RECOVERY RESISTANCE CALCULATIONS

Purpose

To reliably estimate the load required to recover a stuck vehicle.

To show how to include recovery resistance calculations in a Stuck Assessment.

Resistance Factors

- The load required to move a stuck vehicle is a function of its Total Resistance [TR] to being moved
- TR = Ground Condition + Gradient Factor + Damage Resistance [+ Safety margin]
- All the above are derived as a function of the weight of the stuck vehicle.
- Results in a mathematically based approximation of the load required to move the stuck vehicle

Resistance Factors cont.

- Weight of the Vehicle
- Ground Conditions
- Gradient
- Vehicle Damage
- The sum of the ground conditions, gradient, and vehicle damage as a function of the vehicle weight results in an estimate the load required to recover a stuck vehicle

Resistance Factors cont.

Weight of the vehicle

- This is an obvious factor as recovering a vehicle weighing 10,000 lb. is going to require more load than recovering a 2,000 lb. vehicle if they are stuck in the same conditions
- Weight of the vehicle as a function of tires size and pressure and their respective influence on rolling resistance.

Resistance Factors cont.

Ground Condition Factor [GCF]

- Different ground conditions influence the rolling resistance of the vehicle.
  - Sand can have 30 times more rolling resistance than sealed surfaces
  - As such one can estimate a value [factor] that may be applied to calculating the resistance factors with regard to terrain type [and relative tire pressure]
  - For vehicle bogged to the axles subtract 1 from numbers below
- Types of terrain and ground condition factors [GCF] include
  - Smooth road 25
  - Grass 7
  - Hard wet sand 6
  - Gravel 5
  - Loose dry sand 4
  - Loose wet sand 3
  - Shingle 3
  - Shallow Mud 3
  - Deep Mud 2
  - Soft Clay 2

See also: Ken Sibly *The New Zealand 4 Wheel Drive Handbook.* Shoal Bay, 2004, page 195

Resistance Factors cont.

Gradient

- The simplest way to describe the influence of gradient is to picture the two extremes
  - A 90° vertical lift – If a 2,000 lb. vehicle was on a sealed surface, lifting it vertically into the air would require 2,000 lbs..
  - If this same vehicle was stuck axle deep in clay it would require 2,000 lbs.. plus what was required to overcome the suction of the clay on the vehicle.
  - On the other hand a vehicle on a sealed surface facing down hill will roll down hill under the influence of gravity

Resistance Factors cont.

Gradient cont.

- One calculates the gradient factor by taking 1/60 of the vehicle weight for each degree of gradient up to 45°
- It is safer to over estimate the gradient

- Restricting obstacles and ground clearance
  - “Jack and stack” and/or “Jack and push”
  - Spade
  - Tire pressure
  - Etc.

Resistance Factors cont.

Vehicle Damage

- If a vehicle is damaged and unable to assist then more load is required to recovery it
- Since the vehicle rolls on its wheels, if wheels are flat or missing and components are dragging on the ground, then greater effort is required.

Resistance Factors cont.

Safety Margin

- It is advisable to add 25% of the sum of the prior load resistance factors as a safety margin

Equation

- Ground Condition [GC] = weight of vehicle ÷ GCF
- Gradient Factor [GF] = weight of vehicle * gradient of slope in degrees ÷ 60
- Damage resistance [DR] = weight of vehicle x wheels missing ÷ number of wheels on vehicle
- Safety margin [SM] = ¼*[Ground Condition (CG) + Gradient Factor (GF) + Damage resistance (DR)]

Total Resistance [TR] = GC + GF + DR + SM

Resistance Factors cont.

- Example: A 3500 lb. Jeep is stuck in soft clay. It has a damaged rear wheel. The gradient is 15°
- GC = 3500 ÷ 2 = 1750 lbs..
- GF = 3500 * 15 ÷ 60 = 875 lbs..
- DR = 3500 * 1 ÷ 4 = 875 lbs..
- SM = ¼ * [1750+875+875] = 875 lbs.
- TR = 1750 + 875 + 875 + 875 = 4375 lbs..
- TR = weight to be taken up by a winch.

Real World Recovery Resistance

	Real World Field Testing				Weight
	Stuck Vehicle	SWB Nissan GQ Patrol			4200
	Recovery Vehicle	Landcruiser 100 Series			6000
	Snatched from	Recovery Load			
1	Flat Ground, No Obstructions	770 lbs..			
2	Slight Incline, No Obstructions	3140 lbs..			
3	Bogged to rear diff, Dry Sand	4370 lbs..			
4	Bogged to both diffs, Dry Sand	6300 lbs..			
5	Bogged to rear diff, Wet Sand	5000 lbs..			
6	Bogged to both diffs, Wet Sand	7800 lbs..			

Real World Recovery Resistance

		1	2	3	4	5	6
Calculations							
Ground Condition Factor							
Hard wet sand	6						
Dry Sand	4						
Wet Sand	3						
GC = Weight/GCF		700	700	1400	1400	2100	2100
Gradient Factor = weight*gradient/60		0	1050	0	0	0	0
Damage/bogged Resistance							
DR = Weight*wheels missing/vehicle wheels		0	0	2100	4200	2100	4200
Safety Factor							
		175	438	875	1400	1050	1575
Real World Data		770	3140	4370	6300	5000	7800
Total Resistance Calculations		**875**	**2188**	**4375**	**7000**	**5250**	**7875**

Resistance Factors cont.

- Let's assume one elects to use a kinetic strap to recover the vehicle instead of a winch line.
- The kinetic strap introduces the added influence of momentum, which is the energy of the vehicle pulling out the stuck Jeep because the pulling vehicle is moving at speed. [Galileo's Theory of Inertia and Newton's Laws of Motion]
- The momentum of the pulling vehicle is the foundation for the kinetic energy.

Resistance Factors cont.

- Momentum = weight of vehicle [kg] * speed of vehicle [m/s]. We will simplify.
- So, the momentum of a 4000 lb. vehicle traveling at 5 mph is calculated as follows:
  - Weight in kilograms = 4000 ÷ 2.2 = 1818 kg
  - **1 meter per second = 2.23693629 miles per hour**
  - So 5 mph = 2.235m/s
  - Momentum = mass*velocity = 1818*2.235 = 4063 kgm/s

Resistance Factors cont.

- Assume the screw pin D shackle brakes off the stuck vehicle at the moment the kinetic line is fully loaded.
- The momentum of 4063 kgm/s would be transferred into the shackle and strap
- Assume the shackle weighs 1 kg and the 30’ 2” wide kinetic strap weighs 1.5 kg. The combined weight is 2.5 kg [5.5 lbs.]

Resistance Factors cont.

- The speed that the strap and D shackle would travel at would be calculated as follows:
  - Velocity = momentum ÷ weight
  - Velocity = 4063 kgm/s ÷ 2.5kg = 1625 m/s
  - Or simply put the speed of the kinetic strap and screw pin D shackle would be 3636 mph!

Resistance Factors cont.

- The 357 Magnum 125 grain JHP bullet has a muzzle velocity of approximately 440 m/s [1450f/s]
- Momentum = weight * velocity = 0.009 kg * 440m/s = 3.96kgm/s
- The momentum of our 4000 lb. vehicle traveling at 5 mph is = 4063 kgm/s, which is the equivalent momentum of the kinetic strap and screw pin D Shackle.
- The much heavier D shackle would travel approximately 3¾ times faster than the 357 Magnum bullet!
- The Kinetic Strap and D shackle would hit you more than 1000 times harder than a 357 Magnum bullet.
- If you think you can survive that, go ahead, make my day

Resistance Factors cont.

- Usain Bolt stands 6’5” tall, weighs 207 lbs. and runs the 100m sprint in 9.58 seconds [almost 10.5m/s = 23.5 mph]
- This is like being hit by a Usain Bolt running at 193 mph or hitting the pavement after stepping off a 112 story building.
- Similarly, the static winch line would have the equivalent of approximately 4375 lbs.. of stored [potential] energy
- Should the winch line break or pull off a tow hook it would hit you more than 800 times harder than a 357 Magnum bullet, like stepping off a 90 story building.
- Note: Terminal velocity for a free fall skydiver is about 120 mph and is achieved after stepping off approximately 50 stories so I am assuming continued acceleration beyond terminal velocity, which can be achieved if the person is rolled into a ball = 200mph terminal velocity.
- Again - if you think you can survive that, go ahead, make my day.

Recovery Myths

- Even though the prior examples clearly illustrate the extreme danger associated with the release of energy associated with a recovery failure, there are myths that need to be corrected.
- “When a 3500 lb. vehicle is stuck and being pulled out by a 4000 lb. vehicle, the load on the kinetic strap is 7500 lbs..” Simply adding the combined vehicle weights is not accurate.

Recovery Myths cont.

- The static load that a pulling vehicle can create is a function of:
  - Traction of the wheels on the terrain [Friction coefficient]
  - Torque of the pulling vehicle [ability to do work]
  - Power of the pulling vehicle [rate work is applied]
  - These factors are limited by
    - Gearing
    - Drive train component strength
- Tractor pulls demonstrate this

Recovery Myths cont.

- The load required to move a stuck vehicle is a function of its Total Resistance to being moved
- TR = Ground condition + Gradient Factor + Damage Resistance + Safety margin
- All the above are derived as a function of the weight of the stuck vehicle.
- Results in an approximation of the load required to move the stuck vehicle

Recovery Myths cont.

This is not accurate for the following reasons:

- For a kinetic pull, the *max load applied* by the pulling vehicle is a function of its momentum [mass * velocity] at point of recovery.
- However the *load required* to recover the vehicle is a function of the Total Resistance of the stuck vehicle
- For a kinetic pull, the terrain under the pulling vehicle determines the sustained traction available to the pulling vehicle to progressively stretch the kinetic strap to point of recovery.
- Going from good traction when building speed to poor traction when stretching the kinetic strap will significantly reduce the load applied at point of recovery.
- With a static pull [i.e. absent momentum] the terrain under the pulling vehicle determines the load it can apply to the [kinetic] strap. Ice vs. sealed pavement.
- In a static and kinetic pull, traction aids – the number of turning wheels of the pulling vehicle – determine the load it can apply of the stuck vehicle.

Recovery Myths cont.

- The load when winching is a function of the Total Resistance [TR] associated with the stuck vehicle as described above.
- The load when recovering with a kinetic strap is a balance between the Total Resistance [TR] associated with the stuck vehicle and the speed and weight of the pulling vehicle at point of recovery.
- When the momentum of the moving vehicle is enough to overcome the TR of the stuck vehicle, the stuck vehicle will be pulled out.
- However, pull more than required [>>TR] and the stuck vehicle is extracted at a higher speed.

Recovery Dangers

- Even with a kinetic strap, but much more so with a chain, it is possible to travel at a speed that at point of recovery will result in an impact load greater than is required to unstuck the vehicle and instead of pulling out the stuck vehicle will cause the equipment to fail with severe consequences.
- This can also happen in winching if slack is created in the winch line and the vehicle rolls back against the slack creating a shock load.
- These shock loads can easily exceed the tow hook and recovery equipment capacities
- Water skiing: Dry start vs. wet start
- Golf swing : from zero to 204 mph at impact

Conclusion

- Properly evaluate the expected Total Resistance of the stuck vehicle
- Systematically minimize total resistance [GC, GF, DR] based on proportional influence prior to recovery:
  - Clear out wheel path, check tire pressure
  - Release clay suction, use mats or sand ladders
  - Repair damage so stuck vehicle can assist in recovery
  - Unload vehicle if necessary
- SAFETY IS EVERYONES RESPONSIBILITY
  - Keep away from the DANGER ZONE

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