AC 2011-723: COUNTERBALANCED TRANSPORTATION, IT IS A DESIGN THAT WILL ATTEMPT TO KEEP THE LOAD STABLE NO MATTER THE INCLINATION OF THE TERRAIN

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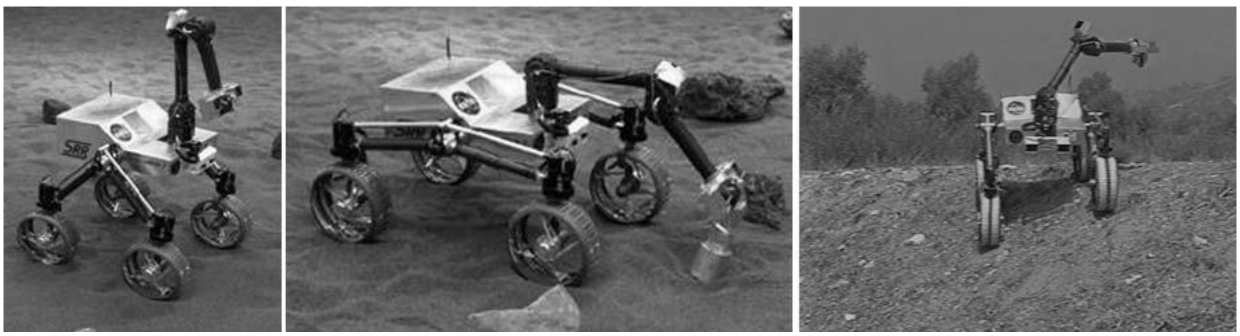
Counterbalance Transportation System

Introduction

The idea of our robot came from a Sample Return Rover[1] that was created by NASA. The Rough terrain mobility of a mobile robot could easily be increased by simply shifting the center of gravity of that robot. On an inclined surface, active suspension can hold the main body horizontal which makes navigation easier. NASA's Sample Return Rover (SRR)[2] which has been designed to collect soil and stone sample from Mars surface. SRR has active suspension system with variable angle between linkages.

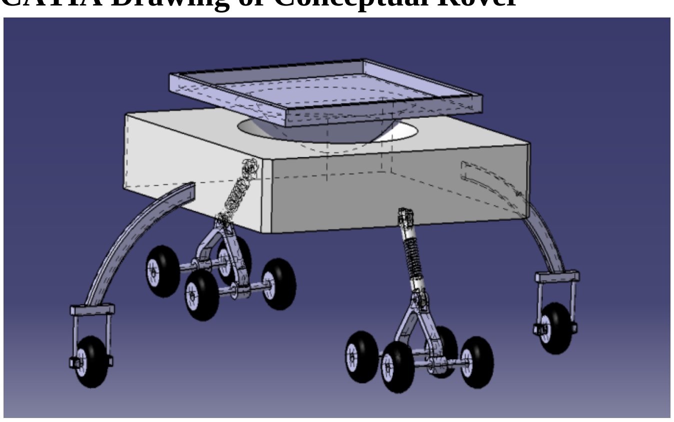


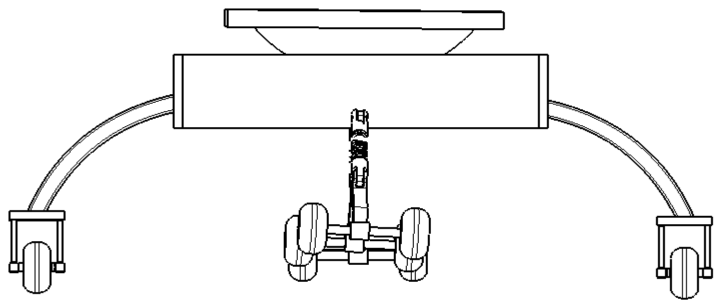
Sample Return Rover - (SRR) (Courtesy of NASA/JPL-Caltech)

Using a similar theory we came up with a design that would allow a robot to transport weighty sample specimens without causing any major disruption in the performance and mobility of that rover. To aid in this process we implemented a swiveling platform that would allow the load to be perfectly balanced at all times. This means having the load stay in a horizontal state even if the rover was attempting an uphill maneuver.

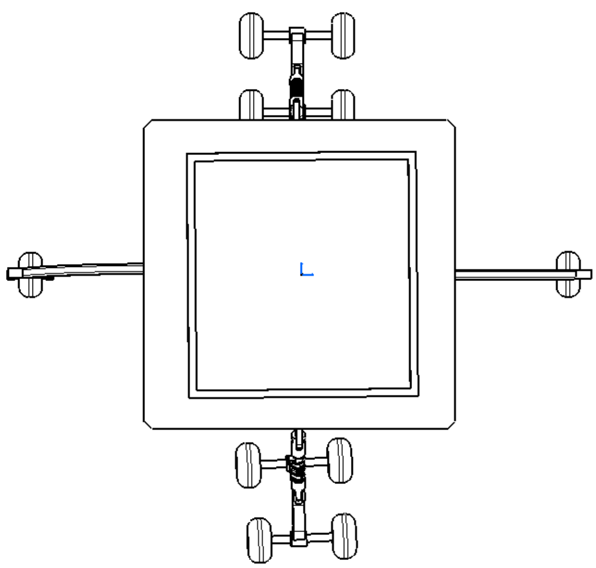
The key to the robots success will not depend on adjustable legs as in NASA's SSR but will depend on a counterbalance theory. IF the weight of the transported load is acting at an incline when the robot is going uphill a sensor system will detect this and readjust the center of gravity of that load allowing it to continue to act perpendicular to the base[3].

CATIA Drawing of Conceptual Rover

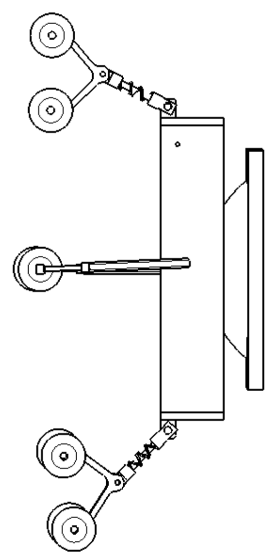




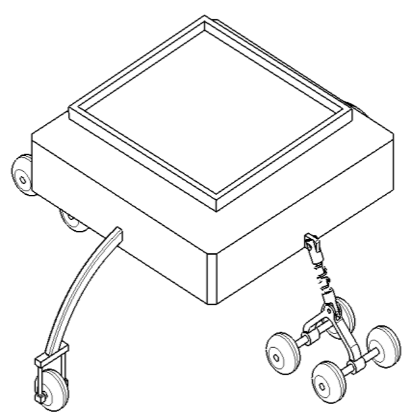
Bottom view



Front view



Left view



Isometric view

Theoretical Design

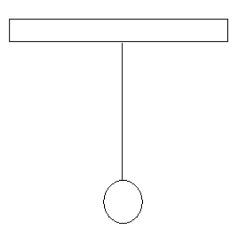
As we progressed in our design, we realize that similar concept can be used in our everyday lives. Instead of using dual swivel system we can use the same design of counterbalance in everyday transportation system. We can replace swivel system with hydraulic jacks to keep the load horizontal to the ground. Maintaining the same center of gravity of the load can prove more efficient when going up/down hill. We will attempt to apply the same concept towards everyday transportation of fluids.

Since tractor trailers and tanker trucks are some of the most commonly used vehicles to transport fluids, we have created our design based on them. Adding a counterbalance system to trailers and tankers can dramatically reduce their fuel consumption and provide more stability when carrying liquids.

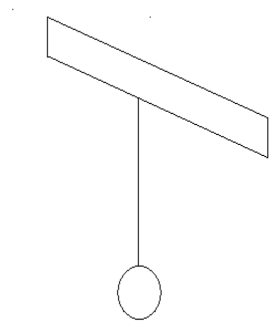
A tanker truck is a motor vehicle designed to carry liquefied loads, dry bulk cargo or gases on roads. The largest such vehicles are similar to railroad tank cars which are also designed to carry liquefied loads. Large tank trucks are used for example to transport gasoline to filling stations, concrete, milk, water and industrial chemicals.

The design for our CB Trans was based on a simple pendulum. Studying the motion of a pendulum we observed that the suspended weight remained vertical even though the object that suspended it was inclined. If we replaced the ball weight that was used for the pendulum and placed a rod the theory remained true once that rod was connected at a point where its center of gravity acted. In the case of a uniformed rod the center of gravity acted through the exact center. When applying the theory to an unevenly distributed object the center of gravity had to first be calculated before being connected before the object could be suspended horizontally. On this basic theory we designed our CB Trans system which is will keep the center of gravity of any load equally distributed.

Using a simple pendulum theory we devised a concept that would allow the center of gravity of that body to remain vertical at all times.

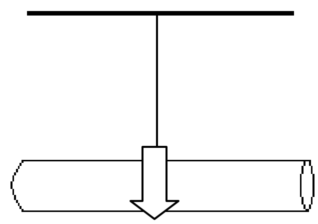


Our concepts which is based on Newton's 1st law of motion; a body at rest will stay at rest unless acted upon by an external force



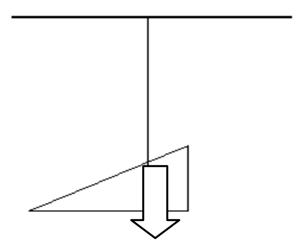
Although the object on which the pendulum has been suspended from is no longer horizontal the body will still return to its state of rest or the position in which the center of gravity of that body acts. These two diagrams describe exactly how an object's center of gravity will act on a horizontal plane and how it will then change from an evenly distributed load to a triangular load as the plane becomes inclined.

Suspended uniformed Rod



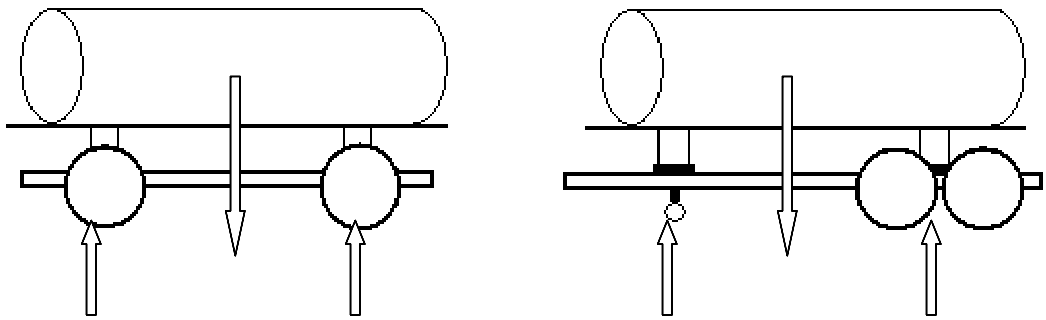
This is used to show that the location of a center of gravity on a uniformed object will act directly in the center of that object.

Triangularly Distributed load



This diagram shows how the liquid load will act when going uphill and the location of its center of gravity as the load becomes a triangular shape inside the cylindrical tank. (Note: this is for a half filled tank and is only used to convey our concept and state of thought)

Our concept will be based a theory that attempts to reduce the backward force acting on the rear wheels. The idea came to us while paying attention to a pendulum and the way the weight at the end of the string always hung vertically. This observation sparked the idea in which we will attempt to prove. Our aim is to maintain a perfectly horizontal load no matter the terrain just as the pendulum will stay vertical even if the object that it is suspended by is inclined. To do so we will add a pair of hydraulic jacks that will be attached to a solid base on the tractor trailer or tanker truck. The jacks will be used to adjust the angle of the tank to match the angle of the slope, which will then cause the tank to return to its leveled state. It is imperative that the jacks be placed directly above the wheels of the trailer. The reason for this is to eliminate the moments that would be created around the axle if there is a distance between the jacks and the wheel.



Each hydraulic will work independently; during a forward uphill movement the back hydraulic jack will lift the latter part of the tank to make it horizontal to the ground. Likewise forward downhill movement will trigger the front hydraulic jack to raise the front part of the tank to until leveled. Our design not only eliminates the uphill and downhill strain of load hauling but it will also increase the safety of everyday trucking. Considering the rising cost of fuel and the prominent requirements for timely deliveries this theoretical concept should prove as a better option.

Application

Firefighters often use tankers to transport water to areas beyond a water supply system. To save lives, those tankers have to move fast to reach the destination; and faster response requires more efficient and user friendly system. Hydraulic adjustment will provide same center of gravity of the load throughout inclined and declined moments, which allows drivers to maintain a faster averaged speed when during uphill and downhill movements. A faster response time for fire fighters arriving to a remote location means will give them a better chance at saving lives and even the building.

Advantages

Advances in vehicle design will increased safety and reduced the possibility of accidents. Primary reasons that justify the relevance of our design are:

- Safety
- Efficiency
- Reliability and endurance

Safety

Safety is a key factor everywhere we turn; businesses are always sacrificing time for safety. It is imperative to not only complete the accepted job but to complete it in a manner that eliminates the risks and hazards of losing a equipment or even more an employee. Safety was taken into consideration because we wanted to make our design practical. Having the load remain in the horizontal position means less forces acting on the tie downs (straps or chains) when descending and ascending on an inclined terrain. A properly displaced center of gravity will allow a driver to stop the truck more effectively during a downhill descent; which will allow a greater time window if ever he needs to apply a sudden emergency brake.

Increased Efficiency

A normal truck will consume a substantial amount of fuel when going uphill. The reason being is the load that was once distributed equally along the bed has now transformed into a more concentrated load acting mainly on the back wheels. Keeping the load horizontal while the truck ascends the inclined plane means a continuously distributed load. Implementing this will result in better gas mileage, a more constant averaged speed and overall shorter delivery times.

Reliability and Endurance

Maintenance is necessary but constantly maintaining a vehicle can prove costly in the long run and takes away from your profit. Having our CB Trans system implemented means less/lighter braking. There is a lot that goes on whenever a vehicle brakes and especially if that vehicle is hauling tons of load. Every time you brake it means you will sooner or later have to accelerate again which simply uses more gas. It also causes more stress and strain on your mechanical components. The steady variation between compression and tension of the pins and bolts used to connect individual components can cause wear and tear to occur even faster. Having our system will greatly reduce tire wear and tear, extend the life span on mechanical parts and reduce the downtime of a vehicle due to maintenance.

Force analysis in the uphill direction prior to the automatic adjustment

Considering the tank is filled with the fluid at an angle of α in the uphill direction, the objective is to compute the backward force (F_{HB}) and wheels reactions due to fluid in the tank.

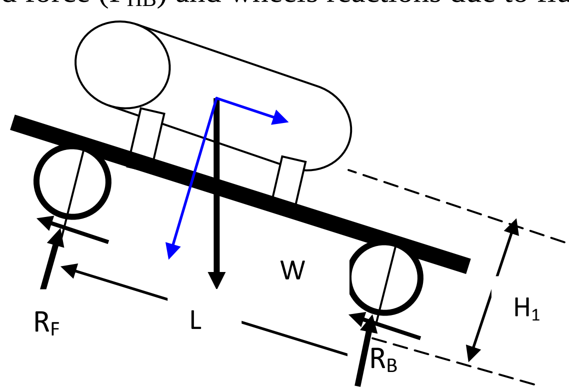


Figure 1: Tank's condition in the uphill direction

The weight (downward force in the Y direction) for a tank that is full with the fluid can be expressed as

$$W = V\gamma = \pi R^2 L\gamma + W_S \qquad (1)$$

where γ is the fluid specific weight and W_S is the weight of solid tank
The vertical (F_{VY}) and horizontal (F_{HY}) components of F_Y (fig. 1) can be calculated as

$$F_V = (\pi R^2 L\gamma + W_S)\cos\alpha, \quad F_H = (\pi R^2 L\gamma + W_S)\sin\alpha \qquad (2)$$

Hence, the backward force (F_{HB}) in the uphill direction can be expressed as

$$F_{HB} = (\pi R^2 L\gamma + W_S)\sin\alpha \qquad (3)$$

This backward force will slow down truck movement in an uphill direction.
By setting the statics equilibrium equations, the vertical reaction at the back wheel (R_B) and the front wheel (R_F) can be calculated as

$$R_B = \frac{1}{2}F_V + \frac{(H_1 + R)}{L}F_H \qquad (4)$$

$$R_F = \frac{1}{2}F_V - \frac{(H_1 + R)}{L}F_H \qquad (5)$$

Where, H_1 is the vertical distance from bottom of the tank to the ground.
After the automatic adjustment, the tank and its containment moves to the horizontal position as shown in figure 2.

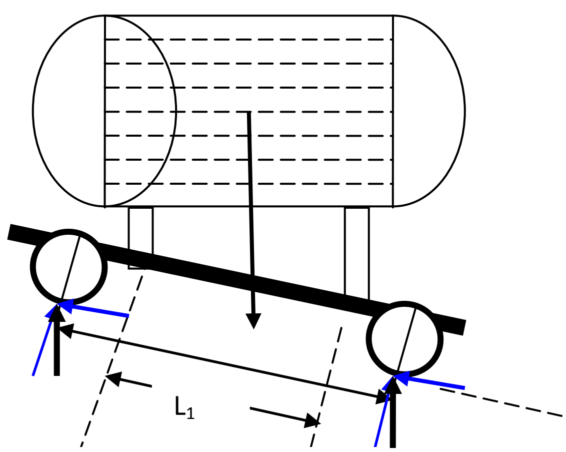


Fig. 2: Tank's condition after the automatic adjustment

Considering the tank is filled with the fluid, the vertical reaction force on the front and the back wheels can be determined as

$$R_{BY} = \frac{1}{2}W \quad \rightarrow \quad R_B = R_{BY}\cos\alpha = \frac{1}{2}(\pi R^2 L\gamma + W_S)\cos\alpha$$
$$R_{FY} = \frac{1}{2}W \quad \rightarrow \quad R_F = R_{FY}\cos\alpha = \frac{1}{2}(\pi R^2 L\gamma + W_S)\cos\alpha \qquad (6)$$

By considering L= 30$'$, H_1 = 5$'$, R = 4$'$, and $\alpha = 15^o$, the following table provide the horizontal backward force and the reaction forces on the wheels before and after automatic adjustment

Table1: Forces in uphill direction before and after automatic adjustment

Tank Condition	**Horizontal Backward Force, F_{HB}**	**Back wheel Reaction, R_B**	**Front wheel Reaction, R_F**
Before Automatic Adjustment	124.23(πγ)+0.259W_S	269.09(πγ)+0.56W_S	194.55(πγ)+0.405W_S
After Automatic Adjustment	-	231.18(πγ)+0.483W_S	231.18(πγ)+0.483W_S

Prior to the automatic adjustment, the large backward horizontal force in addition to the inertia force and fluid pressure will slow down the truck movement in the uphill direction. After automatic adjustment, the backward horizontal force due to weigh has been eliminated and it created a balance load distribution through the structure of the truck. The automatic tank adjustment in horizontal position not only increases truck movement performance in the uphill direction but also reduces the fuel consumption and fast tires wearing.

Force analysis in the downhill direction

In a similar manner, the forward horizontal force and wheels reactions in the downhill direction prior to the automatic adjustment can be expressed as

$$F_V = (\pi R^2 L\gamma + W_S)\cos\alpha, \quad F_{HF} = (\pi R^2 L\gamma + W_S)\sin\alpha \qquad (7)$$

$$R_B = \frac{1}{2}F_V - \frac{(H_1 + R)}{L}F_H \qquad (8)$$

$$R_F = \frac{1}{2}F_V + \frac{(H_1 + R)}{L}F_H \qquad (9)$$

After the automatic adjustment, the vertical reaction force on the front and the back wheels can be determined as

$$R_{BY} = \frac{1}{2}W \quad \rightarrow \quad R_B = R_{BY}\cos\alpha = \frac{1}{2}(\pi R^2 L\gamma + W_S)\cos\alpha$$
$$R_{FY} = \frac{1}{2}W \quad \rightarrow \quad R_F = R_{FY}\cos\alpha = \frac{1}{2}(\pi R^2 L\gamma + W_S)\cos\alpha \qquad (10)$$

By considering L= 30$'$, H_1 = 5$'$, R = 4$'$, and $\alpha = 15.47^o$, the following table provides the horizontal forward force and the reaction forces on the wheels before and after automatic adjustment

Table2: Forces in downhill direction before and after automatic adjustment

Tank Condition	**Horizontal Forward Force, F_{HB}**	**Back wheel Reaction, R_F**	**Front wheel Reaction, R_B**
Before Automatic Adjustment	124.23(πγ)+0.259W_S	194.55(πγ)+0.405W_S	269.09(πγ)+0.56W_S
After Automatic Adjustment	-	231.18(πγ)+0.483W_S	231.18(πγ)+0.483W_S

Prior to the automatic adjustment, the large forward horizontal force in addition to the inertia force and fluid pressure will fast accelerate the truck movement in downhill direction. After automatic adjustment, the forward horizontal force due to tank's containment has been eliminated and created a balance load distribution through the structure of the truck. The decrease in horizontal forward force due to the automatic horizontal tank adjustment not only stables the truck movement in the downhill direction but also reduces braking and increases brakes life cycles.

Conclusion

As it can be observed, the automatic adjustment of the tank to the horizontal position in either uphill or downhill produces many benefits in the truck performance, materials life, and cost savings, these can be categorized as follow;

1) The balance loads distribution on the wheels reduces the tries wearing and increases tires life cycles.
2) Decreases the backward horizontal force in the uphill direction and consequently increases the truck performance efficiency in the uphill direction and reduces the fuel consumption.
3) Decreases the forward horizontal force in the downhill direction and consequently it is easier to control truck movement in the downhill direction which reduces braking and increases brakes life cycles

Analytically it has been shown that after automatic horizontal adjustment both the horizontal forward (downhill direction) and backward forces due to weight and fluid pressure can be eliminated. Hence, this will enhance truck performance in the uphill and truck stability in the downhill directions.

The presented analysis is based on the forces acting in XY plane. However, a pitch angle in YZ plane may creates both pressure and force in Z direction, a future study will consider the effect of forces in YZ plane and tank's automatic adjustment in this plane.

References:

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3. Firat, B. (2004), *Design of a Mars Rover Suspension Mechanism* (Master's thesis). Izmir Institute of Technology, Izmir, Turkey