# MOBILE POWER UNIT - FINAL REPORT

IDES 4310 : April 2008 : Bonnie Van Tassel

The Mobile Power Unit is designed for use by wildland forest fire fighters in the Ministry of Natural Resource's Aviation and Forest Fire Management Program. The Unit is designed to transport power from base stations throughout the province into the incident site where the fire crews can recharge radio batteries, satellite radios and AA batteries used in various accessory equipment such as flashlights. This report is a comprehensive documentation of the design process undertaken as core curriculum in IDES 4310 Major Project in the School of Industrial Design at Carleton University in Ottawa, Canada. The report covers the concept phase through to final design, including test phases, design refinement and feedback.

In collaboration with :
Ministry of Natural Resources
Aviation and Forest Fire Management Program

Advisors: Jim Budd and Thomas Garvey

Design Team Support: Melany Bailette,
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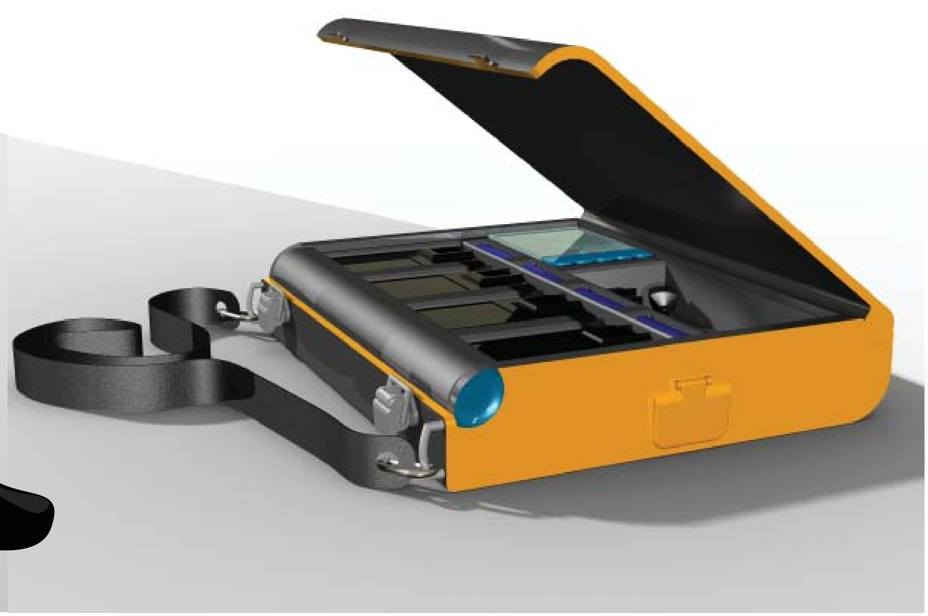

## Acknowledgements

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## Preface

During the last year of Industrial Design studies at Carleton University, it is required for the students to collaborate with external clients and sponsors. This allows the students to experience first hand of working with clients, build strong networks, and truly understand the process of Industrial Design. This year we have the opportunity to work with the Ministry of Natural Resource (MNR) to help develop and design forest fire fighting equipment.

Fortunately we were provided the chance to attend Equip-Ex 2007 which was an equipment exhibition held at the Executive Airport Gatineau-Ottawa (EGO) on October 3 – 4. This opportunity provided the first chance to meet with personnel from MNR in Ottawa. A week later we were invited out by MNR to the Thunder Bay Headquarters for an official meeting on October 10 – 11, 2007. We were taught the structure of MNR, took tours of the warehouse and were briefed on the equipment and opportunities for design innovation. Visiting their headquarters gave us a deeper understanding of the structure, process, and equipment of MNR and gave us insight to aid us in identifying our design direction.

The purpose of the individual project reports is to document the development of the design phases beginning with concepts and proceeding through the testing, refinement and final design details.

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## Introduction and Summation of Relevant Research

In the fall of 2007, research initiatives undertaken at the Ministry of Natural Resources (MNR) AFFM Base in Thunder Bay, Ontario, were presented to the senior Carleton University Industrial Design students who chose to pursue thesis projects in the fire fighting industry. The research was in developing a reliable and dependable means of generating AC power using the Wajax Mark-3 water pumps which are, at the time of the research and of this publication, the standard in Ontario forest fire fighting.

The MNR's AFFM Program, in 2006 alone, consumed over eighty-five thousand disposable batteries. In 2007, the MNR invested in rechargeable communication devices for hard implementation in the 2008 fire season. The biggest question that arose from this information was: "How are the rechargeable batteries going to be managed and charged?" This question came not only from the issues for the fire crews in terms of their being organized, but also for the warehouse workers who must not only effectively manage all of the batteries, but also keep them charged and ready for dispatch. In discussions with the warehouse workers at the AFFM base, the question of feasibility arose when we began talking about the potential of remote battery charging, and the project was conceived based on the obvious needs of the MNR and the wealth of opportunity in MNR and the academic community in power generation and rechargeable technology.

Concurrently, as research was being conducted by the MNR, academic research was reviewed to understand the latest and most effective means of remote power generation. My research showed that for the high-latitude, hilly terrain, solar power and wind power were not reliable or effective enough for the rigid power demands of the AFFM. What did become obvious is that from the beginning, both the MNR and the author overlooked the fact that AC power was readily available at all bases and within 70 km of every incident, no matter where the fire was throughout the province. It was in the final part of the preliminary concept stage that the idea became not of power generation, but of power transport and bringing value to an entire system, not just a charge dock that the fire crews used.

The project focus at the end of the preliminary design concepts was essentially a case (Fig.1) of power cells which was secured under a slotted dock that batteries could be dropped into for charging in the field. What the MPU did not answer were questions of power source, although the project scope had moved away from power generation and towards power transfer. Help from an electronics expert was sought and before long a viable solution for the base hardware was determined. From that point, development of the housing and interface features was possible. Additionally, simple tests for feasibility of general orientation were conducted using simple paper and foamcore models to show scale and fit.

Figure 1
Final Concept Direction - Mobile Power Unit to charge four radio batteries.

## Concept Development Overview

The concepts presented in the preliminary concept presentations were wide in scope and were still strongly focused in the power generation area rather than simply the transfer method which I later chose to pursue. The direction I chose to investigate dealt with two distinct user groups and had the opportunity to be the basis of an entire logistics system. Follwing is the progression of preliminary concepts through to the final direction. The process began by mapping out the important aspects of the system (Fig.2), trying not to concentrate on a product-based solution but

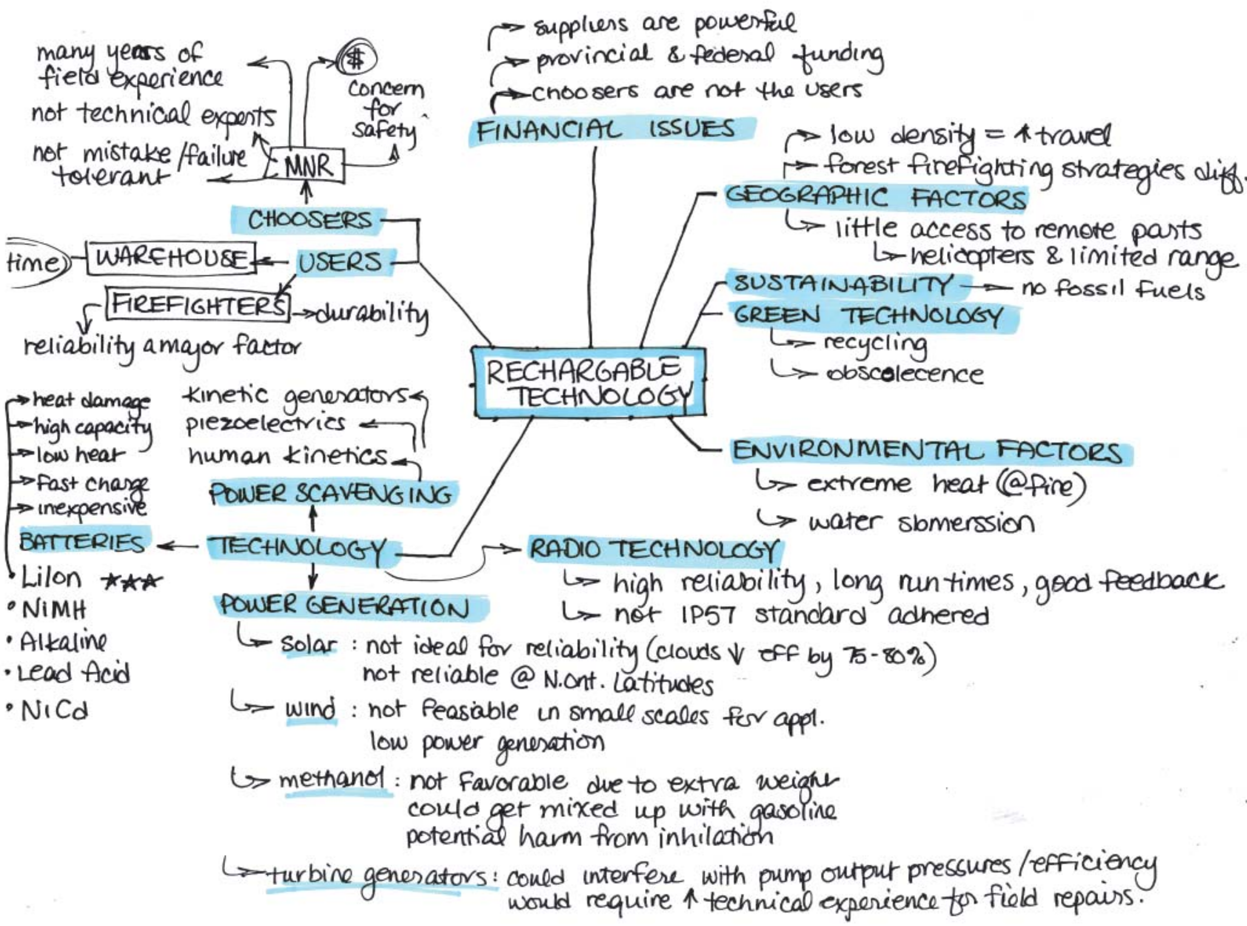



Figure 2: Mind Mapping was used extensively at the beginning of the design process to organize information from the research and help to visualize the opportunities within a solution.

to understand the problem not only from the design point of view, but also from the users and the choosers' perspectives. The exercise revealed important factors that had not been flagged by the advisors directly, such as the sustainability factors associated with the project or the potentially high monetary investment the chooser may have to commit to in order to see this kind of product in action, even for field testing. Additionally, the map underlines the importance of understanding the constituent technologies involved in the peripheral devices because comparisons of very dissimilar components could have lead to false conclusions. Of specific importance is the differences in needs from the chooser, who in this case is the governing body of the MNR above the AFFM, and the user, the firefighters themselves who have the most experience, but little or no decision making power in the organization.

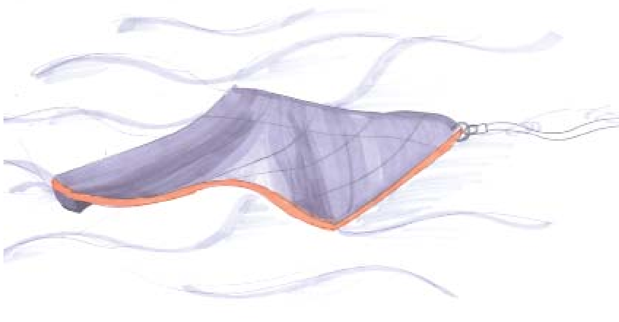


Figure 3: Solar Blanket - possibly for floating on water source near campsite

Figure 4: Solar Blanket - secure to tree near waters edge and for easy retrieval

The next step of the conceptualizing process was to visualize potential solutions keeping in mind the objectives that were set forth throughout the mapping process. The first solution idea was a solar blanket which would be layered with two generating materials and laid on the water for optimal sunlight collection. (Fig.3 & 4) First, the blanket would have a flexible solar film grid with flexible changes for easy folding. Under the solar film, a this piezoelectric layer would generate energy with the movement of the water below it. The fact the blanket would be laid on the water gives it an optimal opportunity for maximum sun exposure. There were significant questions regarding the feasibility of this concept based on the current cost of components for the questionably reliable product. This idea never went beyond the concept phase because there was little research to substantiate pursuing the technology in this area within the scope of the project and the overall project goals.

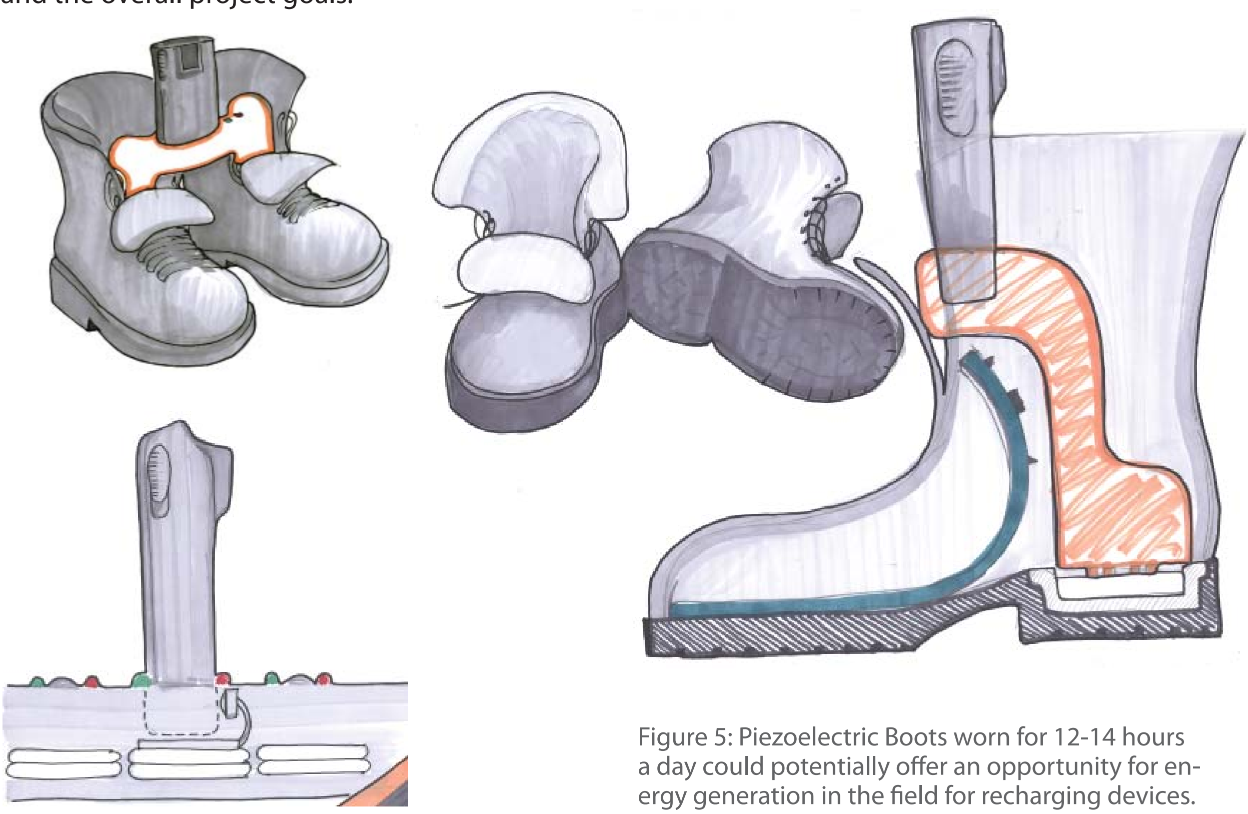


Figure 5: Piezoelectric Boots worn for 12-14 hours a day could potentially offer an opportunity for energy generation in the field for recharging devices.

The second major concept direction came from looking at research coming from Massachusetts Institute of Technology in their pursuit of piezoelectric insoles for runners which, on every footfall, generate a small amount of electric current which can be stored in batteries for later use. In applications suited for the woodland forest fire industry (Fig. 5) there appeared to be an opportunity to modify work boots for piezoelectric modification. With targeted feedback from Pat Beirne, the realistic durability of such a product would likely fall below the expected durability threshold for equipment used by the AFFM Program.

Following the use of solar panels in a stationary blanket, the application of solar cells onto a helmet was an area that was briefly examined. What seems like a good idea up front was soon quelled as it became clear that although solar cells on the helmet (Fig. 6) would optimize the directionality issue, most fire fighters are working in shady, smoky woods most of the day, so the actual exposure to sunlight would not be enough to provide sufficient charging power to the batteries.

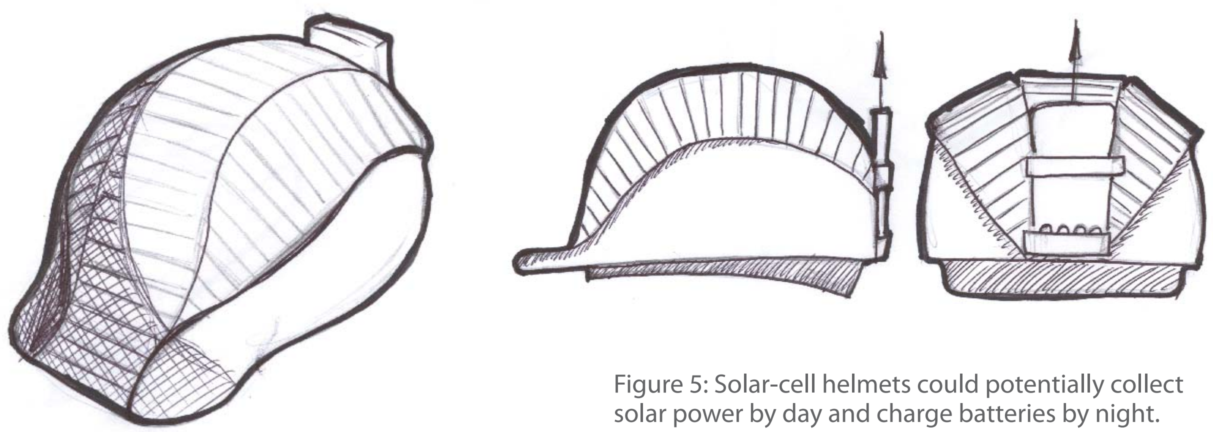


Figure 5: Solar-cell helmets could potentially collect solar power by day and charge batteries by night.

Going back to the original research path that was taken on by the MNR, I also looked at potentially generating energy off the water pump. The approach I took here was an in-line turbine generator which would be connected to the pump then the hose line attached to the turbine. In speaking with MNR specialists I quickly found out that the Ministry does not advocate or support any device or system which would compromise the effectiveness or reliability of the pump. That said, an in-line generator would slow the flow of water down and create more pressure at the pump, meaning strangling would have to happen for shorter time periods and there is an increased chance of tripping the pressure cut-out switch in the pump.

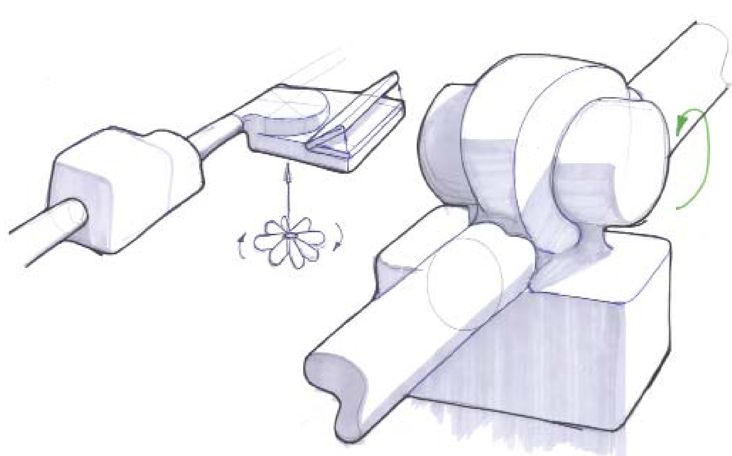


Figure 6: In-Line Pump Turbine: was never meant to be given its effect on water pressure on the hose line.

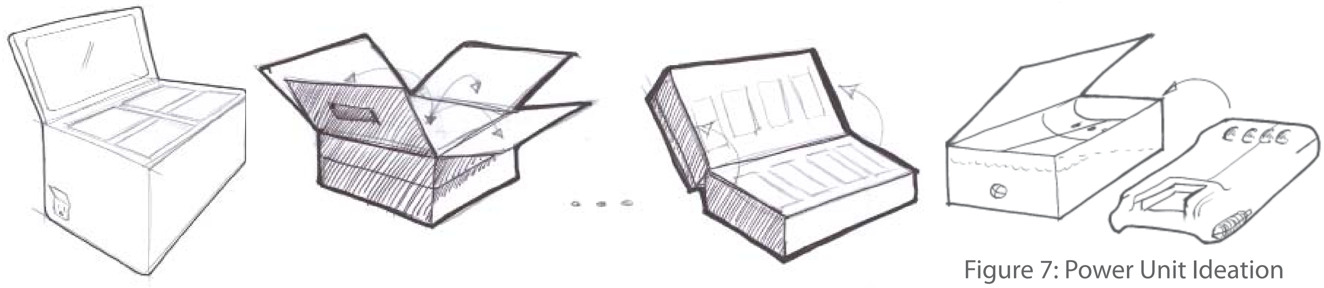
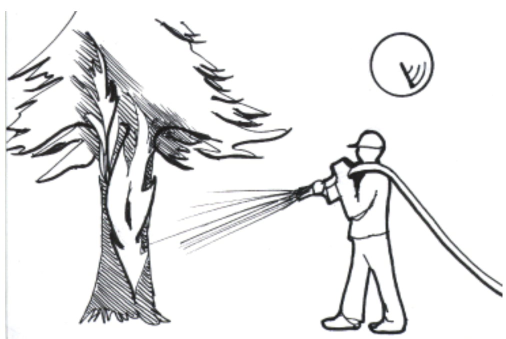


Figure 7: Power Unit Ideation

The final challenge in the concept phase was to form a solid use scenario to properly understand the use and benefits of the Mobile Power Unit.

1. The helicopter lands at the incident location

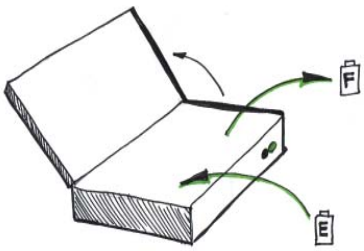
2. The equipment is unloaded from the helicopter and the fire fighters leave the gear in a safe place



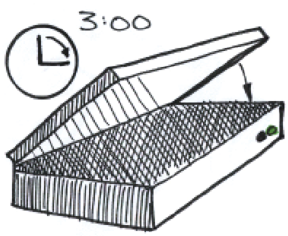
3. The crews suppress fire all day until dusk

4. At camp, the camping equipment is set up and the Mobile Power Unit is brought out

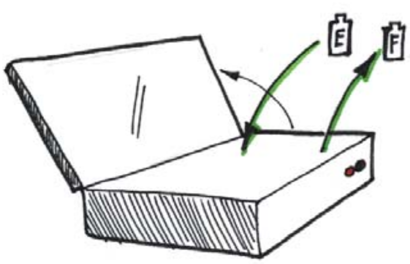
5. Crews remove dead batteries from radios




6. Radio batteries are switched out

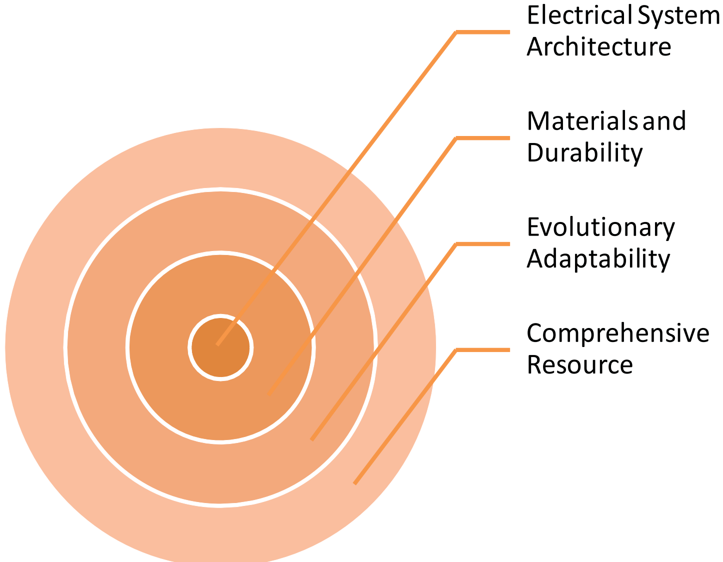



7. Batteries are left for recharging




8. Batteries are ready to be used in 3 hours

Based on this use cycle I was able to establish a basic use pattern as would be seen by the fire crews using the Mobile Power Unit in the field. It was also very important to establish the other side of the use scenario because part of the design value is not only for the fire crews, but coming back to the original goal of the project, to manage the batteries for the crews and the warehouse and logistics. Thus, it would be very important going in to the test phase to get critical feedback about the warehouse end of the project and quickly establish the best way of dealing with the power unit and its' contents.




An important part of the project progression was to establish a hierarchy of priorities to describe the aspects of the project that I found most important for the success of the design. (Fig. 8) The core values are most important and the peripherals are less important. It is notable that the MNR contacts found the priorities to be mostly congruent, however, they rated the comprehensiveness as higher than was rated on the chart in Fig. 8

Figure 8: Project Priorities

## Testing

The testing phase consisted of three stages and three areas of study. The three stages of testing were:

1. Planning: all tests were plotted out on a time line allowing for information processing between

2. Prototyping and Preparation: measures were taken to create sufficient number and quality of prototypes to answer the questions posed in the tests.

3. Execution: all the tests were carried out under the parameters of the ethics contract and the test plan formed prior to the tests.

There were three areas of study:

1. Hardware: the internal components
    A. Scenarios
    B.. Compatibility
    C. Performance
2. Software: the virtual components
    A. Navigation
    B. Comprehension
3. Ergonomics: the human contact factors

| Test | Feature Observed | Test Objective | Measures of Success | Test Subject | Testing Device | Output | Outcome |
|---|---|---|---|---|---|---|---|
| General Handling | Semantics | Ensure cues are under-stood | User knows how to open, lift and carry | SID students, people aged 35-50 | wooden model | Observations, qualitative feed-back | High Contrast colors were preferred |
| Lift and Carry | Ergonomics | Assess com-fort & ease of handling | User finds MPU comfortable and well balanced | SID students, people aged 35-50 | weighted model with strap | qualitative feed-back | rounded back edge good and detach-able strap |
| Fasteners | Dexterity thresholds | Find the best faster | Fastener is found to be easy to use and durable | SID students, people aged 35-50 | various fasteners attached to nylon strap | observations and qualitative feedback | Carabineers were well liked, aside from buckles |
| Navigation | Software Interface | Assess the intuitiveness | User can navigate the software | SID students, people aged 35-50 | Interface Binder | observations and qualitative feedback | Too many op-tions, simplify |
| Iconogra-phy | Software Graphics | determine if icons are better than words | definitive evi-dence that one is better tan the other | SID students, people aged 35-50 | Interface Binder | observations and qualitative feedback | Icons were more work to produce and less effective |
| Scenarios | Hardware | MPU hard-ware would be able to handle all scenarios | theoretical factors weigh in and success comes when it should all work | none | Proof of concept model (POCM) | testable hard-ware setup plans | components would theoreti-cally be able to be supported by housing |
| Compat-ibility | Universal connectors | find a means to replace charge tray | simple solution found | none | various electric connectors | working connector | connectors too large, would be custom job |
| Perfor-mance | System | know that the system can indeed function | internal type batteries can charge a radio battery, then recharge | none | POCM | observation of model | model suc-ceeded, concept was proven to be feasible |

Figure 9: Test Plan

Figure 10: laptop bag handling observations

Figure 11: weighted wooden model

Figure 12: lift/carry test

The general handling test was put together after making numerous observations of people with their laptop bags. (Fig.10) It was observed that people were more careful with heavier bags and that when possible, they would prefer to have the bag out of the way when the contents were in use. From this information, I thought I would test the possibility that the bag could be removed from the equation and an open-concept carry system could be developed. The general format that I pursued for the test model was a rectilinear form with radii on the front and back edges to assist in the setting down and opening of the unit. (Fig.11) For the purposes of the tests that would be conducted with the weighted model, it was decided that the internal components could be tested separately at that point in the development and later on it would make send to test the system as a whole.

The lift and carry test and the fastener test were both a success, in terms of validating my ideas about the MPU and what it needed to do. The lift and carry test was conducted with eight people of both genders and aged from 18 to 35. The test (Fig.12) revealed that the projected weight and the distribution were not cumbersome nor would they hinder someone from stepping over obstacles. What I was not able to account for was the posture or the lifting technique employed by the test subjects. In the testing disclaimer it clearly stated that the lifting method would be demonstrated in order to ensure that nobody was injured, however. even with the demonstration, some people (Fig. 12) did not practice proper posture which threatened the validity of the test.

The final ergonomics test was the fasteners test, which essentially focused on the strap fastener and its attachment with the casing. The approach taken was simple, the fasteners were each attached to a demo loop and taken off, several times each, while looking and when looking another direction. The purpose of having the test subject look away is that the fastener would have to be easy to use and not require sight as a component, since in the fire fighting environment there are numerous instances where visibility is significantly reduced. The strap itself was only advocated in two thirds of the sample, indicating the possible interest in something detachable for use in the field as well as for storage.

Figure 13: fasteners

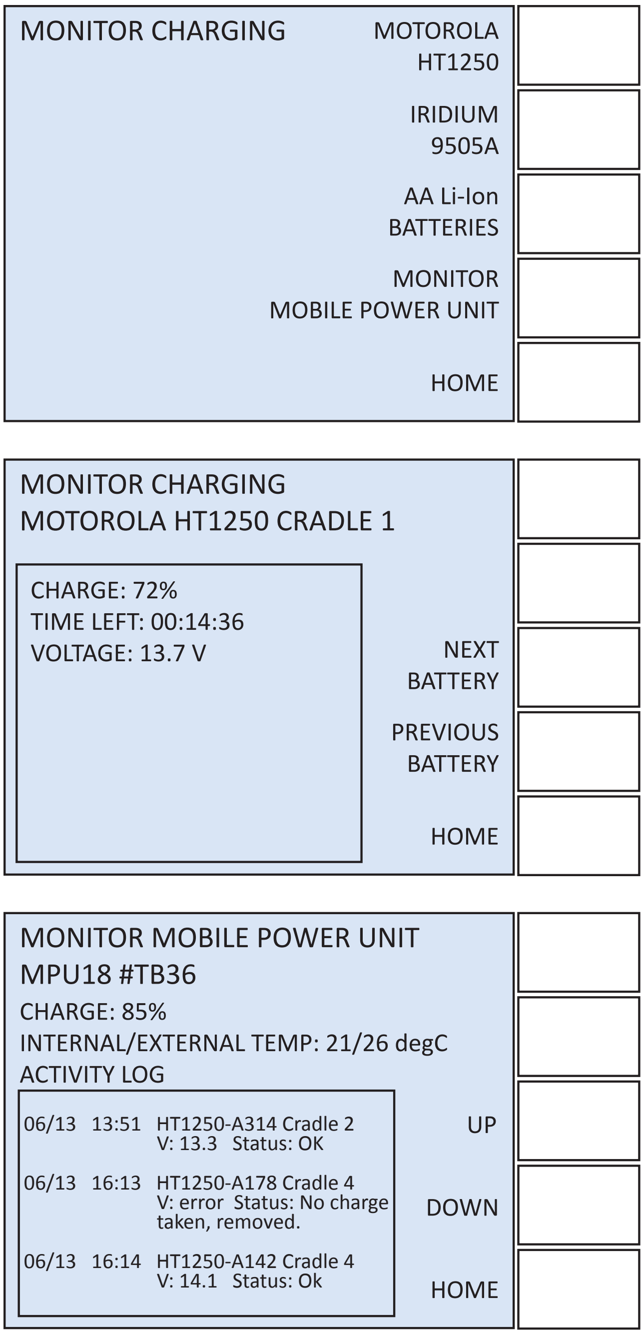



Figure 14: interface

The software interface testing was conducted for two main reasons. First, it was necessary to validate the interface structure, to know if the commands and functions made sense appearing in the order they did. Second, it was necessary to validate the language of the software and test if icons would be more effective as a means of navigation than the words. Also, the language itself needed to be tested to ensure that the nomenclature would be understood and that the information was clear and consistent.

The navigation tests revealed that only three screens, were necessary for the MPU to get all of the information needed. Secondly, it was found that the testers preferred to see the actually product name with model number rather than just the general terms for the device. An example: "Iridium 9505A" was preferred to "Satellite Phone".

The language and icons test was conducted using the same interface binders and then using icons from the Microsoft Windows XP system for commands such as Go, Home, and Charging. What the test revealed to me is that people like the look of the icons, however, they slowed down the learning process as they had to study instructions to learn the icon commands. This finding suggests that while iconography has its' place in more sophisticated software systems, the most cost-effective and reliable means for navigating the software is a text-based system which leaves no room for interpretation.

The hardware testing was simpler in some ways than the user testing because there were fewer variable factors that arose from individual differences in respondents that could have confounded the results. The hardware testing had two stages, the hypothetical scenario stage where "worst-case" scenarios were narrated and hardware specifications were articulated based on the equipment demands to perform reliably in any of the hypothetical scenarios. This exercise was a challenge because if the underlying research was unsound and the as-

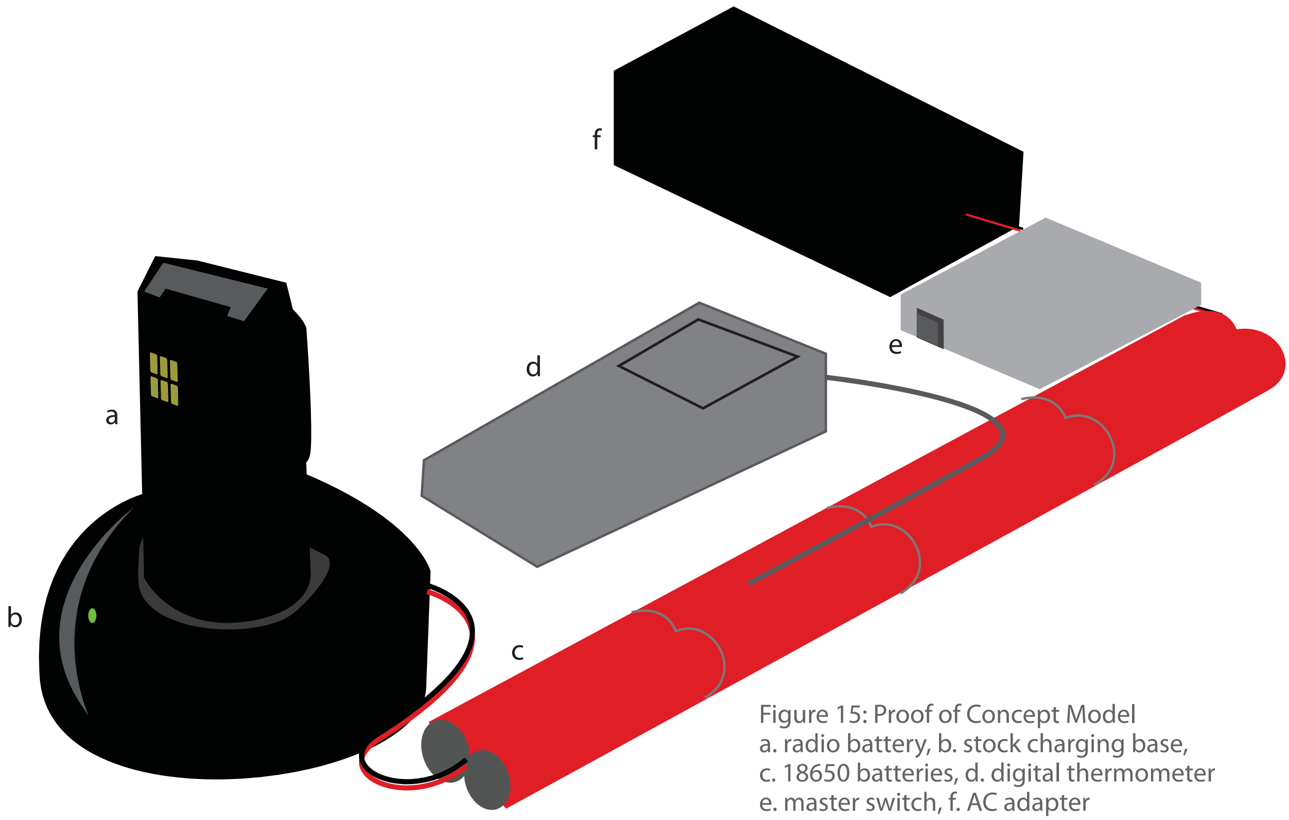



Figure 15: Proof of Concept Model
a. radio battery, b. stock charging base,
c. 18650 batteries, d. digital thermometer
e. master switch, f. AC adapter

sumptions were faulty, the entire test would be invalidated. What the scenarios indicated was that the MNR fire crews would need access to at least two charge cycles, so one primed set of batteries in the MPU and one charge ready to go inside the MPU's internal power storage. These conclusions helped shape a new use scenario and understand what the roles of the two user groups: fire crews and warehouse workers, were, and how would they work together.

The compatibility testing was done using a combination of off-the-shelf connectors and in consulting with Pat Beirne, who helped me understand the variables and constraints involved in making the MPU an evolving device. The tests revealed that there are few, if any stock connectors which would be durable enough, you contain the capacity to transfer large amounts of electricity to the charge docks. The conclusion for this test is that a universal connector for this application would have to be a custom part, meaning that the overall cost for the MPU would be higher than previously expected, especially in smaller runs of the project.

The performance testing was executed in using the proof of concept model, which contains the same type of components as the MPU, but in more rudimentary forms and in proportions which would yield the effect of the system, but are not the same proportions as the system components. The results of the test were very promising. In a circuit containing only an AC adapter, switch, batteries and a charge base, the model was able to demonstrate the charge cycle hypothesized in the concept phase. The model's performance was a clear sign that with more sophisticated hardware, the system would perform the assigned task of charging, but with the addition of sensors and software, the system could in fact be a comprehensive charging source. The next step for the testing would be to get the prototypes into the hands of the MNR fire crews and warehouse workers for further testing.

## Definitive Design

The testing phase indicated that there were some refinements which could happen in the definitive design to better serve the user groups who were the focus of the project. The design is focused on taking the components which were proven to function in the testing of hardware and incorporate them into a product which would interface nicely with the existing communication devices and batteries. The use scenarios which were developed for the concept phase had effectively stayed the same, and the focus shifted at this point to the manufacturing which would be involved in the making of both small and large runs of the MPU.

The drivers for the MNR always include cost, so it was very important to underline the cost savings of using the MPU instead of simply purchasing more radio batteries. There were also significant logistics efficiencies gained through the use of the MPU, where the management of batteries in the field and in the warehouse has been streamlined and organized.

The radio slots were oriented in such a way that the side of the battery which has the internal contact strips faces down in the MPU, leaving the rugged back of the battery and the main charge plates facing up. (Fig 16) The batteries can be inserted with either hand and when lowered into the charge cradles, the batteries snap in at the end, giving feedback that they are securely placed and ready to charge. The charge contacts on the MPU are specified to be gold plated for corrosion-resistance and are loaded with a spring behind them so that when the batteries are slid into the slot, the gold contact scrapes away any corrosion on the battery charge plates and an optimal charge contact is established.

Similar principles are applied in the AA slots in the MPU, where there are contacts on the ends of the slots for the battery terminals and a small spring-loaded button in the bottom which pops the battery up every second time it is pressed from above; similar to the kind of latch seen on glass cabinet doors. This method

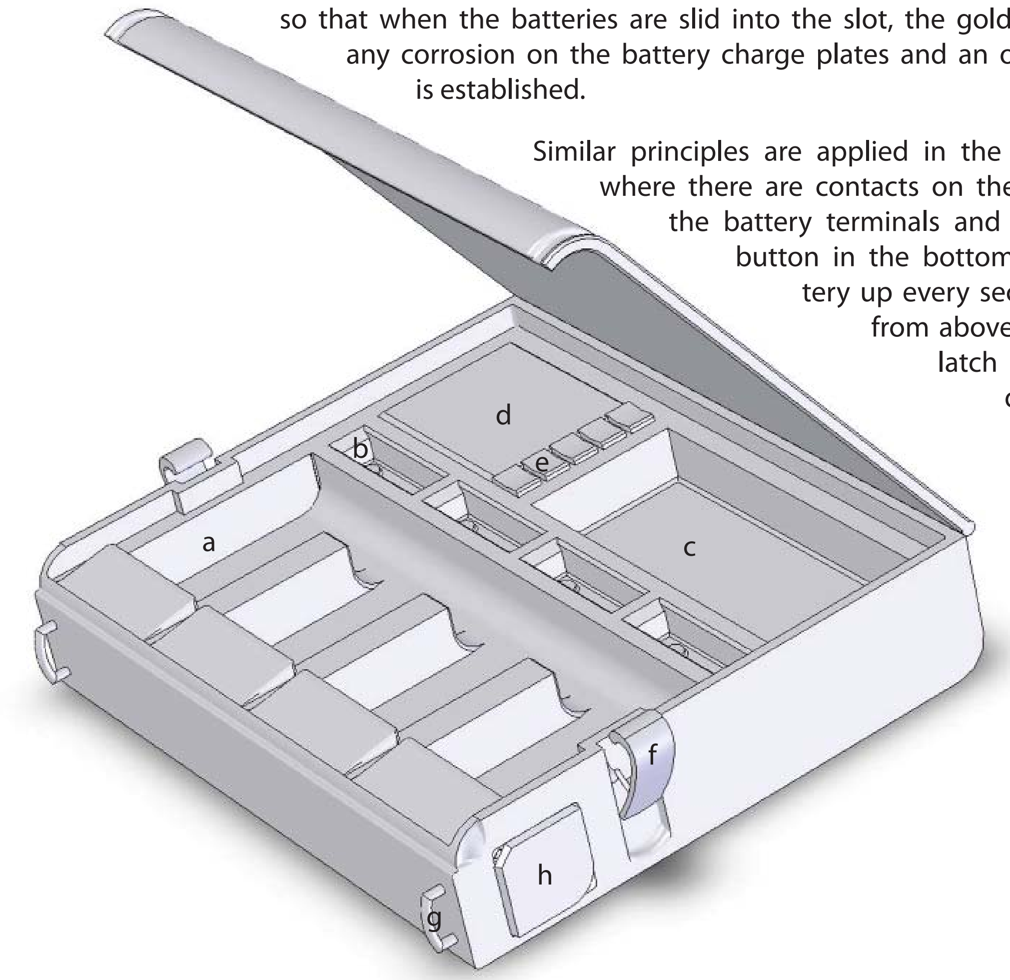



Figure 16: MPU Definative Design
a. radio slots
b. AA slots
c. satphone slot
d. control screen
e. control buttons
f. pressure locks
g. strap loops
h. AC outlet

was used because it reduced the amount of space needed on the main charge surface (Fig 17), making the MPU less crowded and easier to use. Additionally, since the AA batteries are small enough to lose easily, the MPU has an over-charge protector in the circuitry so that a full set can be left in the MPU at all times when not directly installed in the peripheral devices.

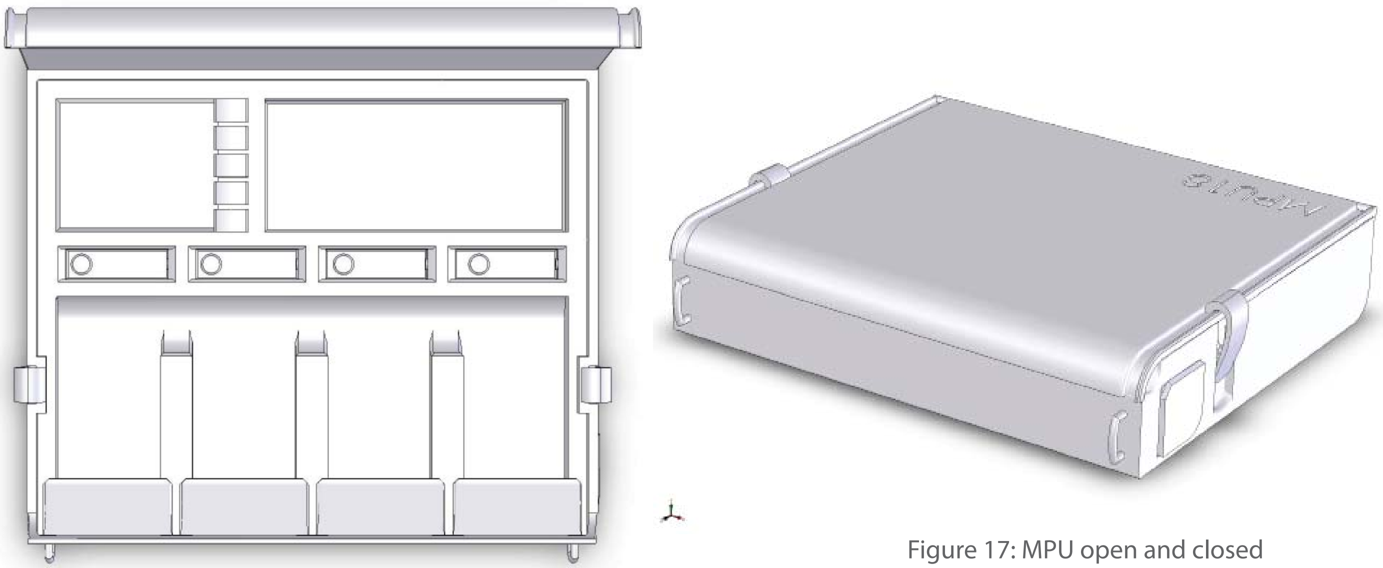



Figure 17: MPU open and closed

The charge method for the MPU was to use  a 5-sided, 3-pronged AC power cord which would supply the unit with 120V of power, and would charge the unit in 60-90 minutes, depending on the temperature. With the lithium-ion batteries, when their temperature drops below 5 degrees Celsius, the accessible power goes from 100% down to 60% and below freezing, that drops again to as low as 25%. The MPU is outfitted with an internal and external temperature sensor to  regulate the use of a small heater which would periodically activate if the temperature of the MPU drops below freezing to keeps the temperature inside the insulated casing above zero.

The external features of the casing are steel strap loops and the pressure fasteners. The strap loops are located strategically to absorb any impacts on the front corners of the casing. Additionally, it was found in the testing phase that the strap arrangement is variable and apart from removing it altogether, he strap can be adjusted to be short, medium or long, depending on the will of the crews. The pressure fasteners were incorporated to seal the lid of the MPU to provide water resistance and protection against damage from dirt and dust.

The overall capacity of the MPU was projected to be one charge for every battery in the unit; meaning that the fire crews would go out to an incident with a full battery in each device, one full set of spares in the MPU and one full charge stored in the MPU's power cells. This amount of energy was  assumed to be more than enough for the needs of a 24-30 hour mission. The other important fact is that although radio use is high with the crew boss and crew leader, the other crew on the ground do not use their  radios nearly as much, so their demand for fresh batteries is much less urgent.

## Feedback and Design Refinement

Presentations were made to the faculty at the School of Industrial Design and to the MNR for feedback on the project's progress. The general feedback was very positive, and much praise was received for the innovations that came from the collaborations with the MNR contacts and within the group.

There were a few points of constructive feedback that were brought up in the presentations. First, when the MNR contacts were shown the MPU they immediately wanted to know if they would be able to plug in other devices like lap tops or cell phones or cameras to charge. This was not something I had considered at this point and would be a factor I would consider for the final design. As it turned out, because the power supply rationing for a small-capacity MPU would be more trouble than it was worth, I projected that the female AC outlet could be available on larger versions of the MPU where less power rationing was required.

Second, there was questions surrounding the manufacturing of the MPU. Because low run and high run mass production procedures are so different, it became obvious that it would be very important to have some idea of what processes would be used in both run sizes and the associated cost of each. Finally, it came to my attention that the AC hardware specified for charging the MPU would be inappropriate for the task, and a male plug would need to be fit in instead. This change was not critical, but did affect the layout of the circuit inside the bottom casing.

The final design took shape quickly after the definitive design phase and focused on refining the details such as the hinge, the finger divots, the shape of the profile, etc.

## Final Design

The Mobile Power Unit is an energy transfer system that charges, manages and organizes batteries used in the wildland forest fire fighting industry. The Unit is equipped with eighteen 18650 lithium-ion batteries, an industry standard in the computing industry. These internal power cells deliver power to custom battery trays which charge not only the Motorola HT1250 nickel-metal-hydride batteries, but also AA rechargeables and the Lithium-Ion battery in the Iridium Satellite Phones used by the AFFM Program.

The MPU is an industry first in the movement towards standardized mobile power sources and is feasibly used in any North American fire fighting environment. The benefits are not only financial, where the cost of one unit is recouped when ten less radio batteries are purchased, but also logistical and environmental.

The Mobile Power Unit is a tool for enabling fore crews to become more autonomous and responsible for their equipment, while at the same time, management's interests are in mind. The warehousing issue has been addressed in a way that, compared to having 300 charging docks and as many loose batteries, the Mobile Power Unit is made to contain and charge all of it's contents so battery kits are ready for dispatch at any time and need not be assembled separately.

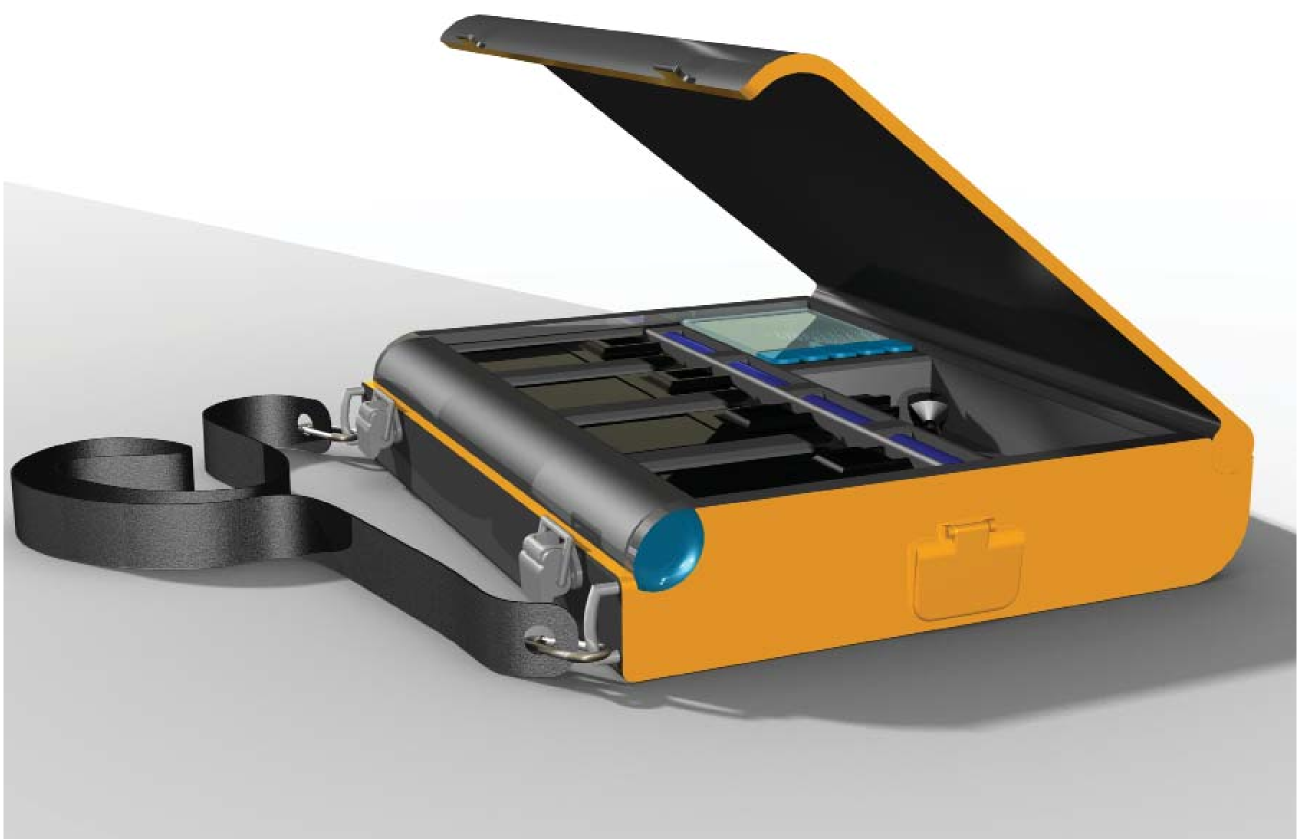


Figure 18: MPU Final Design

Figure 19: MPU on user

The Mobile Power Unit weighs less than half the equivalent amount of batteries, making it lighter and more easily managed for the fire crews who shoud be focused on the supression, not on the peripheral devices. The size is small, only 6 x 25 x 35 cm (Fig.19)makes it comparable to laptop computer in size. The operating temperatures range from -5 degrees to +35 degrees Celcius, which covers the average Ontario summer. The Mobile Power Unit is equipped with water resistant seals which protect it in case of rain or wet conditions around camp. The unit is easily charged at any wall outlet, taking 90 minutes for a full charge ofthe unit and all batteries inside.

The electrical circuitry (Fig. 20) is simple in nature and ruggedly designed for the Canadian woodland environment. Power is fed into the system through the AC adapter, where it splits and travels through gates to the power storage cells and to the microprocessor. The batteries are set in pairs, which, because they are small sets, means that if one battery fails, only the pair are deavitvated, compromising only about 5% of the power storage. The microprocessor controls all of the charging and discharging, as well as the sensors which speak to the software display on the charge deck.

Gates are distributed throughout the circuit in key areas that control the flow of energy, in case of malfunction or overheating. Also in the circuit are temperature sensors which contstantly monitor the power cells for the unlikely event of overheating, in which case they would be shut down and a warning displayed on the screen to indicate to the user that a maintenance check is required.

The circuit is suspended in a hardware rack inside the casing on rubber standoffs which are in place to cushion and concussions and guard against any problems with static.

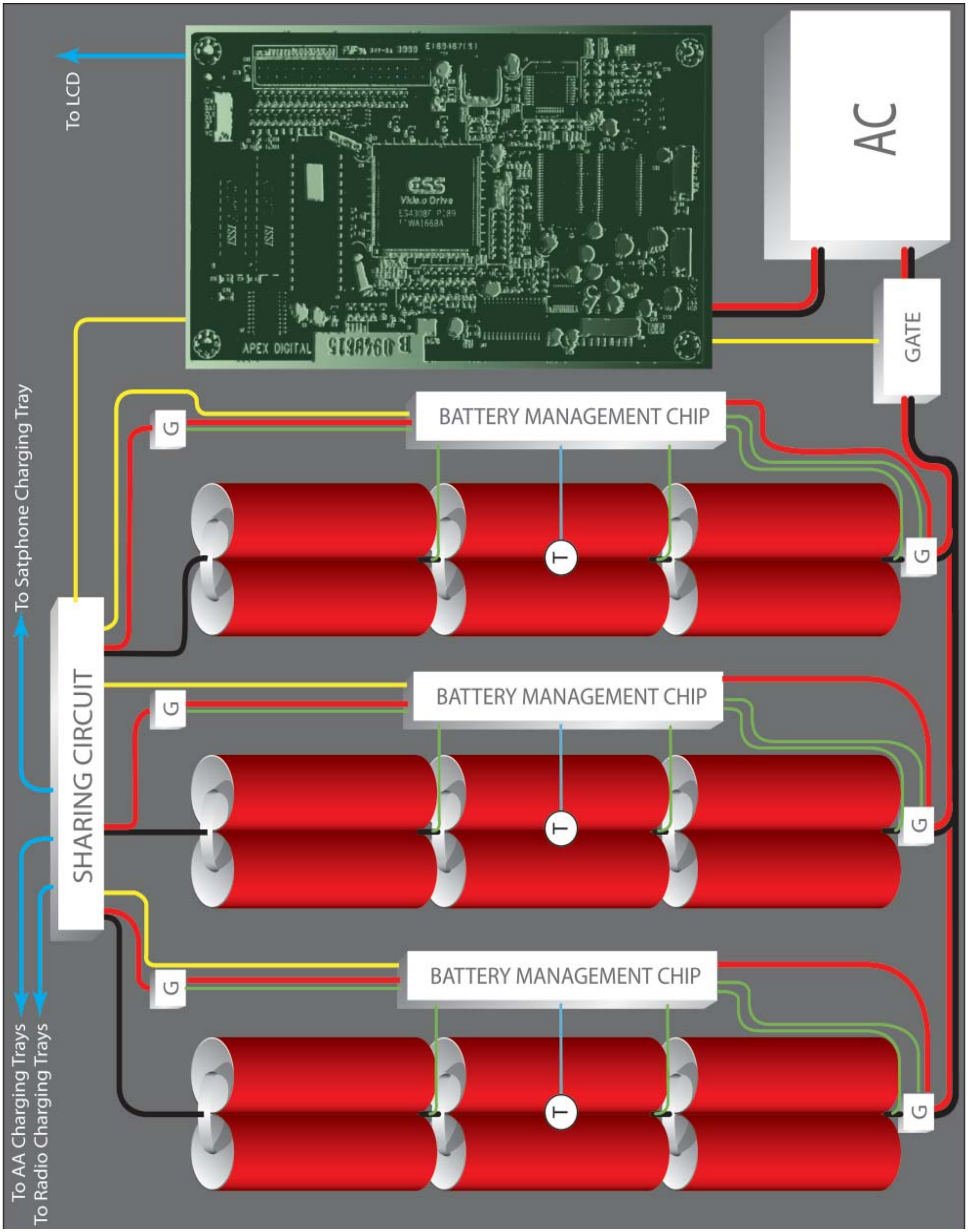



Figure 20: Circuit Diagram


Figure 21: Exterior Details

The electrical system seen in Fig.20 is charged at any 120V outlet with the included AC power cord. (Fig. 22) In the likely event that further development of this project will include a larger capacity unit for project fires, the number 18 [indicating the number of internal power cells] was added to the MPU title on the casing so that the users can differentiate between the sizes.

The manufacturing analysis (Fig.23) was conducted to demonstrate the differences in the processes and costs of manufacturing on a small and large run. The implications for fabrication and recycling are important as not all parts in either scale will be recyclable. There is, however, a much higher likelihood of self-disassembly in the larger run versions as they will be more precisely manufactured and will be made to come apart for regular maintenance.

Figure 22: Interior Details

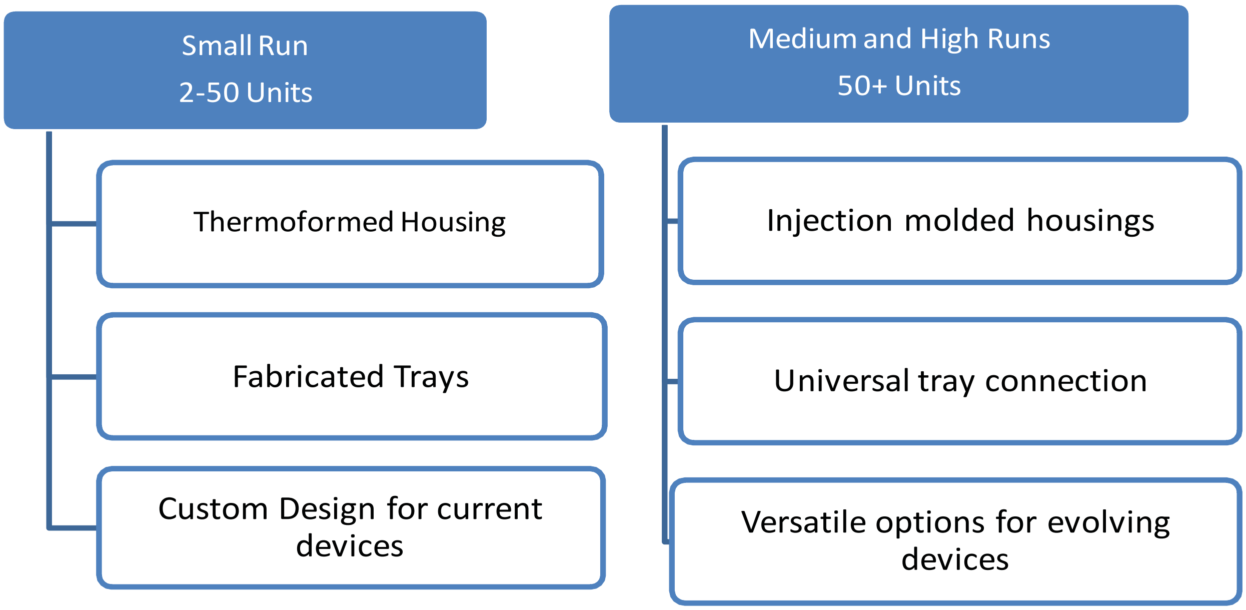



Figure 23: Manufacturing Analysis

## Presentations and Graduation Exhibition


Formal presentations were made to the MNR on Saturday, April 19th, 2008 at the Graduation Exhibition at Carleton University. The feedback was very positive and they spoke highly of the outcome of the project. All projects are in review for further development by and for the AFFM Program.

It should be noted that the thesis group that worked with the MNR's AFFM Program this academic year was selected as the recipient of the Innovation through Collaboration Award, as selected by the faculty of the School of Industrial Design. This award was given for the strong collaborative work done with the MNR in these projects and also the collaboration within the group.

The Graduation Exhibition was open April 18th to 22nd and each day, the Mobile Power Unit was shown successfully to the public and some interested members of the design community.