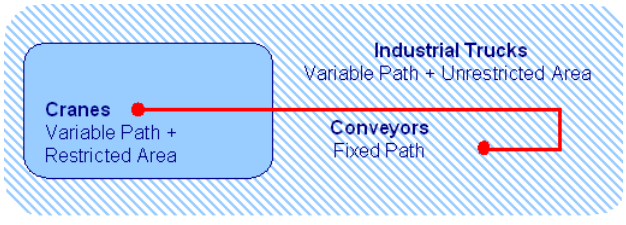
Mechanical Engineering Department
Carlos III University

POWERED INDUSTRIAL TRUCKS

TRANSPORTATION

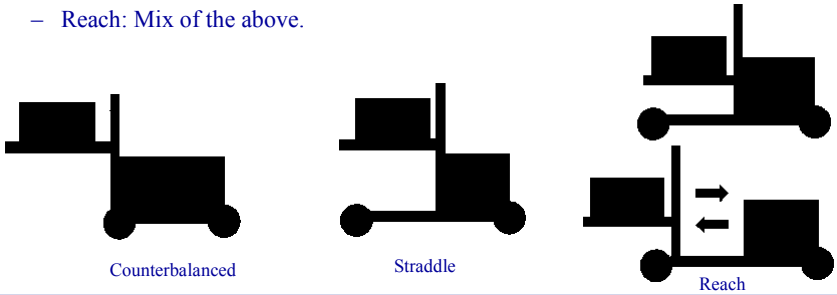
Advantages

- Used to move materials along variable paths, without an area restriction.
- Allow vertical movements.
- Used when material flux is not sufficient to justify the use of, for example, belt conveyors.
- Endow flexibility of movement, compared with belt conveyors and cranes.



Lift trucks I

- The most used to transport in and out of the warehouse. They are also used to load and unload lorries.
- Transport is carried out using pallets. Transport process is comfortable and simple.
- Classification:
  - Counterbalanced: Load situated outside the stability triangle
  - Straddle: Centre of gravity of load inside the stability triangle. Load as cantilever
  - Reach: Mix of the above.



Counterbalanced Straddle Reach

Lift trucks II

- Features:
  - Short travelling distances.
  - Continuous accelerations and decelerations.
  - In some cases 50 % of the work is done backwards (rear gear).
  - Steering is situated at the rear axle.
  - Steering axle endows a wide turning angle:
    - Vehículos equipados con ejes pendulares: hasta 85 º.
    - Vehículos tipo triciclo o ejes de dirección tándem: hasta 90 º.
  - Compared with other vehicles, maximum speed is relatively low ($\leq$ 25 km/h).
  - Designed to work in narrow aisles.
  - Autonomous load of materials
  - Big self weight compared with the transported load:

$$\frac{\text{Lift weight}}{\text{Load material weight}} \geq 1.5$$

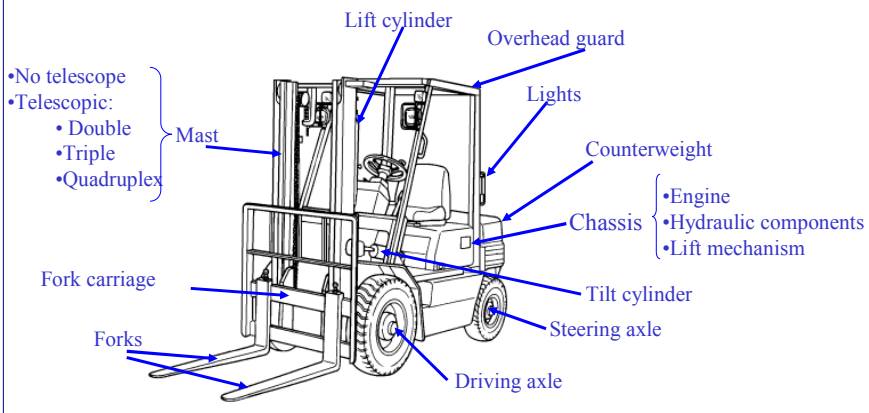
Lift trucks III

- Reduced panoramic vision:
  - Because of the mast, accessories and the load.
- Total weight cocentration in front axle when the vehicle is loaded:
  - Unloaded: 50 % in front axle, 50 % in rear axle.
  - Loaded: 85-90% in front axle, 10-15% in rear axle.
- Great variety of attachments can be put.
- Selective loads in the three directions.

- Types:

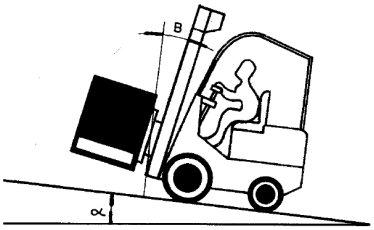
Type of lift truck		Load gravity centre
From 1000 to 2000 kp	Electric or internal combustion engine. Interior	0.5 m
From 2000 to 3000 kp	Electric or internal combustion engine. Interior	0.5 m
From 3000 to 5000 kp	Internal combustion engine. Exterior	0.5 m
From 5000 to 10000 kp	Internal combustion engine. Exterior	0.6 m
From 10000 kp	Especial machines	

Lift trucks: elements



Grades

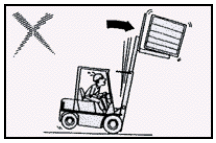
- Travelling in grades:
  - If the slope is lower than the maximum fork inclination ($\alpha < ß$) the truck can travel ahead while descending, with the precaution of the mast being tilted at the maximum angle.
  - When the truck has to descend by a grade bigger than the maximum tilting fork angle ($\alpha > ß$), necessarily it must be done in reverse gear.
  - To move upwards the truck must travel in forward speed.

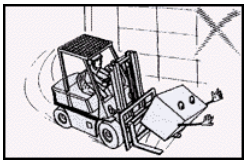


Lift Truck Stability

Feature of a lift truck to keep in static and dynamic stability over its wheels

- Safety factors:
  - The distance between the front and rear axle.
  - The distance between wheels of the same axle (wheelbase).
  - Load transfer.
  - Vehicle self-weight.
  - Support surface.
  - Counterbalance position
  - Vehicle centre gravity without load.
  - Vehicle and load centre of gravity position:
    - Counterbalanced
    - Straddle
    - Reach
  - The load.
  - The dynamic forces.
  - Tilting operations.





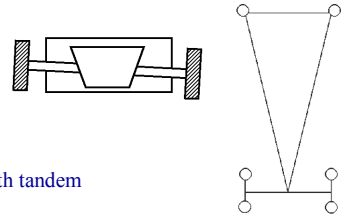
STABILITY TRIANGLE BASIS

Lift Truck Stability

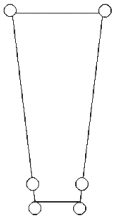
SUPPOR SURFACE

Three wheel lift truck

Lif truck with 4 wheels with a tilting steering axle



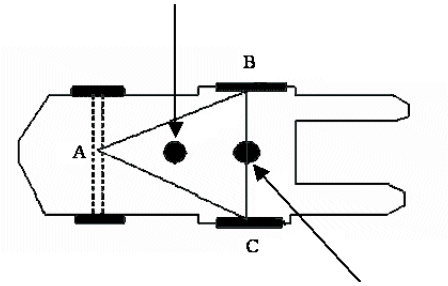
Lift truck of 4 wheels with tandem steering axle



Lift Truck Stability

STABILITY TRIANGLE

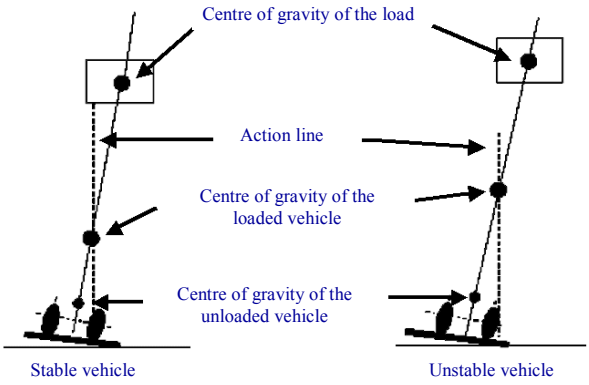
Centre of gravity of the vehicle without load



Centre of gravity of the vehicle with maximum load

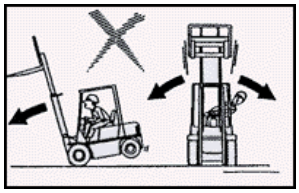
Lift Truck Stability

ACTION LINE



Lift Truck Stability

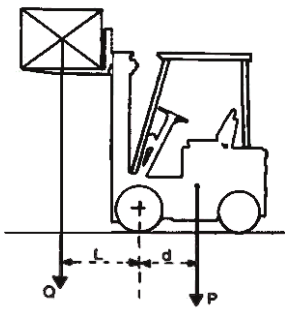
- Longitudinal stability
- Lateral stability



- While stacking
- During movement

Lift Truck Stability

LONGITUDINAL STABILITY DURING STACKING



Vehicle moment = $P \cdot d$

Load moment = $Q \cdot L$

Static safety:

$$Q \cdot L = P \cdot d$$

To guarantee dynamic safety:

$$\frac{\text{Vehicle moment}}{\text{Load moment}} \geq 1.3$$

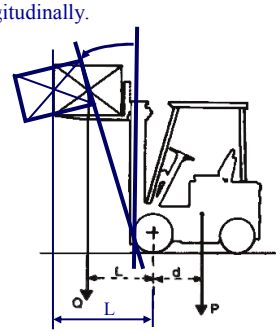
Good lift trucks from 1.4 to 1.7 with loads lifted to heights > 5 m

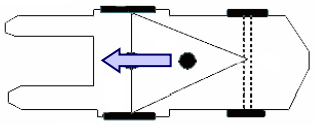
POWERED INDUSTRIAL TRUCKS

Lift Truck Stability

LONGITUDINAL STABILITY DURING STACKING

- It does not depend on the height at which load is.
- If the mast is tilted forwards:
  - The centre of gravity of the load is also moved forward.
  - If the total centre of gravity is moved out of the stability triangle: the vehicle rolls over longitudinally.



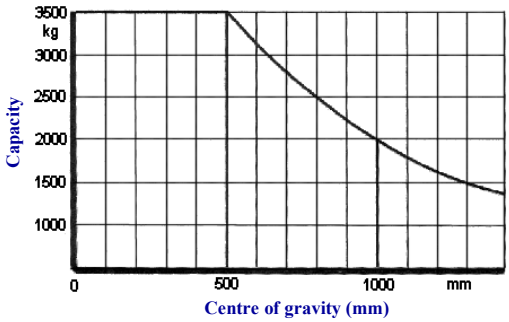


Lift Truck Stability

- Nominal capacity:

  Is the load capacity under certain conditions and a specific centre of gravity (load).

  Relationship between the distance and the load capacity.

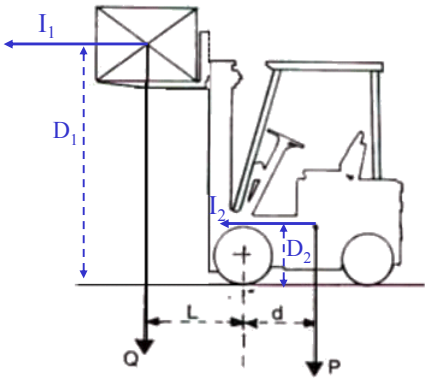


Lift Truck Stability

LONGITUDINAL STABILITY DURING MOVEMENT

If the truck:
- Moves forwards and brakes
- Moves backwards and accelerates

$$I_1 \cdot D_1 + Q \cdot L + I_2 \cdot D_2 = P \cdot d$$

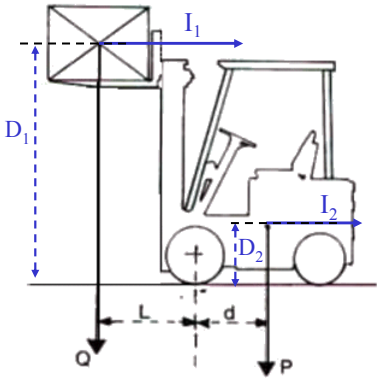


Lift Truck Stability

LONGITUDINAL STABILITY DURING MOVEMENT

If the truck:
- Moves forwards and brakes
- Moves backwards and accelerates

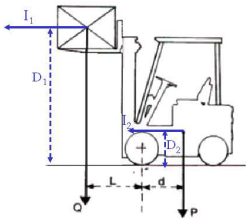
$$Q \cdot L = P \cdot d + I_1 \cdot D_1 + I_2 \cdot D_2$$



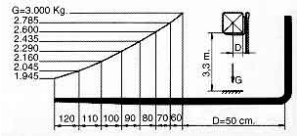
Lift Truck Stability

LONGITUDINAL STABILITY DURING MOVEMENT

- The most unfavourable situation:
  - The truck moves forwards and breaks
  - The truck moves backwards and accelerates.



$$I_1 \cdot D_1 + Q \cdot L + I_2 \cdot D_2 = P \cdot d$$



- Influence, in the stability, of the height at which the load is:
  - The higher the load is, the worse the truck stability is.

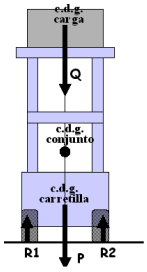
When lift trucks move load must be in the lower transportation height.

Lift Truck Stability

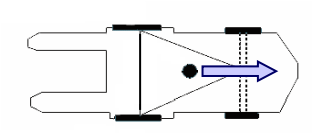
LATERAL STABILITY DURING STACKING

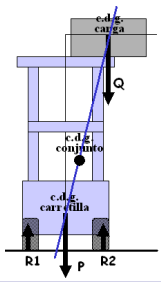
•During stacking operations, the lift truck does not move or if it moves speed is very low, so that vehicle and load accelerations can be considered neglible.
•The actuating forces are:
- •The force due to the weight load.
- •The force due to the vehicle unloaded.

If the load is centred and the mast is in the vertical position, the lift truck is stable and does not rollover laterally.



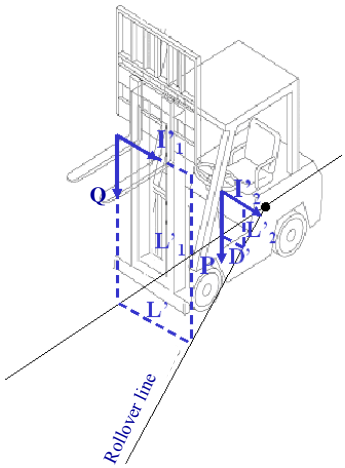
Problems:
- •If longitudinal stability is desired to be increased and the mast is tilted backwards.
- •If load is not centred.





Lift Truck Stability

LATERAL STABILITY DURING MOVEMENT



$$I_1' \cdot L_1' + I_2' \cdot L_2' = Q \cdot L' + P \cdot D'$$

If the load is tilted forwards, the distance L' increases, so that the equilibrium moment is also increased

Lift Truck Stability

LATERAL STABILITY DURING MOVEMENT

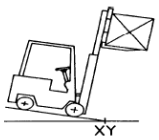
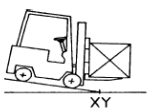
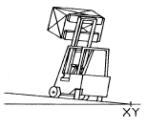
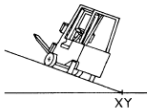
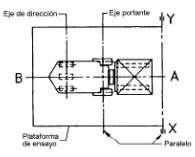
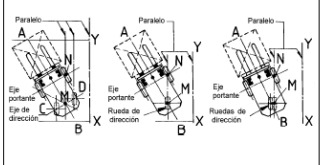
- The parameters that mostly influence negatively in the lateral truck stability are:
  - The speed in bends. The bigger the speed, the bigger the centrifugal force is (I'_1) generating a bigger moment and, therefore, the lift truck will be able to support less load weight.
  - Load height. The higher the load is positioned the bigger is the distance L'_1, the bigger is the generated moment and, therefore, the load truck capacity is diminished.
- These situations aggravate if the load is not centred to the interior bend direction because L' is reduced, and the load moment generated is diminished.

$$I'_1 \cdot L'_1 + I'_2 \cdot L'_2 = Q \cdot L' + P \cdot D'$$

The better stability against rollover is achieved with the loaded vehicle and the load situated in the lower position.

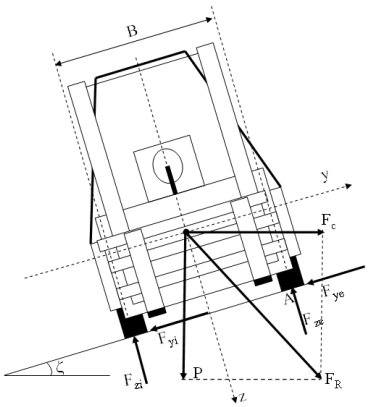
POWERED INDUSTRIAL TRUCKS

Lift Truck Stability

Ensayo nº		1	2	3	4
Estabilidad		**Longitudinal**		**Lateral**	
Utilización		Apilando	Desplazándose	Apilando	Desplazándose
Carga		Carga de ensayo	Carga de ensayo	Carga de ensayo	Sin carga
Altura de elevación		Máxima	Baja (véase el apartado 4.3.6)	Máxima	Baja (véase el apartado 4.3.6)
Posición del mástil		Vertical	Inclinación máxima hacia atrás (para carretillas con mástil inclinable)		
Posición sobre la plataforma de ensayo		Figuras 5 y 9	Figuras 6 y 9	Figuras 7 y 10, 11 ó 12	Figuras 8 y 10, 11 ó 12
Inclinación de la plataforma de ensayo	Capacidad nominal ≤ 4 999 kg	4%	18%	6%	(15 + 1,4 v) %* (50% máx.)
	Capacidad nominal 5 000 kg ≤ 50 000 kg	3,5%	18%	6%	(15 + 1,4 v) %* (40% máx.)
Posición de la carretilla sobre la plataforma de ensayo		 Fig. 5	 Fig. 6	 Fig. 7	 Fig. 8
AB: Plano medio longitudinal de la carretilla CD: Eje de simetría del eje de dirección MN: Eje de vuelco de la carretilla XY: Eje de inclinación de la plataforma de ensayo.		 Fig. 9		 Fig. 10 Fig. 11 Fig 12	

* v = Velocidad máxima de la carretilla sin carga en km/h.

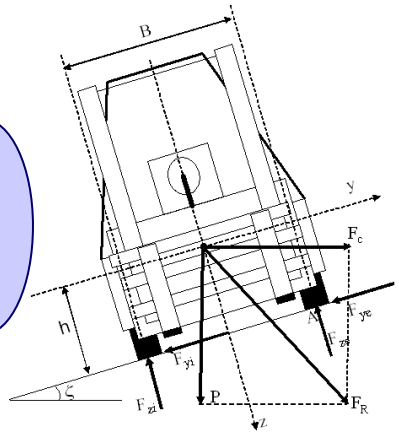
Rollover and skid speed



Rollover and skid speed

SKID SPEED

$$F_y = F_{yi} + F_{ye} = -Psen(\zeta) + F_c\cos(\zeta)$$
$$F_z = F_{zi} + F_{ze} = P\cos(\zeta) + F_c sen(\zeta)$$
$$F_{ye} + F_{yi} = \mu_y \cdot \left(F_{ze} + F_{zi}\right)$$
$$F_c = \frac{PV^2}{gR}$$
$$V = \sqrt{gR\frac{\mu_y + tg\zeta}{1 - \mu_y tg\zeta}}$$



If $\mu_y=\mu_{ymax}$: skid speed

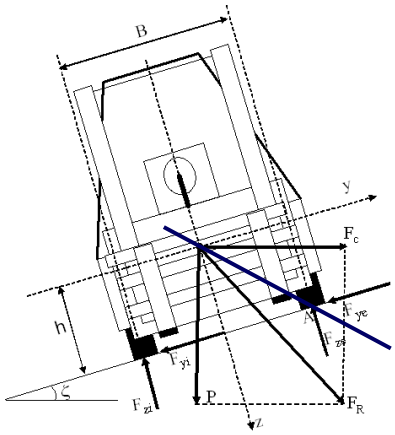
$$V_{skid} = \sqrt{gR\frac{\mu_{ymax} + tg\zeta}{1 - \mu_{ymax} tg\zeta}}$$

Without grade: (ζ=0)

$$V_{skid(\zeta=0)} = \sqrt{gR\mu_{ymax}}$$

Rollover and skid speed

ROLLOVER SPEED



The rollover limit takes place when the resultant F_R of the forces that act in the vehicle centre of gravity (weight and centrifugal force) intersects the rolling surface in the exterior point of the tire contact patch of the exterior tire

$$\frac{F_y}{F_z} = \frac{F_c\cos(\zeta) - Psen(\zeta)}{P\cos(\zeta) + F_c sen(\zeta)} = \frac{B/2}{h}$$

$$F_c = \frac{PV^2}{gR}$$

Rollover limit speed:

$$V_{rollover} = \sqrt{gR\frac{B/2h + tg\zeta}{1 - B/2h \cdot tg\zeta}}$$

Without grade: (ζ=0)

$$V_{rollover(\zeta=0)} = \sqrt{gRB/2h}$$