

# Technical Paper

## DARPA Grand Challenge

5 September, 2003



**NORTHROP GRUMMAN**  
*Electronic Systems*



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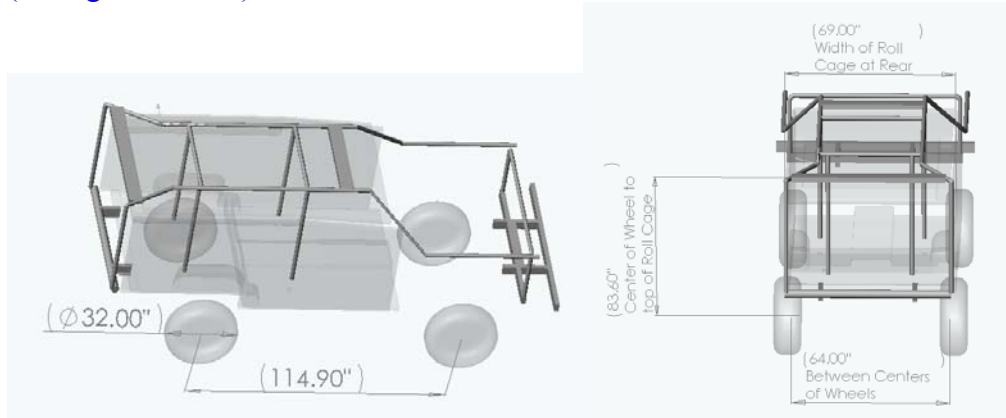
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1. System Description

a. Mobility.

1. Describe the means of ground contact. Include a diagram showing the size and geometry of any wheels, tracks, legs, and/or other suspension components.

Our vehicle platform, a 2-door 1996 Chevy Tahoe, will contact the ground with 4 mud terrain tires. The tires are 285/75/R16, filled with foam for puncture resistance (see figures below).



2. Describe the method of Challenge Vehicle locomotion, including steering and braking.

The challenge vehicle is a standard production vehicle (1996 Chevrolet Tahoe K1500 4x4) with the steering column removed and replaced with a servomotor driving the stock rack and pinion power steering system. A linear actuator is connected to the rear of the brake pedal via a cable for autonomous braking, using the stock front disk and rear drum brakes. Throttle control is accomplished using a linear actuator connected to the cruise control cable.

3. Describe the means of actuation of all applicable components.

Our Challenge Vehicle has actuators installed to allow computer control of the vehicle's motion. The engine is a 5.7 liter Chevy Vortec V8, with a manually controlled automatic transmission and transfer case. The transfer case will be used only in high range four wheel drive mode (i.e., there will be no transfer case actuator). The stock driveline powers standard truck tires (see 1.a.1. above) that have been foam-filled for puncture resistance.

The brakes are controlled by an Ultramotion™ linear actuator, which is connected to the brake linkage by a steel cable attached behind the brake pedal. The actuator is driven by a Quicksilver SilverMax™ motor and control system which is in turn connected to the computation system by a serial port. Since the brake pedal is pulled by a cable, an operator riding in the vehicle can still press the pedal (the cable attached to it simply buckles). A gas spring is installed in parallel with the linear actuator. If power is lost to the actuator (e.g., during a hard e-stop), this gas spring applies sufficient force to quickly stop the vehicle.

The vehicle's throttle is controlled by a proportional Addco ERC linear actuator which is controlled by a potentiometer connected to the on-board computers through

a parallel port. The actuator connects to the stock cruise control cable allowing a human to manually control acceleration with the gas pedal.

The transmission is controlled by a positional Addco ERC linear actuator which is preset with 4 positions. The control is connected to the computing system by a parallel port. A gas spring automatically places the vehicle in neutral if power to the actuator is lost.

The steering is controlled by a Parker servomotor connected to the input of the power steering gearbox. The servo is controlled via a serial port on the control computer. The steering wheel is replaced with a video-game steering wheel that can be used for manual control of the steering. If the operator uses the video-game steering wheel, the computer control system will be disabled and the human can take control.

b. Power

1. What is the source of Challenge Vehicle power?

All electrical power will be supplied by a Honda EV6010 RV generator, capable of delivering 6000W continuously at 120VAC. Two uninterruptible power supplies by Acumentrics (RuggedUPS 2500) will provide backup power to all critical systems for approximately 40 minutes. The rated output of each of these devices is a continuous 2000W at 120VAC. Run in parallel, the system will provide 4000W. DC Power will be provided by a Cosel ACE900 900W power supply providing 300W each of 12VDC, 24VDC, and 48VDC. Driveline power will be supplied by the stock 5.7 liter Vortec V8.

2. Approximately how much maximum peak power (expressed in Watts) does the Challenge Vehicle consume?

The Challenge Vehicle's electrical system will consume a maximum of 6000W electrical power. The power generated and used by the Vortec V8 is unknown.

3. What type and how much fuel will be carried by the Challenge Vehicle?

The generator will require no more than 10 gallons of unleaded gasoline, enabling power generation for 10 hours at peak load. The fuel tank for the Challenge Vehicle engine will contain 30 gallons of unleaded gasoline. An additional 30 gallons of fuel will be carried on board, in either one or two separate tanks. One of these tanks will provide fuel for the generator. Therefore a total of 60 gallons of 87 octane unleaded gasoline will be stored on the vehicle at the start of the race.

c. Processing

1. What kind of computing systems (hardware) does the Challenge Vehicle employ? Describe the number, type, and primary function of each.

The Challenge Vehicle will contain 8 regular desktop, IBM, Pentium 4, 3.0Ghz computers and one PC-104 computer. Six of the IBM computers will be devoted to processing stereovision and generating obstacle maps. One computer will be devoted to taking those obstacle maps plus global maps that are stored on board and performing macro route planning and obstacle avoidance. The last remaining IBM

computer will be dedicated to LADAR mapping and state estimation. State estimation includes combined filtering from an inertial measurement unit, a magnetometer, and a DGPS unit to obtain position, heading and tilt angles. Our software is modularized such that if a computer stops functioning, the system can shift processes to a different computer on-the-fly. The PC-104s primary function is to interface with all of our peripherals (sensors, actuators, etc). It has 34 serial ports, 2 parallel ports, and 54 digital I/O lines.

2. Describe the methodology for the interpretation of sensor data, route planning, and vehicle control. How does the system classify objects? How are macro route planning and reactive obstacle avoidance accomplished? How are these functions translated into vehicle control?

Stereovision cameras are our primary terrain sensor. Our software takes simultaneous images from two cameras along with state estimation data, and through a complicated method of raytracing is capable of producing four maps. The maps are a north-oriented, Cartesian grid (20cm x 20cm per cell) that is relative to the vehicle. The first map contains the elevation of each cell plus a confidence value for that number, once again relative to the vehicle. The second map contains the terrain type for each cell. Terrain types include vegetation, dirt, water, and paved road. Terrain type is determined by RGB color value of the stereo images. The third map contains believed-to-be-obstacles (both above ground and depressions) based on elevations of adjacent cells. The fourth and final map represents an approximate roughness for each cell, which is determined by analyzing all pixels that fall in that and adjacent cells. It can for instance tell the difference between rocky trails and a smooth trail.

Our LADAR is currently implemented to serve as a “bumper” aimed several meters in front of the vehicle so it can be used to quickly detect obstacles that may damage the vehicle if struck at high speeds. We hope to incorporate it into the mapping process (including terrain differentiation) described above if time permits.

Macro route planning is accomplished using a D-Star algorithm we have modified that was originally developed for Mars rovers. It takes current position and a goal position and will generate a set of waypoints that can be navigated. The input to this algorithm is described in section 1.d. - Internal Databases. The vehicle will try to drive this path until it encounters obstacles that prevent it from doing so. At that point it will add those new obstacles to its maps and calculate a new path. Velocity constraints are also implemented to prevent the vehicle from making sharp turns at high speeds.

Reactive obstacle avoidance is accomplished by calculating possible paths the vehicle could traverse out to the stopping distance of the car. Starting with the position of the vehicle and a heading, it will calculate N (currently 23) arcs the vehicle could drive from lock-left (steering wheel turned all the way to the left) to lock-right. Given the information in the maps generated by the stereovision code, the computer will calculate the cost/benefit of traversing each arc, giving low scores to the ones with obstacles, etc. Finally, there is a (currently unpolished) negotiation stage between the best arcs that the obstacle avoidance code provides and the

direction the macro route-planner would want to go. Thus, the car avoids obstacles when necessary and stays on a predefined route otherwise.

Steering control is simple given our setup because the arcs that are calculated are circular, so we can simply set the steering actuator (which is just a servo motor) to the appropriate angle/position, and the car will drive that arc.

In general, appropriate driving velocity is determined by both the macro- and obstacle-avoidance-level modules and the minimum of the two is taken. The brake and throttle actuator positions are continuously updated by a feedback loop that tries to stay at its set velocity.

d. Internal Databases

1. What types of map data will be pre-stored on the vehicle for representing the terrain, the road network, and other mobility or sensing information? What is the anticipated source of this data?

We have obtained 1m resolution images of the entire possible race-course, minus censored data over military bases. The computer alone will not know what to do with the RGB maps, so we will “paint” terrain types onto the maps. Based on color pixel value the computer will be able to distinguish roads, railroad tracks, overpasses, water, mountains, buildings, dry lakes, vegetation areas, and off-road trails. Each terrain type has an associated cost of driving on it, and the D-Star algorithm will then determine the “least-expensive” path to take. Cost is roughly equivalent to the inverse of traversable-velocity, as roads, for example, would have a low cost and could be driven at high speeds. The course boundary is represented as an infinite cost, thus the route planner would never allow the vehicle to stray out of the course.

Our maps were downloaded from U.C. Davis and U.N. Reno and are part of the USGS data library. They are not new maps and therefore the system will need to adapt to new data collected during the race, including when there is no prior map data at all.

e. Environment Sensing

1. What sensors does the challenge vehicle use for sensing the environment, including the terrain, obstacles, roads, other vehicles, etc.? For each sensor, give its type, whether it is active or passive, its sensing horizon, and its primary purpose.

<b>Sensor</b>	<b>Type</b>	<b>Active or Passive</b>	<b>Sensing Horizon</b>	<b>Primary Purpose</b>
Four (4) forward-looking cameras	Sony DXC-390: 3ccd 768x494 analog-output cameras	Passive	61° horizontal field of view, 56° vertical field of view.	Primary obstacle avoidance and local navigation system. Used for detecting terrain, obstacles, roads, and other vehicles.
Two (2) down-	Hitachi KP-D50: 1ccd color	Passive	120° horizontal	Used for obstacle detection as the vehicle crests a hill,

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looking cameras	768x494 analog output		field of view	since the front-looking cameras are pointed skywards in that situation.
4 Side-looking cameras	Hitachi KP-D50: 1ccd color 768x494 analog output	Passive	Will be determined by testing (60 - 120° horizontal field of view)	To build a more detailed map around the perimeter of the vehicle in order to navigate out of tough spots.
Two (2) Back Cameras	Hitachi KP-D50: 1ccd color 768x494 analog output	Passive	120° horizontal field of view	Obstacle avoidance for reverse maneuvers.
1 Long-wave Infrared camera	To be determined: wavelength 800-1400 nm; Vanadium Oxide or comparable detector.	Passive	Unknown	Terrain differentiation - primarily detecting vegetation vs. ground/rocks, the presence of negative obstacles, and road vs. non-road surfaces.
LADAR	SICK LMS-221-30206 single-axis	Active	100° horizontal plane	High speed, long-range obstacle detection (may also be used for terrain differentiation - primarily positive identification of vegetation).

One other terrain sensor we are currently considering is 90 GHz RADAR. This may be added in a subsequent technical paper addendum.

- How are the sensors located and controlled? Include any masts, arms, or tethers that extend from the vehicle.

Refer to the figures below for sensor locations.

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The 4 front forward-looking Sony DXC-390 cameras and the LADAR unit are mounted on the roll-cage over the roof, just above the windshield.

The long-wave infrared camera will be mounted above the forward looking cameras.

The 2 down-looking Hitachi KP-D50 cameras will be mounted in front of the radiator at roughly hood-height.

Each pair of the 4 side-looking Hitachi KP-D50 cameras will be mounted above the roof, pointing in a direction to be determined by testing.

The 2 back-looking Hitachi KP-D50 cameras will be mounted at the rear of the vehicle pointing downwards.

All of the cameras (visible and IR) and LADAR can be computer-controlled over RS-232. They will all be fixed in one orientation, i.e., none of the terrain sensors are mounted on pan-tilt mechanisms.

f. State Sensing

1. What sensors does the Challenge Vehicle use for sensing vehicle state?

For navigational and attitude state determination, the vehicle will use a combination of three different sensors. A Navcom SF-2050G DGPS system will provide latitude, longitude, and heading/velocity (when the vehicle is in motion). The heading reference generated by the DGPS system will be fed into a Northrop Grumman LN-200 Inertial Measurement Unit running in AHRS (Attitude, Heading, and Reference System) mode which then generates pitch and roll information. The LN-200 will be initialized using data from a PNI TCM2-50 3-axis magnetometer, which will provide heading, pitch, and roll data when the vehicle is stationary. Vehicle diagnostic state will be provided by the car's built-in On-Board Diagnostic system, which will provide, among other data, engine temperature, engine RPM, and present gear.

How does the vehicle monitor performance and use such data to inform decision making?

The vehicle will receive all sensor data through a centralized "comm box" (PC104 stack), including OBD-II, GPS, IMU, component health, and temperature sensor data. This data will be processed in software to generate a single vehicle navigation state vector (from GPS + IMU) and a diagnostic state vector (from OBD-

II, temperature sensors, and component health information). The master driving software will monitor both the navigation state and the diagnostic state during driving. Navigation state will obviously influence the direction and speed at which the vehicle drives. Diagnostic state will influence operating conditions; for example, if the engine is overheating, the vehicle will slow down.

g. Localization

1. How does the system determine its geolocation with respect to the Challenge Route?

The vehicle determines its geolocation with respect to the grand challenge route through differential GPS.

2. If GPS is used, how does the system handle GPS outages?

In cases of GPS outage, the vehicle will use the IMU and magnetometer to navigate. Zero-velocity updates will be used to reset the biases on the IMU, and the vehicle will integrate the delta-Vs and delta-thetas generated by the IMU to get position and attitude information. During the zero-velocity updates, the vehicle will also wait to see if GPS has been reacquired and use that information as an update to the inertial navigation.

3. How does the system process and respond to Challenge Route boundaries?

The route boundaries are superimposed on our global maps, and are given infinite cost of traversability. Therefore, the macro route-planner will never allow our challenge vehicle out of the course way.

h. Communications

1. Will any information (or any wireless signals) be broadcast from the Challenge Vehicle? This should include information sent to any autonomous refueling/servicing equipment.

No signals will be sent during the race. We use 900MHz Freewave ([www.freewave.com](http://www.freewave.com)) ethernet radios for testing, but they will be removed for the race.

2. What wireless signals will the Challenge Vehicle receive?

DGPS is the only signal our vehicle will receive. We have a Navcom DGPS unit which can receive GPS corrections from their Star-Fire satellite. This is a commercially available unit and signal.

i. Autonomous Servicing

There will be no autonomous servicing.

j. Non-autonomous control.

1. How will the vehicle be controlled before the start of the challenge and after its completion?

To control the vehicle, one must switch to human-control-mode by pressing the indicated button. The driver will then have control of the stock accelerator pedal,

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stock brake pedal, transmission shift switch, and video-game steering wheel. Actuators can be individually turned off using cutout switches located to the right of the steering wheel.

In brief, the method of operator interface includes:

- Brake pedal
- Accelerator pedal
- Steering wheel (video game-controller)
- Transmission shift switch
- Actuator cutout switches

2. If it is to be remotely controlled by a human, describe how these controls will be disabled during the competition.

The vehicle may be remotely controlled by a human via an Ethernet radio link, for testing purposes only. During the race, these radios will be removed from the vehicle, disabling this function.

## 2. System Performance

- a. Previous Tests. What tests have already been conducted with the Challenge Vehicle or key components? What were the results?

Three major system tests have been performed in the field.

1. St. Luke's parking lot, Pasadena, CA, August 1, 2003: The challenge vehicle was tested in a large empty parking lot to test the ability of the software to actuate the vehicle (braking, steering, throttle, etc.). The steer-by-wire capability was demonstrated, and some generator issues were identified and resolved.

2. Santa Anita parking lot, Arcadia, CA, August 14, 2003: Further testing of the actuation was accomplished. More generator issues were discovered and resolved. Computing integration issues (software bugs, processor speeds) were discovered and resolved.

3. El Mirage Dry Lake Bed, near Adelanto, CA, August 20, 2003: GPS and magnetometer data was collected. Further testing of computer-controlled actuation.

Additional sub-system tests have been performed:

1. El Mirage Dry Lake Bed, near Adelanto, CA, May 11, 2003: This trip had several purposes.

- a. Hard drive survivability: The purpose of this test was to determine what hard drive mounting methods, if any, would protect them from damage while driving off-road. Computers with spinning hard drives were installed in the back of the stock 1996 Chevy Tahoe. 6 hard drives were tested. Two were installed via a standard mount, two were encased in foam rubber, one was suspended by an 8-point spring mount, and one was mounted on rubber washers. The only disk to fail outright was the spring-mounted drive. (For the race, only one of the 8 computers will need to use a mechanical hard drive at any time [for map data]. The other 7 computers will all hold the map data, but their disks will be spun down. The rated non-operating shock of these drives is 300G for a 2ms pulse, or 1.04Grms for vibration. This is much more than we expect to see. Thus, 8 independent failures would be required to disable the vehicle, an unlikely occurrence).

b. Maximum accelerations: A small 2-axis accelerometer was mounted in the vehicle to measure maximum accelerations inside the vehicle while traveling off-road.

Maximum accelerations were measured under 2g.

c. OBD-II data collection: We used an off-the-shelf system (AutoTap) to read data from the On-Board Diagnostic (OBD) system that is part of all 1996 and later vehicles. We found the data from OBD-II to be less than reliable. Further testing is required to determine if any of the OBD-II data will be useful.

2. Infrared camera (El Mirage, August 9-10): We evaluated the performance of the Indigo Omega (long-wave infrared) and the Indigo Merlin NIR (near-infrared) cameras. The images of the NIR camera were similar to those of a monochrome visible-light camera. The images of the long-wave camera, however, highlighted vegetation, negative obstacles, fence posts, and roads, even though the data was highly subject to cloudiness and time of day. The end result of the test was the decision to purchase a long-wave infrared camera.

3. SICK LADAR: Basic tests of our LADAR software have been performed. The LADAR was mounted on a donated shopping cart and driven through hallways to test the functioning of our software. In the future when the IMU (Inertial Measurement Unit) is running, testing of the software that builds a 3-D map from the LADAR data will be performed.

4. Visible camera: Tests of the physical ruggedness of the camera have been performed. Also, we have performed basic tests of the functionality of our cameras and the framegrabbers (images have been successfully captured).

5. GPS: We have tested the ability of various materials to block antenna reception. Flat sheets of aluminum and Lucite were unable to block the GPS, as multi-path reflections off of the ground still reached the antenna. Wrapping the antenna in aluminum foil cut off reception (we can selectively cut off satellites and simulate GPS outages). Also, we have checked the accuracy of the GPS coordinates of our maps.

6. Computing results: The IBM desktops can process 6.8 frames per second of stereo data at the required resolution. Our IPC software can exchange messages in 30us. The miscellaneous digital I/O on the “comm box” can switch in 1.3us.

b. Planned Tests. What tests will be conducted in the process of preparing for the Challenge?

In general, the goals of future tests will be to demonstrate robust:

1. Software-controlled actuation, “drive-by-wire”.
2. Waypoint following via GPS.
3. Obstacle detection (positive, negative, water, etc.).
4. Obstacle avoidance.
5. Road following.

Initial testing will be accomplished in a large parking lot (Santa Anita), and at El

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Mirage dry lake bed. As the vehicle matures, system testing will be performed in representative environments (as shown in pictures on DARPA Grand Challenge website). The current plan is to test once every two weeks during the fall, and once a week in the winter. The ultimate goal, of course, is to push our averages speeds up as high as possible on all terrains.

In addition, the following sub-system testing will be performed:

1. IR cameras: Data will be gathered with the long-wave infrared camera such that image variations due to cloudiness and time of day can be characterized.
2. Component failure testing: To test the robustness of our vehicle, we will deliberately cut power to individual components, to ensure that a power failure in any part of the system will not result in uncontrollable behavior.
3. Stereo camera system: Extensive terrain classification and obstacle detection tests will be performed throughout the fall and up to race day.
4. E-stop: The performance of the e-stop system will be extensively tested (this will be high priority in the fall).

3. Safety and Environmental Impact

a. What is the top speed of the vehicle?

55 mph. This is dictated by the foam in our tires (the foam breaks down at higher speeds). We are also investigating the use of Kevlar-lined tires, which would allow for a higher maximum speed.

b. What is the maximum range of the vehicle?

Greater than 250 miles, assuming (worst case) 5 miles/gallon, and 50 gallons of fuel (a total of 60 gallons will be available at the beginning of the race, 10 gallons of which will be used by the generator. See 3.c.1.).

c. List all safety equipment on-board the Challenge Vehicle, including

1. Fuel containment

The challenge vehicle will have both the stock 30-gallon gas tank and one or two auxiliary tanks (the auxiliary tanks will hold at least 30 gallons). The fuel system is fully sealed and pressurized, tested to meet California standards for emissions and crash survivability. The stock tank will be protected along with the rest of the undercarriage-mounted components by a large skid plate bolted to the frame rails. This will prevent it from being punctured by rocks or other obstacles. The auxiliary tank(s) will be mounted in the cargo area, inside of the roll cage, which will protect it (them) from punctures in case of rollovers.

2. Fire suppression

A fire suppression system will be installed on the vehicle to detect and extinguish fires in the engine compartment and the passenger/cargo space. The system is composed of pressurized hoses which burst when exposed to a large temperature gradient, releasing fire suppression gasses. The computer system can detect (via a relay) activation of the fire suppression system and respond accordingly

– turning off necessary systems or activating a software E-Stop.

3. Audio and visual warning devices

The vehicle will have several flashing lamps mounted externally as well as an audible warning device which meets DARPA requirements to indicate that the vehicle is under automated control. There will also be signs warning to stay well clear of the automated vehicle.

d. E-Stops

1. How does the Challenge Vehicle execute emergency stop commands? Describe in detail the entire process from the time the on-board E-Stop receiver outputs a stop signal to the time the signal is cleared and the vehicle may proceed. Include descriptions of both the software controlled stop and the hard stop.

The E-Stop signal is received by a specially designed circuit which is capable of executing both a soft and a hard E-Stop.

Hard E-stop: When a hard E-Stop signal is received, our E-Stop circuit will cut power to the brake and throttle actuators. The throttle actuator free-floats and will be forced by the vehicle's throttle mechanism to its off position (just as it would if a human let his foot off of the gas pedal). The brake actuator will remain where it is when power is cut, but a solenoid which holds back a gas spring will release and depress the brake pedal. Once released, the gas spring will hold the brake pedal firm to the floor. The steering actuator also free-floats if power is cut, but its position at the moment the e-stop signal is sent will vary, and may flip the vehicle if the wheels are not pointed straight and the vehicle is moving at high speeds. Therefore we will not be cutting power to the steering actuator during a hard e-stop.

Soft E-stop: A soft E-Stop, on the other hand, will simply send a signal from our E-Stop circuit to the computing system. The computing system will then depress the brake fully and release the throttle in software. The vehicle will remain in a standby state (actuators locked) until allowed to resume (another signal sent to computing system).

The E-Stop circuit also acts as a watchdog, making sure the computing system is still active. If the computers do fail, power will be cut to the actuators just as if a hard E-Stop signal was received.

2. Describe the manual E-Stop switch(es). Provide details demonstrating that this device will prevent unexpected movement of the vehicle once engaged.

The manual E-Stop switches will be large, red, mushroom switches located around the vehicle. These mushroom switches are connected to our E-Stop circuit. When activated, a hard E-Stop will be executed, and the vehicle will decelerate and remain motionless (see 3.d.1. above).

3. Describe in detail the procedure for placing the vehicle in “neutral”, how the “neutral” function operates, and any additional requirements for safely manually moving the vehicle. Is the vehicle towable by a conventional automobile tow truck?

If power is lost to the vehicle it will automatically be placed in neutral by a gas

spring. The stock transfer case shift lever can also be used to shift into neutral if necessary. There will be a control box located near the dash with a clearly marked selector switch which can also be used to place the vehicle in neutral.

The vehicle may be towed using a conventional tow truck, however highway speeds (45 + mph) should not be maintained for an extended period of time due to the foam-filled tires.

e. Radiators

1. Itemize all devices on the Challenge Vehicle that actively radiate EM energy, and state their operating frequencies and power output. (E.g., lasers, radar apertures, etc.)

Device: SICK LMS-221 single-axis LADAR

Operating frequency: Infrared

Power output: Class 1 Laser.

2. Itemize all devices on the Challenge Vehicle that may be considered a hazard to eye or ear safety, and their OSHA classification level.

There are no devices on our challenge vehicle that are considered a hazard to eye or ear safety (except possibly the DARPA-required audible warning device).

3. Describe any safety measures and/or procedures related to all radiators.

Our SICK LADAR uses a class 1 laser, which is neither hazardous to eyes nor capable of acting as an ignition source. Accordingly, it is unnecessary to take safety precautions related to our only radiator.

f. Environmental Impact

1. Describe any Challenge Vehicle properties that may conceivably cause environmental damage, including damage to roadways and off-road surfaces.

The vehicle will produce approximately the same level of emissions as an unmodified pickup and is well within California standards for gaseous and particulate emissions. The vehicle will achieve approximately 8-10 miles per gallon, assuming standard conditions. The generator will consume an additional 1 gallon per hour. The vehicle is equipped with standard radial tires so damage to road surfaces will be minimal.

2. What are the maximum physical dimensions (length, width, and height) and weight of the vehicle?

The width of the challenge vehicle is 80 inches, the height will be less than 106 inches (to be determined by final placement of GPS antenna), and the length is 205 inches. The final weight of the vehicle will be about 6000 lbs.

3. What is the area of the vehicle footprint? What is the maximum ground pressure?

Each tire footprint is about 90 square inches, so assuming a 30% tread void given our Firestone Destination M/T tires, the maximum ground pressure is approximately 24 psi.