Dynamic analysis of airport tractor and five baggage container dollies using ADAMS

A..H. Boezeman

Abstract

In this paper the dynamic road holding behaviour of an airport tractor and five container dollies is discussed. The researched combination is currently operated at a number of airports including Schiphol Airport in the Netherlands. The combination is used to transport passenger baggage between the handling services department and the handling device for loading the cargo bay of the plane. The vehicle was researched in a cooperative effort of the transport technology section of the department of Design Construction and Production of the Delft University of technology and Boezeman Transport Research.

The dollies have track following characteristics. In this way five coupled dollies need only little space to manoeuvre around the airplane or in the baggage handling area.

A side effect of these properties is that the combination will reach the vehicle dynamic critical velocity in operating conditions. Experience has proven that the combination has an inherent instability with respect to road holding that causes the dollies to swerve violently at velocities higher than 23 km/h.

The main goal of this research is to determine the origin(s) of the instability phenomenon mentioned above. In a later stage design alternatives to reduce the effects of this problem will be looked at.
A reduction of the swerving or a higher critical velocity (preferably above 30 km/h) would enable efficiency improvements due to shorter cycle times (higher velocity) and capacity expansion per combination (more container dollies per combination).

This study is based on “on the road” and laboratory experiments and multi body modelling using ADAMS.

It can be concluded that:

- The instability has successfully been modelled.
- By modifying the steering system it is possible to influence the critical velocity.

Introduction

With passenger numbers growing every year the need for a efficient logistical handling system becomes more and more evident on Europe's mayor airports. Schiphol Airport (Amsterdam, The Netherlands) is no exception to this rule. The steady growth that Schiphol has experienced for a successive number of years has resulted in bottleneck situations in already complex logistic process of a large airport.

The large number of vehicles with differing characteristics renders the handling process to be vulnerable to accidents, malfunctions and other distortions.
A known problem that is the subject of research in this paper is the dynamic instability of baggage container dollies (figure 1).

Figure 1. TCR container dolly

The container dollies are coupled to form a combination consisting of a maximum of five trailers. These are towed by a tractor between an airplane and the baggage handling department. The combination is used to transport AKE or DPE half-size lower deck containers filled with passenger baggage.

KLM ground services uses dollies that are manufactured by the company TCR in Steenokkerzeel, Belgium and at Schiphol they are maintained by a Dutch subsidiary; TCR Nederland BV.

The dollies have track following characteristics. In this way five coupled dollies need only little space to manoeuvre around the airplane or in the baggage handling area. In order to get this kind of behaviour the rotation of the rear axle is coupled to the rotation of the front axle. Also a mechanism is used to transfer the tow bar rotation to the front axle.

A side effect of these properties is that the combination can reach a vehicle dynamic critical velocity in operating conditions. Driving at higher velocities than critical induces dynamic instability that causes the rearmost dollies to swerve violently.

Experience has proven that drivers cruise at a velocity that is very close to or just over the critical velocity. An other way of putting this is that the driver determines the cruising velocity by looking in the mirror and stops increasing the velocity when the rear most dollies swerve too violently.

The main goal of this study is to determine which properties of the dollies influence the instability phenomenon. Some design modifications to reduce the effects of this problem are discussed.

Experiments

Road tests

Some driving tests were executed and recorded on videotape. On a quiet stretch of public road an unloaded five-trailer combination was driven at velocities up to some 30 [km/h]. In figure 2 a screen capture of the combination in an unstable state is given.

Figure 2. Test driving, tractor driving in a straight line.

The black traces on the road are tire marks caused by the large lateral shift of the tires due to the instability. It is noted that the tractor drove in a perfectly straight line during this experiment and did nothing to start the swerving (except increasing velocity).

The critical velocity proved to be some 23 to 25 [km/h].
The period of the lateral motion proved to be some 2.5 [s] for large yaw motions and a little under 2 [s] in case of relatively small yaw motions (<20[^{0}]).

Tire Measurements

One new and one worn out tire / rim set where made available for measurement purposes. The tire characteristics were determined on a so-called flat plank at the transport technology department of the Design production and construction faculty of the Delft University of Technology.

In the flat plank tire tester the tire is attached to a instrumented wheel hub (figure 3). The hub and tire arrangement is pushed against a long flat 'road' surface that is positioned above the tire (up side down). Low speed driving is simulated by a forced longitudinal displacement of the 'road' surface.

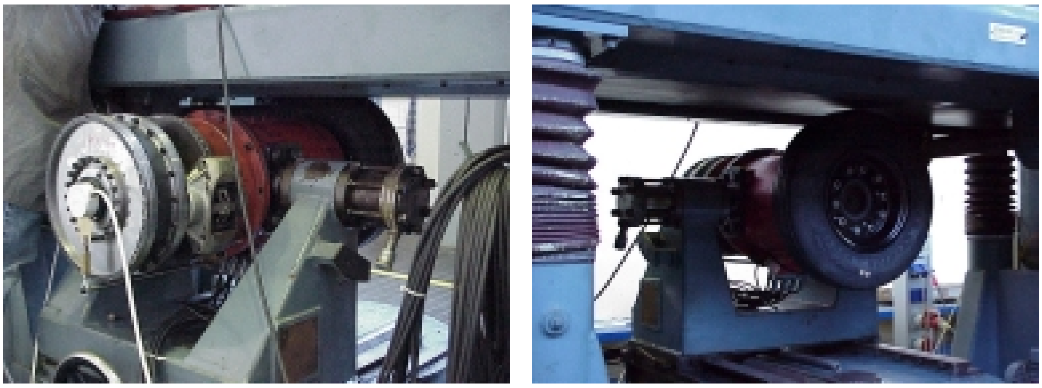

Figure 3. Two side views of instrumented wheel hub of flat plank tire tester

The wheel hub is instrumented with sensors so that forces (3 directions) and torques (2 directions) can be recorded during testing.

The tire characteristics were determined by executing some 30 to 40 runs per tire under varying conditions. In this case the tires were tested for load case combinations of varying vertical force and slip angles.

Prescribed motions induced both the vertical compression (and thus vertical force) and slip angles. Each run covers one load case combination.

The results of the experiments were processed and corrected for irregularities in the tire or flat plank geometry. This was done be subtracting the zero-slip angle run results from every non- zero slip angle run results.

The measured tire characteristics and the results of a virtual tire tester in ADAMS are given in figure 5.

Model description

The vehicle combination is modelled as a rigid body model. In figure 4 an outline is given:

Figure 4. Overview of vehicle combination model.

The play (slop) in the mechanisms of the steering system of the dollies was incorporated in the model. In figure 5 a comparison of the tire measurements and the lateral stiffness characteristics as they are implemented in ADAMS is given for the dolly tires. The ADAMS results were obtained by means of a virtual tire tester.

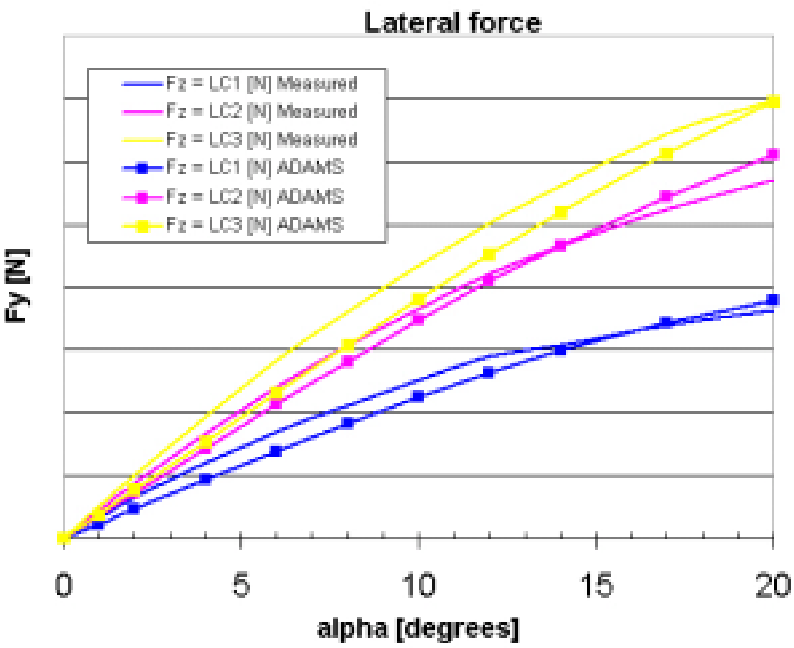

Figure 5. Comparison of tire measurements and the characteristics implemented in ADAMS .

Results

One of the findings in this study is that the instability phenomenon in the simulations could already be observed in a single dolly case. Therefore simulation time could be reduced by studying a relatively small tractor and single dolly model. An other implication is that (future) road tests that are executed with a single dolly combination could already yield sufficient proof for the increased stability of implementing a modification. The results mentioned here concern single dolly simulations, unless specifically mentioned otherwise.

Performance indicators

In order to be able to evaluate the behaviour of a mechanical system performance indicators have to be established. In this case the focus is on the driving stability at high speed. It is evaluated by comparing the lateral acceleration of the centre of Gravity (COG) of the dolly in number of parameter settings. The velocity at which the lateral acceleration demonstrates amplification (without an initiating tractor motion) is called the “critical velocity”. In the end the main objective of this study is increasing the critical velocity above 30 [km/h]. In the validation also the lateral motion period was taken into consideration.

In a next stage of the redesign process also the cornering behaviour (track deviation, swept path) at low speed will become a point of interest.

Validation

In figure 6 the essential performance indicators are given for two different starting conditions (initial velocity 15 [km/h] and initial velocity 20 [km/h]) of a tractor and single dolly combination. The velocity of the combination is increased by the application of a driving force of 500 [N]. Thus the left side of the graph can be interpreted as the starting point. Moving to the right in the graph means making a progress in the simulation with a steadily increasing velocity (with respect to time).

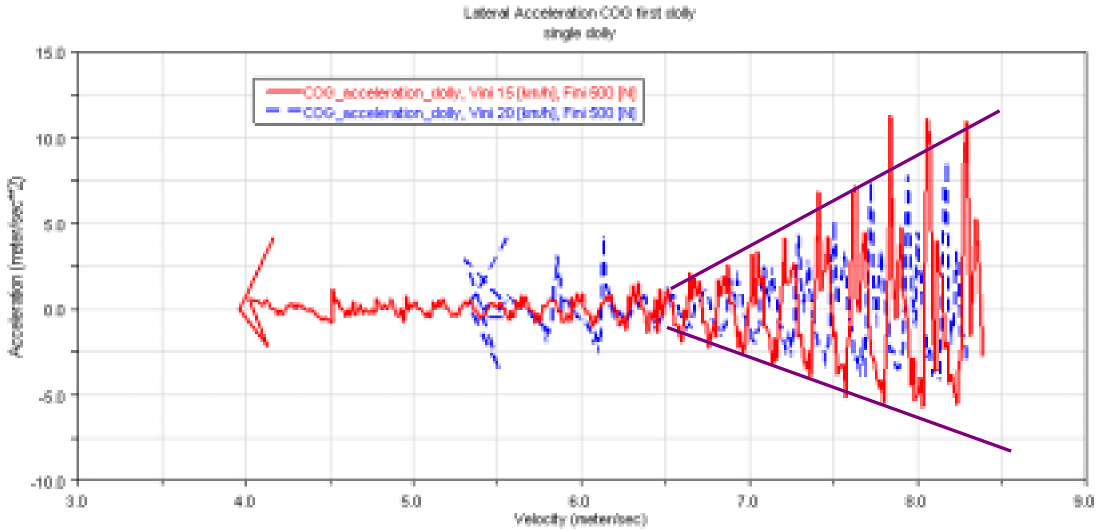

Figure 6 Validation simulations for two different starting conditions (initial velocity 15 km/h and initial velocity 20 km/h).

Determining the starting point for the amplification of lateral acceleration can approximate the critical velocity in the model. By tracing back the purple lines a critical velocity of some 6.5 [m/s] or 23 [km/h] can be abducted.

In the measurements a critical velocity of some 23 to 25 [km/h] was observed. Therefore it can be stated that the results display a satisfying correspondence.

The simulation with 15 [km/h] initial velocity was chosen to be normative in the remainder of this study. The other simulation results are compared to this simulation. Two out of five researched modifications are discussed here in more detail.

Presence of play in steering system
During the study it became apparent that the steering system of a dolly has to have a degree of freedom for the instability to occur at the correct velocity. This is in coherence with the shimmy phenomenon in an airplane landing gear {Den Hartog}. To illustrate this in figure 7 the results *with* and *without* the presence of play in the steering system are displayed by the red line marked “normative” and blue line marked “noplay” respectively.

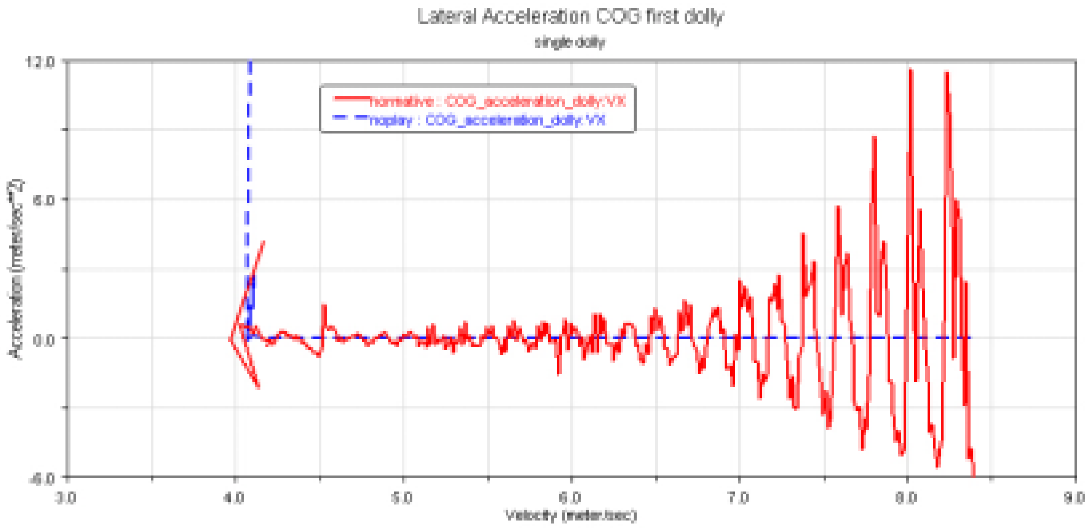

Figure 7. Results with and without the presence of play in the steering system.

It can be concluded that an additional degree of freedom in the steering system has to be modelled in order to get the correct critical velocity.
In the airplane gear shimmy case it is known that it does not matter how this degree of freedom is implemented. Examples could be: existence of play or flexibility in one or more elements (the stiffness value is not really important).

It is important to remember that in a real vehicle eliminating play will be hard, and could also prove to be an ineffective measure. As mentioned before the degree of freedom for instability could also be obtained from flexibility of elements and this cannot be eliminated.

Notes:
- The initial peak in the noplay simulation indicates an initialisation issue and should be ignored.
- In a simulation without play the system will also reach a state of instability albeit at a much higher velocity.

Kinematic transfer function of front axle to rear axle
Previous research on vehicle dynamics of multiple trailer combinations (e.g. studies concerning multi trailer system stability) has demonstrated that the kinematic transfer function of the rotation of the front axle to rear axle has a considerable influence on vehicles stability. One of the problems in this respect is that vehicle stability and vehicle manoeuvrability pose different demands.

The relation between the two axle rotations was modified by changing the position of the connection point of the steering bar that transfers the front axle rotation to the rear axle. In figure 8 the two modified steering system layouts that were researched are outlined.

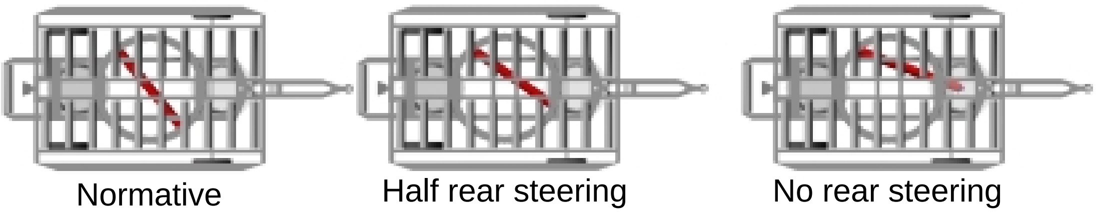

Figure 8. Researched steering system layouts.

The results in figure 9 clarify that the stability increases with a decreasing transfer function of the steering angle of the front to rear axle.

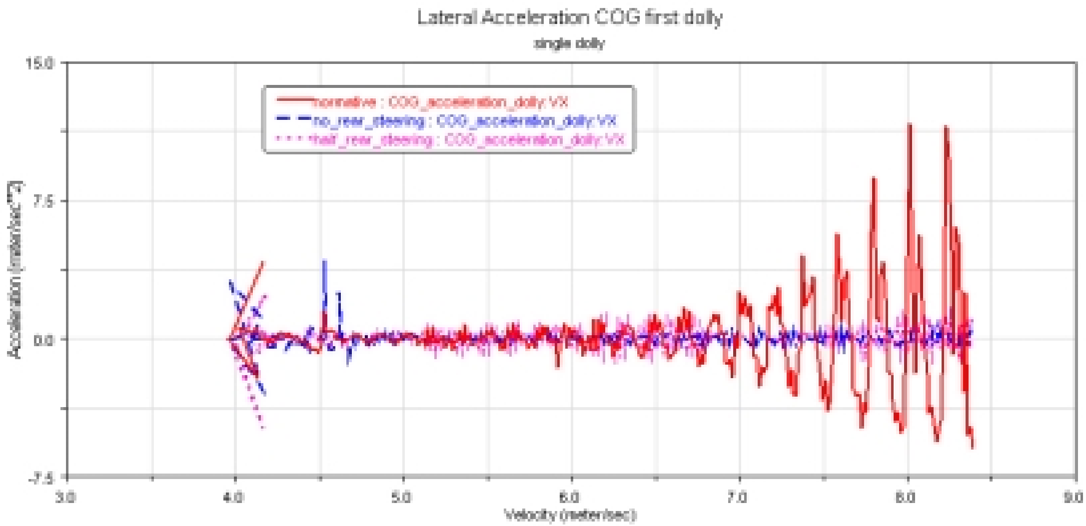

Figure 9. Results displaying the effect of modifying the kinematic transfer function of front to rear axle.

Note: These modifications influence the off-tracking behaviour

Other researched parameters

Other parameters that have been studied are the tire cornering stiffness of the dollies, the kinematic transfer function of the tow bar to front axle rotation and the offset of the axles with respect to their steering rotation axes.

Conclusions

The instability phenomenon is present in one single dolly. However, the effects are amplified resulting in more severe motions of the rearmost dolly in a multiple vehicle combination.
Road tests that are executed with a single dolly combination could already yield sufficient proof for the increased stability of implementing a modification.

Play or flexibility have to be present in the model of the steering system in order to give a correct critical velocity.

Having a rear axle steering angle that is (close to) equal to that of the front axle gives a poor stability behaviour.

The behaviour of tires with half the current lateral stiffness seems to be a little better. However, the stiffness of the current tire is already very low. It would be hard if not impossible to obtain tires with an even lower stiffness.

There are four options to consider for steps to improve the stability of the dollies:

1. Looking for a compromise between manoeuvrability and stability. In other words: improving stability while decreasing manoeuvrability characteristics.
2. Introducing a velocity dependency in the steering system.
3. Try if implementing one or more suggestions of this study give sufficient improvement.
4. Trying to develop a mechanism for the front to rear axle rotation that has a very low kinematic transfer function at small input angle and a very large transfer function at large steering angles.

References

{Winkler} Winkler et al., Rollover of heavy commercial vehicles, 2000, Society of Automotive Engineers inc., Warrendale, PA, USA

{Den Hartog} Hartog, J.P. Den, Mechanical Vibrations; fourth edition, New York: McGraw-hill, 1956.

{Schiphol1} Statistical annual review 2000, Amsterdam Airport Schiphol, 2001, Schiphol C.

{Schiphol2} Annual report Schiphol group 2000, Amsterdam Airport Schiphol, 2001, Schiphol C.

{Willeke} Willeke, H., Messung und modellierung der Fürungseigenschaften von Nutzfahrzeugreifen, Fakultät für Maschinenwesen der Universität Hannover,1996, Hannover.