Instrumenting an All Terrain Vehicle with Off-Road Mobility Sensors

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I. Abstract

One way for researchers to collect vehicle mobility data and terrain information is to fully instrument their vehicle with many sophisticated and expensive vehicle performance sensors, as is the case with CRREL's Instrumented Vehicle (CIV). Yet, researchers seeking to collect mobility data with a low-cost, portable system or install mobility sensors on smaller vehicles cannot go this route. In an effort to overcome cost and size limitations while maintaining functionality, an all-terrain vehicle was instrumented to collect mobility information with low-cost sensors.

At the U.S. Army's Ethan Allen Firing Range, mobility performance tests, such as coast down and drawbar tests, were performed alongside the CIV for comparison, while cross range test runs were performed to demonstrate the system's capabilities.

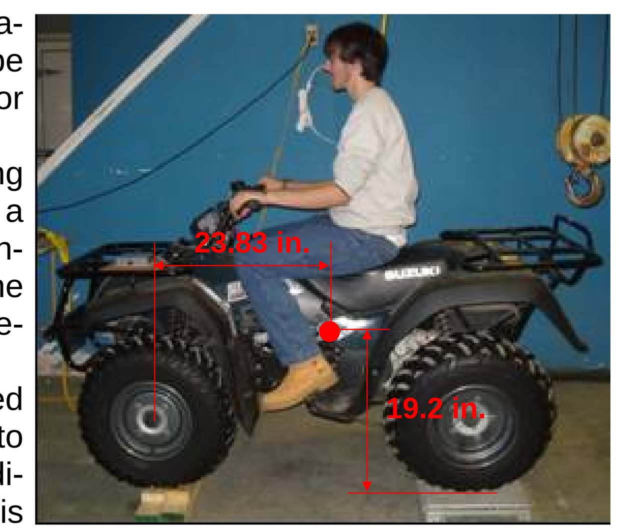
Further uses of such low-cost, portable vehicle mobility instrumentation systems would allow for accurate vehicle simulations and mobility awareness that can be used *in situ* by the Warfighter and lead to more extensive applications in force protection/border patrol scenarios.

II. ATV Specifications and Testing

Vehicle dynamic measurements and engine specifications were taken for accurate mobility measurements and to model the ATV in a virtual world vehicle simulation. Aside from the ATV's basic geometry and weight, the two most important vehicle characteristics needed to model the ATV are the center of gravity and the engine characteristics.

Center of Gravity Calculations

When putting instrumentation on a vehicle or when modeling a vehicle in a simulator, it is critical that the location of the center of gravity (CG) is known because this is the point about which the vehicle rolls, pitches, and yaws. Therefore, when a motion pack measuring the angular velocities and angular accelerations of the vehicle is mounted on a test vehicle, its location with respect to the CG must be known so that a correction factor can compensate for the offset.



The CG on the Suzuki King Quad 300 was determined from a series of weight measurements under the front and rear wheels of the ATV while it was level and on a decline.

The lateral CG is measured from the centerline of the vehicle to the lateral CG. A positive value indicates that the center of gravity is closer to the right side of the ATV from the rider's perspective. The longitudinal CG is measure from the center of the front tire back, and the vertical CG is measured from the ground up.

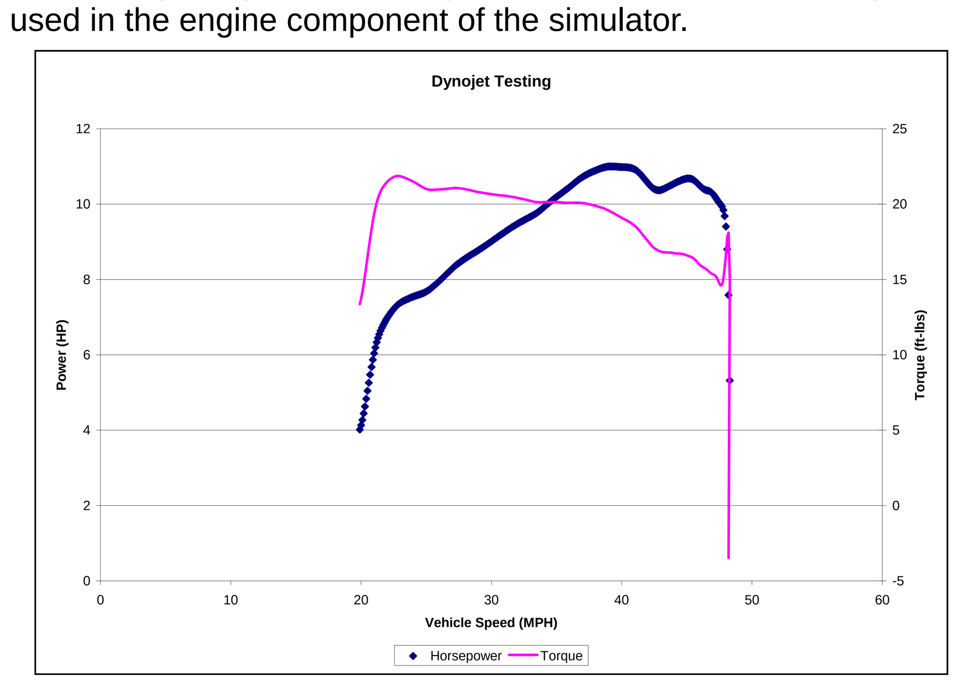
		Right Front	Left Front	Right Rear	Left Rear
Without Rider	Level	152.8 lbs	157.0	167.7	146.0
	7.5° Decline	204.0	192.0	--	--
With Rider	Level	183.0	193.5	211.5	195.0
	7.5° Decline	255.0	239.5	--	--

Dynamometer Testing

Dynamometer testing on the ATV was conducted to measure torque at the rear wheels.

Dynamometer runs were conducted from an engine speed of 1500 rpm to the maximum engine rpm for gears one through four in both high and low gear. The different throttle settings were required for a full range engine torque map of the ATV. Each test started at an engine speed of 1500 rpm, the throttle level was pegged until the maximum rpm of the ATV was reached, and then the throttle was released.

For each run, the engine speed, rear wheel torque, rear wheel horsepower, and rear wheel speed were recorded. The torque versus engine speed for one gear at the four throttle settings was used in the engine component of the simulator.



III. ATV Instrumentation

Data Acquisition System

The Campbell 23x data acquisition system (DAS) collection rate is 10 Hz from the accelerometer and 5th wheel and 1 Hz from the GPS. The data are stored in a storage module and can be downloaded via Bluetooth to a computer for analysis as an ASCII comma separated file.

Inertial Navigator System

The accelerometer is an O-Navi Analog Inertial Sensor Gyrocube 3F. The Gyrocube 3F is a six degree-of-freedom inertial measurement unit module that measures acceleration in three axes and roll, pitch, and yaw rates. Angular rates range is ± 400 °/s and accelerations can be measured up to ± 10 g. The sensor output was adjusted to the SAE tire axis system.

Vehicle Speed

The TrackTest 5th wheel is an accurate way to determine true vehicle speed. The unit has a performance meter that reads optical pulses and displays the speed. The display was mounted on the front rack to be visible to the rider. The 5th wheel was attached to the ATV's rear rack.

Geographic Location

The Garamin GPS was essential to plot vehicle position for post processing procedures and to synchronize the vehicle position with video. The GPS was mounted to the roof of the DAS box with a steel plate. The GPS system attached records positioning data into the DAS at 1 Hz. It will not record data unless there are at least three satellites available to define its position.

Drawbar Load

The Lebow load cell is used to measure rolling resistance and traction coefficients.

Video Documentation

A Sony Handycam camcorder was attached to a camera mount on the front of the ATV to record terrain conditions.

IV. ATV Mobility Testing

All Terrain Vehicle sensor and instrumentation testing was conducted at the U.S. Army's Ethan Allen Firing Range (EAFR) in Jericho, VT on 11-13 June 2006. EAFR was picked for its varied terrain that had recently been modeled in a simulated world.

- **Draw Bar Pull** (SAE J939, SAE J1270, SAE J1269, or SAE J2452): Draw bar tests are used to calculate the coefficient of traction from the load cell and 5th wheel speed sensor, the traction coefficients can be calculated as functions of wheel slip or speed. During a draw bar test, the ATV pulls a heavy vehicle such as the CIV.
- **Coast Down Test** (Bosch 2004): Coast down tests are one way to determine rolling (motion) resistance coefficients. Together with speed, the rolling resistance can be calculated from one of three different formulas.
- **Rolling Resistance Pull Test** (SAE J939 or SAE J872): The average pulling force divided by the vehicle weight produces the coefficient of rolling resistance.
- **Circle Breakout Test** (SAE J2181): The circle tests allowed yaw rate to be verified and the user to gain some feel for the vehicle dynamics.
- **Trail Traverse**: Tests were performed on trails throughout EAFR to collect data for an accurate vehicle simulation and side-by-side comparison between the real and virtual data. Using the data that was collected from the DAS and the video camera, the video and data were synchronized using a post processing program.

- **Snow Testing**: Snow Testing was performed in March of 2003 at the Claremont, NH airport. The test setup was similar to EAFR testing with the ATV in 2WD high or neutral. Drawbar and rolling resistance tests were performed.

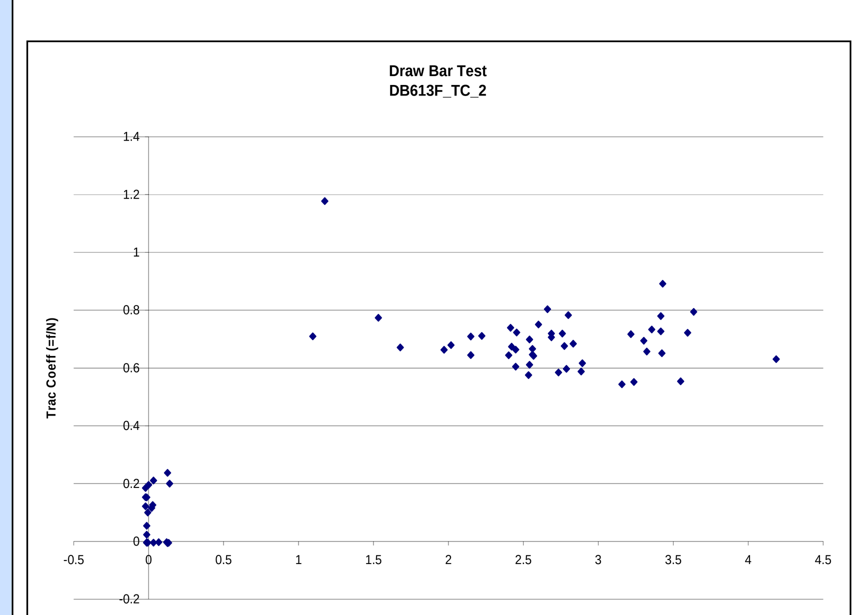
V. Data Analysis

Traction Tests: Draw Bar

Traction coefficients are calculated by dividing the longitudinal force by the vertical force acting on the vehicle during a draw bar test. They are unitless values that indicate how well the vehicle can grip the terrain. It is essential to make sure that the wheel gradually slips on the surface during the test so that maximum traction is reached. Since there were no wheel speed sensors on the ATV to indicate wheel slip, wheel spin was observed during testing.

Traction coefficients for the ATV at EAFR on gravel ranged between 0.55 and 0.75. On snow, the traction coefficient was approximately 0.35.

A typical drawbar test result is shown below. Traction coefficients are plotted versus speed.



Rolling Resistance: Coast Down Test and Rolling Resistance Pull Test

Three equations were used to estimate the coefficient of rolling resistance from the coast down test. One such equation is:

$$RR_x = \frac{CV_i^2}{e^{\frac{2Cx_s}{m_v}} - 1}$$

where

RR_x = the resistive force of the vehicle (N)

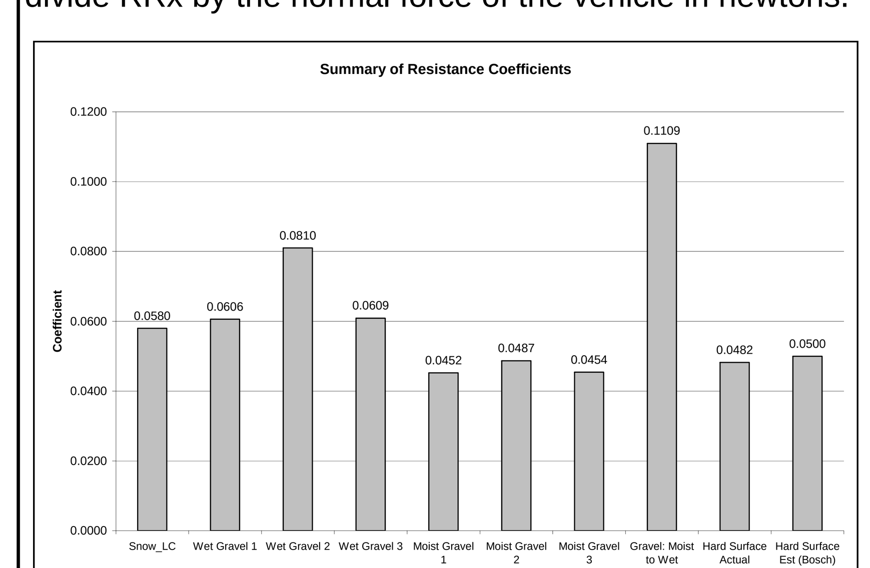
C = an aerodynamic drag factor (0<C<1)

V_i = velocity at the start of the test (m/s)

m_v = is the mass of the vehicle (kg)

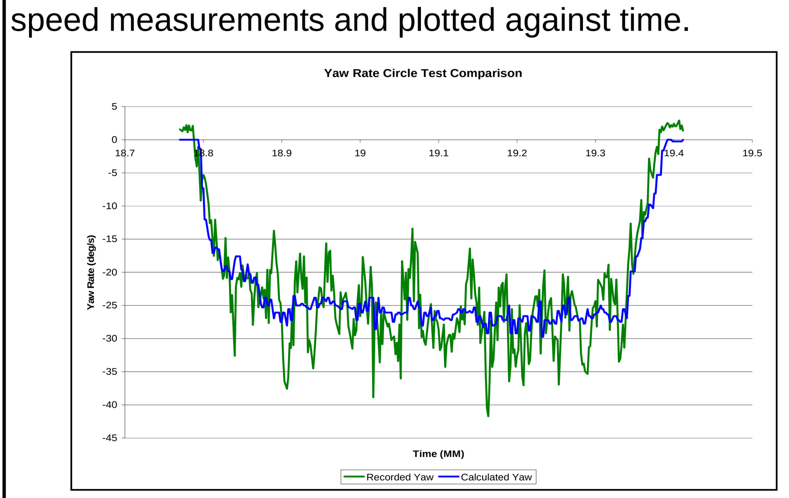
x_s = the stopping distance (m).

To get the coefficient of rolling resistance, simply divide RRx by the normal force of the vehicle in newtons.



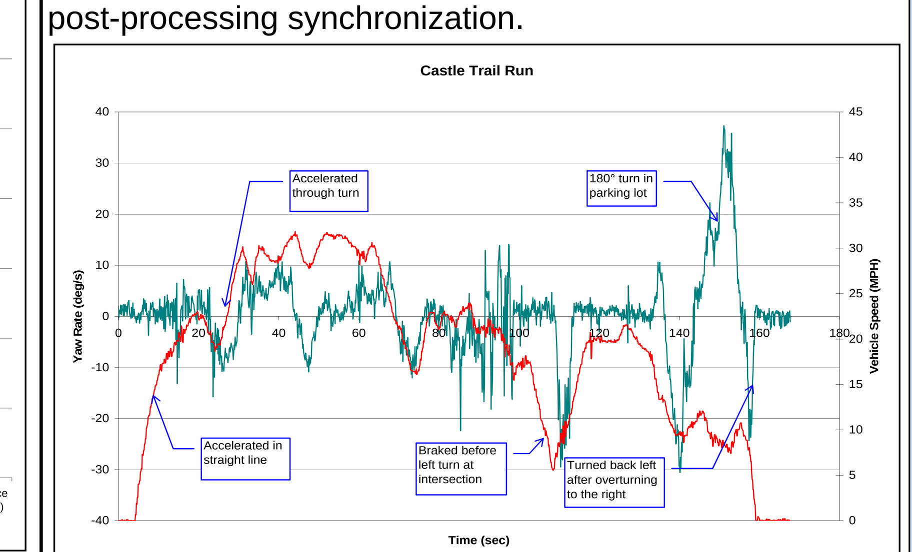
Circle Test

To validate the yaw rate, calculations were made from the speed measurements and plotted against time.



Trail Traverses

ATV data from EAFR trail runs was used for video-data post-processing synchronization.



VI. Summary

- Low-cost, portable systems for **mobility analysis** of small, lightweight vehicles are instrumental in determining proper use requirements during field operations.
- Gathering necessary **mobility data for a simulation** would allow for accurate predictions of an ATV's capabilities in varied terrain conditions.
- **Synchronized output** of all sensor data with video could lead to an evaluation of terrain-vehicle-driver interaction.
- Real-time data analysis with a visual output could enhance the driver's situational awareness of his vehicle's capabilities.
- Since the **Department of Homeland Security** uses ATVs to protect the border and solider use ATVs in combat, proper instrumentation of ATVs and understanding of their mobility would increase their applicability and functionality.
- Collection and analysis of such data would make the realization of **robotic ATVs** that much more affordable and effective for security operations around the world.