Tribolt
HEAVY EQUIPMENT CORPORATION

To: Engineering Transition Team
From: Paul Proudy, VP Engineering <Tribolt.EngMgr@gmail.com>
Re: Welcome to the Team

Dear Transition Team:

Welcome to what was formerly the JemStOrr's Mining Truck Division, now the Tribolt Mining Truck Division. My name is Paul Proudy and I was formerly the manager of Engineering for JemStOrr. As you probably know, the acquisition contract states that I will stay on as "Engineering Consultant" for no less than a period of one year with an option to renew the contract for the next five years. In this role I will be around to answer questions while leaving you with full authority and responsibility for decisions made by Engineering.

As you prepare to take over the Engineering function, I suggest you do the following:

1. Carefully read the Mining Truck Schematic & Overview of Key Components. In addition to outlining the key components of a mining truck, you will get insights into how those components work to drive truck performance.

2. Review the current BOM and CTQs for the T1000 Mining Truck. This information can be found on our company website: https://Tribolt.us/products

3. Familiarize yourself with the Engineering Calculation Methods manual. The calculations manual provides detailed information on how to calculate performance CTQs (Critical to Quality) of mining trucks. You will be responsible for developing new trucks using these calculations.

Try to be as familiar as you can with how Tribolt mining trucks work. I'm sure you will have many questions. I will help in any way I can. I look forward to meeting you at the beginning of the year.

Sincerely,

Paul A. Proudy

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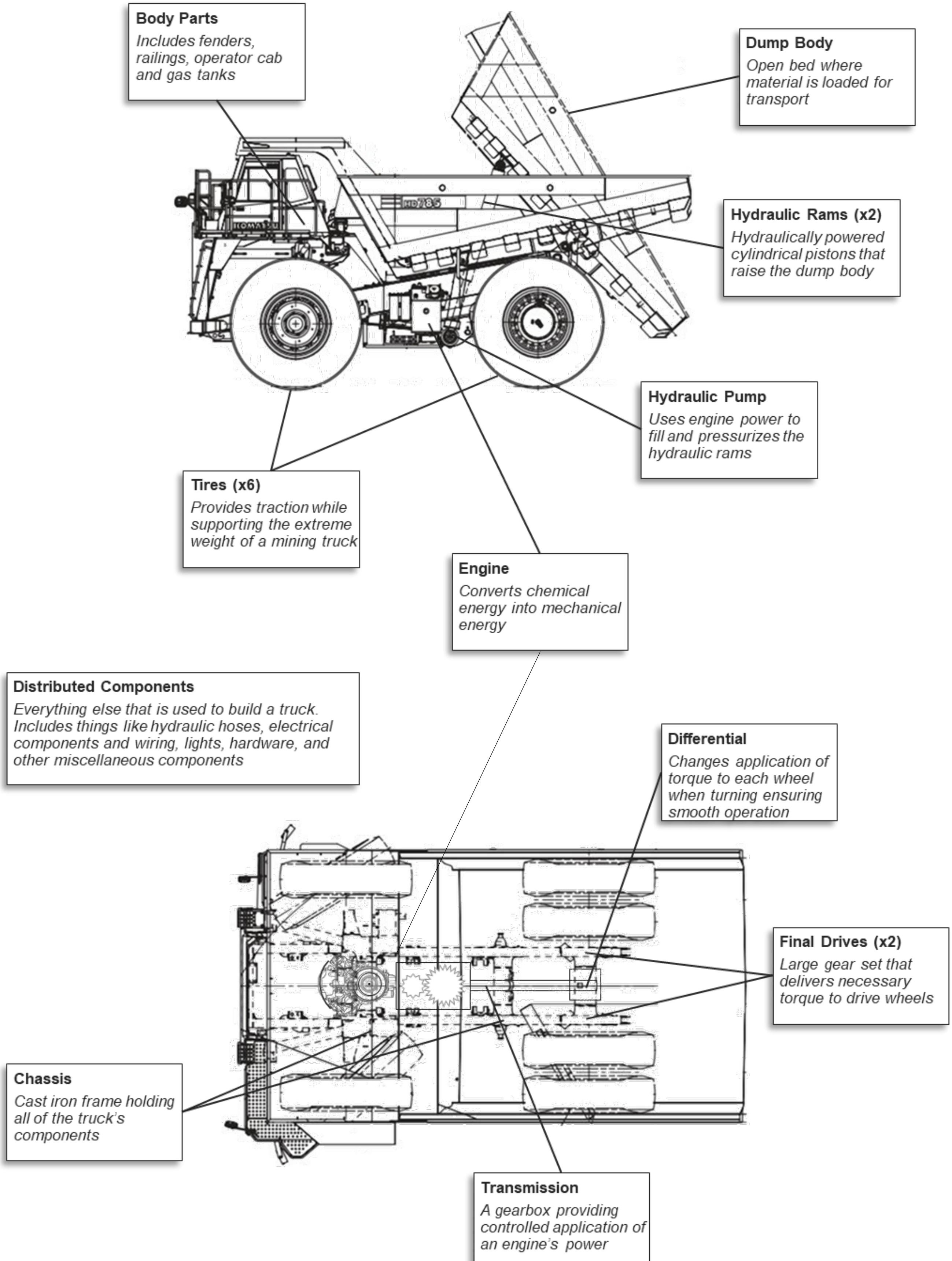
MINING TRUCK SCHEMATIC & OVERVIEW OF KEY COMPONENTS



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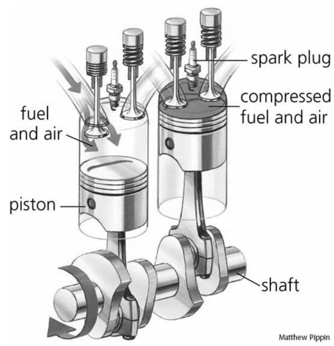
Mining Truck Key Component #1: **DIESEL ENGINE**

How Does it Work?
An internal combustion engine is a machine designed to convert chemical energy into mechanical energy (energy associated with motion).

- A diesel engine first turns diesel fuel into heat energy by introducing an oxidizing agent (air) and a spark from a spark plug, causing an explosion within the engine.
- This energy is transferred to the pistons of the engine creating linear mechanical motion.
- The linear motion of the pistons are transferred to a twisting force by the crank shaft. This twisting force is what is used to drive the wheels, created motion in a mining truck.



Key Components of an Internal Combustion Engine

Which Specifications are Important?

- **Torque:** The twisting force being exerted to the crank shaft of an engine. Torque measures the maximum amount of resistance that can be overcome by the engine without stalling. Torque is a critical factor in determining your trucks ability to climb steep inclines.
- **Horsepower:** The amount of power an engine can generate over a given amount of time. For example, one horsepower equals 33,000 foot-pounds of work per minute - that is, the power necessary to lift a total mass of 33,000 pounds one foot in one minute. Horsepower plays a role in determining your trucks maximum forward speed, fuel consumption and operational availability.
- **Rotations per Minute:** The speed at which the engine rotates the crank shaft. An engine is capable of operation at a range of RPMs but is typically rated (and operated) at an RPM that generates peak performance (horsepower, torque and fuel efficiency). RPMs are important to understanding the maximum speed of a mine truck.
- **Gallons / Hour / Horsepower:** A measure of efficiency for the engine, calculated by understanding the amount of fuel consumed by the engine over time to create a specific amount of power. This specification will be critical in determining the fuel efficiency of your mining vehicle.

Mining Truck Key Component #2: **Transmission**

How Does it Work?

A transmission is a gearbox which provides controlled application of an engine's power. It uses gears and gear trains (systems of more than 2 gears) to change the speed (RPM) ratio between the engine and the wheels of an automobile.

- The transmission uses a range of gears -- from low to high -- to make more effective use of the engine's torque as driving conditions change. Gears have to be shifted in order to avoid not only overworking the engine, but also to maintain it running at optimal RPM for performance.
    - A mining truck with first gear only would accelerate well from a complete stop and would be able to climb a steep hill, but its top speed would be limited to just a few miles an hour.
    - A truck with only a final gear may be capable of going 40+ mph but would have almost no acceleration when starting out and wouldn't be able to climb hills.

Example: Mining Truck Transmission

Which Specifications are Important?

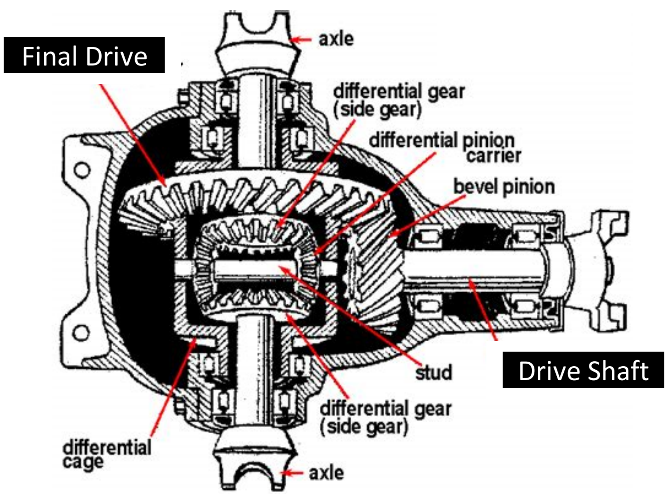
- **First Gear:** The lowest possible gear, creating the lowest number of tire revolution per rotation of the engine crank shaft. This gear maximizes the amount of torque for a mining truck. This is important for determining how steep of an incline your mining truck can climb.
- **Final Gear:** The highest possible gear, creating the highest number of tire revolutions per rotation of the engine crank shaft. This gear maximizes the speed at which the tires can spin. This is important for determining the forward speed of your mining truck.
- **HP Rating:** The amount of horsepower the transmission is designed to tolerate during operation. Higher HP ratings denote better materials of construction and a more robust transmission. HP ratings will be critical to determining the availability of your mining truck.

Mining Truck Key Component #3: **Differential**

How Does it Work?

A differential is a gear train with three shafts that has the property that the rotational speed of one shaft is the average of the speeds of the others, or a fixed multiple of that average.

- Essentially, the differential is a device that splits the engine torque two ways, allowing each set of rear wheels to spin at a different speed.
- The differential is critical for smooth operation while turning. It allows the outer rear wheel to rotate faster than the inner rear wheel during a turn. This is necessary when the vehicle turns, making the wheel that is traveling around the outside of the turning curve roll farther and faster than the other. The average of the rotational speed of the two driving wheels equals the input rotational speed of the drive shaft. An increase in the speed of one wheel is balanced by a decrease in the speed of the other.
- Differentials will also have slightly different gearing properties



Differential Illustration

Which Specifications are Important?

- **Gear Reduction:** The factor by which your torque is increased and your speed is decreased. This is critical in determining your ability to climb hills, and your max forward speed.
- **HP Rating:** The amount of horsepower the differential is designed to tolerate during operation. Higher HP ratings denote better materials of construction and a more robust differential. HP ratings will be critical to determining the availability of your mining truck.

Mining Truck Key Component #4: **Final Drives**

How Does it Work?

The final drive is the last part of a set of gears that delivers the necessary torque to turn the wheels of a vehicle. It connects to the differential which connects to the wheels.

- Mine truck engines typically operate over a range of 1,800 to 2,000 revolutions per minute, while the trucks wheels rotate at around 80 rpm. The difference is a result of gearing.
- As your engine spins a gear with ten teeth (represented by the small gear), against another gear with one hundred teeth (the larger gear) the engine must spin the small gear 10 times to spin the large gear once. This means that you can deliver 10x the force (torque) from the engine over one revolution by adding the large gear final drive. However, the enhanced force comes at a price, decreasing the number of rotations by a factor of 10 also reduces your max speed by 10x.
- Unlike the transmission, the final drive is a *fixed* gear system that regulates the amount of torque delivered to the wheels of a mining truck. There is no gear ratio better than any other, there are only tradeoffs.

Final Drive Illustration

Which Specifications are Important?

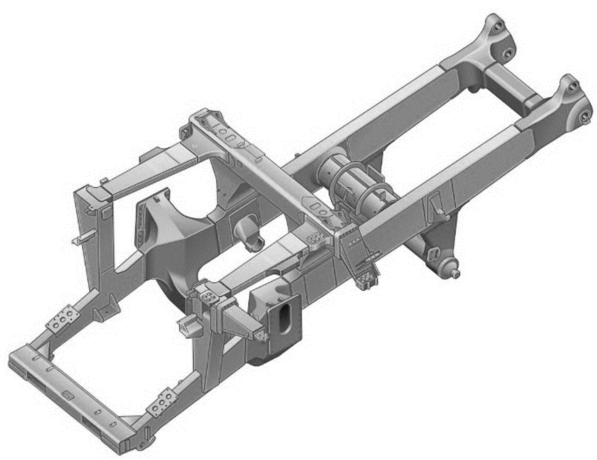
- **Gear Reduction:** The factor by which your torque is increased and your speed is decreased. This is critical in determining your ability to climb hills, and your max forward speed.
- **HP Rating:** The amount of horsepower the final drive is designed to tolerate during operation. Higher HP ratings denote better materials of construction and a more robust final drive. HP ratings will be critical to determining the availability of your mining truck.

Mining Truck Key Component #5: **Chassis**

How Does it Work?

A chassis is the load-bearing frame which structurally supports the object as a whole in its construction and in operation.

- The chassis of a mining truck is critical in supporting the immense weight of the vehicle itself and of the tremendous loads it carries.
- The chassis is a robustly made cast iron structure weighing almost 1/3rd of the entire vehicle weight.
- The chassis serves as a point of installation for most components, including the engine, transmission, dump body, and nearly all other heavy/critical components.



Chassis Illustration

Which Specifications are Important?

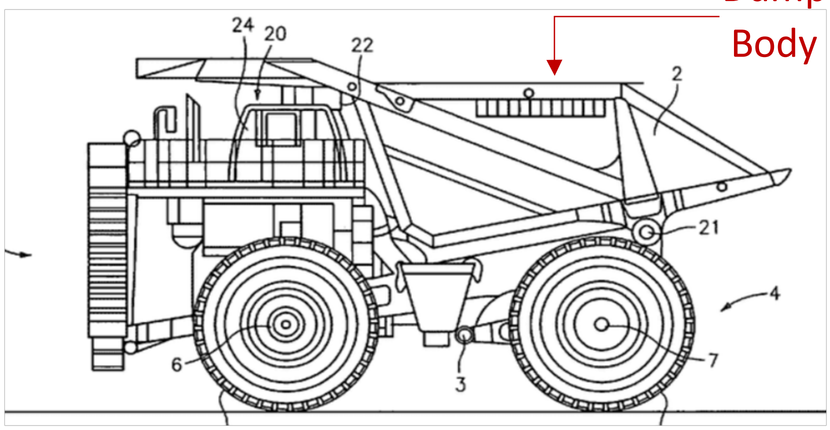
- **Gross Vehicle Weight Rating:** The GVW is the amount of total weight, including payload, that the chassis is rated to hold safely. This makes the choice of chassis critical when deciding how much payload a mining truck is able to carry.

Mining Truck Key Component #6: **DUMP BODY**

How does it work?

The dump body is a large, open bed that allows you to transport a load of material from one place to another. The dump body's volume is the main determining factor of the truck's payload, the part of a vehicle's load from which revenue is derived.

Dump Body



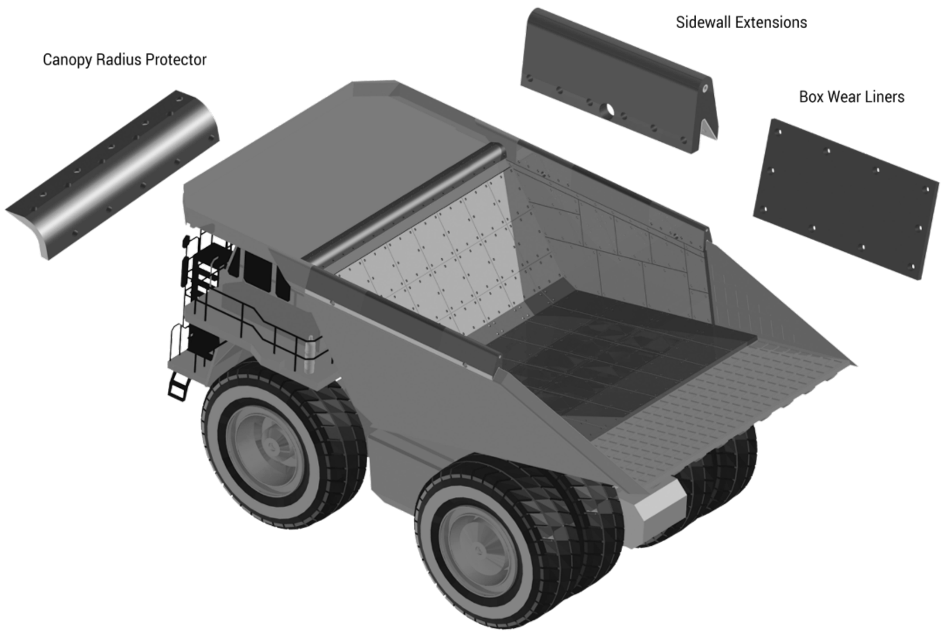
Which Specifications are Important?

- **Payload Capacity**: The maximum weight that the dump body can hold. As previously mentioned, the dump body is the main determining factor of the trucks payload. Typically, the truck is sized to take three full scoops of material from the excavators and must be sized appropriately.

Mining Truck Key Component #7: **FABRICTAED BODY PARTS**

What is included?

Fabricated body parts are large components of the trucks that include fenders, railings, operator cab and interior, and gas tanks. Similar to a car, there are different feature packages that you can select when purchasing a mining truck.



Which Specifications are Important?

- **Truck Features**: Certain customers may have a preference for different features such as luxury vs economy interior packages (leather seats, plush cab, heated seats & steering wheel) and driver awareness packages (cruise control, rear view cameras, blind spot monitoring to full self-driving capabilities).
- **MTBUO & Duration:** Higher quality components improve the construction of the mining truck and typically last longer than cheaper alternatives. The longer those components last, the less downtime a truck will have. In additional, using high quality components can give the impression of a higher quality truck to customers.

Mining Truck Key Component #8: **DISTRIBUTED COMPONENTS**

What is included?

Distributed components are everything else that is used to build a truck and includes things like hydraulic hoses, electrical components and wiring, lights, hardware, and other miscellaneous components. They're purchased from a distributor since they're commodity components and can add little performance differentiation. However, higher quality components will last longer.

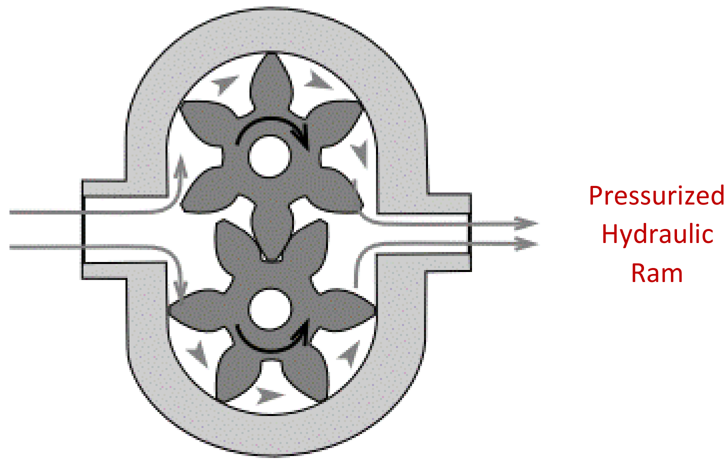
Which Specifications are Important?

- **MTBUO & Duration:** Higher quality components improve the construction of the mining truck and typically last longer than cheaper alternatives. The longer those components last, the less downtime a truck will have. In additional, using high quality hardware, electrical and hydraulic components can give the impression of a higher quality truck to customers.

Mining Truck Key Component #9: **Hydraulic Pump**

How Does it Work?

A hydraulic pump is a mechanical source of power that converts mechanical power (I.e. spinning) into hydraulic energy (i.e. flow, pressure). It fills and pressurizes the hydraulic ram to lift the dump body.



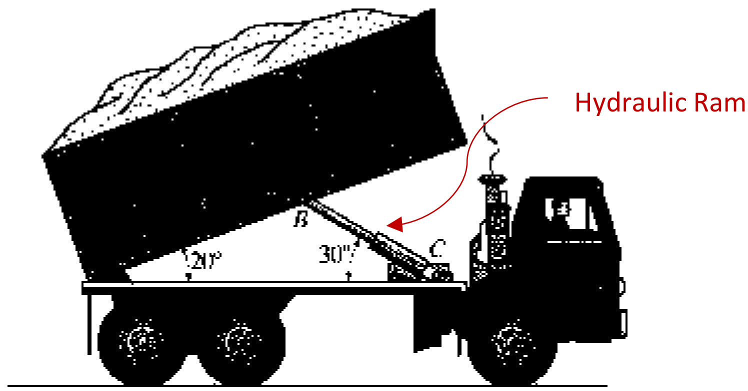
Which Specifications are Important?

- **Max Pressure:** The pump needs to be appropriately sized to match the maximum pressure of the rams. If the pump is oversized it can damage the ram and if it is undersized the ram will not be able to lift as much as it is capable of**.**

Mining Truck Key Component #10: **Hydraulic Rams**

How Does it Work?

A hydraulic ram is a hydraulically powered cylindrical piston that raises the dump body of the truck to empty the material it's transporting.



Which Specifications are Important?

- **Max Pressure:** The maximum pressure the hydraulic ram is rated to handle under normal operating conditions. The pump can not be set to pressure the hydraulic ram any higher than it is rated for. If your pump does not supply enough pressure for the ram, then the ram is not going to be able to lift its maximum weight.
- **Lifting Force at Max Pressure**: As it sounds, the force (in pounds) that the ram can lift. A mining truck has two rams, one on each side of the dump body.

Mining Truck Key Component #11: **TIRES**

How Does it Work?

Mining truck tires & wheels come pre-assembles from the manufacturers and include the rim, hub, spokes and tire. A tire (full wheel) transfers the vehicle load and torque coming from the rear axle to the ground, exerting a force on the road that propels the car forward. It also provides traction on the surface to climb hills, take turns at speeds, etc.

New Tires for a Mining Truck

Which Specifications are Important?

- **Diameter:** Given the same number of rotations from the drive shaft, the tire will spin the same number of times regardless of the tires diameter. Therefore the larger the tire diameter, the faster the truck is able to move over the same distance. However, a large diameter tire exerts less tractive force on the road or surface, reducing its ability to go uphill.
- **Max Weight**: A truck's tires have to be rated to support the Gross Vehicle Weight (including the payload) of the truck to ensure safe driving conditions.
- **Wear Rate:** The wear rate helps answer the question, *"How often do my tires need to be replaced?"* The faster the rate, the quicker they have to be replaced, increasing truck downtime.
- **Tread Depth:** Tread is the pattern of ridges cut into the tire to provide traction on the road or surface. To improve traction on softer surfaces, tread depth is often increased. As tires get used, tread is worn away (Wear rate) and need to be replaced when tread depth is equal to the 20% of its original depth.

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Mining Truck Engineering and Design Methodology

Contents:

Section I: Basic Mining Truck Engineering

Forces:

There are two forces acting on a mining truck. These forces can be seen in figure 1.

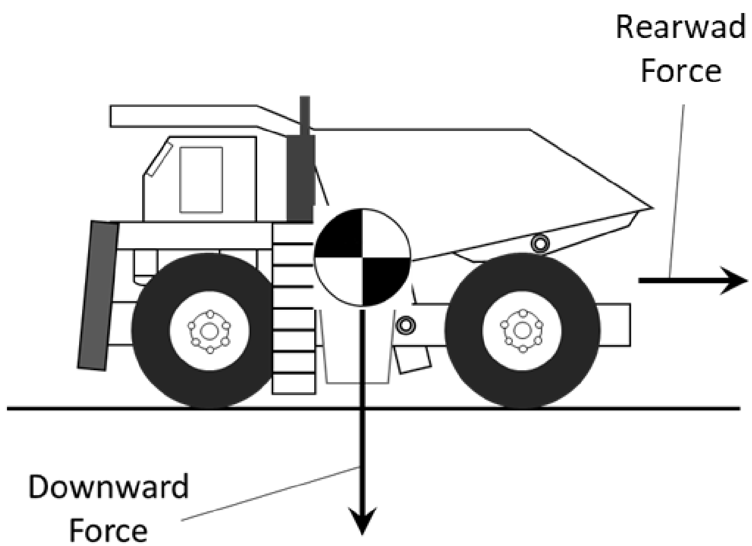

Figure 1: Forces Acting on a Mining Truck

<u>Downward Force</u> – Downward force is defined as follows:

Downward Force = Curb Weight + Payload

Where Curb Weight is the weight of the vehicle before any overburden is placed in the dump body. Payload is defined as the weight of material added to the dump body during operation in the mine.

<u>Reward Force</u> – is defined as follows:

Rearward Force = Frictional Forces + Gravity Forces + Wind Resistance + Acceleration Forces

Downward Forces:

Downward forces are relatively straightforward to calculate. The following method is used to calculate the curb weight and fully loaded weight of the T65 truck. The following variables are needed to compute curb weight and GVW (Gross Vehicle Weight).

- Weight of Frame
- Percentage weight of frame to curb weight
- Volume of Dump Body

We need the data in tables 1a and 1b to make this calculations:

Maker	Model	Weight of Frame (lb)	GVW Limit (lb)
Filco Steel Fab	FSF12	42,000	570,000
Filco Steel Fab	FSF13	65,500	850,000
Filco Steel Fab	FSF14	86,000	1,300,000

Table 1: Frame Weight and GVW limit of Tribolt Mining Trucks

Component	Percent of Curb Weight
Frame	30%
Engine	10%
Transmission	7%
Differential	7%
Final Drives	5%
Miscellaneous (radiator, etc)	11%
Body Parts*	20%
Dump Body	10%

*Includes Operator's Cab

Table 2: Percent Curb Weight of Various Components

Tribolt mining trucks use one of three frames as described in table 1. The T65 uses frame FSF12 with a weight of 42,000 lb. The total curb weight of the truck can be calculated as:

Curb Weight = Frame Weight/0.30

Curb Weight = 42,000/0.3 = 140,000 lb

Knowing curb weight, we can calculate GVW as:

GVW = Curb Weight + Dump Bed Payload Based on Volume

In the case of the T65, the dump body is capable of carrying 50 tons of standard soil with an average density of 2.2 g/cm^3.

GVW = Curb Weight + 50 tons = 140,000 lb + 100,000 lb = 240,000

A quick check shows that frame FSF12 with a GVW limit of 570,000 is more than strong enough to carry a payload of 50 tons.

Now that we know the GVW for the T65 we can calculate its reward forces.

Reward Forces:

As indicated in the equation for reward forces (aka "Pull") there are four components that must be taken into consideration. Let's look at each one individually.

<u>Frictional Forces</u> – All rolling vehicles, no matter how efficient, have some rolling friction. This includes tire and road friction, bearing friction in the wheels, etc. (see figure 2).

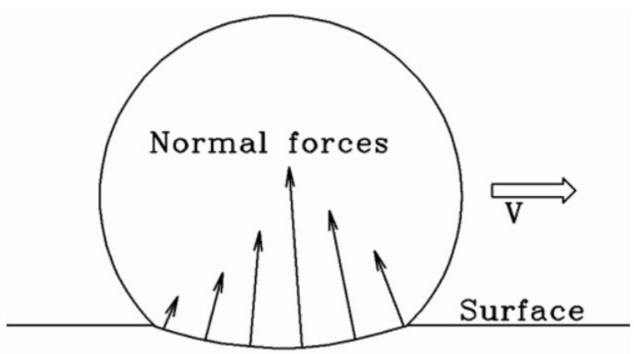

Figure 2: The Principle of Rolling Resistance

The equation for calculating frictional forces is:

$$F_r = \mu N$$

Where F_r is the reward force generated by rolling friction, μ is the coefficient of rolling friction, and N is the total downward force. Typical frictional coefficients in a mining environment are shown in table 3.

Surface	μ
Packed Clay	0.04
Loose Gravel	0.1
Wet Organic Soil	0.2

Table 3: Coefficient of Rolling Friction on Various Mine Surfaces

Using the above values the rearward force generated by rolling friction for the T65 (fully loaded) on loose gravel would be: 24,000 lb.

Gravity Forces – When the truck is driving on perfectly level ground there are no rearward forces generated by gravity. However, when the truck begins to ascend or descend an incline gravity forces can be significant. Figure 3 shows gravitational force adding to the reward force on a haul truck.

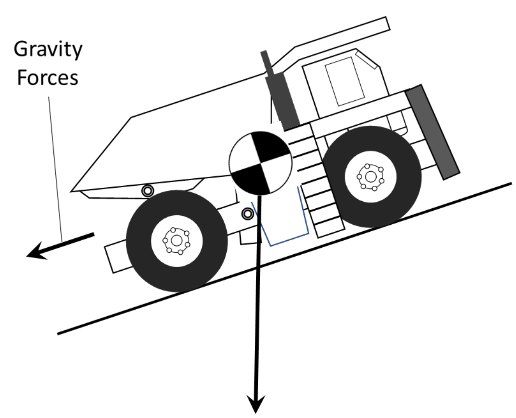

Figure 3: Rearward Force Caused by Gravity

The rearward pulling forces caused by gravity can be obtained by simple vector analysis. The gravitational force pointing straight down is broken into its component parts as shown in figure 4.

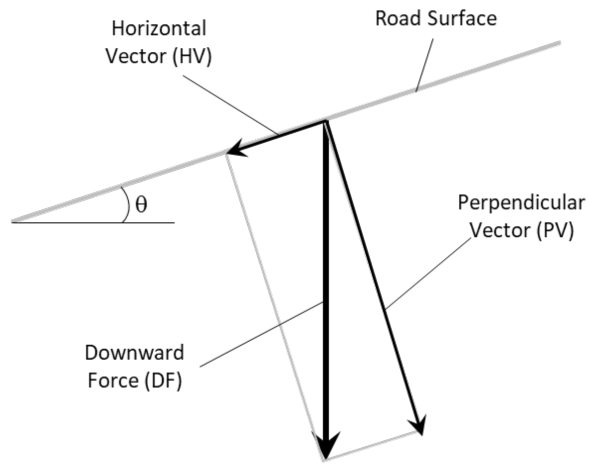

Figure 4: Vector Analysis of Downward Force

It is relatively easy to solve for the horizontal and perpendicular vectors using basic principles of trigonometry. A graphical solution can also be used. The vectors can be found using the following equations:

$$\text{Rearward Force}_{\text{gravity}} = \sin(\theta) \times \text{GVW}$$

$$\text{Perpendicular Force}^{1} = \cos(\theta) \times \text{GVW}$$

<u>Wind Resistance</u> – Although wind resistance is the smallest rearward force acting on a haul truck, it is still worth considering, especially when calculating maximum forward speed of the truck:

$$\text{Rearward Force}_{\text{wind}} = (C_d \times \rho \times \text{Area})/2 \times V^2$$

Where,

Cd = Coefficient of Drag (dimensionless)

ρ = Air Density (lb/ft3)

V = Velocity (ft/s)

[1] Perpendicular forces are those pushing down on the truck perpendicular to the road surface.

Acceleration Forces – Acceleration forces are relatively easy to calculate using Newton's second law of motion:

$$F = ma$$

We can use this equation to answer the question: How much force is required to accelerate a fully loaded T150 truck from zero to 10 mph in five seconds?

First let's convert mph into ft/s.

$$1 \text{ mile/hr} \times 5{,}280 \text{ ft/mile} \times 1 \text{ hr/60 minutes} \times 1 \text{ minute/60 seconds} = 1.46 \text{ ft/s}$$

$$1 \text{ mph} = 1.46 \text{ ft/s}$$

Therefore to convert velocity in miles per hour to feet/second we multiply mph times 1.46. Use this to convert the starting and ending velocities:

$V_1 = 0$ mph $= 0$ ft/s

$V_2 = 10$ mph $= 14.6$ ft/s

We can now calculate the acceleration required to move from zero to 10 mph in five seconds:

$$a = (V_2 - V_1)/\text{time} = (14.6 - 0)/5 = 2.92 \text{ ft/s}^2$$

Using Newton's second law we can compute the force required to accelerate 500,000 lb at 2.92 ft/s^2:

$$F = ma$$

$$500{,}000 \text{ lb} = m \times 32.2 \text{ ft/s}^2$$

$$m \text{ (slugs)} = 15{,}528$$

The tractive effort required to accelerate 500,000 lb at 2.92 ft/s^2 (10 mph in 5 seconds) is:

$$F = 15{,}528 \text{ slugs} \times 2.92 \text{ ft/s}^2 = 45{,}342 \text{ lb}$$

Section II: Payload Capacity

Factors to Consider:

When calculating total payload capacity of a haul truck, a number of factors must be considered:

1. Volume of the Dump Body
2. Strength of Dump Body
3. Strength of the Truck Chassis
4. Lifting power of Dump Body hydraulic rams
5. Tire Rating

Example of Payload Calculation:

The following calculations use the T65 as an example. Table 3 shows the density of various soil types in g/cm^3. The industry standard average soil density used when calculating payload capacity is 2.2 g/cm^3.

Soil Type	Density g/cm3
Sandy Loam	1.44
Silt Loam	1.28
Clay	1.20
Dolomite	2.75
Limestone	2.25
Marble	2.60
Shale	2.30

Table 3: Average Density of Various Soil Types

Volume of Dump Body – Based on the dimensions of the T65 dump body the un-heaped volume is:

Volume = 27.0 cubic yards

Assuming an average soil density of 2.2g/cm^3 or 3,707 lb/yd^3, the weight of 27.0 cubic yards at an average soil density of 2.2g/cm^3 is 27.0 x 3,707 / 2,000 = 50 tons.

Based on the above calculation, the T65 has a volume capacity of 50 tons.

Strength of Dump Body and Frame – Determining the strength of the Dump Body and Chassis is a very complex calculation performed at the corporate R&D center using finite-element modeling. All dump bodies are designed with a factor of safety of 2.0 and therefore strength is not an issue unless overburden of extreme density (2x 2.2g/cm^3) is being hauled. Chassis limits can be seen in the table 1.

Force Generated by Hydraulic Cylinders – All haul trucks are dumped using two hydraulic cylinders. Using the geometry in figure 5, the required force of the two cylinders acting together can be calculated as follows:

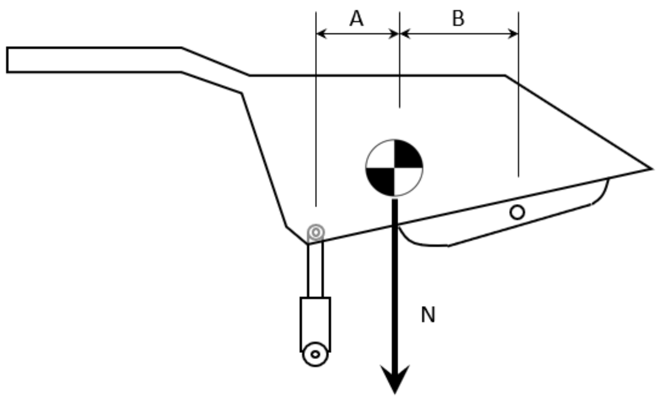

Figure 5: Dump Body Lever Points

$$F \times (A + B) = N \times B$$

Where F is the required force of the hydraulic rams, A is the distance from the center of gravity to the pivot point of the hydraulic ram, B is the distance from the rear pivot point to the center of gravity of the Dump Body, and N is the combined weight of the Dump Body and its contents. Note: Typical Dump Body weight is 10% of payload, for T65 slightly more.

Using the following values for the T65 we can calculate the required size of the hydraulic lifting rams:

Model	A	B	Payload (lb)	WDB* (lb)
T65	4	5	100,000	16,500

* WDB = Weight of Dump Body

Table 5: Values for Calculating Hydraulic Ram Size

We use the T65 in this example:

Hydraulic Force >= 116,500 x 5/(4 + 5) = 64,722 lb

Remembering that there are two hydraulic rams, each must lift 32,361 lb. The standard T65 is equipped with two 20-ton hydraulic rams, making it capable of dumping its load of 50 tons.

Tire Rating – The center of gravity of a haul truck is positioned toward the rear of the truck. On average, 70% of the truck's weight is supported by the rear wheels and only 30% by the front wheels.

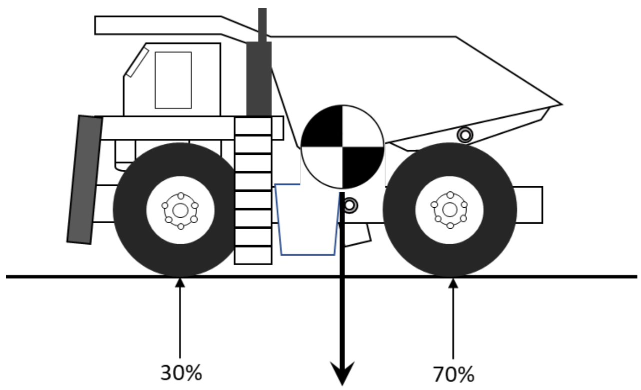

Figure 6: Weight Distribution in a Typical Mining Truck

Taking the T65 as an example, its 70% of its GVW of 300,000* lb is supported by the rear wheels. This means that each of the four tires must support 52,500 lb. Each of the front tires must support 45,000 lb.

The table below shows tires currently in the Tribolt catalog of approved haul truck tires.

Tires								
Maker	**Model**	**Max Pressure (psi)**	**Max Weight (lb)**	**Lead Time**	**Diameter**	**Wear Rate (in/hour)**	**Tread Depth (inches)**	**Price**
Michelin	M24	65	70,000	4	10	4.29×10^{-5}	1	$50,000
Michelin	M25	65	75,000	4	10	4.86×10^{-5}	1	$60,000
Michelin	M26	70	80,000	4	12	5.21×10^{-5}	1.25	$70,000
Goodyear	G12	65	90,000	3	10	5.88×10^{-5}	1.25	$45,000
Goodyear	G14	65	100,000	3	10	6.02×10^{-5}	1.25	$50,000
Goodyear	G16	70	210,000	3	12	6.23×10^{-5}	1.25	$60,000
Contentintal	C31	80	260,000	4	14	5.34×10^{-5}	1.75	$75,000

Table 6: Tire Options in the Tribolt Catalog of Approved Tires

Section III: Stall Grade

Definition:

Stall grade is defined as the maximum grade that can be climbed by a fully loaded haul truck.

Calculations:

Calculating the stall grade of a haul truck is slightly more complicated than other calculations in this manual. Factors that must be considered are:

1. Gravity Forces
2. Rolling Friction
3. Maximum Engine Torque
4. Maximum Gear Reduction
5. Tire Diameter

Gravity Forces – were covered in Section I. Reward forces will be calculated as:

$$\text{Reward Forces} = \text{GVW} \times \sin(\theta)$$

Where GVW is gross vehicle weight (fully loaded weight) and θ is the angle of ascent.

Rolling friction – (also covered in Section I) will be calculated as:

$$\text{Rolling Friction} = \text{GVW} \times \text{cosine}(\theta) \times \mu$$

Total Gear Reduction – is the total gear reduction that takes place from the output shaft of the engine to the rear axle and involves the transmission, differential, and final drives. Gear reductions for the T65 can be seen in the table below:

Component	T65
Transmission	5.0:1
Differential	1.45:1
Final Drives	16.7:1

Table 10: Gear Reductions for T65 Mining Truck

Total gear reduction for the T65 is:

$$\text{Total Gear Reduction}_{T65} = 5.0 \times 1.45 \times 16.7 = 121:1$$

Maximum Tractive Effort – is defined as the force horizontal to the road surface created by the torque applied to the rear wheels. Maximum Tractive Effort can be calculated as follows:

$$\text{Tractive Effort}_{max} = \text{Engine Torque}_{max} \times \text{Total Gear Reduction}/(\text{Tire Diameter}/2)$$

Stall Grade – is defined as the grade at which Maximum Tractive Effort equals all reward forces. It can most easily be calculated by an iterative solution of the following equation. After entering all know forces and coefficients we iterate θ until the forces just match.

$$\text{Engine Torque}_{max} \times \text{Total Gear Reduction}/(\text{Tire Diameter}/2) =$$
$$\text{GVW} \times \sin(\theta) + \text{GVW} \times \text{cosine}(\theta) \times \mu$$

Below we perform this calculation iteratively for a T65 with a Cummins C1 diesel engine with a maximum torque of 4,493 ft-lb.

$$\text{Tractive Effort}_{Max} = 4{,}493 \text{ (ft-lb)} \times 121 / 5 \text{ (ft)} = 108{,}730$$

% Slope	Angle (θ) in Degrees	Reward Force (lb)
28%	15.6	104,770
29%	16.2	107,760
30%	16.7	110,725

Table 11: Iterative Solution for Stall Grade

Based on the above iterative solution, a fully loaded T65 with a Cummins C1 engine has a stall grade of 29%.

Approximate Solution – An approximate solution can be obtained by using the two charts below. Begin by finding the tractive effort in figure 7.

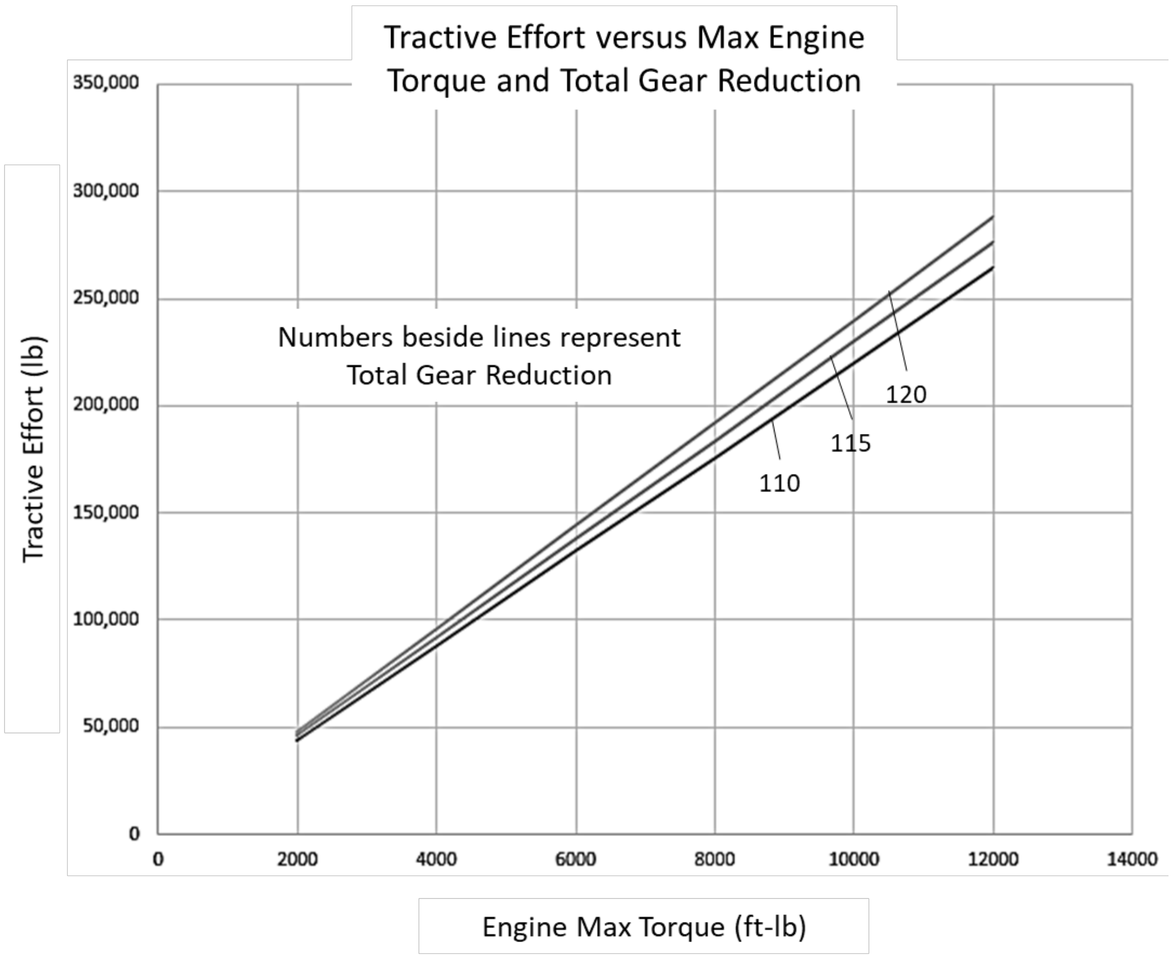

Figure 7: Determining Tractive Effort

After determining maximum tractive effort from figure 7, draw a horizontal line in figure 8 where the reward forces are equal to maximum tractive effort. Then draw a vertical line from GVW. Where to two lines intersect is the truck's stall grade.

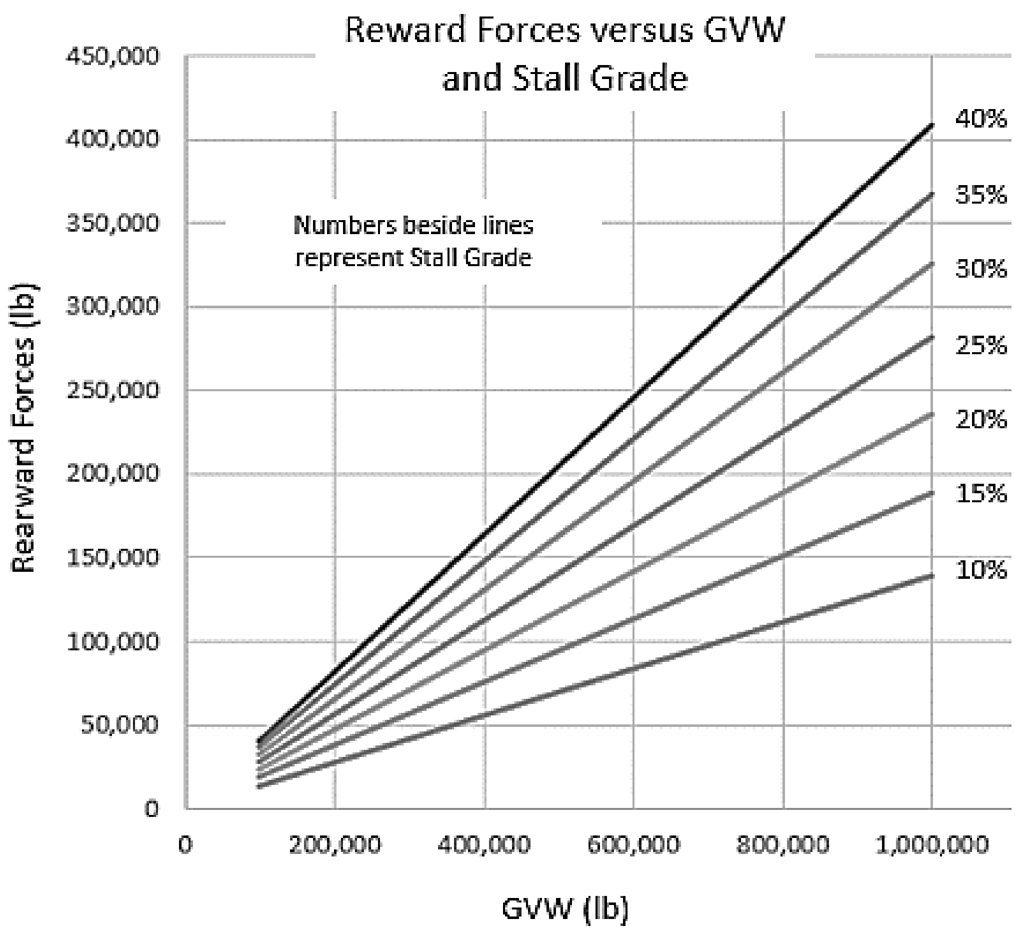

Figure 8: Determining Stall Grade

Section IV: Availability

Factors to Consider:

When calculating Availability of a haul truck the following factors must be taken into consideration:

MTBO – Mean Time Between Overhaul

MTBUO – Mean Time Between Unscheduled Outages

Duration – Length of Outages

With these factors we can calculate average annual outage time and Availability as follows:

$$\text{Average Annual Outage Time} = D_1/\text{MTBO} + D_2/\text{MTBUO}$$

$$\text{Availability (\%)} = (52\text{-Average Annual Outage Time})/52$$

Values of Availability Factors – Typical values of various factors for the T100 and T150 trucks can be seen below.

Overhaul Schedule:

Factor	T65
MTBO	30,000 hours
Duration of Overhaul	1.5 weeks

Table 7: Mean Time Between Overhaul for T65

Unscheduled Outages[2]:

Component	MTBUO	Duration
Diesel Engine	5 years	1 week
Transmission	4 years	2 weeks
Differential	6 years	1 week
Final Drives	6 years	2 weeks
Other	10 years	1 week

Table 8: Typical MTBUO and Duration for Haul Truck Components

For unscheduled outages we use the following equations:

[2] Data for components can vary. Data in table is for example only. Consult product specs for actual MTBUO.

$$MTBUO_{Total} = \sum_{1}^{n} Duration_n/\text{component } MTBUO_n$$

Note: For three components (transmission, differential, and final drives) there is an additional consideration for determining MTBUO. For these components, the ratio of rated horsepower to actual horsepower modifies the base level MTBUO (called MTBUO_base) according to the following equation:

MTBUO_actual = MTBUO_base x rated horsepower of component/horsepower of engine

Standard Truck Use Assumption – For all calculations of Availability, the haul truck industry uses the following assumption:

Hours of operation per year = 16 hours/day x 52 weeks/year x 7 days/week = 5,824 hours

Example – For Tribolt's T65, using data from the previous page, we calculate the following availability:

MTBO = 30,000/5,824 = 5.15 years

Average duration of overhaul = 1.5 weeks

MTBUO = 1/(1/5 + 2/4 + 1/6 + 2/6 + 1/10) = 1.13 years

Average duration of unscheduled outage = (1 + 2 + 1 + 3 + 1)/5 = 1.6 weeks

Average Annual Outage Time = D_1/MTBO + D_2/MTBUO = 1.5/5.15 + 1.6/1.13 = 1.71

Average Annual Availability (weeks) = 52 – 1.71 = 50.3 weeks

Average Annual Availability (%) = 50.3/52 = 97%

Section V: Fuel Consumption

The fuel consumption of an average diesel engine is 0.048 lb/hr/hp. A rough approximation for fuel consumption of the Tribolt T65 (or any haul truck) can be predicted using figure 9 below:

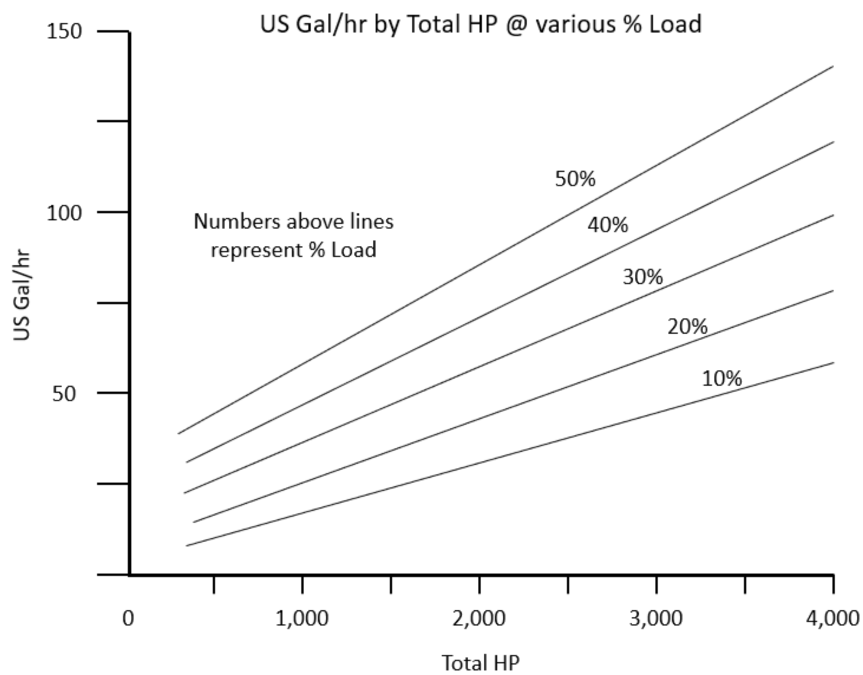

Figure 9: Average Fuel Consumption versus Horsepower

Actual fuel consumptions must be calculated using the manufacturer's specifications and the formula below. Consumption at 50% load is approximately 10% greater than consumption at 10% load, thus the formula is adjusted to account for this.

$$\text{Fuel Consumption} = (\text{Consumption}_{@10\%\ \text{load}} + 1.1 \times \text{Consumption}_{@50\%\ \text{load}})/2$$

Maker	Model	Power (Horsepower)	Torque (ft-lb)	Rated RPM	Fuel Consumption (Gal/hr/hp)
Cummins	C1	1,400	4,493	1,800	0.039
Cummins	C3	1,600	5,171	1,950	0.041
Cummins	C7	1,800	5,971	1,900	0.046

Table 9: Fuel Consumption of Selected Engines

Calculating fuel consumption for a Cummins C7 engine is as follows:

$$\text{Fuel Consumption} = (\text{Consumption}_{@10\%\ \text{load}} + 1.1 \times \text{Consumption}_{@50\%\ \text{load}})/2$$

$$\text{Fuel Consumption}_{\text{Cummins C7}} = (.046 \times .10 \times 1{,}800 + 1.1 \times .046 \times .50 \times 1{,}800)/2 = 53.8\ \text{Gallons/Hour}$$

Section VI: Maximum Forward Speed

Maximum forward speed for a haul truck can be calculated as follows:

Factors to consider:

1. Wind resistance
2. Rolling Friction
3. Engine Horsepower
4. Gearing and Engine RPMs

<u>Wind Resistance</u> – of a haul truck is calculated using the following formula:

$$F_{wind} = 0.00256 \times V^2 \times A \times C_d$$

Where:

F_{wind} = force generated by wind load

V = wind velocity in miles per hour

A = area in square feet

C_d = coefficient of drag (Dimensionless)

Using a typical drag coefficient for haul trucks of 0.65, taking the frontal area of the typical haul truck (25' x 25') and assuming a maximum forward speed of 40 mph, the wind resistance experienced by a mining truck is calculated as follows:

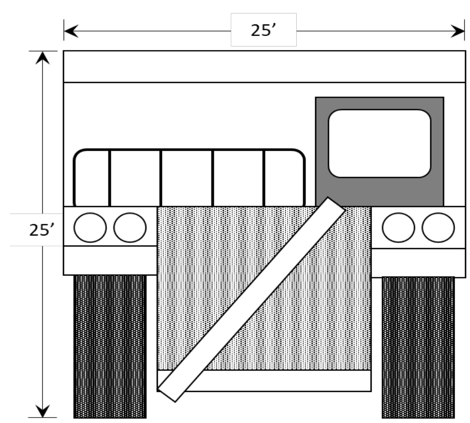

Figure 10: Frontal Area of Typical Haul Truck

$$F_{wind} = .00256 \times 40^2 \times (25 \times 25) \times 0.65 = 1{,}664 \text{ lb}$$

Calculating exact wind resistance results in a complex iterative calculation. For simplicity, and because it has only a minor effect, wind load is assumed to be 1,500 lb for all trucks and all velocities.

Rolling Friction – of a haul truck is calculated using the following formula (covered in Section I):

$$F_r = \mu N$$

Where:

F_r = Rolling Friction Force

μ = Coefficient of Rolling Friction for a given surface (in this example packed clay)

N = Normal Force to Roadway

The resulting value for a haul truck (with a GVW of 300,000 lb) on a level road is:

$$F_r = 0.04 \times 300{,}000 = 12{,}000$$

Total Reward Forces – So the total reward forces on this truck would be:

$$F_{reward} = 1{,}500 + 12{,}000 = 13{,}500 \text{ lb}$$

Horsepower – must be considered when calculating maximum speed. This calculation answers the question of how quickly the power of the engine can move 13,500 lb. For this calculation we need the following assumptions and conversion factors:

1. The engine that is rated at 1,400 brake horsepower at 1,800rpm.
2. One horsepower = 550 ft-lb/s
3. One mph = 1.46 ft/s

$$\text{Forward Speed}_{\text{limited by horsepower}} = 1{,}400 \times 550/13{,}500 = 57.0 \text{ ft/s}$$

$$\text{Speed in mph} = 57.0/1.46 = 39.1 \text{ mph}$$

In this example the haul truck only has enough power to move 13,500 lb at a speed of 39 mph.

Gearing – must also be considered when calculating maximum speed. It is not recommended that haul trucks exceed the rated rpm of the engine. Here we want to answer the question of how quickly the speed of the engine can move the haul truck. For this calculation we need the following assumptions and conversion factors:

1. Transmission Ratio (7th gear) = 1:1
2. Differential Ratio = 1.45:1
3. Final Drive Ratio = 16.7:1
4. Engine Speed = 1,800rpm
5. Tire Diameter = 10 feet

RPM of rear axle = 1,800rpm/(1 x 1.45 x 16.7) = 74.3 rpm

Forward Speed = 74.3 rpm x 3.14 x 10 feet x 1 minute/60 seconds = 38.9 ft/s

Converting into mph = 38.9/1.46 = 26.6 mph

So the maximum speed of the haul truck in this example is limited by its gearing rather than horsepower and is 26.6 mph.