LIFT TRUCK PERFORMANCE

INTRODUCTION

The overall performance and capability of a lift truck is dependent on many factors. The purpose of this section is to isolate those factors for discussion in an effort to better understand proper lift truck application. It is often the job of the salesman to strike the best balance of performance characteristics in a lift truck recommendation. Not all specifications will be ideal in every situation, but one must know how individual truck specifications relate to the work capability of the vehicle. This discussion will include dimensions, maneuverability, performance, and capacity.

DIMENSION SPECIFICATIONS

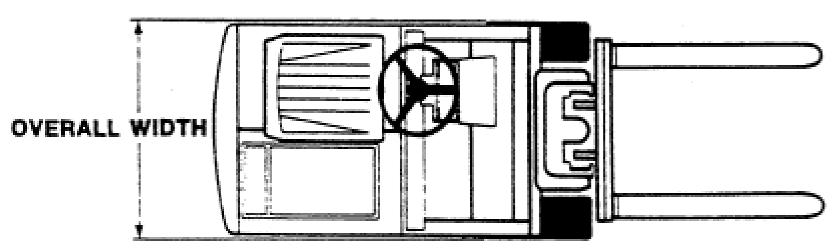
In almost every lift truck application, there are obstacles and space constraints to deal with. Doorways, ramps, railcars, vans, containers, and aisles place dimensional limits on the size and maneuverability of the vehicle. Therefore, many critical lift truck dimensions must be examined to determine the suitability of that unit for a specific working environment. The most common considerations include:

1. Overall width.
2. Overall height.
3. Length to the face of forks.
4. Outside turning radius and counterweight contour.
5. Right angle turn dimension or stacking aisle width.
6. Intersecting equal aisle width.
7. Underclearances.
8. Grade clearances.
9. Wheel base.
10. Angles of steer.
11. Tail width.

OVERALL WIDTH

The most important truck dimension is the distance across the widest point — the drive axle. (*Figure 1.*)

FIGURE 1.
TRUCK WIDTH



This width over the drive tires is critical with respect to the following:

1. Doorways occasionally limit vehicle width.

2. Aisles must be wider than the truck even if they are one way traffic aisles. (OSHA requires that one-way aisles be not less than three feet wider than the vehicle with a typical load. In two-way aisles, the requirement is six feet more than the width of two loaded trucks.) It is generally accepted that a two-way aisle is narrow if it is eleven or twelve feet wide.

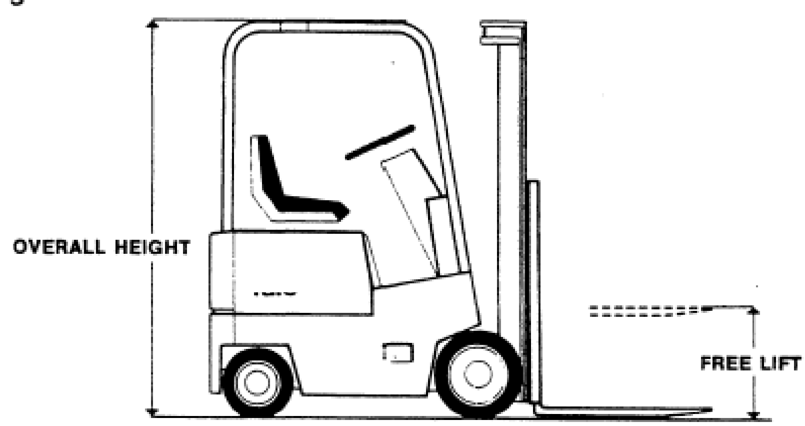
3. In stacking situations where loads are stacked side by side and more than one load deep, the ideal truck should be no wider than the load. This is important in closely stacked, open aisle inventory or drive-in racks, where the truck will be expected to operate retrieving and stacking double or triple deep loads.

4. Turning radius and right angle stack capabilities of four wheel trucks are affected by truck width. The wider this width is, the greater the turning radius required.

OVERALL HEIGHT

Overall truck height is restricted in the following ways. (*Figure 2.*)

FIGURE 2.
Overall Height



1. Doorways and overhead clearances vary greatly in each facility. Experience has shown that typical sizes are common. The lowest of these is seven feet. Therefore, most cushion tire trucks that operate indoors are 83 in. high or less.

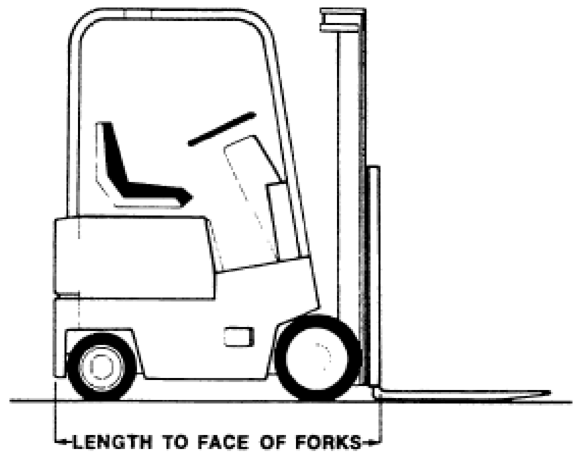
2. Container openings can differ, but a 79 in. vehicle height is sufficient to operate inside the lowest I.S.O. (International Standards Organization) container with adequate allowance for bridge-plate and clearances.

3. Box car and trailer limits can be troublesome, especially in older models. Most newer units, however, offer openings of 107 in. high or more. Inside vans, box cars, and trailers, the mast elevation can be restricted in stacking situations. Most masts incorporate a certain amount of free lift, permitting the forks to be raised some distance without mast or backrest elevation above the collapsed height. Some two-stage and three-stage masts have increased free lift capabilities, making them more suitable for such applications.

LENGTH TO FACE OF FORKS

This dimension is important if a truck is backed against a wall and then must make a right angle turn from this position. If the right angle stacking dimensions are acceptable, however, considerations of overall length will be less important. (*Figure 3.*)

FIGURE 3.
LENGTH TO FACE OF FORKS



OUTSIDE TURNING RADIUS

Turning radius is the radius of the smallest possible circle within which the truck can turn. While a fork tip or load corner can determine the turning radius by virtue of being farther from the steering point than any other part of the truck, for most applications the contour of the counterweight determines turning radius. When operating in confined spaces, the turning radius can be a very important consideration.

Where loads and obstacles are more or less randomly placed, a small turning radius helps maneuverability. Opening in aisles, however, can be limited by turning radius. Whether determined by counterweight contour, fork tip length, or load corners, the turning radius of the vehicle will limit what is called the minimum operating aisle. This term is more fully discussed later in the section on aisles.

A counterweight that is efficiently rounded to "eliminate" snag points also helps minimize turning radius in tight quarters. The contour, as seen from above, creates somewhat more length than a squared-off version might. This added length is not ordinarily considered a drawback.

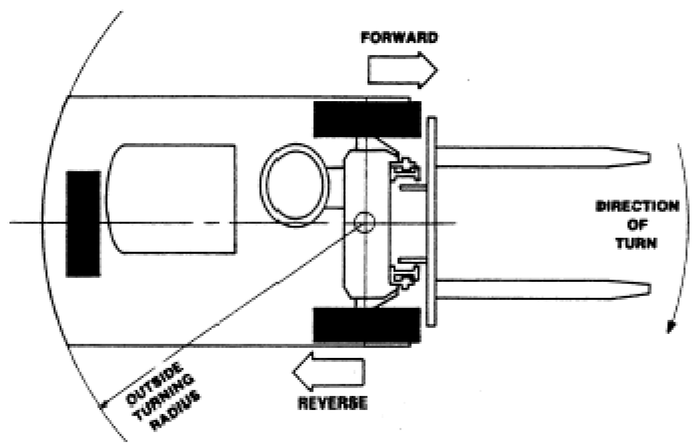
Turning radius figures shown on specification sheets are sometimes theoretical. They are determined from a drawing that assumes a steer point based on the angle of steer, wheelbase, and the drive axle width, but they do not show compensation for actual steering geometry, tracking or prevailing torque, tire, and floor conditions. On all our products, turning radius is confirmed by actual tests of driving the truck in a circle very slowly.

THREE WHEEL TRUCKS

Three wheel trucks usually have a smaller minimum turning radius than four wheel trucks of the same capacity. Three wheel trucks steer around a point that is located where the center line of the truck intersects the center line of the front axle. (*Figure 4.*)

If a truck has the drive unit in the rear, the inside front tire will rotate in the opposite direction from the outside tire when turning at the minimum turning radius. Front wheel drive trucks, if equipped with two separate drive motors, can be designed to rotate the front wheels in opposite directions at the maximum steering position to produce the same effect.

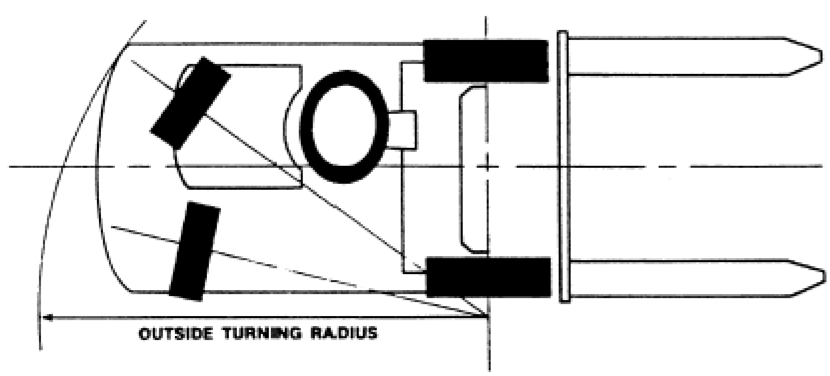
FIGURE 4.
Outside Turning Radius, Three Wheel Truck



FOUR WHEEL TRUCKS

Standard four wheel trucks steer around a point that is located outside the perimeter of the truck. The closest point around which a truck can be turned lies about one-half of a tire width beyond the tire on the inside radius of the turn. (*Figure 5.*)

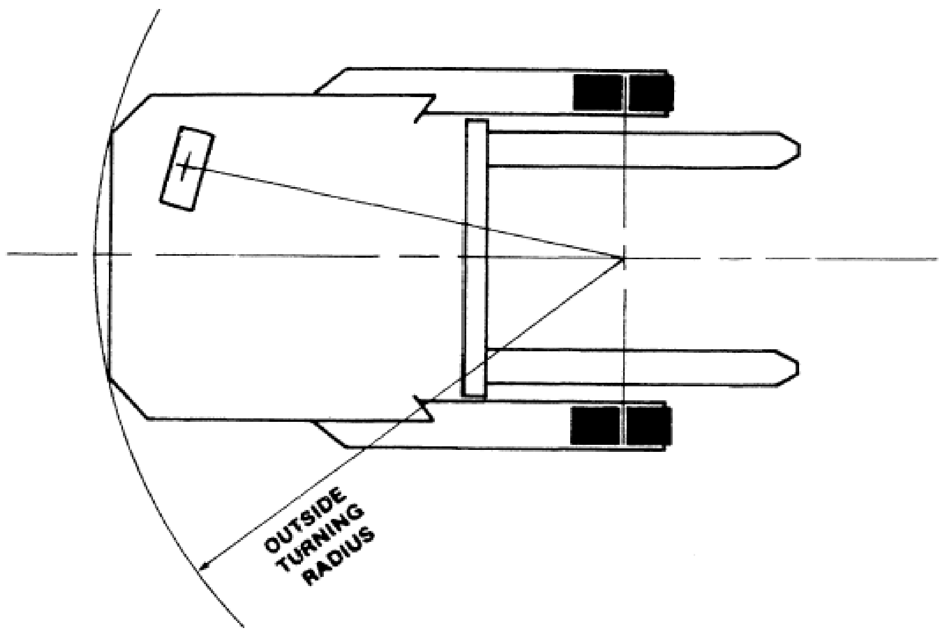
FIGURE 5.
OUTSIDE TURNING RADIUS, FOUR WHEEL TRUCK



NARROW AISLE TRUCKS

Narrow aisle trucks, although different in appearance, perform the same as three wheel trucks. (*Figure 6.*)

FIGURE 6.
OUTSIDE TURNING RADIUS, NARROW AISLE TRUCK



All tires will creep and sideslip except when rolling on a straight path due to two factors. First, when steered, the rear wheels have a sideways force tending to make them follow a path other than the steering arc. This side load causes the tire patch to slide since adhesion to the traveling surface is not perfect. Also, the patch creeps as the tire is deflected sideways, causing it to touch down slightly outside the previous contact point in the turning arc. The amount of tire creep and slip will depend on the operating surface, tire tread and hardness, and loads on the tires, among other factors. Second, the steered tires will track differently when going forward than backwards, empty or loaded, fast or slow. Remember these factors when interpreting the ideal figures on the specification sheets.

RIGHT ANGLE TURN

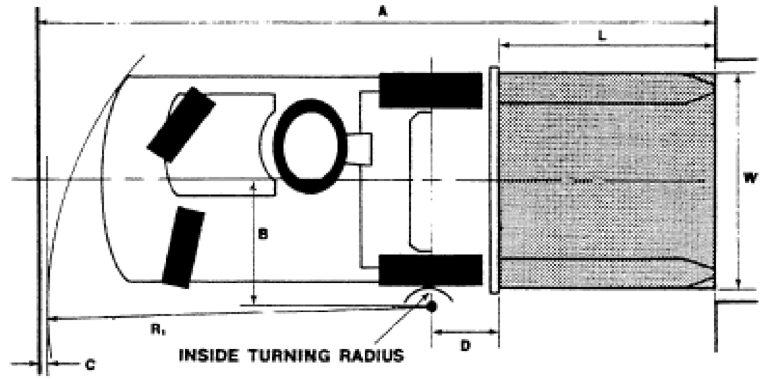
Right angle stacking aisle width is the width required to turn a truck with a typical load (48 in. cubed) 90° to deposit the load at the side of the aisle. Since for narrow or medium loads (see below) the aisle width depends upon the vehicle "right angle turn dimension" it is common to publish this dimension. The right angle turn dimension is equal to the sum of the vehicle turning radius (over counterweight) plus front overhang (distance from centerline of drive axle to face of forks).

1. **Narrow Loads:** A narrow load is defined as having one-half its width (W/2) equal or less than the sum of inside turning radius plus one-half of drive axle width (B). *Figure 7* shows how aisle width is determined for a narrow load. Note that R_1 + D is the right angle turn dimension as explained above.

2. **Medium Loads:** A medium load is defined as one for which one half its width is greater than the sum of inside turning radius plus one-half of drive axle width (B on diagram) and the front corners of the load determine the largest turning radius. *Figure 8* shows how this aisle width is determined. Note that when the front corner of the load need not clear line of the stack, aisle width is the same as for a narrow load and depends upon right angle turn dimension.

3. **Wide Loads:** A wide load is defined as one for which one-half its width is greater than the sum of inside turning radius plus one-half of drive axle width and the rear corners of the load determine the largest turning radius. *Figure 9* shows the determination of aisle width. Note that in all cases load is centered on the forks (laterally). Except in the case of narrow loads, (which are the most common) determination of aisle width is somewhat complex.

FIGURE 7.
RIGHT ANGLE TURN—NARROW LOAD

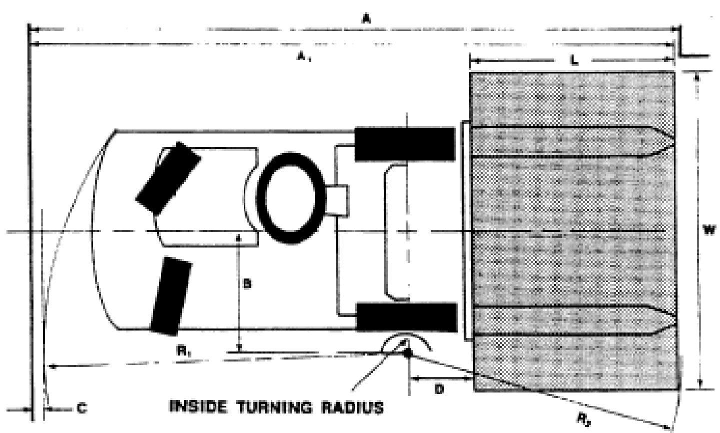


A = Minimum Aisle Width for Right Angle Stacking.
B = ½ Truck Overall Width Plus Inside Turning Radius.
C = Operating Clearance Best Suited for Individual Application and Steer Wheel Creep. (Consult Manufacturer)
D = Distance from Face of Load to Centerline of Drive or Load Axle.
R_1 = Outside Turning Radius. (Empty Truck Under Power at Slow Speed.)
L = Length of Load.
W = Width of Load.

When "W" is not greater than 2B use:

$$A = R_1 + D + L + C$$

FIGURE 8.
RIGHT ANGLE TURN—MEDIUM LOAD



A = Minimum Aisle Width for Right Angle Stacking.
B = ½ Truck Overall Width Plus Inside Turning Radius.
C = Operating Clearance Best Suited for Individual Application and Steer Wheel Creep. (Consult Manufacturer)
D = Distance from Face of Load to Centerline of Drive or Load Axle.
R_1 = Outside Turning Radius. (Empty Truck Under Power at Slow Speed.)
R_2 = Distance from Center of Turn to Indicated Load Corner

$$= \sqrt{(D+L)^2 + \left(\frac{W}{2} - B\right)^2}$$

L = Length of Load.
W = Width of Load.

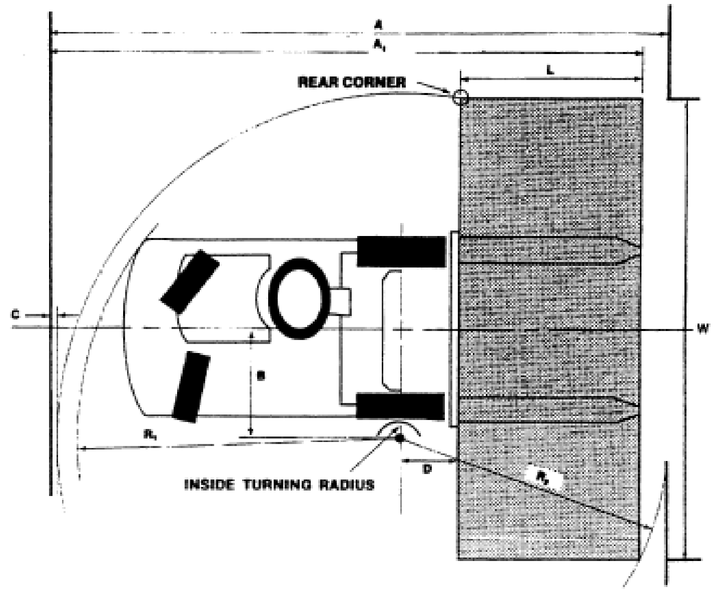
When "W" is greater than 2B but not over $2(R_1 - B)$ use:

$$A = R_1 + R_2 + C$$

If swing indicated by R_2 need not clear line of stack as shown dotted, then use:

$$A_1 = R_1 + D + L + C$$

FIGURE 9.
RIGHT ANGLE TURN—WIDE LOAD



A = Minimum Aisle Width for Right Angle Stacking.
B = ½ Truck Overall Width Plus Inside Turning Radius.
C = Operating Clearance Best Suited for Individual Application and Steer Wheel Creep. (Consult Manufacturer)
D = Distance from Face of Load to Centerline of Drive or Load Axle.
R_1 = Outside Turning Radius. (Empty Truck Under Power at Slow Speed.)
R_2 = Distance from Center of Turn to Indicated Load Corner

$$= \sqrt{(D+L)^2 + \left(\frac{W}{2} - B\right)^2}$$

L = Length of Load.
W = Width of Load.
When "W" is greater than 2B and greater than $2(R_1 - B)$ use:

$$A = \frac{W}{2} + B + R_2 + C$$

If swing indicated by R_2 need not clear line of stack as shown dotted, then:

$$A^1 = \frac{W}{2} + B + D + L + C$$

AISLE WIDTH-NARROW AISLE TRUCKS

The stacking aisle for narrow aisle trucks is calculated differently than for sit-down rider trucks. Some portion of the rack opening, usually three to six inches in depth, is utilized when making a right angle turn in an aisle to deposit a load. This is done to keep the aisle width to a minimum.

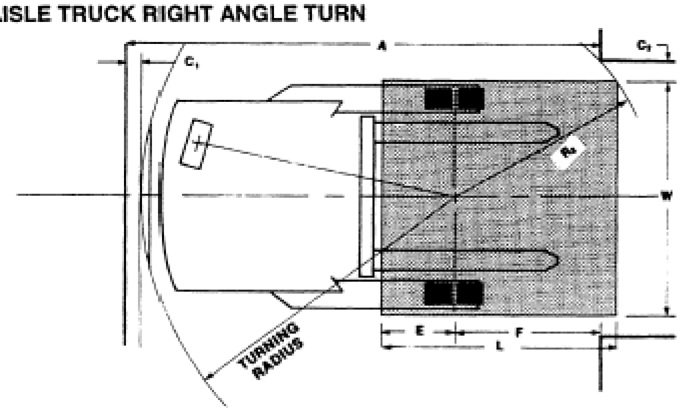
The clearance between loads is also considered. When this clearance is increased, more of the rack opening can be used when making a turn, therefore reducing the required width of the aisle.

The simplest method to calculate the aisle width is to assume the truck is steered around a single point that is located at the intersection of the center lines of the truck and the load wheels. If the drive unit is located on the center line of the truck, this assumption is correct. If it is offset, a more ideal spot can be identified, which will further reduce the aisle width.

Figure 10 illustrates a narrow aisle extend truck operating in a minimum width aisle. Bulletin dimensions and calculation of dimensions "E" and "F" are required to determine the aisle width "A." Special consideration is required for straddle trucks, wide overall width trucks, and wide loads.

When laying out aisles for a new warehouse, contact the appropriate department for confirmation of the calculations.

FIGURE 10.
NARROW AISLE TRUCK RIGHT ANGLE TURN



A = Minimum aisle width for right angle stack

$A = C_1 + R_1 + F$

C_1 = Operating Clearance, best suited for individual application

C_2 = Clearance between loads, minimum recommended 4 inches

E = Distance from face of forks to centerline of load wheels

E = Wheel base + rear overhang - overall length

F = Distance from centerline of load wheels to face of racks or side of aisle (calculated)

$$F = \sqrt{\left(\frac{W}{2}\right)^2 + (L-E)^2 - \left(\frac{W}{2} - C_1\right)^2}$$

L = Length of load

R_1 = Outside turning radius: (empty truck under power at slow speed)

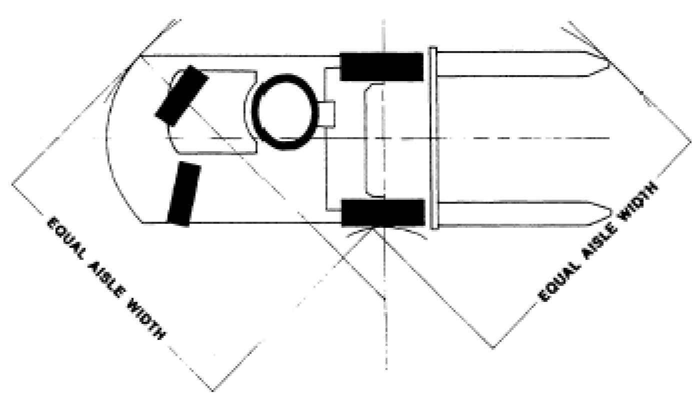
R_2 = Distance from center of turn to indicated load corner. Reference only.

$$R_2 = \sqrt{\left(\frac{W}{2}\right)^2 + (L-E)^2}$$

INTERSECTING EQUAL AISLE WIDTH

The minimum intersecting aisles that an unloaded vehicle can travel through is shown on specification sheets. This aisle width depends upon truck width, truck length, counterweight contour, fork length, and fork spread. As published, the aisle dimension does not relate meaningfully to most operations, unless the front corners of the load coincide with the fork tips.

FIGURE 11.
INTERSECTING EQUAL AISLE WIDTH

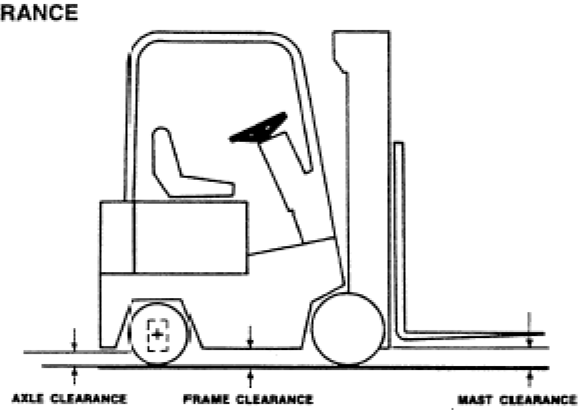


For a loaded truck, load width plus load length must be known to determine intersecting aisle width. Furthermore, many operations employ unequal intersecting aisle widths. Accordingly some manufacturers no longer display intersecting aisle width because there are just too many variables to include on a sales bulletin. Intersecting aisle widths must be determined from a layout drawing. *Figure 11* shows a typical intersecting aisle layout.

UNDER-CLEARANCES

The underclearances of the truck frame, mast drive, and steer (trail) axles can be significant if there are surface irregularities or obstacles to be encountered. Not all underclearances are indicated on sales bulletins. Mast underclearance is generally the lowest point and, therefore, the one dimension most often listed. Where backing over irregularities or obstructions is a factor, steer axle clearance should be known. Since they're intended for less ideal operating surfaces, pneumatic trucks have higher underclearance. (*Figure 12.*) Narrow aisle trucks and order pickers operate on smooth level floors and therefore have minimal underclearance.

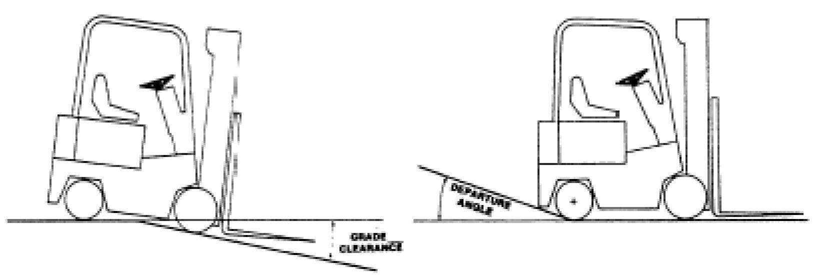
FIGURE 12.
UNDERCLEARANCE



GRADE CLEARANCE

Operation on ramps or over dockboards and bridge plates requires knowledge of the truck's grade clearance capability. The incline (in terms of percent) on which the center of the frame underclearance will just touch when leaving the level for a ramp (going down) or when leaving a ramp for a level (going up) is shown on most bulletins. The so-called departure angle (from wheel arc to vehicle edge) of the counterweight is often shown as well. (*Figure 13.*)

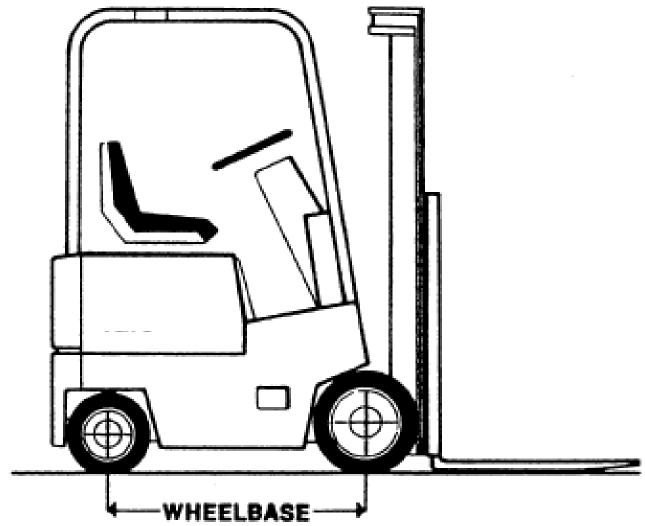
FIGURE 13. GRADE CLEARANCE



WHEELBASE

Wheelbase does not relate directly to maneuvering dimensions (except grade underclearance), but it does affect vehicle behavior. A long wheelbase improves ride, lateral stability, and empty gradeability. However, a longer wheelbase requires greater angles of wheel steer and less efficient steer tracking. (*Figure 14*.)

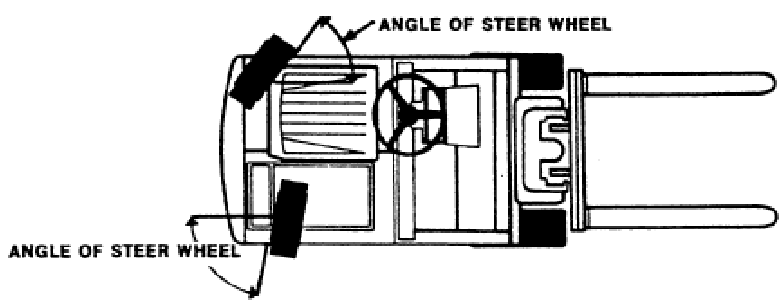
FIGURE 14. WHEELBASE



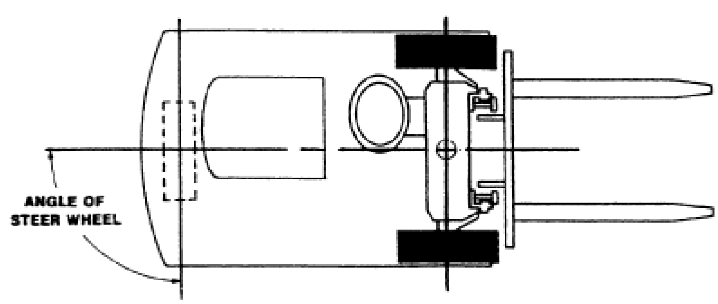
ANGLES OF WHEEL STEER

The steer wheels on four-wheel vehicles are turned to different angles to negotiate a turn: the wheel on the inside of the turn, turn at a higher angle than the outer wheel. Angles of 85° for a cushion tire truck and 75° for a pneumatic are not uncommon. Three-wheel trucks steer to 90°. It can readily be seen how the tractive forces of the drive wheels will cause trail wheel sideslip and creep. Steer tracking may be especially crucial when traveling in reverse with rated load since the trail axle is virtually unloaded. (*Figure 15.*)

FIGURE 15. ANGLE OF STEER WHEEL, FOUR-WHEEL TRUCK



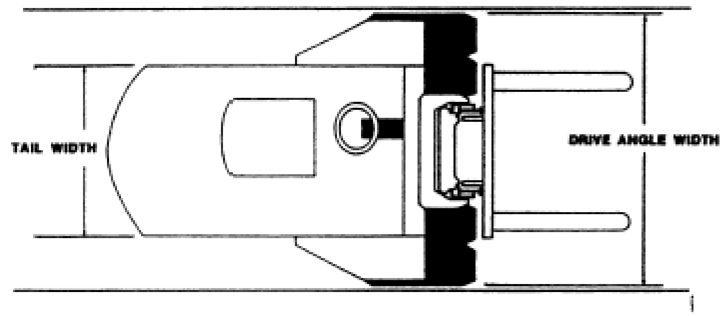
Angle of Steer Wheel, Three-Wheel Truck



TAIL WIDTH

When moving between stacks, loads, or other obstructions, it is desirable to be able to maneuver the rear of the truck to allow steering corrections without striking anything. This means that the tail width should be less than load or drive axle widths. When tail width equals drive axle width, driving in confined areas is extremely difficult except for very short distances. (*Figure 16.*)

FIGURE 16.
TAIL WIDTH



CLEARANCE ALLOWANCES

In any lift truck operation, adequate clearance allowances must be made. These clearances must permit less than perfect steering control and steering corrections. For aisles and other maneuvering constraints no less than 6 inches for smaller trucks (operated slowly) or preferably up to 12 inches should be allowed. More clearance is advisable for larger units wherever possible. Similar overhead allowances should be made but generally less clearance is required.

POWER STEERING

Responsive, low-effort power steering will allow the operator to utilize all the dimensions of the vehicle to the fullest for improved performance and maneuverability.

TRUCK PERFORMANCE

A number of truck specifications relate to lift truck performance and the lift truck's ability to move materials quickly. This section identifies the basic performance factors and explains them in general terms. The performance-related specifications are:

1. Travel speed.
2. Hoist and lowering speed, empty and loaded.
3. Gradeability, empty and loaded.
4. Tractive effort.
5. Drawbar pull.
6. Towing capacity.
7. Acceleration.
8. Braking.
9. Tilt time.

TRAVEL SPEED

Internal combustion engine specification sheets show maximum travel speeds in high gear running forward. (Maximum travel speed is limited by an engine governor on I.C. engine trucks.) These speeds represent travel speed carrying a full-rated load. Except for the very largest vehicles, the empty and loaded speeds are virtually the same once top speed is attained.

Electric truck specification sheets indicate both empty and loaded travel speeds. The loaded speeds are always less than maximum. Because gear ratios may be unequal in forward and reverse, travel speed may not be the same in both directions, but the difference is small. Except on bad surfaces, empty trucks can safely attain top speed, but, with full-rated load, tire bounce on all but the best surfaces will limit travel speed (particularly in the case of pneumatics).

Fast travel speeds should only be used when driving in a straight line when operator and pedestrian visibility is good! The operator should slow down for turns to avoid lateral overturn, especially in the empty condition. Nonetheless, travel speed can have a great effect on the ability to move materials.

HOIST AND LOWERING SPEEDS

Major lift truck manufacturers publish four lift related speeds: **hoisting empty, hoisting loaded, lowering empty, and lowering loaded**. Although operating constraints (space, lighting, the nature of the load, controllability, etc.) can reduce the full use of these speeds, all four affect the vehicles ability to do a job. It is incorrect to consider only one or two speeds, although frequently a customer will be concerned only with loaded hoisting speed or empty and loaded hoisting. The section on cycle time will clarify the situation and explain why this is wrong.

The published hoist and lowering speeds are the average values in feet per minute (FPM) for the total lift of the mast. Loaded hoist is less than empty hoist speed and loaded lowering generally faster than empty lowering. Lowering speed is limited to a flow control valve. Some manufacturers include a pressure (load)-

sensing lowering valve to make empty lowering faster than loaded lowering. In some cases empty hoist speed is boosted even higher by utilizing "regenerative" hoisting. This alone or in conjunction with load sensing lowering control, can improve productivity substantially. Hoist/lowering speeds vary with mast type because of differences in cylinder size and cylinder-to-fork stroke ratio.

GRADEABILITY

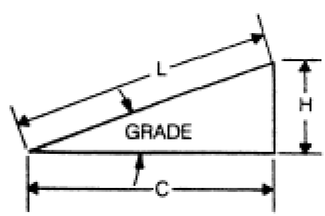
Gradeability is expressed in percent and is often published for the loaded and unloaded conditions, sometimes in several gear ranges. In almost all instances loaded gradeability (with a full load) is limited by engine output or drive motor torque, the drive train gear ratio and efficiency. Empty gradeability is limited by drive wheel adhesion which, in turn, depends on the friction between the tire and the ramp (called the coefficient of adhesion) and the weight on the drive axle.

The coefficient can vary greatly and be as high as .9 for good tires on dry brushed concrete or as low as .6 for the same tires on wet concrete. On metal, oily, or wet slick surfaces, the friction coefficient is almost zero. Published gradeability figures specify the coefficient of adhesion to which they apply, but the determination of the coefficient in many operations is difficult at best.

Many manufacturers publish gradeability at one mile per hour. For torque converter transmissions as well as electric trucks, loaded gradeability varies widely with speed, dropping off drastically as speed increases. Manual transmissions behave somewhat differently, and within any given gear range, gradeability is proportional to maximum torque in that range.

Gradeability also relates to the ability to travel on rough or soft surfaces, as well as to climb over obstacles or out of potholes. No specifications or measures can be given, but improved gradeability means improved operation on most adverse surfaces.

The formula to calculate grade percentage is as follows:



$$\%\ GRADE = 100 \times \frac{\text{TOTAL RAMP RISE (H)}}{\text{HORIZONTAL RAMP LENGTH (C)}}$$

$$\%\ GRADE = 100 \times \frac{H}{C}$$

(Equation 1)

If only the ramp slope length "L" and the height "H" can be measured, use the formula:

$$\% \text{ GRADE} = 100 \times \frac{H}{\sqrt{L^2 - H^2}}$$

Where L is length of the inclined surface.

(Equation 2)

Both drive and trail wheels must be on the ramp when starting in order for published gradeabilities to apply.

If a vehicle must operate on a steep grade, also confirm that the braking system is adequate to stop the vehicle on the same grade.

Motorized hand trucks, narrow aisle trucks, and order pickers have very limited gradeability.

TRACTIVE EFFORT

Tractive effort is the driving force of the truck parallel to the operating surface produced by the maximum output of the drive unit (at the drive wheels) at a given speed. It is tractive effort that overcomes rolling resistance on ramp incline and vehicle inertia to produce acceleration. Since vehicle behavior cannot be predicted from tractive effort without taking the effects of rolling resistance, ramp inclination, and inertia into consideration, it is useful only for engineering purposes and is not published in sales literature.

DRAWBAR PULL

At any steady speed, drawbar pull equals tractive effort minus rolling resistance and grade resistance. It is, in effect, a measure of the force left to tow a load or accelerate the truck and trailer. Drawbar pull (DBP) is frequently shown in sales literature though the speed for which it applies is seldom indicated. Since rolling resistance on good surfaces is quite low, drawbar pull is very nearly equal to tractive effort. Drawbar pull depends upon tire-to-ground adhesion as does empty gradeability, so published values are based upon an assumed coefficient of adhesion and, by implication, represent the loaded condition. If not otherwise indicated, an empty vehicle generally has enough tractive effort to spin its wheels.

TOWING CAPACITY

The total weight of trailer load that a truck can tow is its towing capacity. Towing capacity can be calculated from drawbar pull. The total trailer weight (W) that can be towed on level ground comes from the formula:

$$W = \frac{\text{DRAWBAR PULL (DBP)}}{\text{ROLLING RESISTANCE FACTOR}}$$

(Equation 3)

It takes more drawbar pull to start moving a trailer load and to accelerate it than to keep it rolling. Generally, it's wise to allow twice the drawbar pull required for rolling. Because adhesion is improved, a loaded fork-lift truck will pull more than an empty one.

Example: Gas, cushion tire, 3000 lb. truck has 2600 lb. DBP. Assume a rolling distance of 50 lb. per ton of trailer weight.

$$W = \frac{2600 \text{ lb.}}{50 \text{ lb./TON}} = 52 \text{ TONS (ROLLING)}$$

$$W = \frac{2600 \text{ lb.}}{50 \text{ lb./TON} \times 2} = 26 \text{ TONS (STARTING)}$$

ACCELERATION

Acceleration is the rate at which speed increases over time. While good acceleration will improve the rate at which material can be moved, its overall effect on materials handling is generally small. The truck driver will nonetheless gain the impression of much improved work capability. In “Engine Power,” cycle time will explain this in detail.

BRAKING

All lift trucks are equipped **with service and parking brakes**. On some trucks they are the same brake. A.N.S.I. B56.1 stipulates that a minimum braking capability must be provided. The amount of service braking required depends upon maximum travel speed but also need not exceed a braking force in excess of 25% of loaded vehicle weight. For trucks traveling under 8.3 miles per hour, braking force, expressed as a percent of vehicle weight, must equal 3 times travel speed.

Order picker trucks require less braking than other material handling equipment because the operator may be elevated.

B56.1 requires that the parking brake be capable of holding a loaded truck on the maximum grade the truck can climb or a grade of 15% for rider trucks or 10% for motorized hand trucks, whichever is lower. We check every truck in production on a ramp to see that it meets this requirement.

When traveling forward, loaded with forks down, care must be exercised in braking since the braking force required by A.N.S.I. B56.1 will result in a deceleration which exceeds truck stability. The trail axle can lift up, and the load can slide off the forks or the truck will tip.

A common misconception is that brakes which can lock up are superior. Actually, at lockup the adhesion between the tires and the operating surface drops and the vehicle brakes more slowly while losing directional control.

TILT TIME

Shortened tilt time will improve productivity, but with forks elevated, the operator must tilt more slowly in order to prevent dynamic instability.

COMPARING SPECIFICATIONS

Sometimes improving one specification worsens the effect of another, which can have bad results. The wise salesman is aware of these tradeoffs and brings them to the customer's attention so that the best lift truck recommendation will be made to move material quickly, economically, and safely.

1. The smaller a vehicle is (in top view) in terms of wheelbase, length and width, the less load capacity it will have in high stacking operations.

2. The greater the percentage of total weight on the trail axle and/or the shorter the wheelbase (for a given inch-pound rating) the less the empty gradeability will be.

3. The more compact (in top view) a truck is, the heavier it must be to provide a given inch-pound capacity rating.

4. The more stages a mast has for a given fork height, the heavier the mast, and the capacity rating may be reduced, particularly at extreme fork heights.

5. While a longer wheelbase improves lateral stability, it tends to worsen steer wheel tracking

6. While uniform width drive and trail axle will allow a more compact vehicle in terms of length and turning radius, the ability to steer will be reduced in a narrow passage (See Index, "Tail Width").

7. Three wheel trucks usually have a smaller turning radius than four wheel trucks and are more maneuverable.

8. Sharper (higher) angles of wheel steer reduce published turning radius, but will increase wheel slip and creep and will increase tire wear.

9. High travel speed increases productivity (conditions allowing) but increases bounce and the tendency to lose a load. As travel speed increases, A.N.S.I. B56.1 requires a higher lateral stability factor and truck width may increase.

10. High hoist and lowering speeds can increase productivity but will shorten operating time per battery charge and can also present a stability hazard in the loaded condition unless the load is raised and lowered smoothly.

11. For a single speed drive unit, more gradeability means less travel speed and vice-versa.

12. Rapid acceleration and braking tends to improve productivity but increases fuel consumption, reduces operating time per battery charge (on electric powered vehicles), and accelerates brake wear.

13. The difference between empty and loaded gradeability increases as wheelbase decreases (for a given capacity truck).

WHEEL LOADING

Each time a load is lifted, a mast is tilted, or a vehicle moves, the weight distribution of the truck changes. The wheel loading (or axle reactions) of a lift truck vary greatly from one moment to the next during normal operation. This section examines the effects in changes in weight distribution and how this information can be used to prolong component and tire life.

EMPTY TRUCK

Empty truck weight is generally distributed toward the rear of the truck, although some models need to have their center of gravity in about the center of the wheel base. It is important to have enough weight on the trail axle to counterbalance the rated load and enough weight on the tires to keep the wheels on the ground when traveling or steering. Likewise, there must be sufficient weight on the wheels so that an empty truck can still climb reasonable grades and have adequate traction on wet surfaces.

The weight distribution of an empty truck changes whenever the mast is tilted. If the mast is tilted backwards, weight is transferred from the drive axle to the trail axle. When the mast is tiled forward, the reverse occurs. The amount of weight transferred depends on the fork height of the mast when it is tilted and the length of the wheel base of the truck.

Example: Gas cushion 3000# with 83 FFL 3 stage mast

Trail Axle	Drive Axle	Mast Tilt	Fork Height
3640 lbs.	2650 lbs.	0°	12 in.
3720 lbs.	2570 lbs.	5° Backward	12 in.
3990 lbs.	2300 lbs.	5° Backward	190 in.
3540 lbs.	2750 lbs.	5° Forward	12 in.
3280 lbs.	3010 lbs.	5° Forward	190 in.

Chart 1

LOADED TRUCK

A lift truck undergoes the greatest change in weight distribution when a load is placed on the forks. By picking up a load, the drive axle reaction increases by the weight of the load plus the amount of weight removed from the rear axle to balance the load. As much as 90 percent of the total truck and load weight is concentrated on the drive axle in the loaded condition.

Example: Gas cushion 3000# with 83 FFL 3 stage mast

Trail Axle	Drive Axle	Total Weight	
3640 lbs.	2650 lbs.	6290 lbs.	Unloaded
1240 lbs.	8050 lbs.	9290 lbs.	Loaded

Chart 2

Once again, as the mast is tilted back, additional weight is transferred to the rear axle. Because of this change in weight, a truck is more stable when traveling with the mast down and tilted back. As the mast is tilted forward, weight is transferred from the steer axle to the drive axle. This maneuver should be done with extreme caution in the elevated condition because of the limited amount of weight on the rear axle. If the mast is tilted beyond vertical with an elevated load, the truck may overturn.

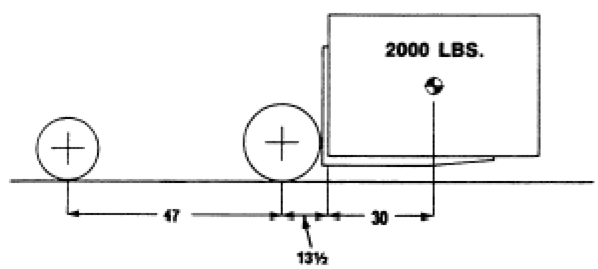
LONG LOAD CENTERS

Placing a long load on a lift truck can have the same effect as placing an overload at 24 inch load center on the forks. In either case, more weight may be transferred off the trail axle than desired and in turn may cause instability. The amount of weight transferred off the steer axle can be calculated by multiplying the distance from the center of the drive axle to the center of gravity of the load by the weight of the load and dividing it by the wheel base of the truck.

This is a simple calculation that can be performed at the customer's site if he wants wheel loading (for any load center).

The wheel loading of a gas, cushion tire, 3000 lb. truck were given above. Determine the new loading with a vertical mast, for 2000 lbs. at 30 in. L.C. (*Figure 17*).

FIGURE 17.



	Trail	Drive	Total
Empty truck wt.	3640	2650	6290
Weight lifted		2000	2000
Weight transferred	- 1850	+1850	
Loaded truck wt.	1790	6500	8290

$$\frac{2000 \text{ lbs.} \times (13\text{-}1/2 + 30 \text{ in.})}{47 \text{ in.}} = 1850 \text{ lbs. Transferred}$$

Chart 3

DYNAMIC WHEEL LOADING

Wheel loadings in the static condition have been described. It should also be noted that the weight distribution of a vehicle changes as it accelerates or brakes. The amount of weight transferred is related to the amount of tractive effort applied by the drive unit or by the amount of braking force and the location of the truck's center of gravity.

When a truck is accelerating in a forward direction, weight is transferred from the front wheels to the rear wheels. This does not normally create a problem unless the drive wheels start to spin in the unloaded condition.

If a loaded sit down rider truck accelerates in reverse, weight is transferred from the steering wheels. The amount of weight on the steering wheels is greatly reduced by picking up a load in the static condition. It is now further reduced because of dynamics. If the truck is overloaded or if the load is not carried in the proper position, the truck may become difficult to steer. Overturn could also occur if the load is elevated and the vehicle accelerated in reverse.

When braking (which is negative acceleration), weight is transferred to the leading axle. A loaded fork lift truck traveling in the forward direction could have the rear wheels lift off the ground if the brakes are applied too hard. Since the height of the center of gravity of the truck is a factor in weight transfer during braking, take care when stacking.

CENTER OF GRAVITY

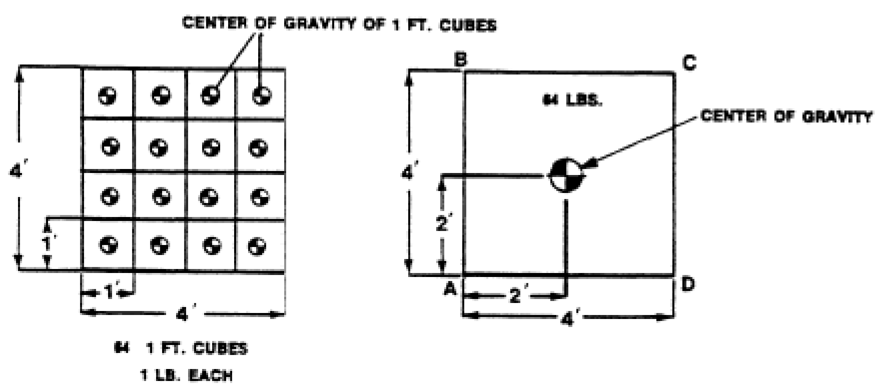
The center of gravity is a well-known concept in the study of physics, but it also plays a vital part in the performance of a lift truck. The following section demonstrates not only what this important concept is, but its practical applications as well.

Every object, regardless of shape and size, has weight and a center of gravity. Although weight is a familiar term, "center of gravity," or **CG**, may not be. The center of gravity of an object is that point where all the weight of all the parts that make up that object can be considered to be concentrated without changing the weight distribution of that object.

A cube, with a side dimension of four feet and a weight of one pound per cubic foot, can be considered either as sixty-four (64) one-foot cubes weighing one pound each or a four-foot cube weight 64 pounds, with the weight concentrated at the center of gravity.

The following figure describes the center of gravity as being located two feet to the right of corner A (horizontal) and two feet above surface AD (vertical). (*Figure 18.*)

FIGURE 18.
CG OF CUBED LOAD

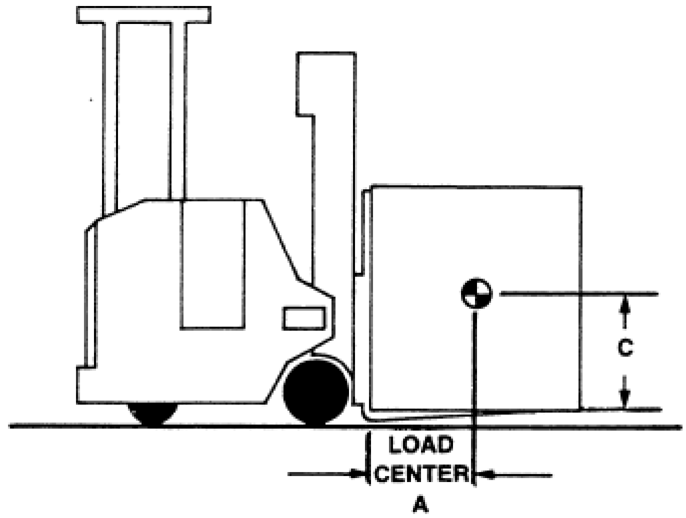


A lift truck has a center of gravity which is located within the truck wheel base and at some dimension above the ground. A load to be handled by a lift truck has a center of gravity which is located at some distance in front of the face of the forks and also at a vertical dimension above the top of the fork tine.

LOAD CENTER

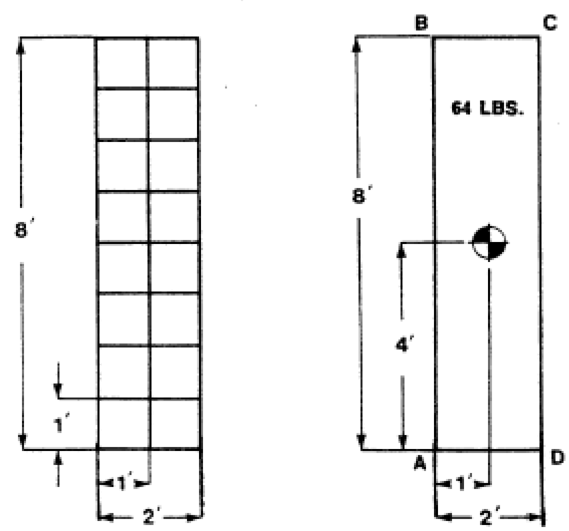
The horizontal distance from the face of the lift truck forks to the center of gravity of the load it is carrying is called the **load center** or **dimension A**. (*Figure 19.*) The vertical distance from the top of the fork tines to the center of gravity of the load is referred to as **dimension C**.

FIGURE 19.
LOAD CENTER



Since the location of an object's center of gravity is dependent on the location of all its parts, if some of these parts move, the location of the center of gravity changes. Using the previous example (*Figure 18*) if the 64 one-foot cubes weighing one pound each, are rearranged into a pattern 2 feet long, 4 feet wide, and 8 feet high, the location of the center of gravity changes. (*Figure 20.*)

FIGURE 20
CG OF LOAD

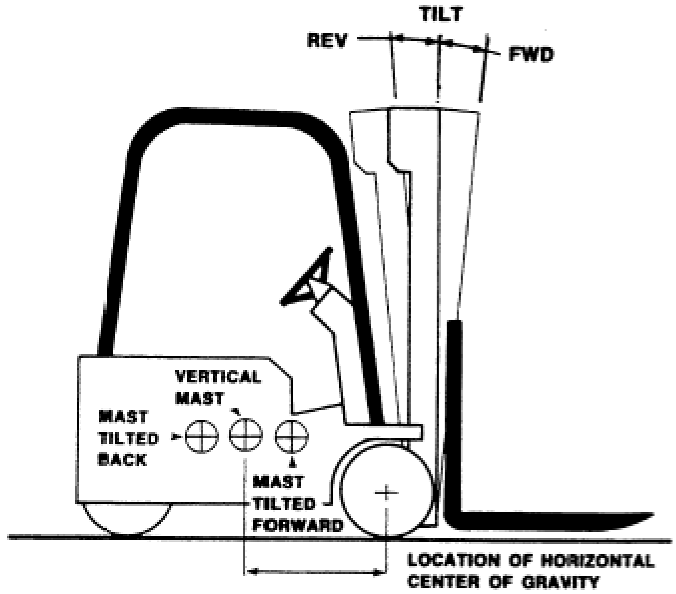


The center of gravity is now located one foot to the right of corner A (horizontal) and four feet above surface AD (vertical).

TRUCK CENTER OF GRAVITY

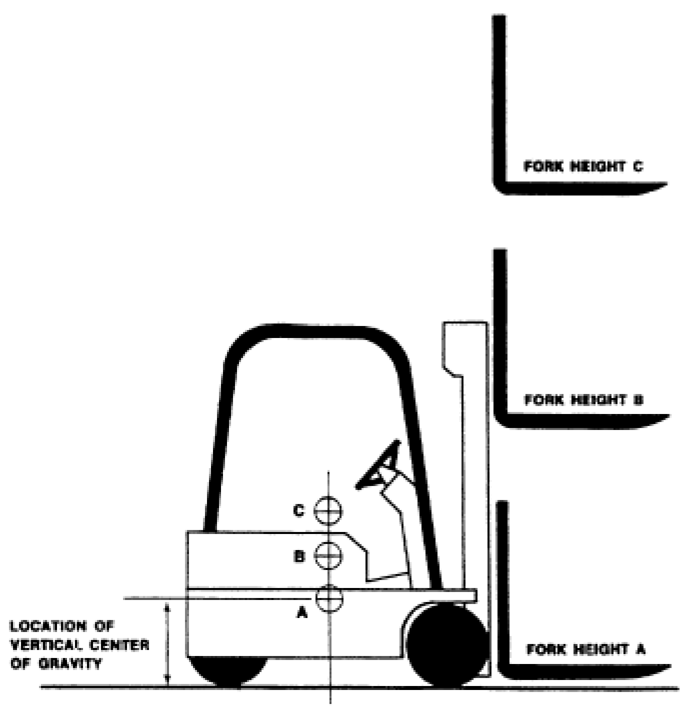
The center of gravity of a fork lift truck changes position as the mast is either tilted or elevated, which changes the wheel loading. This is an important concept since all lift truck capacities are based on the location of the center of gravity. The following illustration shows how the location of the truck **CG** changes as the mast is elevated or tilted. (*Figures 21 and 22.*)

FIGURE 21
HORIZONTAL CG/TILTING FORKS



When the mast is tilted forward, the truck's center of gravity also moves forward. When the forks are elevated, the vertical center of gravity dimension above the ground increases. (*Figure 22.*)

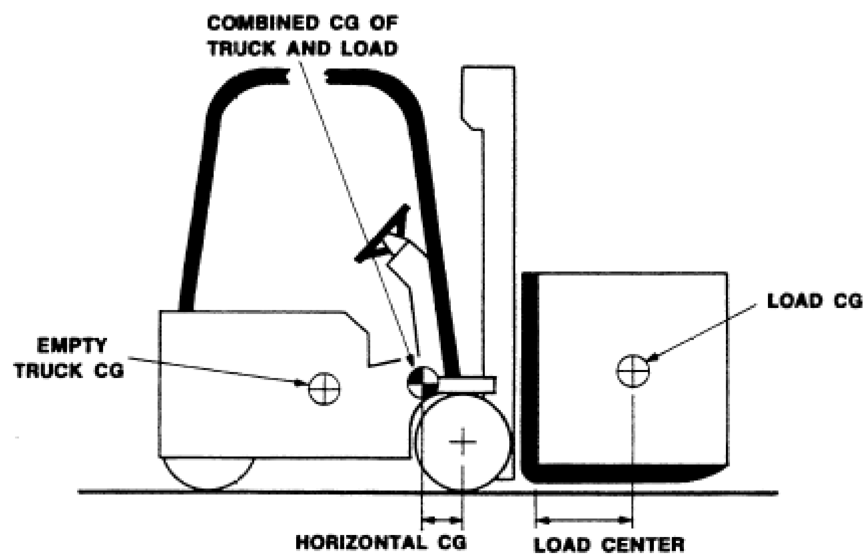
FIGURE 22.
VERTICAL CG/LIFTING FORKS



If additional weight is added to the fork lift truck, the location of the truck's center of gravity changes. Likewise, if a rated load or any other load is added on the forks, the location of the center of gravity again will change.

An empty truck has a weight and center of gravity. The load also has a weight and center of gravity. When the load is placed on the forks, the combined weight of truck and load creates a new center of gravity. (*Figure 23.*)

FIGURE 23.
COMBINED CG OF TRUCK AND LOAD



The location of the horizontal CG for a loaded truck depends upon the weight of the load placed on the forks and its load center. As the weight increases at a fixed load center, or as the load center increases with a fixed weight, the combined center of gravity moves closer to the centerline of the drive wheels.

When the combined center of gravity of the truck and load passes the centerline of the drive wheels, the vehicle will overturn!

STABILITY

Stability is the subject of this section. Its importance to safe and proper truck applications cannot be stressed too strongly. The design of our trucks reflects particular attention to this major aspect of engineering. Stability is the result of many things — wheelbase, overall width at the drive axle, height of lift, and weight distribution.

A lift truck that is standing still will not overturn in either the empty or the loaded condition unless the center of gravity of the truck is loaded outside the stability triangle. When a truck is being driven in forward or reverse, is cornering (empty or loaded), is lifting, lowering, tilting, or braking, there are dynamic forces acting through the truck's center of gravity which can cause the vehicle to overturn.

A study was made many years ago of all the movements a lift truck makes during normal operation. This study listed those conditions which are most likely to cause overturn.

LONGITUDINAL STABILITY

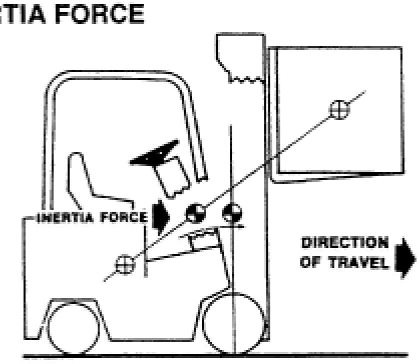
The first and most obvious condition listed is driving in a straight line, both in forward and reverse, empty and loaded. A truck which is accelerating or decelerating has an inertia force acting through its center of gravity in the direction of travel. When the brakes are applied, there is negative acceleration which slows the truck down. If the brakes are applied too quickly, the inertia force tries to overturn the truck about the point where the drive tires contact the ground.

STACKING (LONGITUDINAL)

If an operator is stacking a load, the load is elevated and the mast is tilted back or vertical. He now drives forward to the rack and applies the brakes. This maneuver is more critical with the mast vertical than tilted back. Since the combined center of gravity of the truck and the load is closer to the centerline of the drive tires with a vertical mast, it requires less of an acceleration or braking force to cause overturn around the drive axle. (*Figure 24.*)

A truck will also overturn in the forward direction if an operator accelerates away from a stack with an elevated load.

FIGURE 24.
TRUCK STACKING INERTIA FORCE



Narrow aisle and order picker trucks can overturn in the reverse direction when braking empty or in the forward or reverse direction with a load elevated and braking. (*Figures 25 and 26.*)

FIGURE 25.
NARROW AISLE TRUCK TRAVELING IN REVERSE

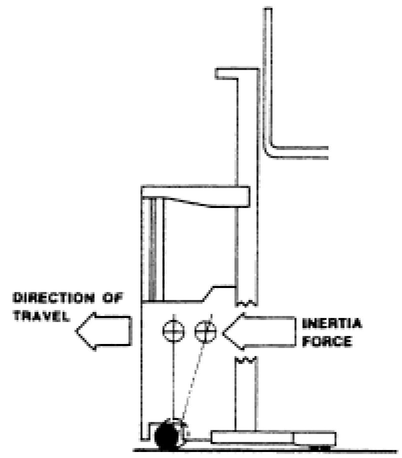
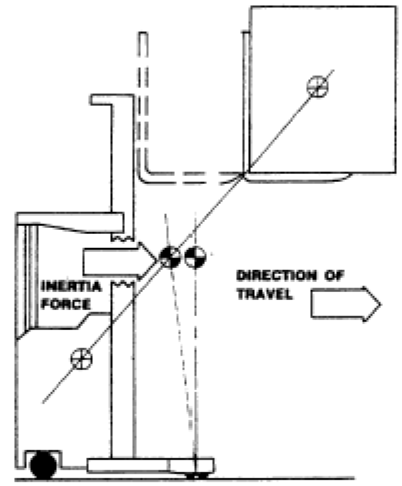


FIGURE 26.
TRAVELING FORWARD

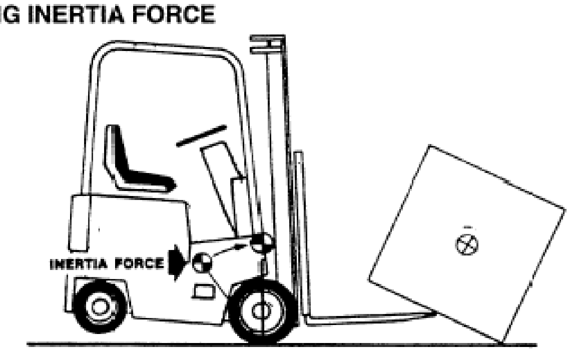


LATERAL STABILITY

TRAVELING (LONGITUDINAL)

When an operator is traveling at a high rate of speed, the load is about 6 to 8 inches off the floor and the mast is tilted back. The same inertia force described in the preceding paragraph acts through the truck's center of gravity. When the brakes are applied, or the truck is accelerated backwards, there is a tendency for the steering tires to lift off the ground. If this occurs, the operator can lose the load and cause damage to both product and personnel. (*Figure 27.*) Most four-wheeled trucks have an articulated steering axle. This means that the steer axle

FIGURE 27.
TRUCK BRAKING INERTIA FORCE



can rotate about a large longitudinal shaft mounted in the rear of the frame. This feature was designed to maintain tire contact on an uneven surface.

ARTICULATED STEERING

Articulated steering axles affect stability. Since the frame of the truck can rock about the same shaft, the lateral line of overturn is from the center of the drive tires to the point where the articulating shaft intersects the center line of the steer axle. (*Figure 28.*)

STABILITY TRIANGLE

Three-wheel trucks have a similar lateral line of overturn except the rear tire is located on the centerline of the truck instead of an articulating shaft. The area enclosed by the lateral lines of overturn and the centerline of the drive axle is known as The Stability Triangle. (*Figure 28.*)

FIGURE 28.
STABILITY TRIANGLE

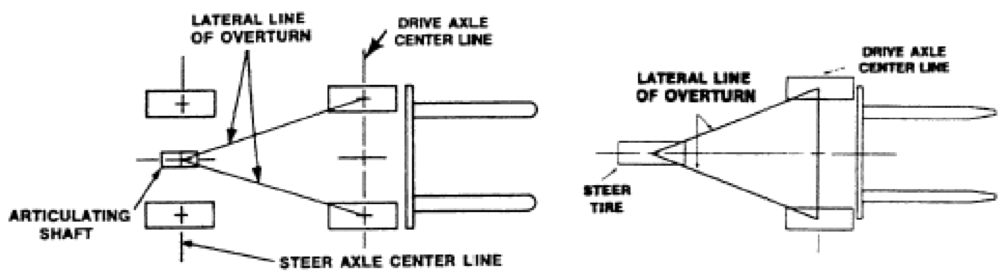
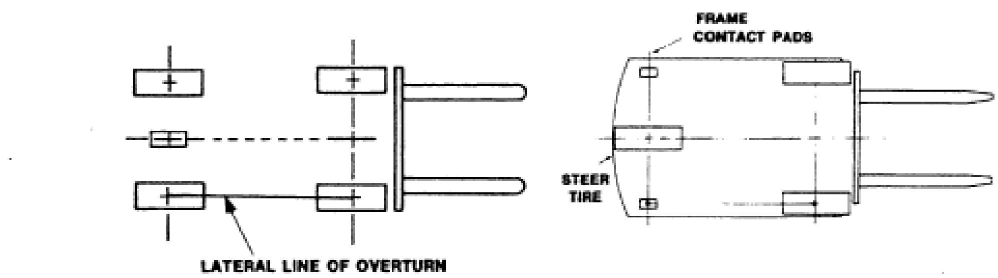


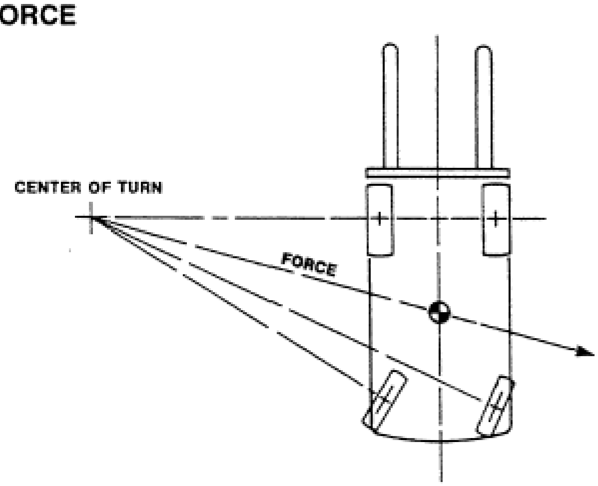
FIGURE 29.
LATERAL LINE OF OVERTURN



The fork lift truck motion study also indicated that there is a tendency for vehicles to overturn in the lateral (sideward) direction. This can occur in the empty or loaded condition when traveling in the forward or reverse direction and making a turn.

This overturning is caused by a centrifugal force which only occurs when a truck turns around a given point. The force acts in a radial direction away from the point of steer and through the center of gravity of the lift truck that is traveling on an arc. As the truck picks up speed, the centrifugal force increases. If the center of gravity moves past the line of overturn, the vehicle will overturn laterally. (*Figures 30, 31, and 32.*)

FIGURE 30.
CENTRIFUGAL FORCE



STACKING (LATERAL) If an operator is working in a stacking aisle and wants to deposit a load on a rack at a right angle to the direction of the aisle, one must elevate the load and travel on an arc. If the operator is retrieving a load, one must travel on the same arc in reverse. As the lift truck is turning, the centrifugal force created by this motion has a tendency to overturn the vehicle away from the center of the turn.

Since the center of gravity of a loaded fork lift truck is higher above the ground than that of an unloaded truck, the loaded truck has greater tendency to overturn.

TRAVELING (LATERAL) If a truck is traveling at a high speed and the operator makes a turn in either direction, there is a centrifugal force acting through the truck's center of gravity. When the truck is unloaded, the center of gravity is located closer to the steer axle than the drive axle.

FIGURE 31.
FOUR WHEEL TRUCK CENTRIFUGAL FORCE/LINE OF OVERTURN

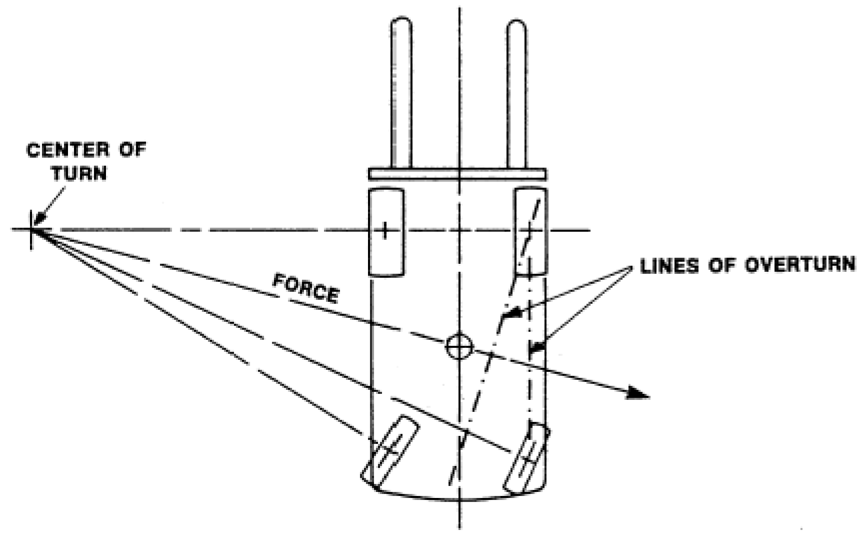
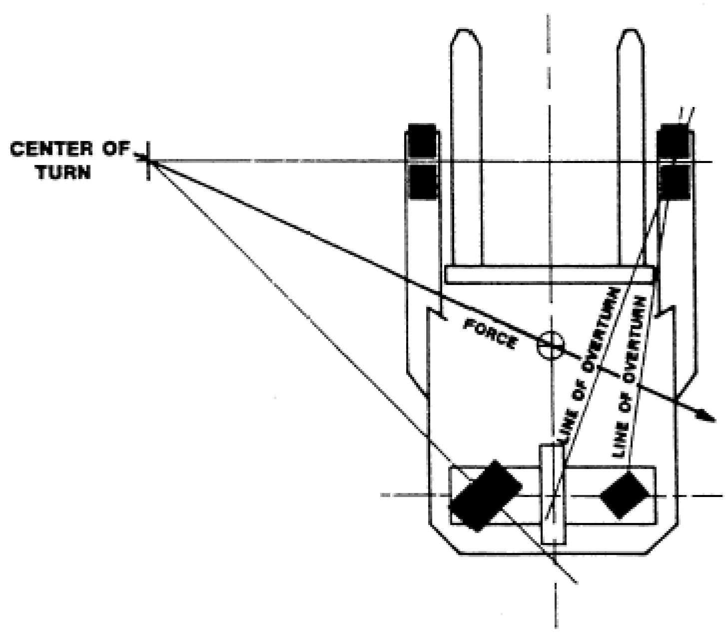


FIGURE 32.
NARROW AISLE TRUCK CENTRIFUGAL FORCE/LINE OF OVERTURN



It is also located closer to the apex of the stability triangle. This force acting through the CG can overturn the truck about its predetermined overturn line. Once again, the faster the truck travels, the greater the centrifugal force, which increases the chance of overturn. (*Figures 31 and 32.*)

When the center of gravity of the truck is forced to rotate around the articulating shaft and reaches the first line of overturn, the inside drive tire will lift off the ground. If the articulating stops making contact, the overturn line transfers to the outer steer tire. The vehicle will overturn if the CG passes this new line of overturn.

A three wheel truck will overturn when the CG passes the first line of overturn, unless the frame makes contact with the ground.

MEASURING STABILITY

Several years ago, it became necessary to measure lift truck stability. The purpose was to form a standard that all manufacturers would follow, so that trucks that were rated alike would have equal and adequate stability. The end result was an A.N.S.I. standard B56.1.

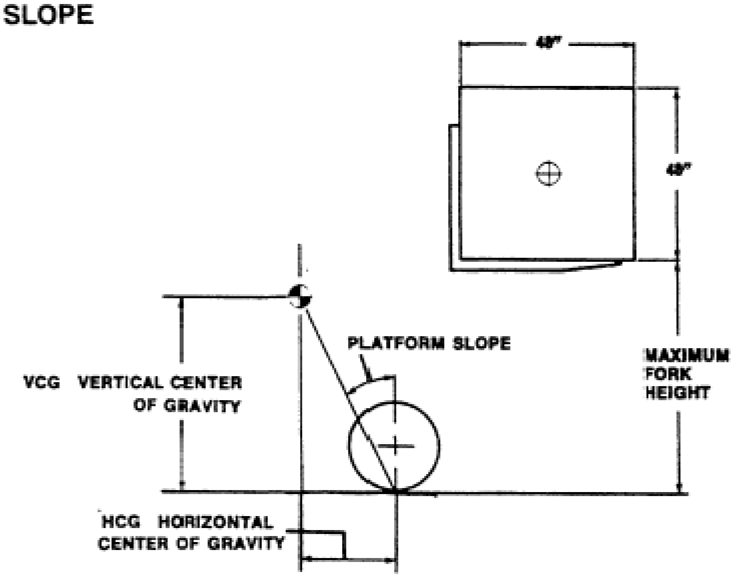
This "Safety Standard for Powered Industrial Truck" contains four tilting platform tests for sit-down rider trucks and a greater number for narrow aisle and order picker vehicles. A lift truck is placed on the platform both loaded and unloaded, the platform is tilted until the truck begins to overturn, and the platform slope is then recorded.

The purpose of these tests is not to determine if a vehicle can operate on a grade, but to find a relationship between the horizontal distance of the CG behind the line of overturn and the vertical distance of the CG above the ground, taking tire and mast deflections into account.

TEST 1: LONGITUDINAL STACKING

The first test was designed to represent the longitudinal stacking condition. A 48-inch cubic load is placed on the forks. The mast is elevated to maximum fork height in the vertical position with the center line of the drive axle parallel to the tilting axis of the platform. The platform is then tilted until the trail wheels leave the platform. At this point the combined center of gravity of the truck and the load is located directly above the centerline of the drive wheels. (*Figure 33.*)

FIGURE 33.
PLATFORM SLOPE



Narrow aisle trucks and order pickers are tested in a similar manner, but consideration is given to both the forward and reverse direction in both the empty and loaded condition.

The platform slope is defined in the same way as the percent grade (see gradeability section). It is also the horizontal distance to the CG divided by the vertical distance to the CG multiplied by 100.

$$\% \text{ PLATFORM SLOPE} = \text{HCG} \div 100$$

In *Figure 34*, a lift truck is in the longitudinal stacking position. The empty truck CG, load CG, and the combined CG are shown for two fork heights. The lower fork height is 130 inches and the higher is 156 inches. As the load is lifted from one fork height to the other, the vertical center of gravity of the truck and load, as well as the combined CG, becomes higher above the ground. Keep in mind that the weight of the load has not changed, only the fork height. The end result is that the platform slope at which the vehicle will overturn is reduced as the forks are elevated.

FIGURE 34.
LONGITUDINAL STABILITY, INCREASED FORK HEIGHT

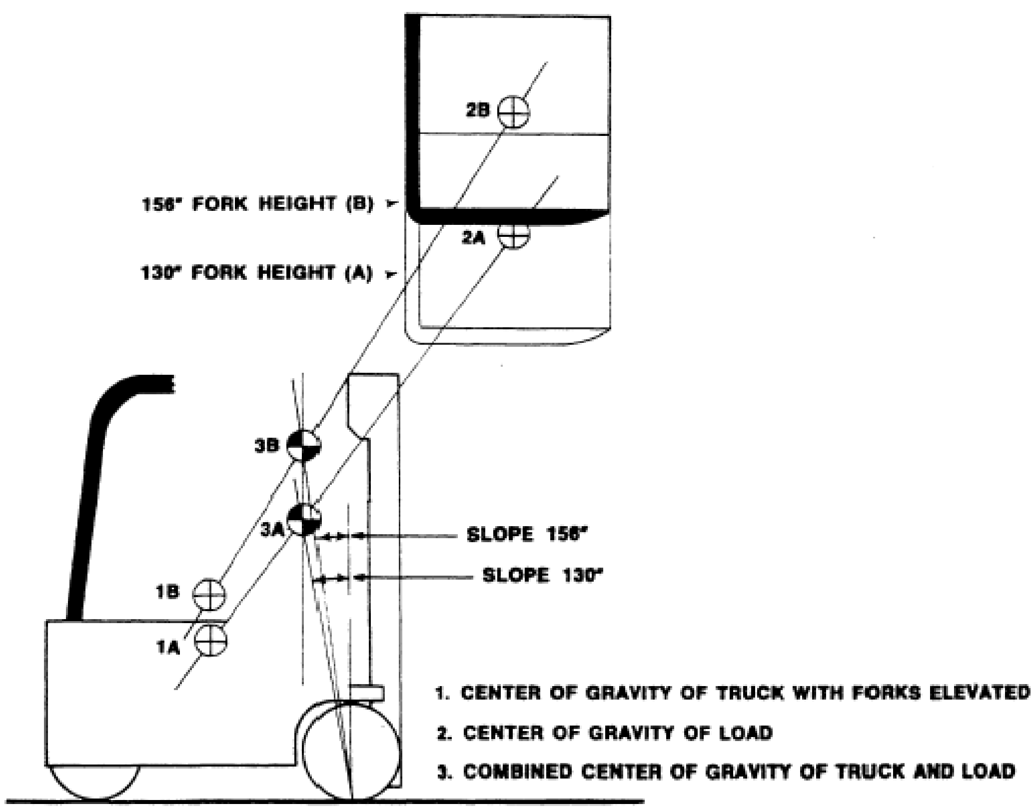
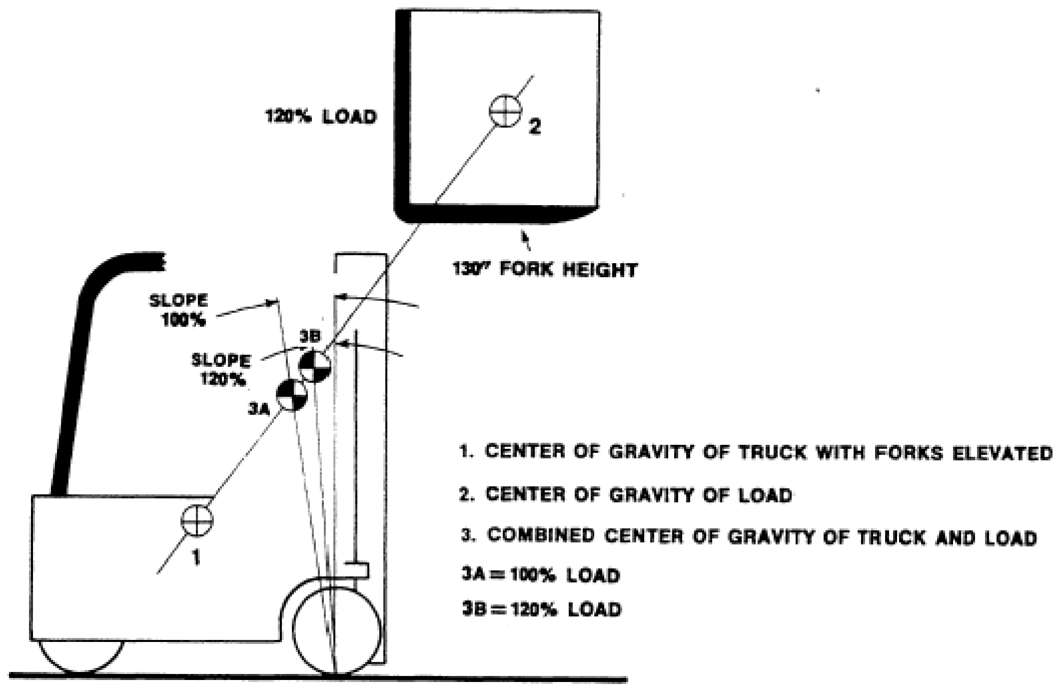


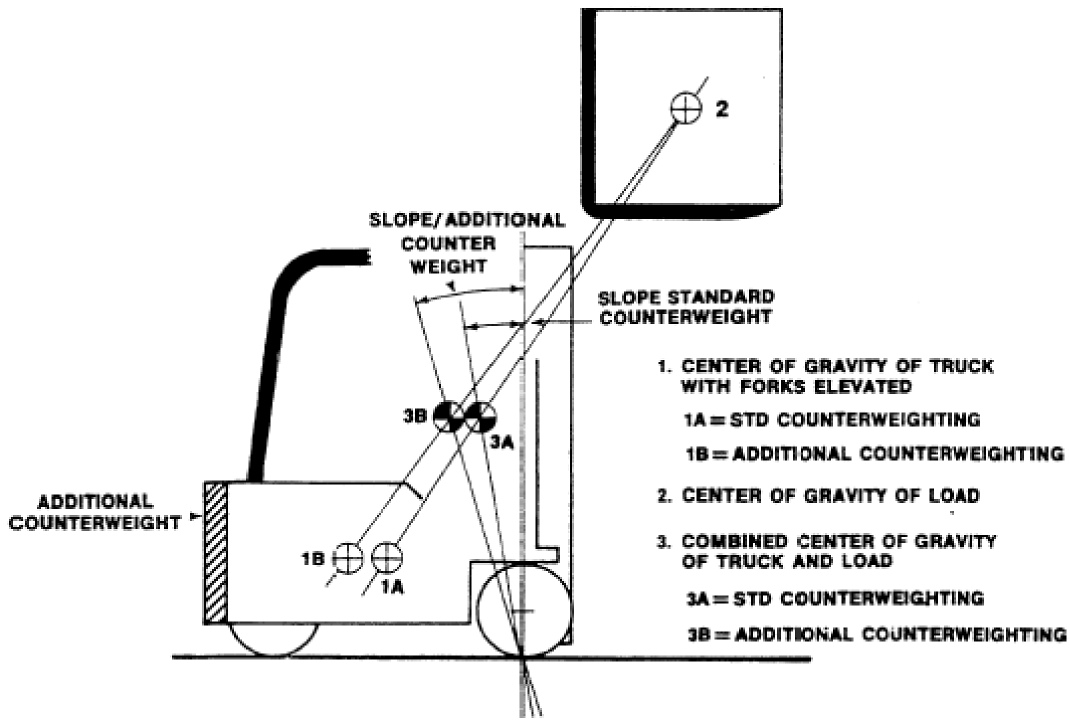
Figure 35 shows the same truck at 130 inches of fork height, except that it now has 120% of the rated load on the forks (example 4800 lbs. on a 4000 lb. truck). The empty truck and load CG's are in the same positions. The combined CG moves closer to the centerline of the drive wheels (line of overturn) and higher off the ground. The truck will now turn over at a much smaller platform slope and is therefore less stable.

FIGURE 35.
LONGITUDINAL STABILITY, OVERLOAD



If the weight of the counterweight is increased on the same truck, the empty CG of the truck moves down and back slightly. The load CG remains in the same location. The truck longitudinal stability has been increased by increasing the horizontal CG and decreasing the vertical CG slightly. (*Figure 36.*)

FIGURE 36.
LONGITUDINAL STABILITY, INCREASED COUNTERWEIGHT



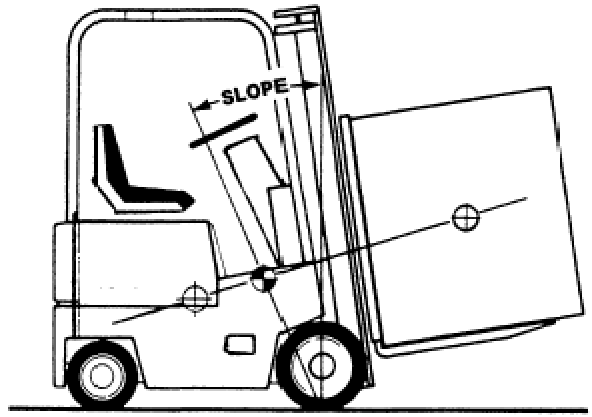
TEST 2: LONGITUDINAL TRAVELING

The second test represents the traveling condition in the longitudinal direction. A load is placed on the forks, the forks are elevated to twelve inches and the mast is tilted back. The loaded truck is placed on the tilting platform, with the centerline on the drive axle parallel to the tilting axis of the platform. The platform is tilted until the trail wheels lift off the platform. At this point, the combined CG is directly above the center of the drive wheels. (*Figure 37.*)

This test is similar to Test 1. If more load is put on the forks, the combined CG moves closer to the centerline of the drive tires and therefore reduces the platform slope and stability. If the load is reduced or additional counterweighting is added, the combined CG moves to the rear of the truck and therefore increases the platform slope and the longitudinal stability.

This test differs from Test 1 in that the resultant platform slope is dependent upon the amount of mast back tilt. If the amount of back tilt is increased, the platform slope increases. If the back tilt is decreased, the platform slope and the stability of the vehicle for traveling in a straight line are decreased.

FIGURE 37.
LONGITUDINAL STABILITY, TRAVELING



TEST 3: LATERAL STACKING

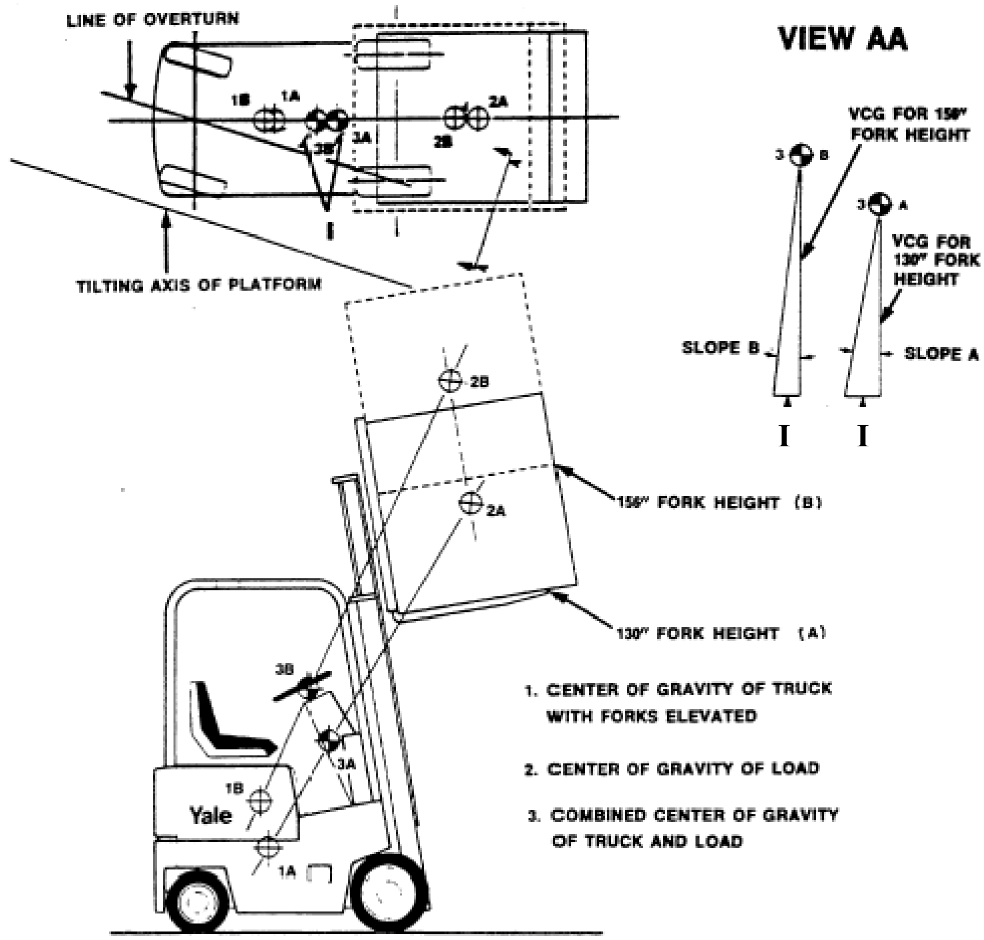
The third test represents lateral stacking conditions. A truck with rated load is placed on a tilted platform with its lateral line of overturn (as defined under stability triangle) parallel to the tilting axis of the platform. The mast is elevated to maximum fork height and tilted to the maximum back tilt position. The platform is then tilted until the drive wheel farthest away from the tilting axis lifts off the platform. At this point the truck will overturn because the combined center of gravity is directly above the line of overturn.

Figure 38 has a side and top view of a truck in a lateral stacking position. This side view indicates the truck and load CG's as well as the combined CG of the truck and load at 130- and 156-inch fork height. Note that as the load is lifted in the back tilted position the combined CG moves up and back.

The top view of the lift truck shows the lateral line of overturn parallel to the tilting axis of the platform. It also shows the distance from the combined center of gravity to the line of overturn (**I**). As the platform is tilted, the combined CG rotates about the tilting axis of the platform until it travels the distance "**I**" to the line of overturn. At this point, the truck will overturn laterally.

This now provides the horizontal distance of the CG from the line of overturn "**I**" and the vertical CG above ground. The platform slope is equal to "**I**" divided by the combined vertical CG multiplied by 100.

FIGURE 38.
STABILITY



PLATFORM SLOPE = VCG X 100

When the forks are elevated to 156 inches, the combined vertical CG is higher than that at 130 inches. The length of "**I**" also is reduced at 156-inch fork height because the combined CG moves back. The platform slope at 156-inch fork height is therefore less than at 130-inch fork height and the truck is less stable. It should now be easy to understand that the higher a load is lifted with the mast tilted back, the less lateral stability the truck has.

In order to increase the lateral stability when stacking:

1. Reduce the weight of the load, which lowers the combined CG and reduces tire deflection.

2. Reduce the mast back tilt, which moves the combined CG forward in the triangle and increase the length of "**I**."

3. Increase the overall width of the drive tires or drive tire tread. This changes the size of the stability triangle and increases the length of "**I**."

4. Reduce the amount of clearance at the articulation stops so the line of overturn is transferred to the rear tire prior to ultimate overturn. This is more effective at lower fork heights and also reduces truck utility.

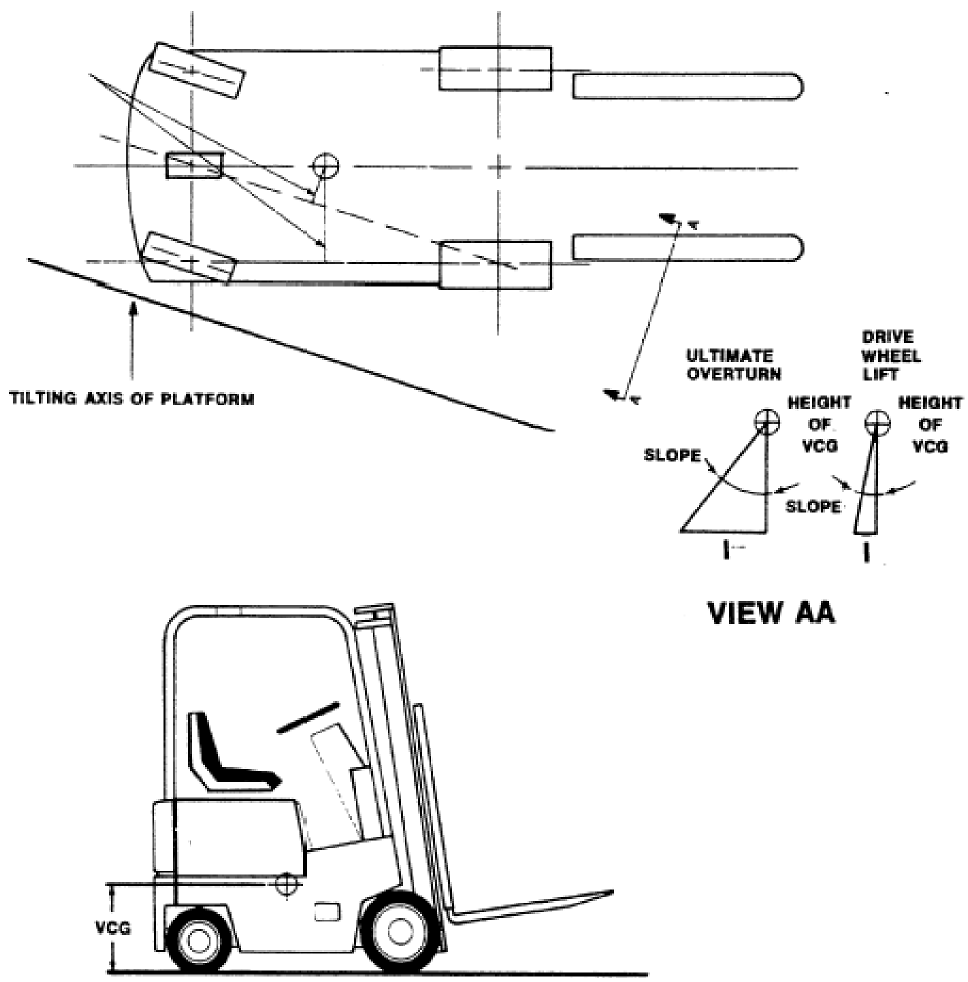
TEST 4: LATERAL TRAVELING

The fourth and last test represents the lateral traveling condition. An empty truck is placed with its original line of overturn parallel to the tilting axis of the platform. The forks are 12 inches above the ground and the mast tilted back. The platform is tilted until the drive and trail wheels up the grade leave the platform.

Figure 39 once again has a top and side view of an unloaded lift truck. Both views show the empty truck's center of gravity. The top view shows the tilting axis of the platform and the lines of overturn. As the platform is tilted, the center of gravity of the truck rotates around the tilting axis of the platform. When the CG is above the first line of overturn, the drive tire will lift off the platform.

A three-wheeled vehicle will reach ultimate overturn at this point unless the frame makes contact with the platform, but a four-wheeled truck will hit the articulating stops. When this occurs, the line of overturn transfers to the outer tire, increasing the length of "**l**" and the lateral stability.

FIGURE 39.
STABILITY



The platform is tilted again until the CG reaches the outer line of overturn. A four-wheeled truck and a three-wheeled truck with frame contact will overturn at this point. The slope is again defined as "**l**" divided by the height of the vertical CG multiplied by 100.

NARROW AISLE TRUCK STABILITY TESTS

Narrow aisle trucks require a more complex series of stability tests since these vehicles can overturn in any of the four directions, and in some cases without a load. Eight tests are required to evaluate all working conditions.

The forward longitudinal tests are similar to the sit down trucks. Three additional rear longitudinal tests were added to evaluate stacking in the empty and loaded condition, and traveling empty.

Two of the lateral stability tests are similar to the sit down trucks. An additional lateral stacking test was required to evaluate the empty truck condition.

The required platform slopes for an empty truck are always equal to, or greater than, the requirements for a loaded truck.

For a more complete description of narrow aisle truck stability refer to A.N.S.I. B56.1 specification, "Safety Standard for Low Lift and High Lift Trucks."

ORDER PICKER TRUCK STABILITY TESTS

Stability testing of order picker trucks is similar to narrow aisle trucks. Forward, rear, lateral, empty, and loaded conditions are measured. This type of vehicle must pass six tests to be rated and sold. The operator of this type vehicle is elevated when picking orders or stacking materials, therefore the platform slope values required are higher for an order picker than for a narrow aisle truck.

STABILITY (SUMMARY)

Lift truck stability has been defined both dynamically and statistically. The platform tests that are required in A.N.S.I. B56.1 specifications have been reviewed. Capacity ratings always comply with the above specifications! In fact, all our trucks exceed the requirement of B56.1.

Try to remember the following things about stability:

Longitudinal condition

1. If the load is greater than the rating of the truck, it can cause overturn when stacking.

2. If the load is higher than the rated load, it can cause overturn.

3. The higher the fork height, the less stable the truck with the same load.

4. By adding additional counterweighting, the truck capacity can be increased, provided the lateral stability is adequate. Adding additional counterweighting may move the CG far enough toward the apex of the stability triangle that capacity will actually decrease.

5. All ratings pertain to a vertical mast during stacking. Do not tilt forward!

6. Increased mast back tilt improves longitudinal traveling.

7. Inadequate back tilt can cause the loss of a load when braking from a high speed.

8. Additional counterweighting increases stability when traveling with a load.

9. Overloading a truck causes the trail wheels to leave the ground when traveling.

10. Narrow aisle trucks can become unstable when braking in the reverse direction with the mast elevated, with or without a load. Travel speed is restricted above free lift fork height to increase safety.

11. Order picker trucks can become unstable when braking in the forward direction, with the mast elevated, with or without a load. Travel speed is restricted or cutout above 24 inch fork height to increase safety.

Lateral condition

1. The centrifugal force tends to cause lateral overturn.

2. Increasing back tilt reduces truck stability when stacking. Reducing back tilt improves lateral stability but decreases longitudinal stability traveling.

3. The higher a load is lifted with the mast tilted back, the less stable the truck is over the side.

4. Increased O.A.W. of the drive tires or outrigger spread increases the truck stability.

5. Restricted rear axle articulation may improve lateral stability, but reduce truck utility.

6. Solid pneumatic profile tires are more stable than pneumatic tires due to less deflection. Polyurethane tires are more stable than rubber tires.

7. Additional counterweighting does not improve lateral stability!

8. High loads reduce lateral stability.

9. An empty truck is less stable than a loaded one when traveling on a curve or making a turn (not stacking).

10. The faster a truck travels on a curve, the greater the tendency to overturn.

11. A fork truck stacking the same weight load is less stable with a short load center than a long load center, i.e., 15 in. versus 24 in.

12. A narrow aisle or order picker truck could have its maximum fork height restricted by the empty truck stability. The geometry of the vehicle would have to change to stack higher.

General comments

The stability platform slopes on which capacities are based represent stability factors for static and dynamic conditions based on the combined experience of lift truck manufacturers who comprise **ITA (Industrial Truck Association)**. These factors assure adequate stability if the truck is driven carefully by a skilled driver, but conformance to A.N.S.I. B56.1 cannot assure safe operation or prevent overturn. OSHA states that "only trained and authorized operators shall be permitted to operate a Powered Industrial Truck."

CAPACITY RATING

The concluding segment deals with another important safety consideration: rating lift trucks for the capacity of loads they can handle. It includes how these ratings can be adapted for long or short load centers, as well as for equipment modified in the field. It also covers a key method for determining lift truck capacity, the inch-pound rating.

Each and every fork lift truck shipped from our facilities is equipped with a name plate mounted in the operator's compartment. This plate not only identifies the vehicle by model, serial number, and class, but it also indicates the capacity rating of the truck. The capacity with an attachment (if so equipped) is also listed.

CAPACITY RATING WITH FORKS

All trucks are given a capacity rating at 24-inch load center to the maximum elevation of the forks. This rating is based on handling a 48-inch cube with the center of gravity at the geometric center. It may be the same as the basic capacity of the truck or it may be reduced because of the height of the mast.

If the truck has a high overall height mast and the capacity is reduced at maximum fork height, the truck may have a second rating. This rating would be the maximum load that the truck can safely lift to a less-than-maximum fork height. It may be the same as the basic capacity of the truck, or it may be reduced.

Example: A gas, cushion tire, 5000 to 8000 lb./123 mast has an 80-inch overall height one-stage mast that provides 123 inches of fork height. This truck has full capacity to maximum fork height, so only one capacity will be given with forks. The rating will be:

5000 lbs. - 24 in. L.C. - 123 in. B

The "B" dimension on this model is the vertical distance from the ground to the top of the fork tines at some fork height. If the same truck is equipped with a 97/218 three-stage mast, the truck will have two capacities with forks. The first will be a reduced load at maximum fork height, and the second the maximum load at a reduced fork height. The rating would be:

4500 lbs. - 24 in. L.C. - 218 in. B

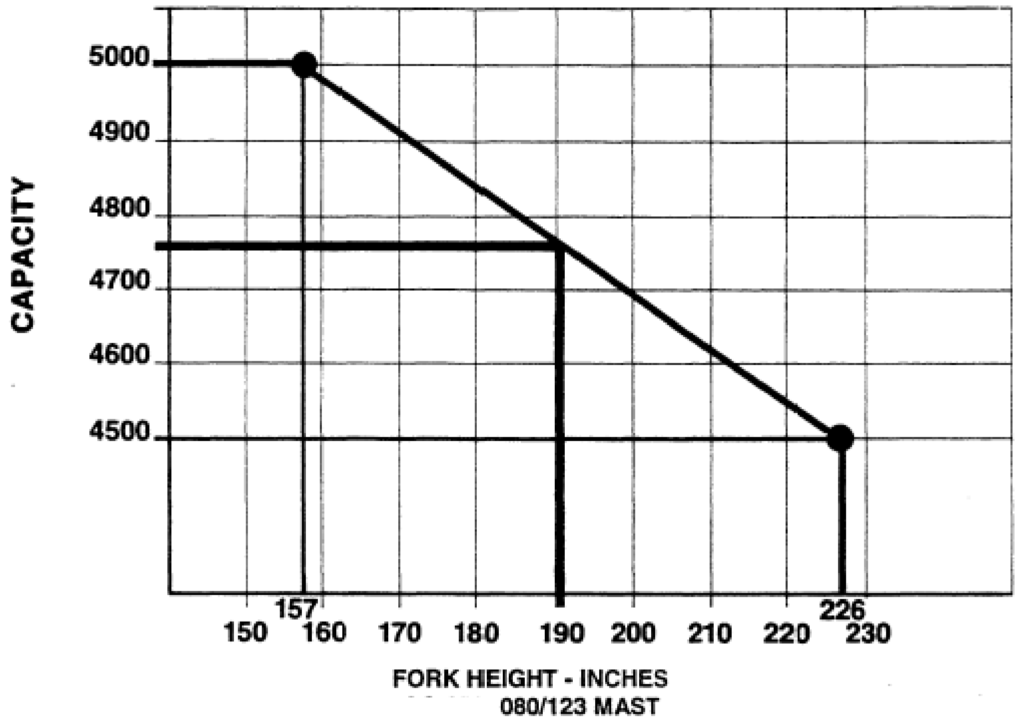
5000 lbs. - 24 in. L.C. - 174 in. B

The capacity rating for all truck models with forks is found in the Technical Data section of our literature. This chart also indicates the drive tires and mast tilt cylinders required to obtain these capacities.

If a customer has a special requirement for overall width (less than specified) or mast tilt (back), an SOR (Special Option Request) and/or TCR (Truck Capacity Rating) form must be submitted to determine the new fork capacity.

When a truck has more than one capacity at 24-inch load center, it can be assumed that the derating between the two rating points is linear. The capacity determined by using this method at an intermediate fork height will always be safe and sometimes conservative. See the following example (*Figure 40*).

FIGURE 40.
FORK HEIGHT IN INCHES



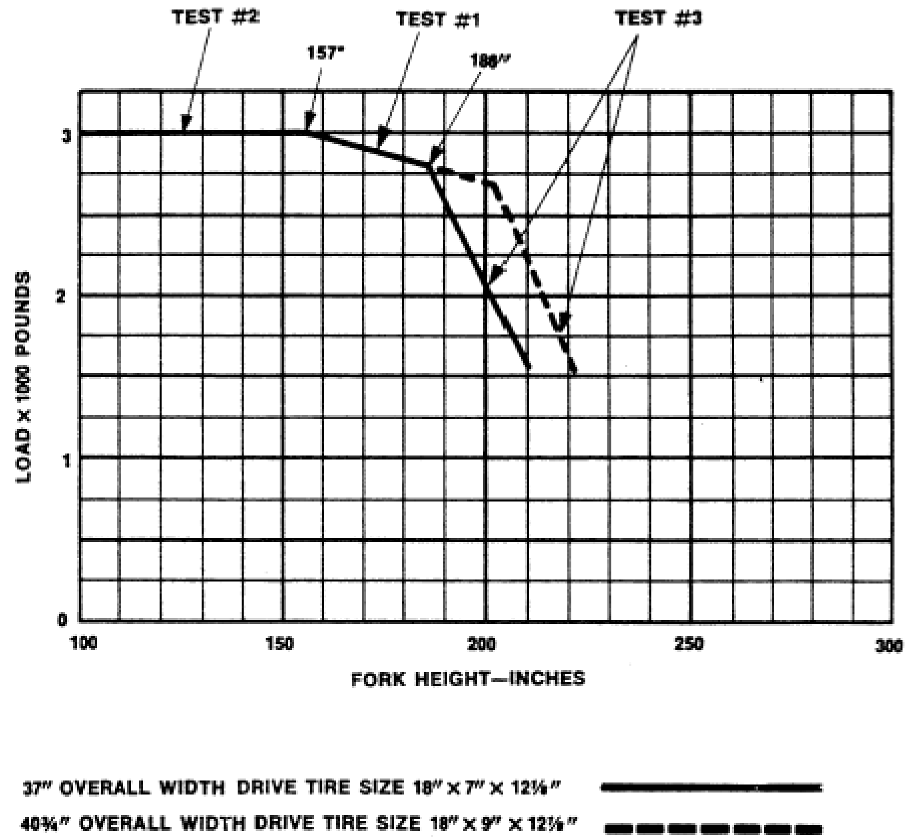
DETERMINING CAPACITY WITH FORKS

In order to rate any sit down fork truck, the truck must pass all four stability platform tests that were described in the previous section. Test 4 (Lateral Traveling) determines the maximum allowable unloaded travel speed for a truck. Test 2 (Longitudinal Traveling) determines the maximum load that can be carried by the truck. Test 1 (Longitudinal Stacking) determines the height to which a load can be stacked or lifted. Test 3 (Lateral Stacking) determines the width of the drive tires and back tilt restriction needed to handle the same load used during the preceding tests.

The safe operating area of the truck, then, is the area found under the curves when plotted for the tested truck.

Figure 41 shows that a 3000 lb. truck can carry 3000 lbs. @ 24 in. L.C. to 157 inches of fork height. The truck then starts to derate along the Test 1 line until it reaches 2800 lbs. capacity at 186 inches of fork height. At this point, the truck is limited by Test 3 and derates much more quickly along the Test 3 line. If the O.A.W. of the drive axle is increased, additional capacity can be gained by moving back to the Test 1 curve.

FIGURE 41.
STABILITY CHART



SHORT LOAD CENTERS

Lift trucks can carry more than their nominal capacity if the load center is less than 24 inches. The amount of weight that it can carry is determined on an inch-pound basis. *Figure 42* is an example of a load versus load center chart. By studying this chart, the capacity of a vehicle at 15, 18, or any other load center less than 24 inches can be determined.

The truck should be able to handle this increased load at ground level. If stacking is required, submit an SOR form for the maximum fork height that this load can be lifted. Normally, it will not be at the same fork height as the 24 in. load center rating.

Some load center-capacity graphs do not indicate an increase in capacity at less than 24-inch load center. This means that there is a structural limitation in the mast, drive axle housing, or drive tires that will not permit the increased rating (*Figure 43*).

LONG LOAD CENTERS

A lift is not capable of carrying its basic capacity at a long load center unless it is specifically counterweighted to do so. The trucks are derated on an inch-pound basis. Once again, use the same "Capacity-Load Center" charts (*Figures 42 and 43*). As the load center increases, the capacity of the truck decreases.

FIGURE 42.
CAPACITY LOAD CENTER CHART

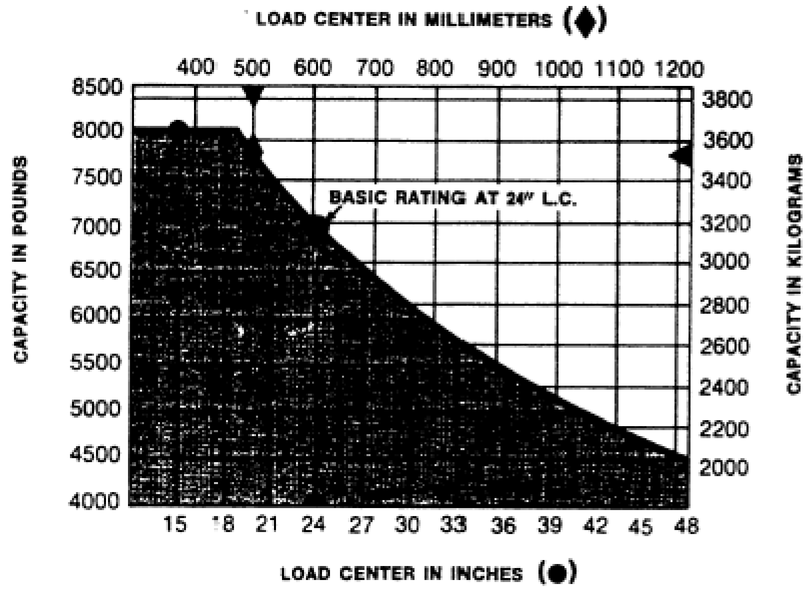
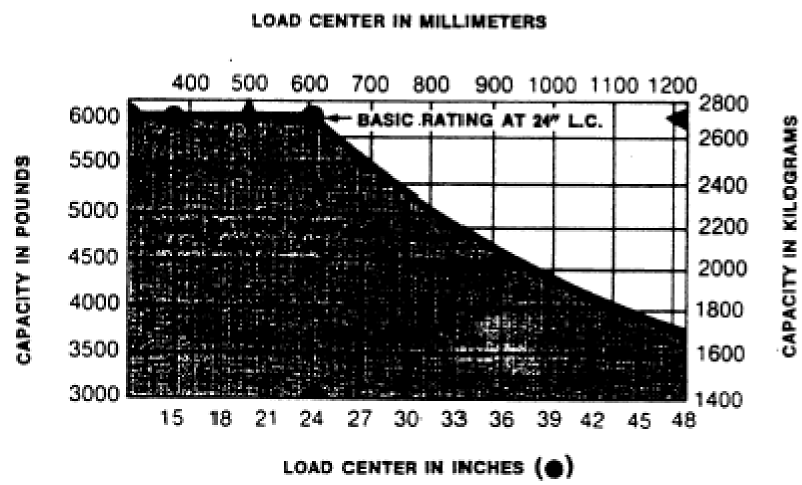


FIGURE 43.
CAPACITY LOAD CENTER CHART-



Several things must be considered when dealing with long load centers:

1. The forks must be long enough to support the load. We require that the forks be 2/3 to 3/4 the length of the load.

2. The capacity at 24 in. load center may be reduced with long forks (60 in., 72 in., 84 in. long, etc.) because of the increased weight of the forks.

3. The strength of the forks or carriage may become the limiting factor when dealing with increased load centers. This means that the mast or forks may not be capable of handling the same load as the truck is capable of balancing. These limitations are not shown in product literature.

4. If the truck is assigned a capacity at a long load center, it is capable of stacking that load to the same fork height as the 24-inch load center rating from which it was calculated.

CAPACITY RATINGS WITH ATTACHMENTS

If a truck is equipped with or arranged for a specific attachment, one or more ratings for that attachment will appear on the truck name plate.

The same rules that apply to fork ratings also apply to attachments. A rating will always be provided at maximum fork height. A second rating may be given if the truck has more capacity at a lower fork height.

All trucks with an attachment must be capable of passing the four platform tests in the same manner as a fork truck. Since there are so many combinations of attachments, most tests are conducted with forks and the attachment capacity is determined on an inch-pound basis. An example of an inch-pound derating is shown in that section.

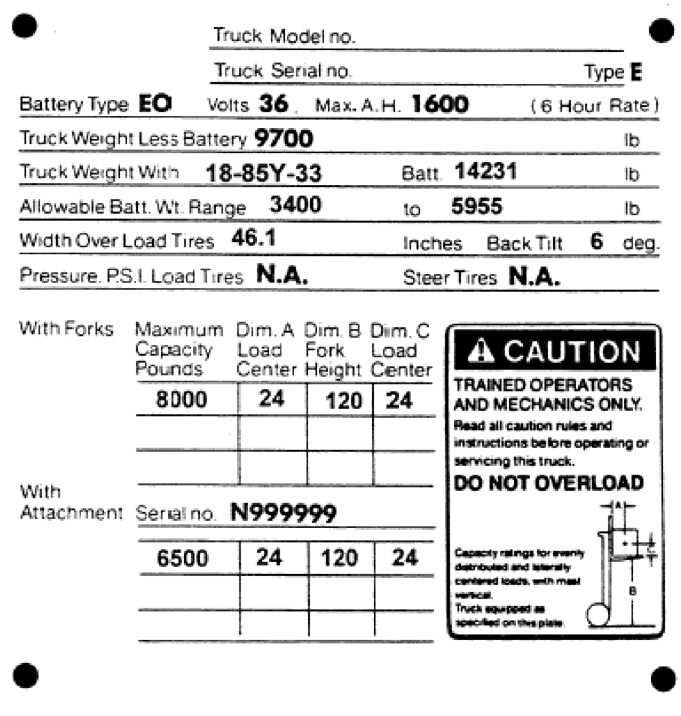
Attachment bulletins may have reduction factors determined by the engineering department. These factors can be subtracted from the fork truck capacity to estimate the capacity rating, with that attachment at its rated load center.

Example 1. Using an electric rider, cushion tire, 8000 lb. truck with a 120 mast equipped with a rotator and 42 in. long forks, the capacity reduction can be computed. According to the **Technical Data Sheets**, the capacity with forks is 8000 lbs. (*Figure 45.*)

The **reduction factor** for an 8000 lb. rating with a rotator is 1500 lbs. Therefore, the net capacity of the truck will be 8000 (- 1500) = 6500 lbs.

For the factory-equipped rotator truck in this example, the **capacity name plate** will show 6500 lbs. (24" load center, 120" fork height). (*Figure 44.*)

FIGURE 44.
TYPICAL CAPACITY NAME PLATE



Truck Model no.
Truck Serial no. Type **E**
Battery Type **EO** Volts **36** Max. A.H. **1600** (6 Hour Rate)
Truck Weight Less Battery **9700** lb
Truck Weight With **18-85Y-33** Batt **14231** lb
Allowable Batt. Wt. Range **3400** to **5955** lb
Width Over Load Tires **46.1** Inches Back Tilt **6** deg.
Pressure P.S.I. Load Tires **N.A.** Steer Tires **N.A.**

	Maximum Capacity Pounds	Dim. A Load Center	Dim. B Fork Height	Dim. C Load Center
With Forks	8000	24	120	24
With Attachment Serial no. N999999	6500	24	120	24

⚠ CAUTION
TRAINED OPERATORS AND MECHANICS ONLY.
Read all caution rules and instructions before operating or servicing this truck.
DO NOT OVERLOAD
Capacity ratings for evenly distributed and laterally centered loads, with mast vertical.
Truck equipped as specified on this plate.

503984500

FIGURE 45.
TECHNICAL DATA SHEET

SINGLE STAGE MAST				CAPACITY-MFH				RATED CAPACITY				DRIVE TIRES		TILT	
Model	OAH In.	MFH In.	FFH In.	Max Cap lbs.	A In.	B In.	C In.	Max Cap lbs.	A In.	B In.	C In.	SIZE	OAW	RWD deg.	FWD deg.
Electric Rider Cushion	84	120	5.0	8000	24	120	24	8000	24	120	24	22x9x16	46.1	6	5
	96	145	5.0	8000	24	145	24	8000	24	145	24	22x9x16	46.1	6	5
	108	169	5.0	8000	24	169	24	8000	24	169	24	22x9x16	46.1	6	5
	126	196	5.0	7900	24	196	24	7900	24	196	24	22x9x16	46.1	6	5

Example 2. With a paper roll clamp on a gas, cushion tire, 6000 lb. truck with a 102/228 mast, the **Technical Data Sheets** show that capacity with forks of this truck is 4150 lbs. (24” load center, 228” fork height) and 6000 lbs. (24” load center, 228” height). (*Figure 46.*)

From information for the applicable Paper Roll Clamp the reduction factor of a 6000 lb. truck is 1700 lbs. In this case, 4500 lbs. @ 25 in. load center is the maximum capacity of the attachment. Take the lower of the two ratings, the maximum attachment capacity or the calculated combined capacity, as the correct figure.

The capacity reduction at maximum fork height is 4150 lbs. - 1700 or 2450-25-228. Since this truck has two ratings the second truck with clamp rating would be 6000 lbs. - 1700 or 4300 lbs., which is less than the attachment capacity, and therefore the correct number.

FIGURE 46.
TECHNICAL DATA SHEET

THREE STAGE MAST				CAPACITY - MFH				RATED CAPACITY				DRIVE TIRES		TILT	
MODEL	OAH In.	MFH In.	Free-Lift In.*	Max Cap lbs.	A In.	B In.	C In.	Max Cap lbs.	A In.	B In.	C In.	Size	OAW In.	FWD deg.	RWD deg.
STANDARD TREAD Gas Cushion	76	163	51	6000	24	163	24	6000	24	163	24	21x8	43.5	5	5
	82	181	57	5800	24	181	24	6000	24	164	24	21x8	43.5	5	5
	84	187	59	5750	24	187	24	6000	24	164	24	21x8	43.5	5	5
	88	193	63	5700	24	193	24	6000	24	164	24	21x8	43.5	5	5
	92	205	66	5550	24	205	24	6000	24	164	24	21x8	43.5	5	5
	94	211	68	5500	24	211	24	6000	24	164	24	21x8	43.5	5	5
	102	228	76	4150	24	228	24	6000	24	164	24	21x8	43.5	5	5

CAPACITY RATINGS FOR FIELD MODIFIED TRUCKS

If a truck is modified in the field and a new capacity plate is required, please complete a Capacity Plate Request form.

A change of any of the following components also requires a new capacity plate:

1. Counterweight.
2. Mast.
3. Tilt cylinders.
4. Overall width of drive tires.
5. Material or type of drive tires.
6. Length of forks.
7. Attachment.

If the components being changed are standard type components, the capacity change can be handled in a routine manner. However, if the components being added are special in nature, please provide as much information about the vehicle and application as possible. A special engineering evaluation will be required.

INCH-POUND RATING

The means of calculating truck capacity for load centers other than 24 inches or with attachments is to utilize the inch-pound rating of the truck.

The first step in employing the inch-pound rating of a truck that has a standard rating of 5000 lbs. at 24-inch load center is to convert the standard rating to inch-pounds. To obtain the new rating, 5000 is multiplied by the distance from the centerline of the drive axle to the center of gravity of the load (*Figure 47.*)

The calculation procedure is as follows:

Assume A = 11 in. and B = 24 in.

(A=B) x (Load Rating) = in. lbs. rating

(11 in. + 24 in.) x 5000 lbs. =
35 in. x 5000 lbs. = 175,000 in. lbs.

This particular truck will handle (counterbalance) any load that exerts up to 175,000 inch pounds on the forks of the truck.

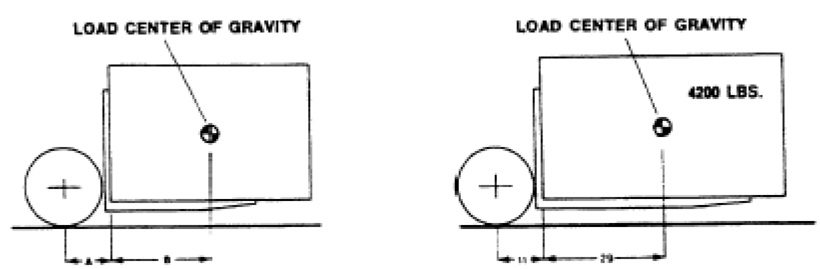
To illustrate how the inch-pound rating can be employed, assume a load that weighs 4200 lbs. Can the truck handle that load at 29-inch load center? (*Figure 48.*)

Compute the moment (inch-pounds) the load will exert as follows:

Assume A = 11 in. and B = 29 in.

(A+B) x (New Load) = in. lbs. req'd
(11 in. + 29 in.) x 4200 lbs. =
40 in. x 4200 lbs. = 168,000 in. lbs.

FIGURE 47.
24IN.LOAD CENTER



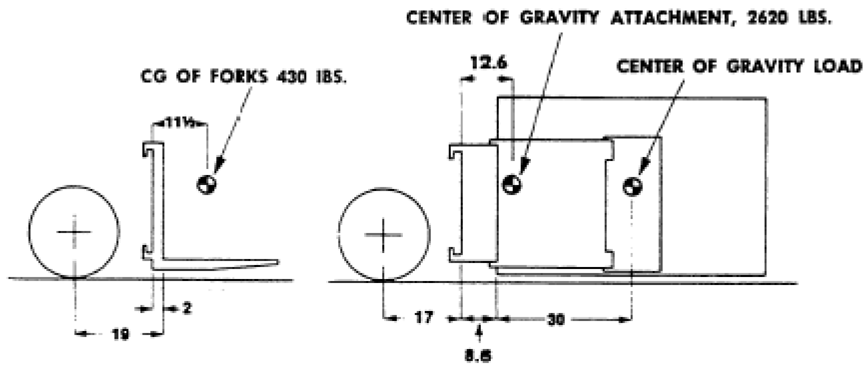
The inch-pounds exerted by the load is less than the inch-pounds exerted by the standard rated load. Therefore, the 5000 pound capacity truck has adequate counterweighting to handle 4200 pounds at 29 in. load center.

In order to calculate the full capacity of the truck at the 29-inch load center, the formula is as follows:

175,000 in./lb. ÷ (A+B)
175,000 in./lb. ÷ (11 in. + 29 in.)
175,000 in./lb. ÷ 40 in. = 4375 lbs.

The second use of the inch-pound rating system is to determine the capacity of a truck equipped with an attachment. Once again, an example is the best illustration. (*Figure 49.*)

FIGURE 49
FORKS AND ATTACHMENTS



This example determines the capacity of a paper roll clamp on a gas, cushion tire, 10,000 lbs. truck.

The paper roll clamp has the following specification:

Weight = 2620 lbs.
Center of gravity (horizontal) = 12.6 in.
Lost load center = 8.6 in.
Maximum capacity = 7700 lbs. @ 30 in. LC

The truck is rated 10,000 lbs. @ 24 in. LC with a front overhang of 19 inches. The 2 x 6 forks for this truck weight 430 lbs. And have a horizontal CG of 11.5 inches.

Since the standard truck can lift its rated load and the weight of the forks, this extra capacity can be taken advantage of when calculating the capacity with an attachment. The available inch-pounds of the truck to handle the load are:

10,000 lbs. x (19 in. + 24 in.) =
10,000 lbs. x 43 in. = 430,000 in./lbs.

When the forks are removed, the inch-pounds of the truck that were required to balance the forks are gained.

430 lbs. x (19 in. - 2 in. = 11.5 in.) =
430 lbs. x 28.5 in. = 12,255 in./lbs.

The inch-pounds (less forks) are the sum of the above two numbers.

430,000
+12,255
442,255 in./lbs.

Now determine the number of inch-pounds required to balance the attachment.

2620 lbs. x (17 in. + 12.6 in.) =
2620 lbs. x 29.6 in. = 77,552 in./lbs.

Subtract "the number of inch-pounds required to pick up the attachment" from "the truck less the forks number."

442,255
- 77,552
364,703 in./lbs.

The capacity of the truck and attachment is 364,703 inch-pounds divided by the distance from the center of the drive tires to the center of the paper roll.

364,703 in./lbs. ÷ (17 in. + 8.6 in. + 30 in.) =
364,703 in./lbs. ÷ 55.6 in. = 6559 lbs.

The capacity of the gas, cushion tire, 10,000 lbs. truck with the paper roll clamp is rounded off to 6550 pounds at a 30 inch load center.