

TALON 2_b

TELE-OPERATED / AUTONOMOUS LAND ORIENTED NAVIGATOR



Submitted to:

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Embry Riddle Robotics Association (ERRA)

EMBRY-RIDDLE
AERONAUTICAL UNIVERSITY

INTRODUCTION

The TALON 2b design team began immediately following the breakdown and failure of the TALON II vehicle in last year's competition. The disappointing performance of the TALON II vehicle led the team to look for fundamental answers on the path to building TALON 2b. The TALON 2b vehicle was born with a focus on reliability and durability while enhancing and maintaining the safety aspects of the original design. The primary tasks for this year's team focused on a more reliable and capable drive train for the vehicle coupled with improved electrical systems and increased software capabilities.

Veteran leadership and experience lead the team away from the discouragement over last year's failures and stressed future goals. Before the end of the summer, many redesign ideas and solutions were already in place. The design team leaders tackled the many design changes with a carefully laid out design process incorporating time and vehicle requirements.

The TALON 2b vehicle took on a life of its own through the design process and finally came into its mantra of: "Designed *2_b* a winner." The Embry-Riddle Robotics Association (ERRA) and Embry-Riddle Aeronautical University are proud of the TALON 2b vehicle and believe it represents a perfect solution to the challenges set forth by the IGVC. Testing and evaluation have shown that the changes and modifications made during this design cycle increase exponentially the ruggedness, durability and capabilities of the original TALON II vehicle while maintaining the aspects of safety and ease-of-use incorporated previously. TALON 2b is truly capable of being a winner.

FACULTY STATEMENT

I hereby certify that the members of Embry-Riddle Robotics Association (ERRA) that worked on the TALON 2b design team have meet the design requirements as stipulated in the rules. The design, analysis and fabrication of the TALON 2b vehicle is sufficient as might be rewarded credit to a student team engaged in a senior design class.

Professor Charles Eastlake

Faculty Advisor, Embry-Riddle Robotics Association

TEAM STRUCTURE and DESIGN PROCESS

As in the past, the Embry-Riddle Robotics Association and the TALON 2b project were a volunteer effort for the students involved. Coupled with course work and other design classes, the TALON project has been a highly successful hands-on project for team members. All TALON 2b team members were returning from the previous year's TALON II team. The team leadership organized a weekly "work day" on which all team members would meet to work together. This time was also used to discuss new ideas and concerns from all team members. Either the Project Leader or Electronics Leader assigned specific individuals tasks to complete.

The team also benefited from a new method of communication that created a real-time paper trail. Beginning immediately after the 9th IGVC, the ERRA TALON team created a Yahoo!® Group. This allowed email communication between members, which is stored on the Yahoo! Server. This free service also included provisions to store files, photographs and database tables for the team. This paper-trail system leaves a fully documented path of all decisions made by the team this year. It proved incredibly valuable to the design team in tracking progress and documenting setbacks. The team also expects this tool to provide valuable information to future design teams in understanding the current team's decisions and setbacks.

The TALON 2b team was also aided by a variety of computer software packages throughout this design iteration. The TALON II vehicle had been modeled in Pro/ENGINEER, however some elements of the final vehicle did not correspond with the CAD model. Therefore areas worked on by the TALON 2b team were measured accurately from the vehicle and modeled to match in a variety of CAD packages including CATIA, Pro/ENGINEER and AutoCAD. AutoCAD was also used extensively throughout the design process of the new power distribution system to help determine efficient component layout. Other systems on the vehicle were modeled in a variety of software packages including Microsoft Excel and Circuit Maker.

The TALON 2b team used a unique perspective on the design cycle from previous years. As the vehicle was undergoing design revisions instead of overall design, care had to put in place that ideas and options explored would fully fulfill the Form, Fit and Function of the vehicle. Form and Fit were especially important as the team worked to maintain the previous vehicle's structural design. The design spiral (Figure 1) concept as illustrated below highlights the path the TALON 2b team was on. As the design

moved in towards the target the team became more aware of false paths taken in the previous year and sought to remedy them. Overall the design spiral allowed the TALON 2b team to take a critical look during every iteration of a particular modification without trying to see every issue simultaneously. The design spiral and the open, efficient communication among team members aided the TALON 2b team in building a more rugged and durable vehicle than in years past; a vehicle capable of winning the IGVC.

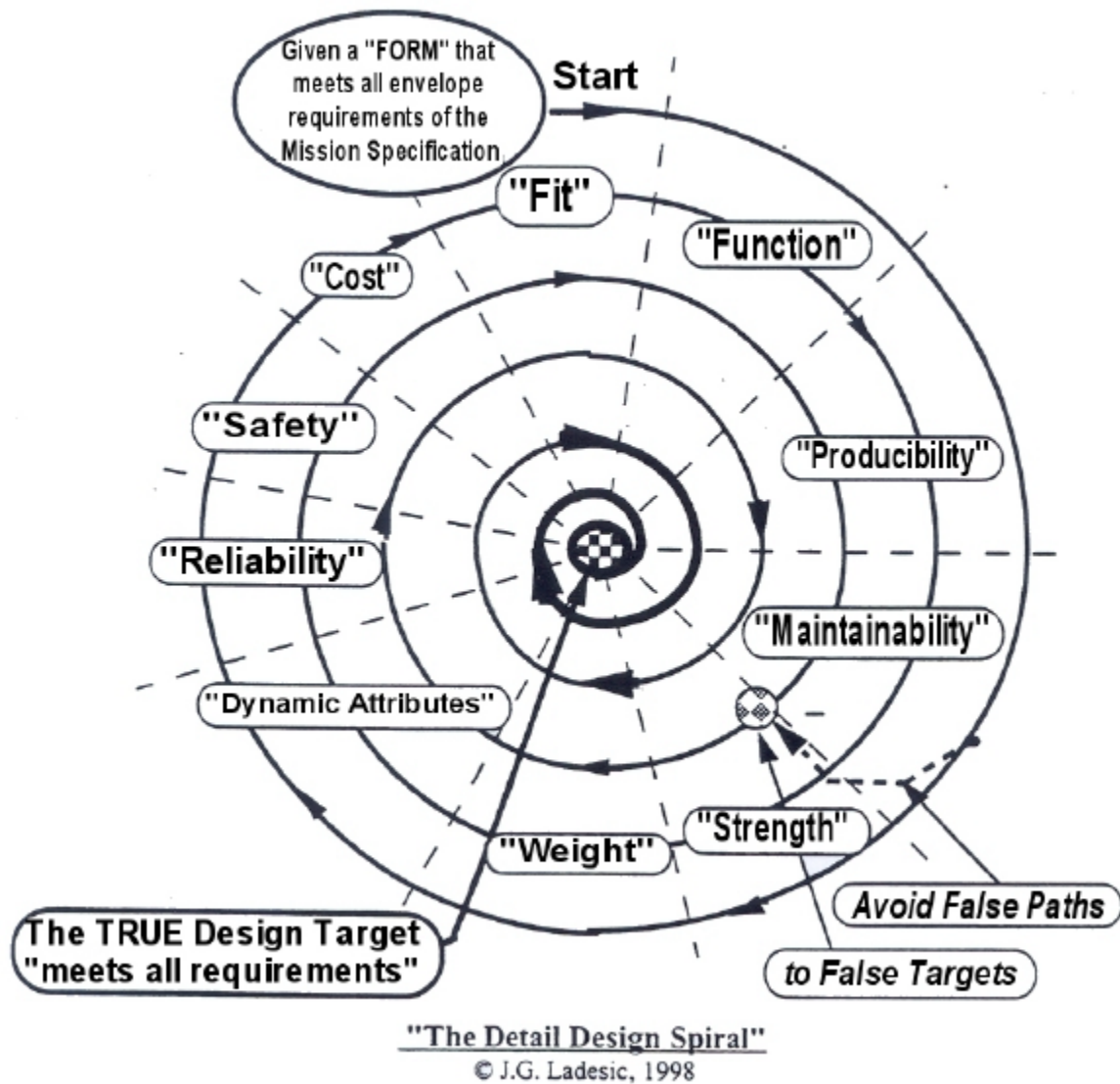


Figure 1 - Design Spiral

TALON 2b team members invested approximately 3000 man-hours into the project; 500 hours on public relations and administration, 800 hours in mechanical systems, 900 hours in software development and 800 hours in electronics. Team members with general assignments, degree program and level and advisors are listed in Table 1.

Table 1 – Team Members and Advisors

Member Name	Team Assignment	Major	Class Level
Danny Kent	Project Leader	AE	Senior
Brian Sharrer	Electronics Leader	AE	Senior
Joel Reese	Software / Electronics	EP	Senior
Tom Galluzzo	Mechanical / Software	AE	Senior
Rich Kulik	Mechanical / Software	AE	Junior
Pat McDermott	Electronics	AE	Junior
Jeff Johnson	Mechanical / Electronics	AE	Senior
Kurt Chewning	Mechanical / Electronics	AE	Senior
Ed Springer	Mechanical	AE	Senior

Advisors

Professor Charles Eastlake Faculty Advisor
 Don Bouvier Mechanical Advisor
 Mike Potash Electrical Advisor

AE – Aerospace Engineering

EP – Engineering Physics

MECHANICAL SYSTEMS

The primary mechanical task of the TALON 2b team was to increase the reliability with regard to vehicle motion. TALON II experienced a severe lack of power rendering it unable to move reliably in grass. The TALON 2b team decided to tackle this problem with a two-fold approach. The team first focused on researching the actual specifications of the motors in use and determining why the TALON II seemed not to possess a full 1 hp of power. Secondly, the team noticed that the two small casters used by the previous vehicle tended to dig into or drag through grass rather than roll evenly across it. The team sought out a solution to decrease this drag while increasing the overall vehicle power. The mechanical tasks completed by the TALON 2b team also included a spring modification to the existing suspension system, a new exterior body design and fabrication and a redesigned control panel. These modifications helped create a much more rugged and capable vehicle that is now extremely reliable in even the most extreme test scenarios.

Signal Amplifiers

Preliminary calculations indicated that the two 24-volt, 1 hp brush-type DC motors could deliver the necessary power for the vehicle when coupled with the 20:1 gear ratio gearbox in use. Initial investigations showed that while rated at a continuous 39-amp value, for maximum lock-down torque the two Leeson motors would attempt to draw upwards of 300 amps. The TALON 2b design team recognized that the issue was a lack of electrical power available to the motors.

The previous vehicle used two Advanced Motion Controls 50A8 PWM signal amplifiers to control the current flow to the motors. These particular amplifiers were rated for 30-amp continuous use and 60-amp spikes for less than 2 seconds. The TALON 2b design team found a more favorable solution in the Advanced Motion Controls 120A10-24 PWM amplifiers. These amplifiers are the rated to handle a peak amperage of 120 amps and run continuously at 60 amps. The 240% increase in continuous amperage corresponds with a 200% increase in available torque. The current system allows each motor to deliver a maximum of approximately 110 in-lbs of torque. This compares to a maximum of approximately 45 in-lbs using the previous signal amplifiers. This improvement gives TALON 2b a maximum of 183 ft-lbs of torque after the 20:1 gearboxes.

Caster Modifications

To overcome the drag-induced problem observed in the previous design, several options were explored. A primary goal of the caster modification was to increase the wheel diameter of the rear wheels and move from a rubber wheel to a pneumatic wheel system. A decision was made to use a single 6" diameter pneumatic caster. This caster required a ground clearance of 10" to mount beneath the existing vehicle. The previous vehicle had a ground clearance of only 6.5" and therefore had to be raised 3.5" to remain level. The additional ground clearance was obtained by including 3.5" spacers at the attachment points for the front suspension system. This raise increased the ground clearance by the necessary amount to allow the use of the larger caster. The design team also had concerns about the stability of the vehicle using a single rear wheel. When the chassis modifications were made to create mounting points beneath the vehicle for the caster wheel, mounting brackets were also placed to allow a switch back to a two-caster system if desired. Extensive field-testing on a variety of inclinations and surfaces has shown more than sufficient stability with the single-caster design.

Suspension Modification

The TALON II vehicle implemented a suspension system incorporating two mountain bicycle shocks attached to the front drive-wheel swing arms. While the suspension system worked, it was too stiff for the vehicle. However, the coil-over shocks were the softest sold by FOX Racing and also the best fit for our system. The TALON 2b team determined the fully loaded force on each wheel using a scale. This allowed the team to calculate a desired spring-rate to replace the one in place on the shock. A spring rate of 75 lbs/in was determined and a corresponding spring with the proper physical dimensions was selected. Field testing has shown that the new softer suspension system, coupled with the single pneumatic rear caster provides the TALON 2b vehicle with much better maintenance of all three ground contact points.

Exterior Body and Control Panel

TALON 2b's control panel continues to utilize a touch-screen LCD. Taking the features and convenience of last year's system, a new control panel design was built in CATIA, a solid modeling program. Many items were enhanced or added to the control panel such as better LED indicator lights, a computer power switch and indicator LEDs and easier to interpret amplifier indicators. The control panel was also fabricated out of aluminum sheet metal so that it would be stiffer and easier to manufacture. (Figure 2)



Figure 2 – Revised Control Panel

The exterior body was redesigned to accommodate the changes in TALON 2b's ground clearance and to incorporate the new control panel. The overall styling of TALON 2b remains consistent with the exterior of the previous vehicle. The body also underwent a material change for TALON 2b. The design team decided an aluminum body would prove easier to manufacture and finish. The previous year's vehicle also incorporated an innovative drawer system. These drawers provided easy access to batteries and a

payload compartment. The TALON 2b preserved this feature in the current vehicle and improved access to them from the exterior. The entire front panel of the vehicle now hinges down providing ample access to the draws and locking mechanism. The end product of all the design modifications to the body is a very rigid and water-resistant covering for the vehicle.

ELECTRICAL SYSTEMS

TALON 2b's computer system was given an overhaul adding data redundancy and improved processing speed. The newer signal amplifiers used to drive the motors required dramatic changes in the power distribution systems and the addition of a WAAS-capable GPS enhanced the point-to-point navigation capabilities of the vehicle. During vehicle testing and evaluation a reliability issue with the remote kill switch became apparent to team members warranting a replacement system to increase both range and ease-of-use. The electrical system modifications made to the TALON 2b vehicle over the previous vehicle help to improve vehicle performance and safety throughout the design. The design team took care to thoroughly evaluate and test every new or existing electrical system for reliability, durability and safety.

Computer Systems

A primary goal of the redesign project was to modernize the computer system onboard the TALON vehicle. The previous vehicle's systems were lagging behind current technology standards and the TALON 2b team focused on upgrading equipment and accessories to meet newer computer capabilities. The older 450 MHz Pentium II system was upgraded to a 1.4 GHz AMD Thunderbird processor. The processor upgrade also brought with it a motherboard upgrade incorporating an onboard RAID controller. TALON 2b's team members took advantage of the RAID architecture by upgrading the storage capabilities of TALON 2b with two 10 GB IBM laptop hard drives. Using these two drives in RAID mode 1, true 100% data protection is guaranteed. This gives TALON 2b the innovative capacity to remain fully function even if it experiences a drive failure. The newer ATX style motherboard also required a change in power supplies. Unlike the previous vehicle, the TALON 2b went with an off-the-shelf ATX power supply designed to operate off 12V DC power. The improvement of processing power and data redundancy increases the reliability of the vehicle's control system significantly.

Power Distribution

The larger and more capable signal amplifiers efficiently solved the drive power issues with the TALON 2b vehicle. However, implementation of the newer amplifiers required major changes to the way

power was routed from TALON's three batteries to its various components. The first significant difference with the new components was a significant change in size. The newer amplifiers could not fit in the custom boxes developed for the TALON II vehicle. The new amplifiers also draw a maximum continuous current of 60 amps. The TALON 2b team recognized this was over the safety limits of the existing wiring scheme. The TALON 2b design team built a new power distribution enclosure that incorporated both amplifiers, three circuit breakers and all power distribution wiring for the vehicle. Larger 2-gauge wire was used to route power from the battery contact to distribution terminals inside the box. Power is then routed through a circuit breaker prior to reaching either amplifier or any 12V sub-component. The TALON 2b vehicle still runs off two 12V batteries in series to power the 24V motors and one 12V battery to power all other devices. Each amplifier is protected by a 60-amp circuit breaker and the 12V system is protected by a relay and 30-amp circuit breaker. The new power distribution box continues the innovative power isolation design of the TALON II vehicle despite the larger currents in use. Preserving the safety of the power distribution scheme developed previously while increasing system capabilities improved TALON 2b's durability over the previous design.

Battery Connections

One truly innovative aspect of the TALON II vehicle was the incorporation of an easy-to-access battery tray mounted on sliding rails. This feature makes changing batteries easier and quicker than ever. To supplement the battery tray idea, a battery cap was developed for the TALON II vehicle that used a three-pronged outlet to transfer power from the power distribution box from the battery cap. The need for larger 2-gauge wire rendered the three-prong off-the-shelf connector idea useless and the design team had to find a new solution. The final design eliminates many of the problems of the older design while increasing ease-of-use and reliability. The long wires needed to be able to pull the battery tray and cap out of the vehicle always caused problems with trying to shut the tray, as they would bind.

The TALON 2b design team overcame the wire obstacle by inventing an innovative solid-contact system. Using a tongue-and-groove system, three copper plates on the battery cap (Figure 3) contact corresponding copper plates (Figure 4) mounted just behind the power distribution system. When the battery cap is placed onto the batteries and the battery tray is closed, the contacts mate to each other and provide power to the vehicle. Disconnecting power from the vehicle is as simple as pulling the battery tray out. This setup increased safety in a variety of ways. One such safety feature is a guarantee that if the



Figure 3 – Battery connector: tongue side attached to battery cap

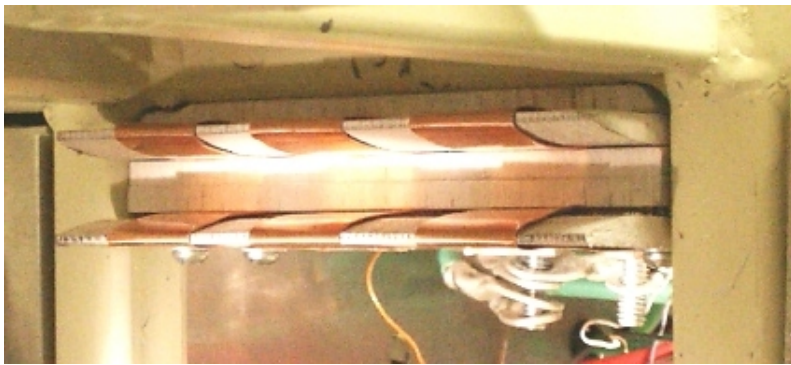


Figure 4 – Battery connector: groove side, attached to chassis

battery tray is removed the vehicle is electrically dead. Secondly since certain devices such as the amplifiers are directly connected to the supply, when removing and replacing the battery cap previously there would be small sparks as various capacitors charged up. This system does not eliminate the spark potential, but does move it away from potential contact with any human contact. The new, innovative solid-contact battery cap and tray system improves upon the original TALON II design, increasing safety, adding reliability and enhancing ease-of-use.

Remote Emergency Stop Control

Testing and evaluation of the remote kill unit in used in the previous year proved insufficient for TALON 2b's performance expectations. Range and reliability were considerably less than desired and often below requirements. The TALON 2b team replaced the existing unit with a more robust and simplistic implementation. Using a remote system designed for car door locks, the TALON 2b team built a "black box" remote kill switch that operates independently of the overall vehicle electrical system. The remote kill system passively kills the vehicle. Therefore if no power is supplied to it, both amplifiers are disabled by default. The newer system also increased the useful range of the kill switch to a minimum of 75 feet. Talon 2b's new remote kill system increases safety with its innovative use of a passive disable system, better range and reliability.

GPS

A completely new feature on Talon 2b is the GPS capability. Talon 2b is equipped with a Garmin twelve channel GPS receiver unit. The GPS is capable of receiving Wide Area Augmentation System (WAAS) signals in order to improve the accuracy and reduce the drift of the outputted navigation information. The WAAS system proves cheaper and more efficient than differential GPS without the need for a land-based differential system. WAAS uses two satellites to provide GPS correction signals from space. System performance specifications state that the Garmin GPS-16 WAAS-enabled system should have an accuracy of less than 3 meters with a 95% confidence. Typical GPS accuracy compares at 15 meters, while differential GPS using US Coast Guard signals typically have accuracies in the range of 3-5 meters.

COMPUTER SOFTWARE AND CONTROL

One thing the TALON II team brought back from last year's disappointment was confidence in the image-processing algorithm designed for the vehicle. Test images obtained on last years course showed a well-designed image processing and decision-making system. The TALON 2b team concentrated on building a more robust and capable interface program and a new control system for the Navigation Challenge. The improvements made throughout the software design greatly increase TALON 2b's ease-of-use and efficiency.

Interface Software

The software that drives TALON 2b has been completely reworked and rewritten to enhance the system by adding new features and functionality, while at the same time maintaining the reliability, integrity and performance that is essential for a winning vehicle. Starting from the ground up has allowed for the elimination of weak points in previous years software, and allowed for the addition of quality user interface components that were not possible in the past.

On the surface TALON 2b's graphical user interface has a familiar look and feel to TALON II, but underneath they are very different. Now each screen is constructed by tapping directly into the Windows Application Programming Interface, allowing custom graphical components such camera and processed images to be displayed in real-time, as they are refreshed in the system. The addition of this feature has been vital in the fine-tuning of the image processing code. Now the operator can observe how the camera image is being processed while the vehicle is on the coarse, and then make the appropriate changes to

maximize vehicle performance. Changes to the control system and imaging process are simpler as well. Instead of having to make code modifications and recompile all the software, the code parameters can be updated by the user while the vehicle is waiting to go before a run. Different groups of parameters can be saved and recalled for later use. (Figure 5)

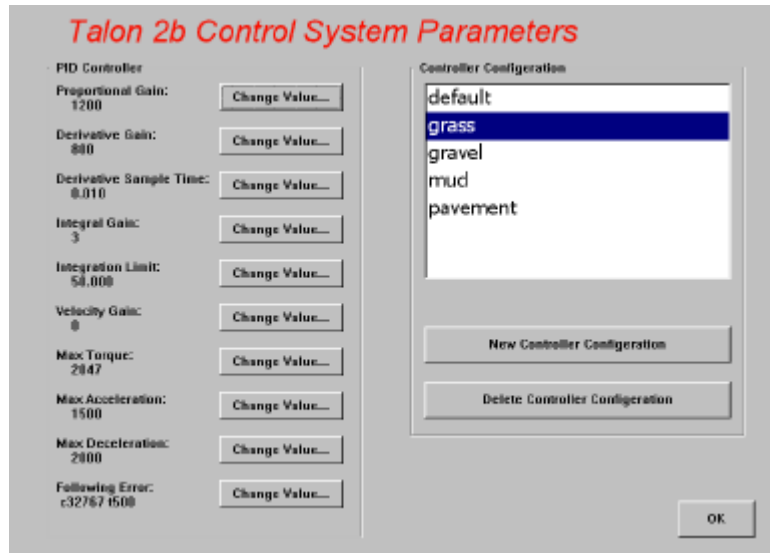


Figure 5 – Store and recall of configuration data

For example, the image processing parameters can be finely tuned for different amounts of sunlight, and then the user can simply reload a particular configuration when it is needed. The same is true for the motor control and autonomous control system parameters.

Navigation analysis

The addition of a GPS system to the vehicle control scheme required a new control system for the Navigation Challenge. As the TALON 2b vehicle was constantly undergoing mechanical and electrical testing throughout the design year, a system simulation was created to simulate the vehicle environment. The OpenGL-based simulator behaves and acts identically to the final software in both function calls and expected performance. The simulation allowed the creation and testing of several navigation schemes prior to vehicle integration. The final control system uses a non-linear heading error control system to maximize omega and velocity values according to perceived error. As the heading error approaches maximum values, which are changeable by the user, the vehicle approaches no velocity and maximum rotational speed. This way Talon 2b attempts to remain in constant motion while accurately arriving at every target. To minimize error from GPS drift, the navigation system averages 10 initial readings to establish a starting position. Relative position is then deduced from current position values as the course is run.

SYSTEM CAPABILITES ANALYSIS

The TALON 2b team sought to improve system reliability throughout vehicle design. A fundamental team belief was that the majority of the equipment and control architecture established on the TALON II design were capable, however unreliable and fragile. Throughout the redesign process vehicle performance consistently improved and approached the estimated capabilities originally sought. At many points the TALON 2b vehicle proved more capable than expected. The mechanical, electrical and software systems onboard TALON 2b integrate smoothly and reliably, creating a vehicle more than capable of meeting all design and performance requirements of the IGVC.

This is not to say the TALON 2b team did not meet obstacles and challenges along the way. Several areas tackled by the TALON 2b team proved bothersome and difficult to solve. The creative and innovative solutions found to these problems took time and creativity. These same solutions also proved to be among the best-engineered components on the finished vehicle.

Vehicle Capabilities

The TALON 2b vehicle meets or exceeds all required performance matrixes imposed upon it by both the IGVC and the design team. The improved drive train is more than capable of propelling TALON 2b through all but the roughest terrain at 5 mph. Testing in a variety of Florida environments from thick grass to soft sand and weeds has demonstrated the vehicles mobility is far superior to any vehicle ever produced by the ERRA group. This very same testing has demonstrated a ramp climbing ability significantly above the required 15% grade of the IGVC rules. The design team sought a 15° incline at a sustained rate of 2 mph and found that the vehicle could do so without trouble. Field-testing also demonstrated a capacity to successfully climb inclines in excess of 25° at slower speeds. A low center-of-gravity highly concentrated over the front-wheel drive system ensured that stability was a non-issue in all extreme inclines and approach angles.

The CCD camera used on TALON 2b can see objects approximately 15 feet in front of the vehicle. The image-weighting mask controls vehicle reaction depending on an objects position within the image. Position dependence causes the vehicle to react to objects with increased attention when the given obstacle is directly in the vehicle's path. If an object suddenly becomes viewable at a very close proximity to the vehicle it would reaction proportionally faster. A confidence factor calculated from image data indicates the probability that driving straight ahead will be an open path. In the case of a dead-end or trap,

the confidence value would become negative, indicating the vehicle should backup until another confident path is found. These two image systems allow TALON 2b to react both quickly if need be and smoothly in all other conditions. The systems also help avoid the traps and dead-ends throughout the course and provide a means of escape should TALON 2b reach such an impasse. Since line navigation and object avoidance are both accomplished by real-time image analysis, potholes present themselves to TALON 2b as no different than round white lines. They are areas of an image marked to be avoided and require no extra planning or means of detection.

The WAAS-capable GPS system from Garmin added to TALON 2b for this year's competition was necessary to successfully compete in the new Navigation Challenge. Vehicle tests by the TALON 2b design team have shown accuracies in the range of .3 meters. This accuracy is accomplished because the vehicle is only concerned with relative position changes and not absolute global coordinates. The TALON 2b vehicle coupled with the WAAS GPS system has demonstrated accuracy and capabilities far beyond those needed to complete IGVC objectives and significantly better than those capable with differential GPS systems. However, as in all GPS navigation, the team found that these accuracies were only available when navigation over long distances such as those used in the Navigation Challenge.

Problem Areas and Solutions

In the course of realistically confronting a number of problems and concerns from the TALON II vehicle, the TALON 2b team faced many complicated issues. Some of the solutions were readily recognized when the right information was presented and others were engineering design issues that baffled team members for months.

One such problematic area was in dealing with the new power requirements of the vehicle. Larger amplifiers meant more current, which meant larger wires. A primary design criterion for the TALON 2b team was to maintain the structural configuration of the vehicle. The original vehicle was already cramped for space in dealing with the wires needed to route power from the batteries to the distribution box. The addition of two five-foot lengths of 2-gauge wire compounded the problem. However, team members were content with it at first. After using this battery cap and accompanying wires for several months of testing, the team decided there must be a better solution and revisited the problem. A solid contact system had been discussed and dismissed earlier by the team for reasons of safety and

reliability. However, a creative tongue and groove implementation method making use of highly conductive copper contacts was given a green light by the team. The final product solves the wire and space issues, but also increases safety, enhances ease-of-use and represents an evolutionary change in the overall battery cap and power distribution system.

A second area team members encountered problems was the implementation of a new caster system. Several replacement systems were designed and debated by team members; these ranged from simple to complex in every way. Topics such as stability and ground clearance caused concern for a variety of designs, while other designs had size and space issues to contend with. The final implementation addressed many concerns including space, aesthetics, cost and stability. The single larger pneumatic tire was salvaged from an earlier vehicle, which competed in the 8th IGVC. This represented the most cost-effective solution available. The addition of three mounting points – one for single-wheeled and two for dual-wheeled – addressed stability concerns of design team members. Mounting to the bottom of the existing frame, this solution used no additional internal space and increase ground clearance – an issue for the previous vehicle. The increase ground clearance meant the vehicle would have no concerns with the peak of the ramp hill and therefore the rear caster was moved aft to the very back of the frame, a more aesthetically pleasing position than in the previous vehicle which had the two casters mounted 11” forward.

COST ANALYSIS

Part	Manufacturer / Model	Quantity	Total Cost	Source
20:1 Gear Box	Grove Gear / 20MF	2	\$980.00	Donation
24V 1HP Electric Motor	Leeson Electric	2	\$549.72	Donation
Nitrogen Spring-Over Shock	FOX Racing Shocks / VanillaR	2	\$298.00	Purchased
Shock Springs	McMaster-Carr	2	\$150.00	Purchased
Wheel Assembly	Walmart	2	\$86.86	Purchased
Pillow Block	Miller Bearing	2	\$30.00	Purchased
Caster	Bryson Inc.	1	\$18.00	Purchased
Frame Materials	N/A	N/A	\$150.00	Purchased
Body Materials	AL 2016-T6	N/A	\$200.00	Purchased
Misc Hardware	N/A	N/A	\$200.00	Purchased
Motor Amplifier	Advanced Motion Controls / 120A10-24	2	\$1850.00	50% Donation
Motion Control Card	PMC Inc. / DC2-PC-140	1	\$995.00	Donation
Framegrabber	Matrox / Orion	1	\$950.00	Purchased
1.4Ghz AMD Computer	Miscellaneous	1	\$1000.00	Purchased
Sunlight-Readable LCD	IDE Inc.	1	\$1,541.00	Purchased
Color CCD Camera	A-1 Services Unlimited	1	\$214.85	Purchased
Shaft Encoder	US Digital	2	\$131.00	Donation
Digital Measurement Unit	Crossbow / DMU-AHRS	1	\$6,750.00	Donation
Mil/LITE Software	Matrox	1	\$250.00	Purchased
Batteries	Powertron	3	\$105.00	Purchased
Misc Electrical Hardware	Miscellaneous	N/A	\$700.00	Purchased

Total Cost (without man-hours): \$17,147.43

Total Donated Costs: \$10,330.72

Total Purchased Costs: \$6,818.71