when forming groups.
Increased workload for the course coordinator, who may need to manage change requests after groups have been formed.

Alternatively, students can be allowed to form their own group, which is the easiest option, but it will obviously result in friends sticking together. Less performing students may find it hard to be accepted in a group.

Once a group has been formed, the student members must determine a project management organisational structure that must include a project leader. The project manager has an important role in coordinating the design process, allocating tasks, ensuring that the team remains on track, etc. Because of the special role, the project manager is assessed on managerial and leadership qualities.

2.2 Project Schedule

Each group is assigned to an academic advisor, who gives guidance and advice to support the group. The advisor, in general, does not direct, assign or demand, but acts a sounding board and give critical feedback on suggestions, ideas and work done. This gives the teams the freedom to make their own decisions and to come up with their own solution, without being influenced by the academic advisor. This is an effective way to learn to be critical of their work and to present arguments to support their decisions.

Weekly lectures and tutorials are scheduled during the project. These lectures and tutorials are used to provide general information to all students and to address any general questions. It is expected that groups have meetings at least once per week, but more meetings can be organised if required. The academic advisor attends a meeting once a week as an observer and offers advice and suggestions if requested. Occasionally, the academic advisor may have to “steer” the project if insufficient progress is made.

In addition to the weekly meetings, a mid-project design review and an end-of-project design review are scheduled. At the reviews, the team presents their concepts, analyses and general progress to their peers and academic advisors. These reviews are valuable to learn presentation skills, discussion and answering questions. These design reviews can lead to intensive discussions, particularly between groups who are working on the same RFP!

2.3 Design Project Topics

The course coordinator prepares the design specifications and will ensure there is a variety of choice. All academic staff can submit RFP proposals as long as they fit within the course objectives. The RFPs are intentionally written to give the design teams a challenge and to appeal to their imagination.

An example of a typical RFP is given in the Appendix, which calls for a proposal of an innovative system to combat bushfires, a significant threat in Australia. The RFP is then translated into a Product Requirements Document (PRD) that outlines the specific system requirements and how they were derived at. The PRD usually contains more requirements than the RFP and are more specific. For example, while the RFP may call for a “low-cost” solution, the PRD may set a specific target, based on initial research.

The teams are encouraged to consider a large number of potential solutions (concepts) to ensure that feasible solutions are not missed. All concepts are subsequently reviewed against an agreed decision matrix and the most promising concept is selected for further study.

3 DESIGN PROCESS

Although the design project should be an exciting exercise with the opportunity to develop a new and innovative aerospace vehicle, some students find the project a bit daunting and are generally lost in how to start. This is perhaps not surprising as up to that point in the curriculum, students have been taught about the physics of flight and flight vehicles, including aerodynamics, structures, propulsion, performance, etc., which are more focused on knowledge gathering and analysis. Students will learn all about calculating the lift and drag of a wing or the stresses in a cantilever beam, but in most of these cases the object of analysis is given.

Come 3rd year design course, the need to synthesis and apply knowledge is a challenge. Only know students start to realise the relevance of what they have learned and how different disciplines interact
with each other. Design brings down the traditional barriers between the specific disciplines and tries to formulate a well-balanced solution.

But a solution is not sufficient. There are many solutions to a problem and students must be able to determine the best ("optimum") one. In order to do so, students must first agree on what metric the best design is selected and in that process they must make decisions which they must be able to defend in a critical review. This is a big ask and not all students are prepared for it.

Nevertheless, this is what is expected in industry. Although, new graduates may be given straightforward analysis tasks initially, it will not be long before they are asked to solve problems.

Some students lack the confidence to tackle design problems, usually not due to lack of knowledge, but because they cannot process knowledge gained in sensible design solution. Sometimes, the fear of giving a "ridiculous" answer may deter them from speaking up in class or group meetings.

Properly managed group projects can train student design skills by following a number of smaller steps:

− Break complex tasks into parts and steps
− Plan and manage time
− Refine understanding through discussion and explanation
− Give and receive feedback on performance
− Challenge assumptions
− Develop stronger communication skills.

In a peer environment, they are better to learn from each other and try methods that may or may not be successful. This learning process will train the student in:

− Critical thinking – understanding the problem and reviewing possible solutions.
− Resourcefulness – collect information from multiple sources, including library, academics and industry representatives.
− Creativity – combine relevant information into a unique combination.
− Management – plan work within time and budget constraints.
− Diligence – follow the engineering design process and double check results.
− Communication – compile results so that it can be easily presented and understood by others.

The project finishes with the submission of a consolidated design report. Although this report reflects the final outcome of the group effort, it does not reflect the contribution of individual students, nor how each has contributed to the design process. The assessment of individual student contribution, as required by university policy, and their involvement in the design process is a challenge in project-based learning. The following section gives some insights on possible methods to manage individual assessment.

4 PROJECT ASSESSMENT

4.1 Group versus Individual Assessment

It is generally accepted that group product or outcomes as well as processes within groups should be assessed, particularly if team work, communication and leadership are part of the learning objectives. The problem is the definition of process and how to quantify it such that a student can appreciate how he/she is progressing. For example, if a staff member wants to assess level of interaction, how might a conscientious student ensure they reach an outstanding level? What is an outstanding level? How can a staff member confidently know the level of interaction that has taken place? Staff must either involve themselves intimately in the workings of each group or rely on student self- or peer-assessment.

The most straightforward approach is assessment focused solely on the product of group work. In this scenario, all members of the team receive the identical grade based on the score assigned by the faculty member to the product of the team effort. If a team project is given a score by the instructor, each member of the team receives the same score for grading purposes. This score is independent of the volume and depth of contributions by individual team members. Differences in performance by
individual students may be noted and commented on, but they are not formally factored into the summative evaluation. They all receive the same grade. In reality, this practice excludes the assessment of the degree of participation and quality of contribution by each individual student involved in the group process. A team, after all, is considered a single coherent unit and its members should share equally in the rewards and punishments stemming from its common performance. It can be argued that this practice emulates the “real” world, ie. in the workplace it usually is the group outcome that matters, not how it was achieved. All members of a winning Olympic team receive the same medal; the entire orchestra shares in the standing ovation; the sales team, as a whole, loses its bonus when the customer cancels the contract. The quality of individual performances may be recognized and remarked about, but the formal consequences of the team performance are often equally shared. In notion that a good functioning team typically delivers a quality product is not always true. For example, a small number of high performing students could ‘take over’ the project, with other students having only minor input. A good outcome, but a poor process. Most commonly, there is an interest in both the process and product of group work and the decision becomes how to distribute the final mark over these two criteria. It is an RMIT University requirement that students are assessed individually based on their performance against the learning outcomes. Therefore, some mechanism must be in place to identify individual student work and contribution. For the capstone aircraft design project at RMIT University, the main deliverable is a consolidated design report, which describes the requirements, design methodology and findings (Fig. 1).

![Figure 1. Concepts and Final Design of a Firefighting Unmanned Air Vehicle.](image)

Students are required to identify in the design report the work of each individual student. This is often done in general terms, eg. aerodynamics, structures, CAD drawing, report editing, etc., not specific per page or chapter. Also, students may be responsible for different parts of the design, which may represent dissimilar work, for example, analysis, programming, CAD, report writing, etc. are all part of project work. For example, as shown in Table 1.

<table>
<thead>
<tr>
<th>Student</th>
<th>Statement of Contribution</th>
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| Elizabeth | Report Sections:  
- Report structure  
- Abstract  
- Systems design process (3.1)  
- Operational environment (4.2.2 to 4.2.5)  
- External payload (Ch 8) with contributions from Salvador for Design considerations (8.3), and winch features and system by Nicholas (8.3.2),  
- Propulsion system (10.1-10.3) with Asher  
- Preliminary Cost Estimation (13)  
- Overview of preliminary design (15.2 to 15.3)  
- Assisted with the Introduction (Ch 1), RFP Analysis (Ch 2), and Conclusion (Ch 17)  
- Future work required (Ch 16) with Nicholas  
- Major report editing  
Design Process:  
- Team leader  
- Research towards fixed-wing configuration |

Table 1. Example Statement of Contribution in Design Report.
| Asher | Report Sections:  
- Outline of the design process (3.2)  
- Fire behaviour (4.2.1)  
- Fixed wing configuration literature review (4.5.1) and configuration selection (5.1.1)  
- Blended wing body and flying wing configuration literature review (4.5.4) and configuration selection (5.1.3)  
- Welding (4.8.11)  
- Composite part manufacturing (4.8.12)  
- Rotor blade / Fan blade materials (7.2)  
- Landing gear (9.7.3)  
- Propulsion system (Ch 10) with Student #1  
- Gearing system (11.1) with Alex |
|--------------------------------------------------|
| Abdulghani | Report Sections:  
- Ground control station (4.6)  
- Avionics (4.7)  
- Wing design (9.6)  
- Avionics (Ch 12) with research from Robert  
- Ground control station (Ch 13) with research from Robert  
Design Process:  
- Preliminary configuration research  
- Avionics and ground control station research  
- Airfoil and wing design |
| Salvador | Design Process:  
- Current fire-fighting aircraft (4.4) with Alex  
- Quad-rotor proposal for group consideration (5.1.2) with Robert.  
- Forward thrust unit & double duct (8.3.3)  
- Stability during forward motion and aerodynamic drag (8.3.4)  
- External payload design considerations (8.3) with Liz  
- Double-duct analysis (9.1.1)  
- Design overview Configuration (15.1)  
- Suggestions for Future work required (Ch 16)  
- CAD Models & Images |
| Robert | Design Process:  
- Research on structures, materials, flight conditions and gearing system.  
Report Sections:  
- RFP Analysis (Ch 2)  
- Quadrotor (4.5.3)  
- Flight Control System (4.7.3)  
- Quadrotor for Group Proposal (5.1.2) with research from Salvador  
- Rudder/Elevon (9.7.1)  
- Thrust Vectoring in Hover (9.7.2)  
- Flight Control System (12.3)  
- Major report editing  
- Report draft consolidation  
- Final report formatting |
| Nicholas | Design Process:  
- Research on structures, materials, flight conditions and gearing system.  
Report Sections:  
- Introduction contributions (Ch 1)  
- Helicopter literature review (4.5.2)  
- Structures literature review (4.8) – with Asher completing welding and composites (4.8.11-4.8.12)  
- UAV materials and manufacturing (Ch 7) – with Asher completing Rotor blade / fan blade materials (7.2)  
- Structural connection and winch system (8.3.2) with Elizabeth  
- Future work required (Ch 16) with Elizabeth  
- Conclusion (Ch 17) |
| Alex | Design Process:  
- Research on helicopter configurations  
Report Sections:  
- Selection of VTOL platform (5.2)  
- Initial sizing and weight budget (Ch 6) with research from Nishit  
- Mechanical systems (Ch 11) with contributions from Asher and research from Nicholas on the Gearing system (11.1)  
- Research towards Current fire-fighting aircraft (4.4) |
In addition to the final report, each student must create and submit a portfolio that documents and provides evidence of their participation. They prepare a compilation of the work products created during the project and a synthesis of their contributions to the team effort. This may include such items as emails, documents, drawings, notes and transcripts. In this approach, the difficult task of tracking down contributions to the common project is borne primarily by the individual team members and the team. The RMIT academic advisor evaluates the student’s reports and reflections and assigns grades accordingly to individual team members. As with all academic work, care should be taken that the portfolio is the student’s work and reflect the work done within the group. This can be done by comparing portfolios and check for overlap or commonalities. Although the written submissions give some indication of individual student work, it only reflects technical outcomes and does not capture student behaviour in the team.

4.2  Peer Assessment

In Project-Based Learning courses, where teams of students meet in the classroom, in lounges around the campus, in coffee shops or private residences after hours, it is virtually impossible for the faculty member to observe directly the contributions of individual students. For the RMIT capstone aircraft design project, the teams meet with the academic advisor at least once a week. This meeting is not intended to observe individual students and it is not enough to make a fair judgement on student contribution. However, it does allow the academic advisor to identify students who are unusually quiet and try to make themselves ‘invisible’. If that is the case, the academic advisor may try to engage them into the discussion or recommend the project leader to keep a closer eye on them. The academic advisor is also copied in on emails or chat communications related to the project and has access to all documentation through a shared drive. This will give some information on the performance of individual students, but is usually not enough to make a fair assessment. Although this provides anecdotal evidence, a more formal mechanism for assessment of student participation is required.

Peer assessment involves the rating of a student’s contribution to the group project by other members of the team or the project leader. The practice has been used often for team projects in face-to-face classes because of the inability of instructors to observe directly the individual behaviors during team projects. Although variations exist in how this process has been put into practice, they each share the characteristic that the members of the team or project leader are provided a rubric for rating the extent and quality of contributions by the members of the team. The variety in peer assessment practices includes the instrumentation used to collect the ratings, how the ratings are factored into student grades, the timing of the ratings, and whether self-ratings are included. In the capstone design project, we have experimented with peer assessment by fellow students or by project leader only. The problem with peer assessment by fellow students is that not all students are intimately familiar with other students’ work or specific contribution. Secondly, there is a concern that peer assessment can be biased by friend or foe relationships. It is expected that this effect will be filtered out in the statistics. Peer assessment by the group leader only follows the industry process where a line manager has the responsibility to appraise the employee. The project leader must be familiar with all student
contributions and must be unbiased as per the responsibility given to him/her. Peer assessment take place twice during the project so students can see how they are rated with the opportunity to improve. If the project leader is the peer assessor, he/she is expected to have face-to-face meetings with each individual student and discuss their performance. The peer assessment is drawn up and signed by both parties.

Perhaps the simplest approach to the process of peer assessment is for each member of the team to rate the performance of every other team member on a single linear scale, for example from 1 to 5 or 10. The instrumentation in other peer assessment systems require students to rate their teammates on a set of criteria rather than a single linear scale. For example, at RMIT University the following peer assessment criteria are used:

- Actively participated in group meetings and discussions
- Encouraging and supporting other team members
- Timely delivery of quality work
- Willingness to contribute equality to the project workload
- Responsibility and commitments to meeting group expectations

Each criterion is scored from 0 (poor) to 4 (best), with a maximum score of 20 for peer assessment.

The combination of design report, individual portfolios and peer assessment seems to work well in general, but problems can remain in certain circumstances. Some of these problems are:

- Students’ judgments of each other can be wildly inconsistent. Not only are students unskilled in evaluating the contribution of their peers, but in most cases have no way of knowing how much time or effort their colleagues might have expended. Their ‘assessment’ of the contribution of the other group members is more a reflection of personal characteristics than any kind of quantitative evaluation. This can be overcome somewhat by delegating the responsibility of peer assessment to the project leader.

- Peer assessment can impact badly on weaker students limiting their opportunities to participate. They are often ignored or allocated only less important tasks ‘where they can do little damage’, which gives them little chance to contribute equally to the group effort. More appropriate team management would permit these group members to become more involved and to contribute to the extent of their ability. It is a responsibility of the project leader to ensure all students are engaged and contributing to their ability. A mid-term peer assessment could flag these issues and should trigger action.

- Peer assessment can be dominated by personal relationships, with the tendency to give friends higher marks than not-friends. Also, friends can collude to agree how to access each other, defeating a fair and consistent peer assessment. This can also be overcome to some extent to delegate the responsibility of peer assessment to the project leader.

- The requirement to provide peer assessment can result in significant personal conflict between group members and reduce true cooperation and teamwork. Many who advocate peer assessment see it as a mechanism to coerce students into participating, however, it would be more useful for groups to learn how to manage non-contributors in ways that could apply equally to the work place.

The ultimate responsibility of assessment remains with the academic advisor, who has the authority to question peer assessment if anomalies are evident, for example perfect score for all students. Intervention by the academic advisor can then lead to a revaluation or a repeat of the peer assessment.

Although peer assessment is an important measurement for team participation and process, it does not necessarily translate directly into an effective contribution to the outcome of the project. For example, students may contribute to discussion, but may not produce practical ideas or progress the project, ie. ‘much talk, but no substance or relevance’. On the other hand, there are the quiet achievers who do not talk much, but deliver quality work that matters.

A new methodology being considered at RMIT University investigated an interesting peer assessment process in which each student was instructed to assign a percentage score to represent the proportion of the work accomplished by that member of the team, where a score of 100% represents an average share of the work. Team members receiving scores higher than 100% accomplished more than their
share while those assigned scores below 100% accomplished less. The scores assigned by each student to the total of his or her teammates had to average out to 100%. This factor could be used to scale the average report mark. This methodology has the benefit that students in the team can allocate marks by distributing a limited allocation of marks, plus or minus, relative to the overall mark given to the group report.

For example, is a group has N team members, the maximum number of points for individual student contribution would be N x 50. Each student is given a score 0 – 100 with the total for all students in the group not exceeding N x 50. If the maximum deviation from the group report mark is BONUS and the score for individual student contribution is IND, the student will receive: BONUS x (IND – 50). This can either be added to the group report mark or processed separately. The effect of this methodology is that the peer assessment becomes more sensitive to individual scores, as not all students can receive high or low scores and thus forces variation.

5 CONCLUSIONS

This paper presented an overview of the aerospace design teaching at RMIT University with a focus on the capstone aerospace design project in the final year of the undergraduate program. One of the most challenging aspects of Project-Based Learning (PBL) is the assessment of individual student contribution to the final deliverable, usually a report or product, and to the design process.

RMIT University has considered a number of assessment techniques of which none are perfect. The current assessment consists of a two design review presentations, a consolidated design report, an individual design portfolio and a peer assessment for individual student contribution to the design process.

The peer assessment remains a source of contention among the students as the assessment can be influenced by irrelevant factors such as student interrelationships, immature or unprofessional behaviour, perception rather than factual observation. For this reason, a new methodology for peer assessment is introduced. This methodology offers a fixed amount of bonus points to be distributed to all students in the team based on their individual contribution to the design process. This methodology stimulates a more critical and serious approach to the peer assessment and more variation in the results.

REFERENCES

APPENDIX: EXAMPLE RFP – FIRE FIGHTING UAV

Overview

Firefighting organisations make use of a variety of fixed- and rotary-wing aircraft which are used for surveillance and mapping, communications and “water-bombing” -- the latter mission including the delivery of foam and chemical retardant as well as water. All are, of course, manned, but it has decided to evaluate the use of Unmanned Air Vehicles (UAVs) in the water-bomber role.

This specification sets out the organisation’s needs in terms of the use of such vehicles. It should be noted that, in order to allow potential suppliers as much design flexibility as possible, many of the requirements are intended as system requirements, which may or may not involve the use of more than one UAV (and associated ground equipment) at a time in a coordinated operation:

1) Mission/Payload

- “Drop rate” -- i.e., the rate at which the payload is delivered on one or more targets -- ≥ 40,000 litres/hour at peak operational rate with a minimum distance from loading point to target of 2 km.
- Payload may be any one of water, foam or retardant as needed; no or an absolute minimum of conversion should be necessary to change from one to another. The option to select one in flight, e.g., to convert water into foam, is considered desirable.
- Payload should be able to be released in multiple passes if full load of a single vehicle ≥ 4000 litres.
- Ferry range ≥ 500 nautical miles OR vehicle(s) must be readily transportable by other means, which must have off-road capability.
- Air vehicle must be able to operate from rough fields, e.g., a dirt strip, with a maximum length of 600 m. Take-off run (brakes release to 50 ft height) ≤ 500 m from a strip at an altitude of 1500 m AMSL on an ISA + 35 °C day.
- Standard sortie to include loiter time of 1 hour.
2) Support Requirements

- Highly mobile: all vehicles, ground and air, must have rough field capability. Base station must be able to move at 10 minutes’ notice or less; UAV must be able to loiter unattended while base moves (this can be considered as part of the loiter requirement mentioned above).
- Distance from base station to fire (targets) should be maximised.
- Rugged, with minimum maintenance requirements when deployed
- As far as possible, independent of fixed base requirements; ground equipment other than base station should not require highly-trained operators
- Ability to scoop water desirable but not mandatory

3) Crashworthiness

- Secure communications links are considered vital; the vehicle(s) must remain in contact with the base station at all times, regardless of location, weather and situation with respect of the fire(s).
- Flight Termination System required in case of comms link loss; return-to-base system preferred soft landing recovery system acceptable.
- Must not start fire if it crashes! Fuel, electronics, etc., must be protected from impact damage.

4) General

- Navigation package to include GPS system; other avionics and sensors to be as considered desirable, but system architecture should be such as to allow easy removal and customisation for specific missions. Such system changes will take place at a fixed base, not in the field, though equipment required for an avionics change should be portable so as to allow changes to be done from a temporary base.
- Design to satisfy regulatory organisation’s UAV Design Standards

5) Cost

- Acquisition cost not to exceed A$2 million for a system capable of meeting the above requirements.
- Operating and maintenance costs to be no more than that of existing aircraft used in this role.