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Stability Analysis of Self-propelled Aerial Man Lift Vehicles

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ABSTRACT:

The objective of our research work is to perform the stability analysis of the aerial man lift vehicle. The stability analysis is performed using equilibrium force analysis and center of gravity analysis. A safe working load taking into account of drag forces on the bucket side-stream wind is established for six configurations depend up the AMLV traversing up or down over a flat or 10° slope surface with its boom at rest or raised up at 65° inclination angle. A standard square cross-section as well as tapered cross-section is also designed for the boom. For the considered designs, the calculated safe loads have been verified using stability pyramid and proved acceptable.

KEYWORDS:

Aerial man lift vehicle; Equilibrium; Center of gravity; Stability; Wind force

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1. Introduction

Self-propelled Aerial Man Lift Vehicles (AMLV) or Mobile Elevating Work Platforms (MEWP) is made up of a boom mounted on a frame supported by three widely spaced wheels [1]. A platform is attached to the distal end of the boom for supporting an operator. The machine is equipped with hydraulic controls which are accessible to an operator on the platform. The machine can be steered by the individually controlled drive wheels. A picking bucket is carried by a separate boom connected to the main boom and accessible to the operator on the platform. The picking bucket can be swung over a box supported on the machine frame. A self-propelled AMLV has an improved hydraulic control system by which the vehicle can be turned around about a vertical axis. More specifically, either one of the two traction wheels may be rotated in either direction, one may be held stationary while the other is driven or both may be driven together in the same direction. Radice et al [2] developed a model for steering control that regulates the angular acceleration of the velocity orientation. This level of control is particularly relevant in the context of planar rigid-body motion. The control design follows the iterative process of integrator back stepping, in which the existing states of the first-order model are recursively used to stabilize the steady motions of the second-order model.

Self-propelled AMLVs are able to drive themselves (on wheels or tracks) around a site. An AMLV in agricultural operation is shown in Fig. 1. Stability is defined as the condition in which the vehicle remains in the operating condition. The vehicle remains stable until the center of gravity (C.G.) of the load lies within the base of the vehicle. For stability, the sum of all moments about the base of the crane must be close to zero so that the AMLV does not overturn. Solazz [3] described the research performed about the dynamical behaviour on the MEWP. Simulations and analytical solutions are widely adopted to investigate the levelling and tip over stability of MEWP [4].

Fig. 1: Self-propelled AMLV in agricultural operation

Yamada et al [5] developed an easily driven MEWP consists of a unidirectional steering system combined with a horizontal stability control device. Papadopoulos et al [6] presented a force-angle tip over stability measure as applicable to mobile manipulators subjected to inertial and external forces, operating over even or uneven terrains. Augustyn [7] defined aerodynamic coefficients of the MEWP in different conditions of operation and for a variable angle of wind attack using wind tunnel testing. Slopes steeper than 33% (one vertical unit rise or fall per three horizontal units) are called critical slopes because they can cause most vehicles to overturn. The self-propelled vehicle tip over due do instability is shown in Fig. 2. In this paper, the stability analysis of the self-propelled AMLV has been undertaken using first principles such as force/moment equilibrium and C.G. Various mobility conditions and terrains are considered in the work. For each of the assessed conditions, an optimum weight in the bucket of AMLV and maximum operating height for a stable state are established.

Fig. 2: Self-propelled vehicle tip over due do instability

2. AMLV Components

Typical AMLV consists of base chassis with engine, boom (HSLA alloy) and a bucket. A free body diagram of the AMLV is shown in Fig. 3. The specifications of the chosen AMLV are as follows:

- Working height = 8m.
- Minimum lift weight in the bucket = 300kg.
- Operation = Climb or descend the ground with 10° inclination angle.
- Power = 16HP twin single cylinder diesel engine with hydrostatic transmission.
- Total weight = 1.5 tons.
- Tyres grip = 6”×16”.

A single non telescopic boom reaching the maximum height of 8m vertically from the ground surface is considered with the following cross-sections:

- Regular square (Fig. 3): 0.25m×0.25m
- Tapered square (Fig. 4): Lower - 0.25m×0.25m; Upper - 0.2m×0.2m

The wall thickness and length of the booms are 0.02m and 6.32m respectively. The mass of both the booms are maintained as constant to draw a comparison. A free-body diagram of AMLV model is shown in Fig. 5.

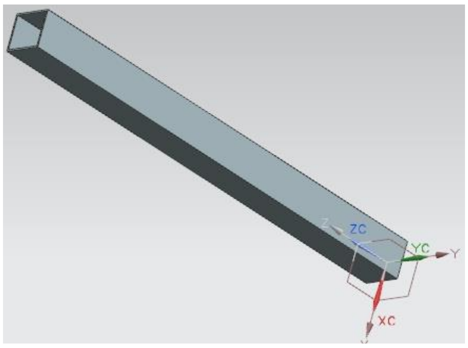

Fig. 3: 3D view of regular square boom

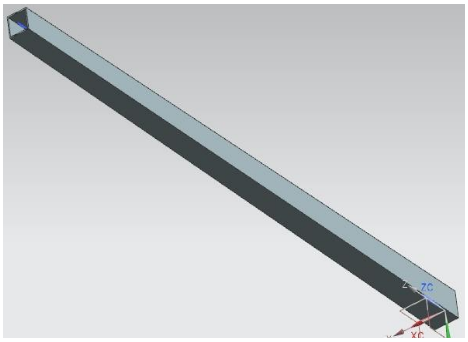

Fig. 4: 3D view of tapered square boom

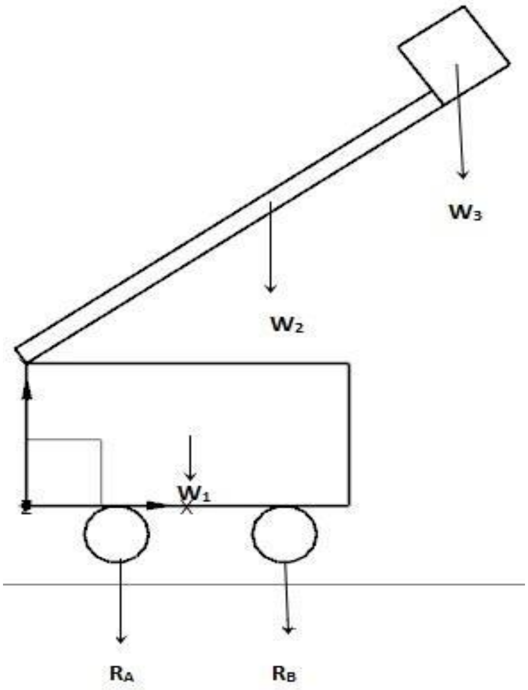

Fig. 5: Free-body diagram of AMLV

3. Analysis method

When applying the equations of equilibrium, one can assume that the body remains rigid. This way the direction of the applied forces and their moment arms with respect to a fixed reference remain the same both before and after the body is loaded. To apply the equation of equilibrium, we must account for all the known and unknown forces (ΣF) which act on the bodies (force method). This way reactions R_A and R_B can be calculated (see Fig. 5). Using moment balance and assuming $R_B = 0$, the maximum bucket load can be established. For this maximum load, a safe working height without tipping can be arrived using the C.G. method. The C.G. of the AMLV can be calculated using the following equations:

$$X = \frac{W_1X_1+W_2X_2+W_3X_3}{W_1+W_2+W_3} \tag{1}$$

$$Y = \frac{W_1Y_1+W_2Y_2+W_3Y_3}{W_1+W_2+W_3} \tag{2}$$

The wind load acting on the bucket can be calculated using dynamic force equation as follows,

$$Fw = \frac{1}{2}\rho v^2 A \tag{3}$$

Where ρ = air density = 1.1455 kg/m^3, v = wind speed = 5.1 m/s for typical south West Indian Ocean and A =

surface area of the bucket = 1 * 2 = 2 m^2. Based on these values, the calculated wind force is 59.58N. For maximum bucket load calculation, the detrimental effect of wind force component has been considered.

Stability triangle is the area in which if the C.G. lies within the region, then the vehicle is said to be stable without tipping over. The stability pyramid shown in Fig. 6 has been developed to show where a vehicle is at is least stable. It is a triangle between the two front support points (tyres or outriggers) and the boom pivot. The dark area within the stability pyramid is the safest area when the vehicle is in operation with the stability being limited once within this triangular area. The blue dot shows where the C.G. is when the machine is in operation. When the vehicle C.G. and load moves past the line between the two front support points, the machine will tip forward or sideways. Most operators are unaware of the contributing factors that cause a machine to tip outside of the stability triangle. This can be caused by the unlevelled ground or an unbalanced/swinging weight or even high cross winds. The manufacturers of vehicle, whilst calling them all-terrain machines, specify that they must be operated on flat surface (usually with a limit of 10° slope). While on flat ground, the C.G. moves from near the geometric center of the AMLV to the forward depending up on the boom extension, boom inclination angle, and load. As the boom is raised, the C.G. moves back and when on a forward rising slope the C.G. moves further back minimizing the lateral slope.

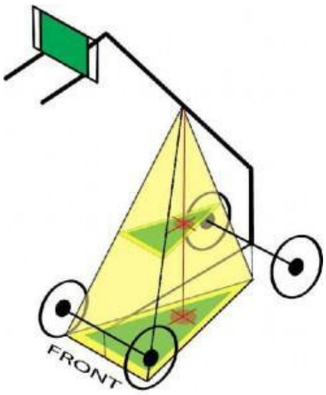

Fig. 6: Stability triangle and pyramid

4. Results and discussions

The following mass and dimension values are assumed for the components of AMLV:

- Bucket: Weight of the bucket = 170kg (156 + 14); cast iron (7800kg/m^3); dimension: 0.2 * 1 * 2m;
- Engine and chassis assembly: Weight considered: 700kg; dimension: 4 * 2 * 1.89m.
- Boom: Length = 6.32m; material: cast iron (7800kg/m^3); weight of the boom: 430kg; Centroid Z = 2.926m.
- Total weight of the vehicle = 700 + 430 + 170 = 1300kg.

The following six positions and operations of AMLV have been manually analysed for the square boom and tapered boom configurations:

- A = Moving on a flat surface and boom at rest;
- B = Moving on a surface and boom raised at 65° inclination;
- C = Goes up on a 10° slope and boom at rest;
- D = Goes up on a 10° slope and boom raised at 65° inclination;
- E = Comes down on a 10° slope and boom at rest;
- F = Comes down on a 10° slope and boom raised at 65° inclination;

These conditions has been analysed using force method and C.G. method. The C.G. of individual components for the considered 6 configurations were taken out directly from NX CAD geometry data. An example C.G. data extracted for tapered boom for the first 4 configurations are presented in Table 1. For those cases, the C.G. at no bucket load, maximum bucket load and safe working heights as established are presented in Table 2. The maximum load that can be added to the bucket for every position is estimated using Eqns. (1)-(3). The optimum weight to be accommodated without tipping of AMLV with the regular square and tapered square boom are presented in Table 3.

Table 1: C.G. (in m) from NX CAD for AMLV with tapered boom

Case	Base, 700 kg		Boom, 430 kg		Bucket, 430 kg	
	X1	Y1	X2	Y2	X3	Y3
A	2.00	1.00	2.90	2.13	6.82	2.85
B	2.00	1.00	1.11	4.69	2.42	8.37
C	1.79	1.33	2.44	2.68	6.17	3.80
D	1.79	1.33	0.40	4.90	0.93	8.68

Table 2: Max. bucket load for AMLV with tapered boom

Case	C.G. no load (m)		C.G. max. load (m)	
	X1	Y1	X2	Y2
A	2.93	1.61	3.69	1.86
B	1.76	3.18	1.96	4.73
C	2.58	2.10	3.63	2.60
D	1.22	3.47	1.11	5.48

Table 3: Stability analysis results – Max. load including bucket

Analysis case	Tapered boom, kg	Squared boom, kg
A	485.59	449.76
B	719.57	764.16
C	708.93	657.93
D	985.84	974.77
E	340.96	383.29
F	555.30	571.87

5. Conclusion

The stability analysis of aerial man lift vehicle has been undertaken to establish the maximum load in the bucket for flat and 10° slope surfaces with rested and 65° inclined boom configurations. Stability analysis of the vehicle has been performed with two types of boom with different cross section has been analysed and maximum load that can be added to the bucket has been determined. Based on the obtained results, the following conclusions have been derived. For the surfaces with inclination, the maximum safe load for the tapered boom is higher than that of regular squared boom. For flat surfaces (Case B), a squared boom can be used considering the first two conditions of the analysis.

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