

## Shimmy

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# SHIMMY, AN INTRODUCTION

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## **ABSTRACT**

In this report shimmy stability is investigated with the use of simple linear analytical models. The nose landing gear of a helicopter which is being developed at DAF Special Products is used as an example.

Shimmy stability is mainly considered to be a function of the trail and the taxi speed of the airplane. The string model is used to model the tire. The variations in the tire parameters have great influence upon the stability, therefore it is difficult to draw firm conclusions. To obtain stability a shimmy damper is required, except when a large trail is being used. The lateral and torsional stiffness of the landing gear beyond a certain value no longer have influence upon the shimmy stability.

This report is meant as an introduction into the shimmy problem and as a start for further research.

## Symbols:

$\alpha$	:	yaw angle
$\sigma$	:	relaxation length
$\theta$	:	swivel angle
$a$	:	half tire footprint length
$B_r$	:	coefficient of viscous damping
$C_{\text{tir}}$	:	cornering stiffness of the tire
$C_{Fy}$	:	static lateral stiffness of the tire
$C_{\text{ma}}$	:	aligning stiffness of the tire
$d_0$	:	inner diameter of the sliding member
$d_1$	:	outside diameter of the sliding member
$e$	:	trail
$E$	:	Young's modules
$F_y$	:	lateral force on the tire
$I$	:	moment of inertia of the swiveling member about the swivel axis
$I_s$	:	inertia sliding member
$K_l$	:	coefficient of the lateral stiffness of the sliding member
$K_r$	:	coefficient of the torsional stiffness of the torque links
$l$	:	effective length of sliding member
$m$	:	total mass of the swiveling part
$v$	:	velocity of the landing gear in the global x direction
$\bar{x}$	:	global coordinate of movement
$y$	:	lateral displacement
$\bar{y}$	:	global coordinate

## SHIMMY, AN INTRODUCTION

### CONTENTS:

	Page
1. Introduction	1
1.1 History	2
2. Analytical model	4
2.1 Introduction	4
2.2 Tire model	5
2.3 Influence rotational damping	5
2.4 Influence lateral stiffness	8
2.5 Influence torsional stiffness	11
3. Conclusions	14
4. Recommendations	15
5. References	17
Appendix A Tire model	19

## 1. INTRODUCTION

"Shimmy" is a word used for a movement caused by self excitation of a mechanical system. The movement can occur with steerable wheels of any vehicle and with wheels in which the flexibility of the suspension is important. The movement can be induced by an external excitation, for example by an unbalance in the wheel or roughness of the runway. The most striking example of this phenomenon is the vibration of one of the wheels of a shopping trolley. Under unfavourable circumstances shimmy can cause the failure of the construction.

Certain aircraft landing gear configurations are highly sensitive to shimmy. One of the problems in the design of aircraft landing gear systems is that of assuring that the system is dynamically stable from a shimmy standpoint.

In this report preliminary predictions about the stability of the shimmy movements of a typical nose landing gear will be drawn with the use of an analytical model.

DAF Special Products has acquired a contract for developing the landing gear of a helicopter (NH90). Therefore the characteristic nose landing gear of the land based version (TTH) is chosen as an application.

## 1.1 History

Since the twenties much has been written about the shimmy phenomenon. The following is a summary of the researches made into shimmy.

W.J. Moreland [10] analyses in his article "The story of shimmy" (1954) a model with four degrees of freedom (d.o.f.).

A tire model is used to relate lateral displacement and force and which also describes the transient behaviour of the yaw angle. The self aligning moment of the tire is not taken into account.

The stability of the model is determined by the Hurwitz criterium. The conclusions which result from this are confirmed by model and full scale tests.

Moreland underlines the influence of the moment of inertia of the wheel, lateral and torsional stiffness of the strut on the stability. Further, he emphasizes that increasing the trail and damping do not in all cases have a stabilizing effect.

H.B. Pacejka [11] (1966) describes in his thesis the transient tire behaviour with the so called string model. Pacejka studied the influence of non linear effects such as friction and clearance upon the shimmy behaviour.

He emphasizes the influence of the different tire parameters upon the shimmy behaviour. The Hurwitz criterium is used to determine the stability.

R.J. Black [2] (1976) observes in his article that it is advisable to include the movements of the fuselage in the shimmy analysis.

D.T. Grossman [8] (1980) demonstrates from an analysis and tests with a F-15 nose landing gear that shimmy is strongly dependent on the torsional freeplay in the landing gear. Parameter variations further demonstrate that the yaw coefficient of the tire and the friction in the damper, which is dependent on the vertical load, have a large influence on the shimmy phenomenon.

In the report [3], "Dynamic analysis of a Fokker 100 main landing gear, the authors point out the large influence of the cornering stiffness of the tire. In this report the equations for a model with a finite number degrees of freedom are obtained by using a special form of the powerful Lagrangian formalism. In this model the tire is modelled with the Pacejka string model.

In the above mentioned articles the analytical models are supported by model and/or full scale tests.

These articles are just an selection of many articles written about the shimmy phenomenon. This selection shows that many factors can affect shimmy stability of an aircraft landing gear.

## 2. ANALYTICAL MODEL

### 2.1 Introduction

The NH90 nose landing gear is a typical cantilevered landing gear arrangement (see figure 2.1). It consists of two wheels which can rotate about the axle. The axle is fixed to the sliding member by the axle fitting. The lower part (wheels, axle, sliding member, torque links) can freely swivel about the vertical strut axis. The main fitting is fixed to the fuselage.

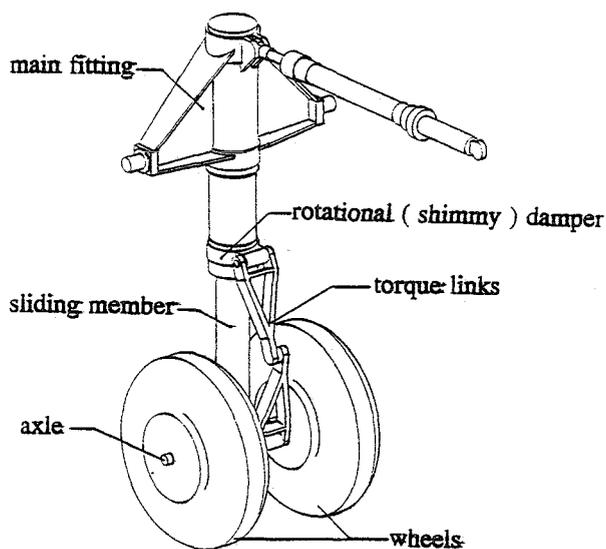


Figure 2.1 NH90 nose landing gear TTH version

In this chapter a simple dynamic model for the free swiveling nose gear of the NH90 will be set up step-by-step:

- The first model consists of one degree of freedom (d.o.f.). This model neglects the lateral, vertical and torsional stiffness of the landing gear. The model is used to investigate the influence of the torsional damping.
- The second model consists of two d.o.f. It is extended to include the lateral stiffness of the gear.
- The third model consists of three d.o.f. It is extended to include the torsional stiffness of the gear.

## 2.2. Tire model

The shimmy phenomenon is largely influenced by the behaviour of the tire. Therefore it is important to model this tire well. In reference [5] it is stated that the "string model" is very useful for making a shimmy analysis.

In this report the string model as described by H.B. Pecejka [11] is used. This string model describes the transient behaviour of a tire in the horizontal plane. A linear differential equation is used to describe the string model. This equation relates the yaw angle ( $\alpha$ ) and the swivel angle ( $\theta$ ).

String equation:

$$\sigma \dot{\alpha} + v\alpha + \frac{r}{y} + a\dot{\theta} - v\theta = 0 \quad (2.2)$$

This model is common to all dynamic models of the landing gear investigated.

Appendix A gives a more detailed description of the string model and the parameters used.

## 2.3 Influence rotational damping

Figure 2.2 shows the simple model for the description of the movements of a nose gear.

The following effects are to be considered:

- freedom of motion in  $\theta$  direction
- damping in  $\theta$  direction (B<sub>1</sub>)
- reaction force and moment on the tire, respectively  $F_y$  and  $M_z$
- drift phenomenon of the tire ( $\alpha$ ) due to lateral elastic deformation and the forward rolling of the tire.

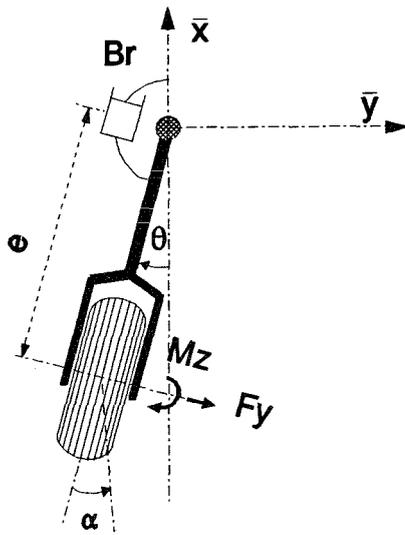


Figure 2.2 Shimmy model 1 d.o.f.

The following assumptions are made:

- only small displacements about the equilibrium position are considered
- the two tires are modelled as one string tire model which is located at the midpoint of the axle
- the velocity ( $v$ ) in  $x$ -direction is constant
- the total mass ( $m$ ) of the swiveling part is concentrated at the axis of the axle ( $m = 40$  kg)
- the sliding member is rigid
- gyroscopic effects due to wheel rotating are not taken into account.

This model neglects the lateral, vertical and torsional stiffness of the landing gear.

The linearised differential equations are obtained by using the Lagrange formalism.

$$(I+me^2)\ddot{\theta} + B_r\dot{\theta} + e2F_y - 2M_z = 0 \quad (2.2)$$

with:  $F_y = C_{ta} \cdot \alpha$   
 $M_z = -C_{ma} \cdot \alpha$   
 $I =$  the moment of Inertia about the swivel axis  
( $I = 1.01 \text{ kgm}^2$ ).

For a complete review of the employed symbols refer to the list of symbols. The numbers between brackets are the defined values for the NH90 nose landing gear. Together with formula 2.1 we get the following set of mixed differential equations:

$$(I + me^2)\ddot{\theta} + B_I\dot{\theta} + 2(C_{f\alpha} + C_{m\alpha})\alpha = 0 \quad (2.3)$$

$$\sigma\dot{\alpha} + v\alpha + \dot{y} + a\dot{\theta} - v\theta = 0 \quad (2.1)$$

with  $y = -e\theta$

Stability of these equations, representing an autonomous system, is determined by calculating the eigenvalues with the use of a computerprogram; MATLAB.

The stability is mainly considered to be a function of the trail (e) and the taxi velocities (v) of the airplane. The stability is determined for different velocities with different values of the trail. In this way stability of the system can be visualized in the (e,v) parameter plane.

Figure 2.3 shows the influence of the damping in the (e,v) parameter plane. It can be seen that if the rotational damping increases the area of instability becomes smaller.

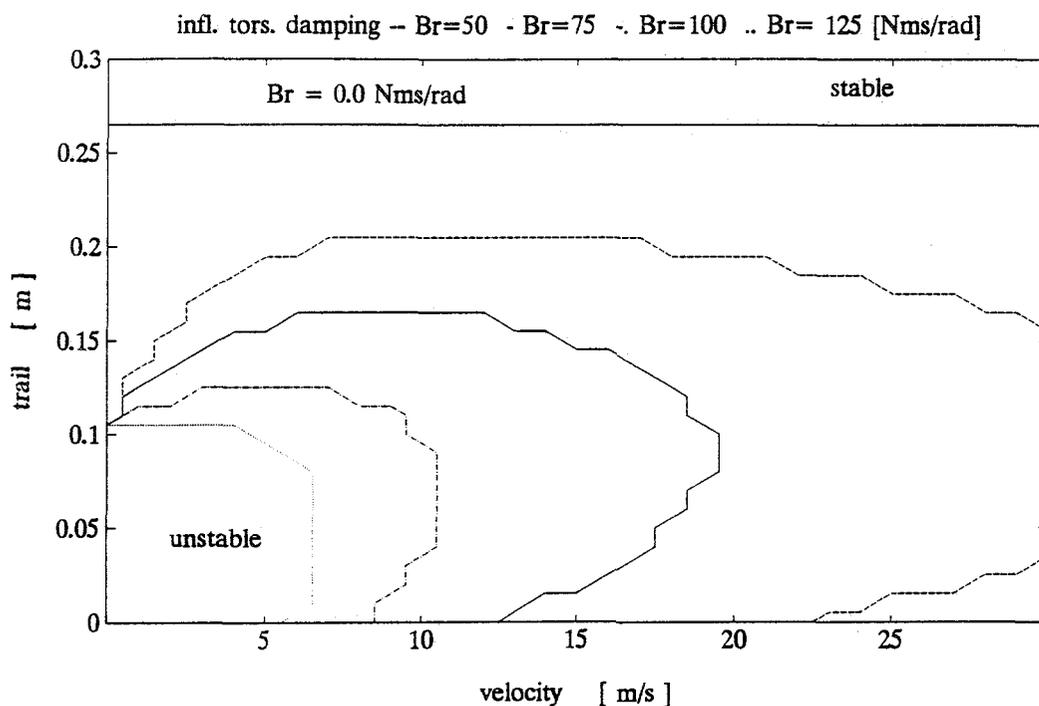


Figure 2.3 Unstable areas in the (e,v) parameter plane

## 2.4 Influence of the lateral stiffness

The model as shown in paragraph 2.3 is extended to include the lateral stiffness of the nose gear (see figure 2.4).

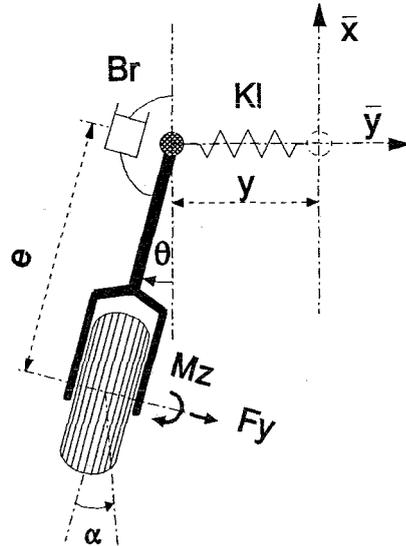


Figure 2.4 Shimmy model 2 d.o.f.

Using this model we get the following set of mixed linear differential equations:

$$m\dot{y} + m\dot{\theta} e + yK_l + C_{f\alpha}\alpha = 0 \quad (2.4)$$

$$I\ddot{\theta} + B_I\dot{\theta} - eK_l y + C_{m\alpha}\alpha = 0 \quad (2.5)$$

Tire model:

$$\sigma\dot{\alpha} + v\alpha + \frac{1}{y} + a\dot{\theta} - v\theta = 0 \quad (2.1)$$

with:  $y = -y - \theta e$

It is assumed that the lateral stiffness of the nose gear is mainly determined by the lateral stiffness of the sliding member. The angular displacements due to lateral displacements are neglected. This means that no vertical displacement due to lateral stiffness is working on the wheels. See figure 2.5.

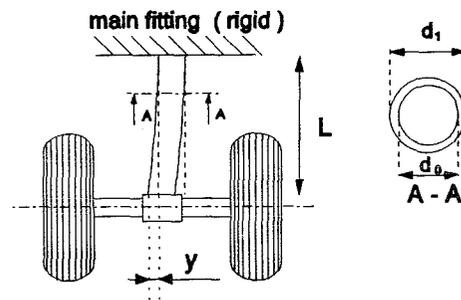


Figure 2.5 Lateral flexibility sliding member

Determination lateral stiffness:

$$k_l = \frac{3EI_s}{L^3} \quad (= 30.3 \cdot 10^6 \text{ N/m})$$

- with:
- E : Young's modulus = 200000 N/mm<sup>2</sup>
  - $I_s$  : Inertia =  $\pi/64 (d_1^4 - d_0^4)$
  - $d_1$  : outside diameter sliding member (88.772 mm)
  - $d_0$  : inner diameter sliding member (82.37 mm)
  - L : length sliding member; taken the stroke of the shock absorber into account (250 mm).

Lateral stiffness is dependent on the stroke of the shock absorber. In this model lateral stiffness is assumed to be a constant value.

Figure 2.6 shows the influence of the lateral stiffness in the (e,v) parameter plane with constant rotational damping. This figure also shows that increasing the lateral stiffness beyond a certain value no longer has an influence on the stability area. At infinite stiffness, this model simplifies to the 1 d.o.f. model of paragraph 2.3.

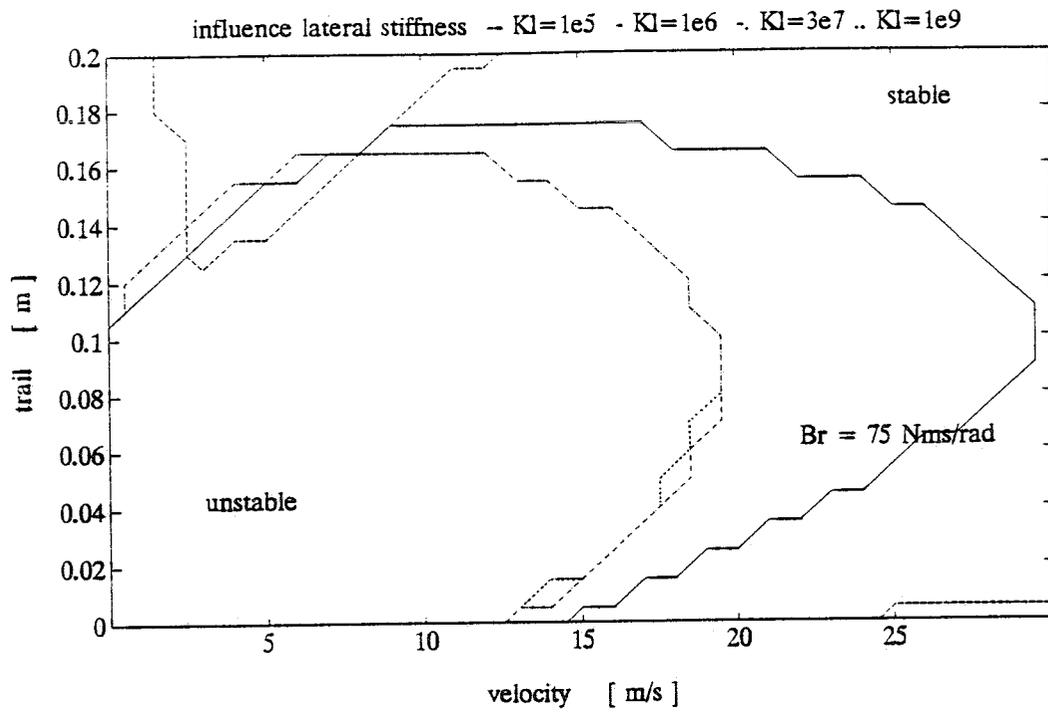


Figure 2.6 Unstable areas in the  $(e,v)$  parameter plane

## 2.5 Influence of the torsional stiffness

Starting point is the same model as is used in paragraph 2.4.

Including torsional stiffness of the sliding member and torque links in this model gives an additional degree of freedom ( $\theta_1$ ). The torsional stiffness between the shimmy damper and the axle is determined by the torsional stiffness of the torque links. The value of the stiffness is obtained by using FEM calculations and is estimated at:

$k_t = 138000 \text{ Nm/rad}$ . Using this model we get the following set of mixed differential equations.

$$m\ddot{y} + me\ddot{\theta} + K_L y + C_{fa} \dot{\alpha} = 0 \quad (2.6)$$

$$I\ddot{\theta} + K_r(\theta - \theta_1) - K_L e y + C_{ma} \dot{\alpha} = 0 \quad (2.7)$$

$$K_r(\theta_1 - \theta) + B_r \dot{\theta}_1 = 0 \quad (2.8)$$

Tire model:

$$\sigma \dot{\alpha} + v\alpha + \frac{z}{y} + a\dot{\theta} - v\theta = 0 \quad (2.1)$$

with:  $\bar{y} = -y - e\theta$

The influence of the torsional stiffness on the stability is shown in figure 2.7. This figure also shows that increasing the torsional stiffness beyond a certain value no longer has an influence on the stability area.

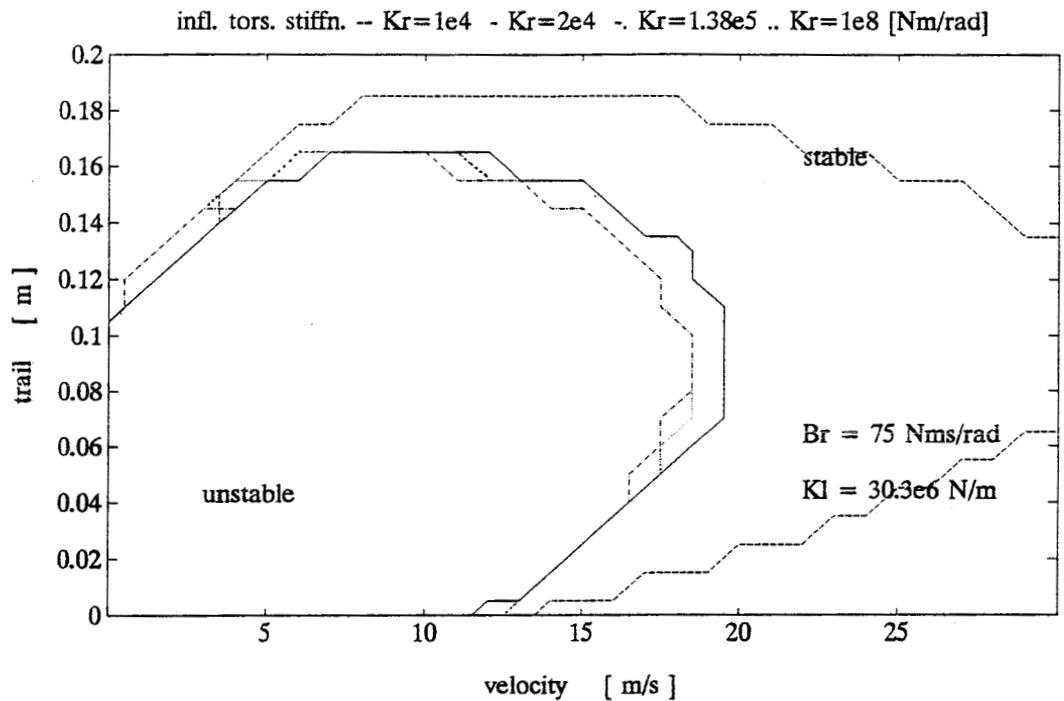


Figure 2.7 Unstable areas in the  $(e, v)$  parameter plane

Figure 2.8 shows the influence of rotational damping for the model with 3 d.o.f.. One can see that, in case of the NH90 model, addition of the lateral and torsional stiffness has no impact on the stability areas. (Compare figure 2.3 and 2.8.)

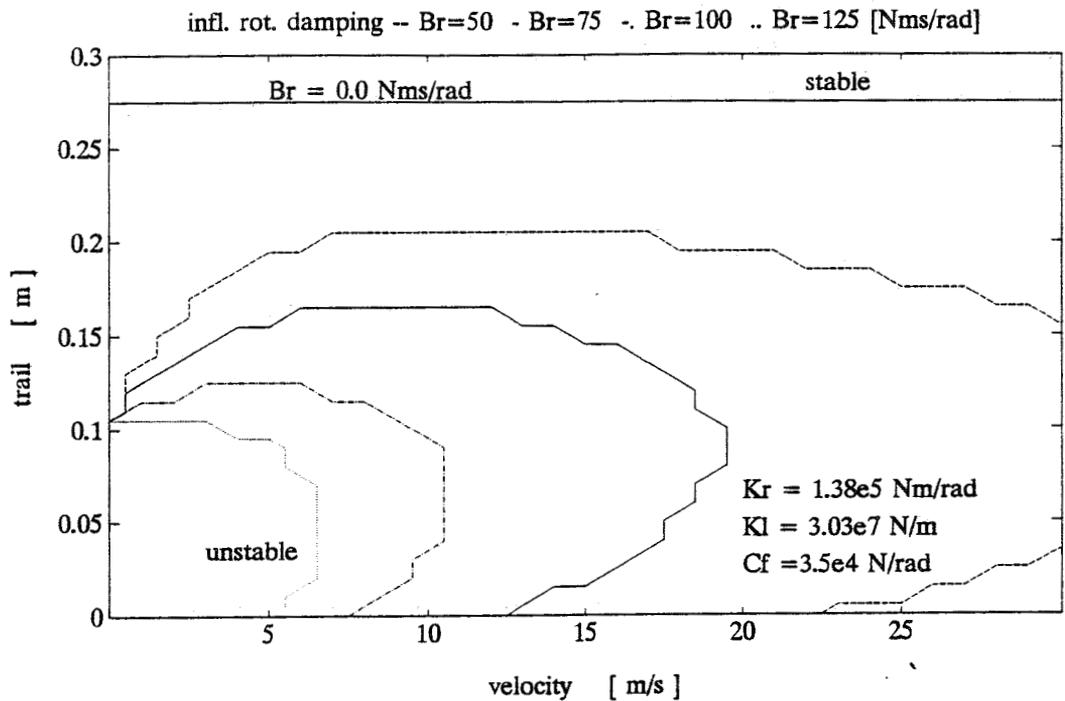


Figure 2.8 Unstable areas in the  $(e, v)$  parameter plane

Passive steering is one of the requirements for the NH90 TTH helicopter. To obtain passive steering with the use of tail rotor trust a trail of 0.0762 m. is needed. Figure 2.9 shows rotational damping needed to obtain stability. Calculations are made assumed constant rotational and translational stiffness.

This figure also shows the influence of the cornering stiffness ( $C_{\alpha}$ ) of the tire.

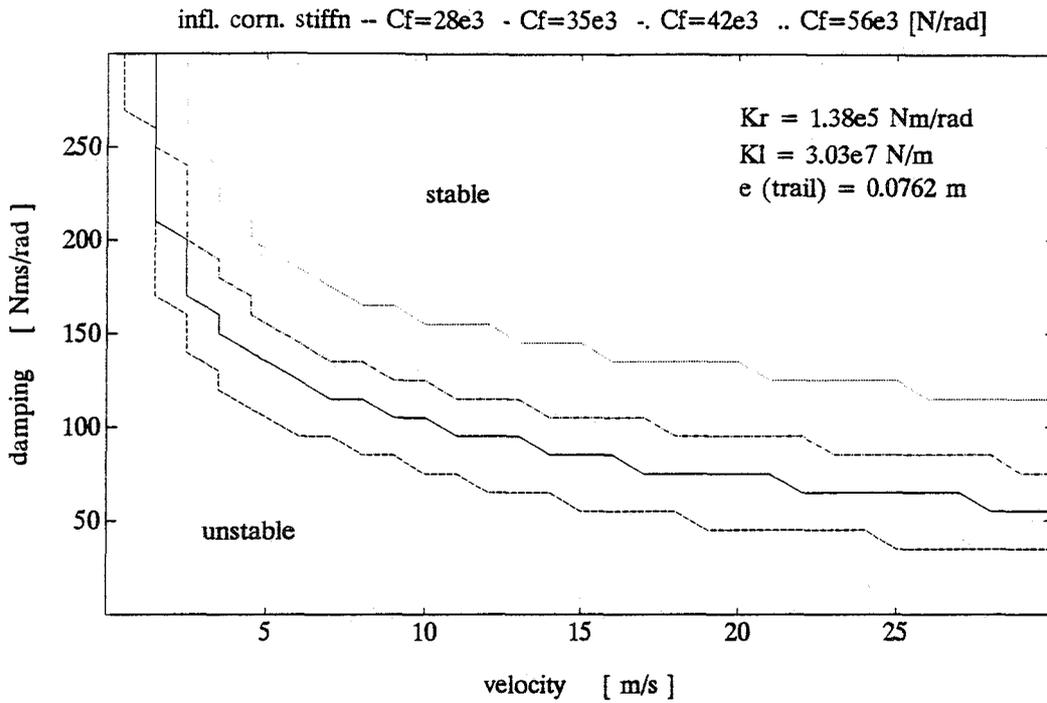


Figure 2.9 Unstable areas in the  $(Br, v)$  parameter plane

### 3. CONCLUSIONS

The main issue in the shimmy analysis is how far the model really describes the behaviour of the real system. In the absence of test data it is not possible to make any statements about this, so we cannot draw firm conclusions. Trends and parameter studies however can be investigated in this way.

The model used in this report certainly contributes to a better understanding of the shimmy phenomenon. The presentations are very useful to determine the sensitivity to the different influencing parameters.

#### Tire

The different tire parameters have a large influence on the stability. To make quantitative statements about damping and stiffness it is necessary to have reliable data for the tire. This is not available, so only qualitative conclusions can be drawn.

#### Damping

The minimum trail of 0.0762 m (required for passive steering) for the NH90 does not assure shimmy stability. Therefore a shimmy damper is required. If no shimmy damping is used a minimum trail of 0.275 m would be required, keeping in mind the restrictions mentioned above.

#### Stiffness

Increasing both the lateral and torsional stiffness beyond a certain value, no longer has an influence on the stability area. From a shimmy stability point of view it is possible to optimize the stiffness which results in weight reduction. This could partly compensate weight growth caused by the shimmy damper.

#### 4. RECOMMENDATIONS

##### Literature survey

Much has been written about the shimmy phenomenon. A more extensive literature survey would be useful.

##### Extension of the model

The model can be extended with:

- addition of a vertical d.o.f.
- addition of angular displacements about the horizontal strut axis
- addition of gyroscopic effects.

##### Non-linearities

In this report linear models are used to investigate the shimmy phenomenon. A more realistic model has to take non-linearities into account such as:

- non-linear damping of the shimmy damper. Damping can be provided by a friction or hydraulic damper (for which the damping force is dependent on velocity squared)
- torsional friction in the bearing of the shock strut which depends upon the pressure and vertical load in the shock strut
- the strut torsional clearance
- large displacements which cause geometric non-linearities.

Solving the stability problems of such non-linear systems requires other solution methods (cf. Fey [7]).

Please note however, Non-linearities can cause the change of an initial unstable solution into a stable limit cycle, linear computations only predict the initialisation of shimmy.

##### Tire

The tire plays a very dominant part in the shimmy analysis therefore a more profound study is necessary. The tire model can be extended to include :

- influence of the tire footprint width
- gyroscopic effects due to elastic deformation of the tire
- non linearities due to large displacements and partial sliding of the tire.

However, extension of the tire model has only limited use for study purposes, if reliable data for the tire is not available.

### Frequency analysis

Serious problems can occur when excitation frequencies are in the range of the natural frequencies and the shimmy damping is not sufficient. These excitation frequencies can be induced for example by the rolling of an unbalanced wheels, uneven runways or the main rotor of the helicopter.

### Tests

Whenever prototypes are available, laboratory tests usually are conducted to check the analytical model. A final verification of the design can be done by airplane tests.

## 5. REFERENCES

1. Beery R.W., Tsien V.C., 1962, Mathematical analysis of corotating nose gear shimmy phenomenon, Journal of the Aeronautical Science, december 1962.
2. Black J.B., 1976, Realistic evaluation of landing gear shimmy stabilization by test and analysis, SAE 760496.
3. Boeschoten R., Odijk F.A., Verbeek B., ter Wylen H.Z., 1990, Dynamica analyses van een Fokker 100 hoofdlandingsgestel, UCN Aerospace, DAF Special Products B.V.
4. van Campen D.H., 1989, Het dynamisch gedrag van constructies, college notes, University of Technologie, Eindhoven, Netherlands.
5. Clark S.K., Dodge R.N., 1974, Nybakken G.H., 1973, Dynamic properties of aircraft tires, Journal of Aircraft, 11(3): 166-172.
6. Curry N.S., 1982, Landing gear design handbook, First Edition.
7. Fey R., 1962, Steady-state behaviour of reduced dynamic systems with local nonlinearities, PhD thesis, University of Technology, Eindhoven.
8. Grossman D.T., 1980, F-15 nose landing gear shimmy taxi test and correlative analyses, SAE 801239.
9. den Hartog J.P., 1956, Mechanical vibrations, Mc. Graw Hill, fourth ed.
10. Moreland W.L., 1954, The story of shimmy, Journal of Aeronautical Science, vol. 21, no. 12.
11. Pacejka H.B., 1966, The wheel shimmy phenomenon. A theoretical and experimental investigation with particular reference to the nonlinear problem, PhD thesis, University of Technology, Delft, Netherlands.

12. Pacejka H.B., 1988, Modelling of the pneumatic tire and its impact on vehicle dynamic behaviour, University of Technology, Delft, Netherlands.
13. Pacejka H.B., Voertuigdynamica B, college notes, University of Technology, Delft, Netherlands.
14. Simley R.F., Horne W.B., 1960, Mechanical properties of pneumatic tires with special reference to modern aircraft tires, Technical Report TR-R-64, NASA.

## APPENDIX A

### String model

The string model (cf. Pacejka [10],[12]) describes the transient behaviour of a tire in the horizontal plane. Figure A.1 shows the string model in the horizontal plane.

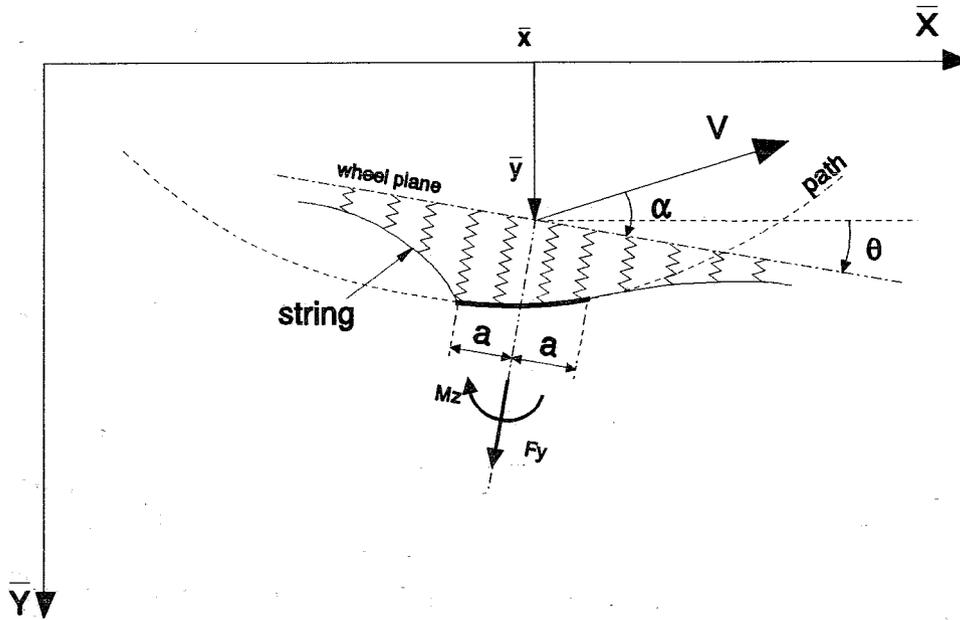


Figure A.1 Top-view of the string model and its position with respect to the fixed frame

The string model emanates from the following assumptions:

- small deflections are considered
- no skidding occurs in the contact plane
- the tire has no mass.

### Determination of the tire parameters.

The different tire parameters have the following relations:

$$C_{m\alpha} = C_{f\alpha} \frac{a\sigma(\sigma + a) + a^3/3}{(\sigma+a)^2} \quad (\text{A.3})$$

$$\sigma = \frac{C_{f\alpha}}{C_{Fy}} - a \quad (\text{A.4})$$

So the determination of the tire parameters is restricted to:

- $C_{f\alpha}$  : cornering stiffness
- $C_{Fy}$  : static lateral stiffness
- $a$  : half the foot print length

These tire parameters are dependent on the vertical load and the tire inflation pressure. For the HH90 predictions of the static lateral stiffness and the foot print length exists. For the shimmy analysis these two items of data estimated at:

$$\begin{aligned} C_{Fy} &= 130000 \text{ N/m} \\ a &= 0.108 \text{ m.} \end{aligned}$$

At this moment no values are known for  $C_{f\alpha}$ , therefore we use formula (A2) for the determination of  $C_{f\alpha}$ .

Assuming  $a \leq \sigma \leq 3a$ ,  $C_{f\alpha}$  reads :

$$28000 \text{ Nm/rad} \leq C_{f\alpha} \leq 56000 \text{ Nm/rad.}$$

$C_{f\alpha} = 35000 \text{ Nm/rad}$  ( $\sigma \approx 1.5 a$ ) is used as the nominal value for  $C_{f\alpha}$ .