Implementation of multiple thermodynamic airspring systems in ADAMS

René van Marrewijk and Edward de Jong NedTrain Consulting
Ralf Ahrens ALSTOM LHB

1. Introduction

In many railway vehicle designs, airsprings are used in the secondary suspension to connect the vehicle body with the bogie frame. Normally these airsprings are connected with each other by means of pipes and valves, resulting in a multiple airspring system. Multiple height control units are commonly used and placed on arbitrary positions on the vehicle

For dynamic as well as (quasi-) static calculations, airspring systems can have a significant influence on the behaviour of the vehicle, accelerations and wheel-rail forces. For instance when calculating the derailment safety, the way various airsprings are interconnected has a major influence on the results.

NedTrain Consulting (the former NS Materieel Engineering) is an independent business unit of the Netherlands Railways (NS) and is a member of the development team for ADAMS/Rail.
On behalf of the complete ALSTOM concern, NedTrain Consulting developed a tool in ADAMS which is able to create multiple non-linear airspring systems including height controls. The base of this tool is the thermodynamic Krettek airspring model, which is as a standard ADAMS/Rail component. NS Materieel Engineering has presented this model on the ADAMS Users' Conference 1998 in Paris.

2. Project activities

The objectives of the project for ALSTOM are:

- Development of the theory of different connections between airsprings and height controls.
- Implementation of the theory in ADAMS/Rail by means of User Defined Entities (UDE).
- Verification of the theory by simulations in ADAMS/Rail.

After realisation of the project, it is possible to create multiple airspring systems in ADAMS/Rail. The influence of these airspring systems on vehicle behaviour can be calculated and optimised. The standard quasi-static derailment safety calculations (according to ERRI B55 RP8) are sensitive for airspring systems and therefor used as a simulation case.

2.1 Development of the theory

When using the single Krettek airsprings, expression for the pressures and temperatures in the airspring volumes are available. The flow to and from the airspring volume is defined as a function of these quantities and the type of connection. This mass flow through the connection is added to the definition of the pressures, temperatures, etc. in the airsprings.
The theory of three different airspring connections is developed and implemented in ADAMS:

- Connection with a pipe
- Connection with a maximum pressure difference
- Connection with a fixed pressure rate.

2.1.1 Connection with a pipe

The flow G through the pipe is dependent on the construction parameters of the pipe like (constant) diameter, length and friction. The laminar and turbulent flow, which is caused by the pressure difference between the airsprings, is taken in account as a function of the Reynolds number.

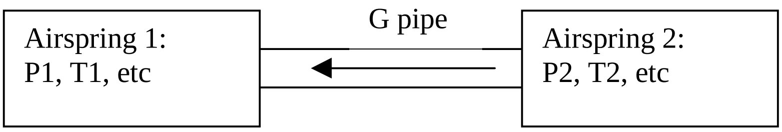


Figure 1*: Connection with a pipe*

The equations defining the flow through the pipe are implemented in a simple model with two airsprings attached to a testrig, see *Figure 2*.

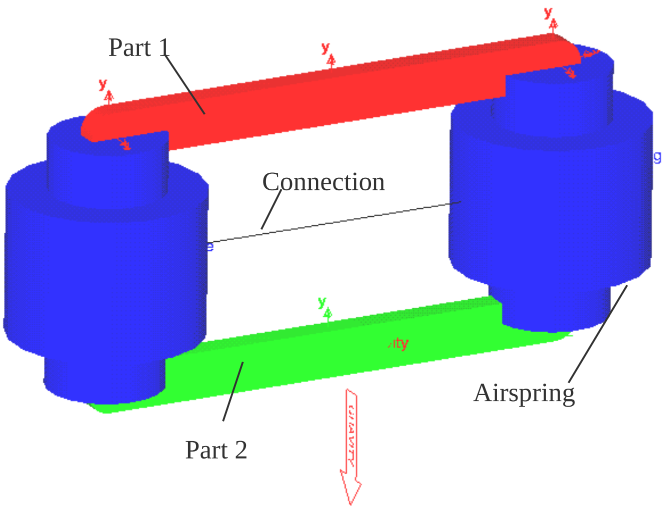


Figure 2*: Simple test model in ADAMS*

The transition from laminar to turbulent flow is obtained by defining a step function in the transition zone from Re=2300 to Re=4000. *Figure 3* shows the definition of the friction factor lambda as a function of the Reynolds number.

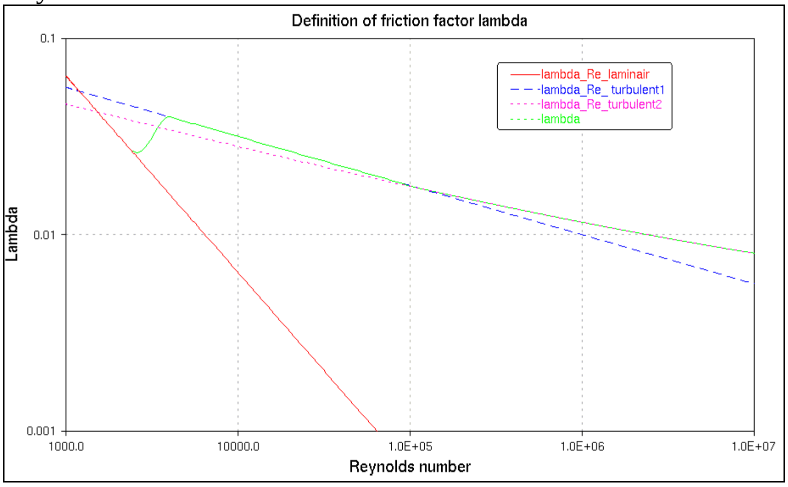


Figure 3 *Definition of the friction factor lambda in a pipe*

For laminar flow the friction decreases rapidly with increasing Reynolds numbers. With turbulent flow this decline decreases. For Reynolds numbers beyond 10^5 a further (however minimal) decline can be seen.

When this theory is implemented in ADAMS model, the connections will define flows rather then pressures. This implies that the equations have to be rewritten resulting in a definition of the mass flow through the connection to both airsprings.

2.1.2 Connection with a maximum pressure difference

For this connection, a limit exists to the maximum pressure difference between the airsprings. A schematic representation of this pressure limiter is shown in the *Figure 4*. With an increasing pressure difference, the valve will move to one side. As soon as the valve opening port is reached, a connection between two airsprings is created, resulting in a mass flow.

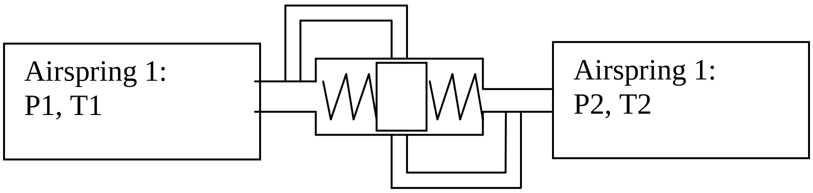


Figure 4: *Connection with a maximum pressure difference*

It is assumed that the displacement of the valve does not effect the volume of the pipe and reservoirs. Also when the maximum pressure difference is reached, the valve will open creating a constant orifice flow area, until the pressure difference drops below the threshold value.

The flow functions are implemented in ADAMS and defined as state variables. A variable representing the mass flow between the airsprings is created and switches at the desired threshold value from zero flow to the flow defined by the flow equations of Saint Vennant. The response of the test model in ADAMS to sinus shaped roll input with amplitude 0.03 m and frequency 1 Hz is shown in *Figure 5*

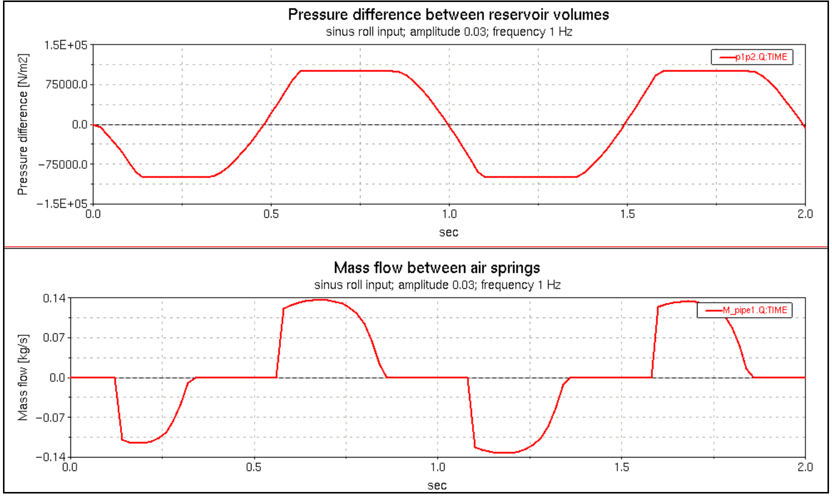


Figure 5: *Pressure difference and mass flow between airsprings*

It shows that the pressure difference does not exceed the prescribed limiting pressure of 10^5 N/m^2. In the lower plot, the mass flow is plotted. Obviously only the situation with an open valve will create a mass flow.

2.1.3 Connection with a fixed pressure rate.

The last defined connection is created to obtain a fixed pressure rate between two airsprings. This connection is shown in *Figure 6*:

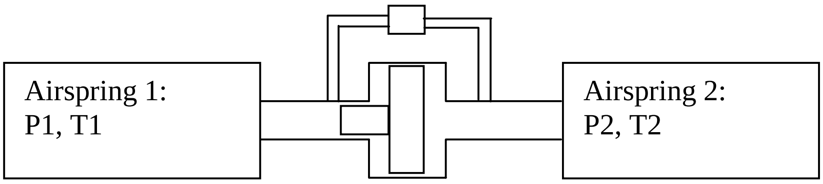


Figure 6: *Connection with a fixed pressure rate*

Figure 7 shows the response of the test model with this connection to a step function of the roll angle for different values of the orifice area A_{valve}.

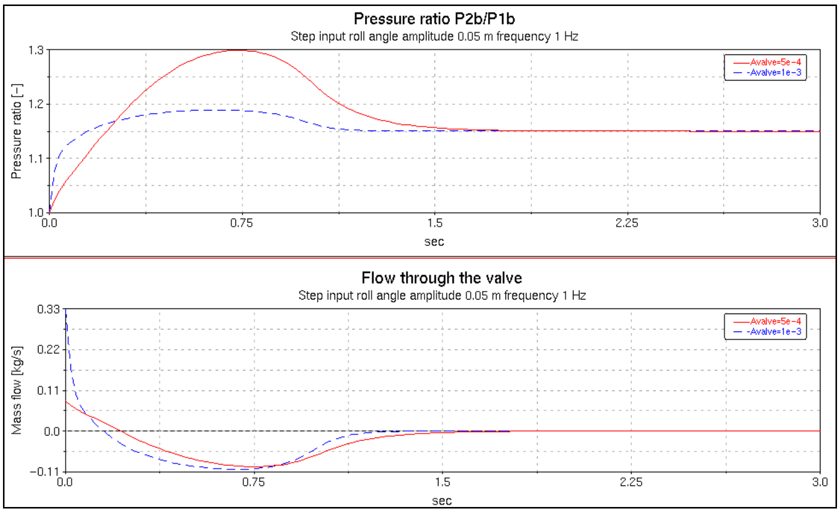
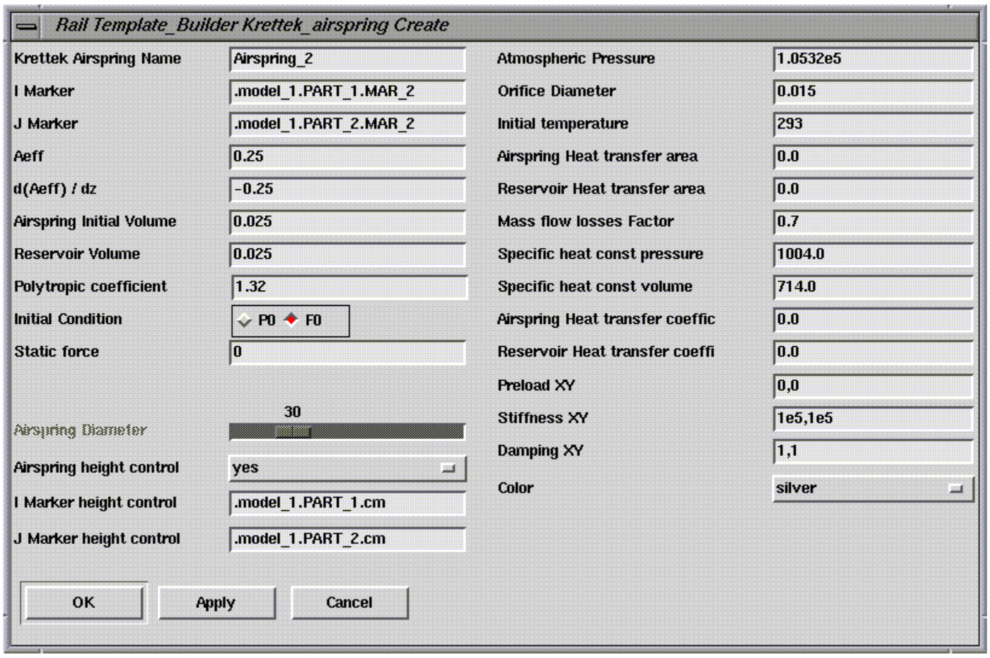


***Figure 7:** Response from test model with fixed pressure rate*

As expected the response for a larger orifice area is faster. It can be seen that the initial pressure ratio equals 1 resulting in an initial flow between the airsprings.

2.2 Implementation as UDE’s in ADAMS

Two User Defined Entities (UDE) are developed: one for the creation of a Krettek airspring and one for the connection between two arbitrary airsprings. Each airspring that is created can have its own height control on an arbitrary position. The characteristic of this height control (including dead zone) can be implemented using a spline. The dialog box of this Krettek airspring is shown in *Figure 8*.

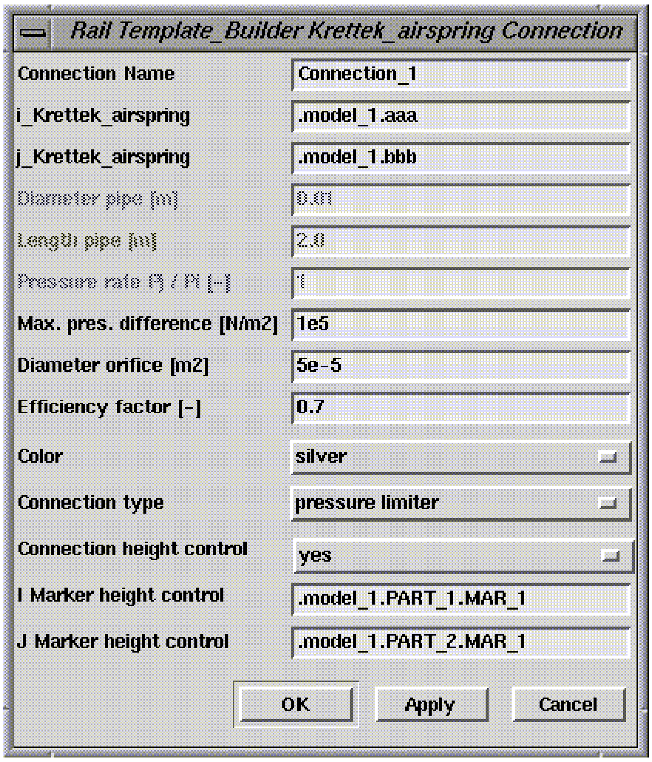

Rail Template_Builder Krettek_airspring Create

Krettek Airspring Name	Airspring_2
I Marker	.model_1.PART_1.MAR_2
J Marker	.model_1.PART_2.MAR_2
Aeff	0.25
d(Aeff) / dz	-0.25
Airspring Initial Volume	0.025
Reservoir Volume	0.025
Polytropic coefficient	1.32
Initial Condition	◇ P0 ◆ F0
Static force	0
Airspring Diameter	30
Airspring height control	yes
I Marker height control	.model_1.PART_1.cm
J Marker height control	.model_1.PART_2.cm

Atmospheric Pressure	1.0532e5
Orifice Diameter	0.015
Initial temperature	293
Airspring Heat transfer area	0.0
Reservoir Heat transfer area	0.0
Mass flow losses Factor	0.7
Specific heat const pressure	1004.0
Specific heat const volume	714.0
Airspring Heat transfer coeffic	0.0
Reservoir Heat transfer coeffi	0.0
Preload XY	0,0
Stiffness XY	1e5,1e5
Damping XY	1,1
Color	silver

Figure 8: *Dialog box of Krettek airspring*

For the airspring connection, a dialog box is created with an option menu for the connection type. Each connection can have its own height control on an arbitrary position, which acts on both airsprings. The dialog box of the connection is shown in *Figure 9*.


Rail Template_Builder Krettek_airspring Connection

Connection Name	Connection_1
i_Krettek_airspring	.model_1.aaa
j_Krettek_airspring	.model_1.bbb
Diameter pipe [m]	0.01
Length pipe [m]	2.0
Pressure ratio Pj / Pi [-]	1
Max. pres. difference [N/m2]	1e5
Diameter orifice [m2]	5e-5
Efficiency factor [-]	0.7
Color	silver
Connection type	pressure limiter
Connection height control	yes
I Marker height control	.model_1.PART_1.MAR_1
J Marker height control	.model_1.PART_2.MAR_1

Figure 9: *Dialog box of airspring connection*

The developed UDE's are implemented for ALSTOM in ADAMS/Rail and railway vehicles are modelled including different airspring systems. In this way, a flexible modelling method is created for all possible airspring systems in railway designs.

2.3 Simulations of airspring systems

For ALSTOM, different airspring constructions for railway designs are modelled using the developed UDE's. One particular construction will be described briefly in this paper which is the three point control with longitudinal connection. An schematic overview of this system is shown in *Figure 10*.

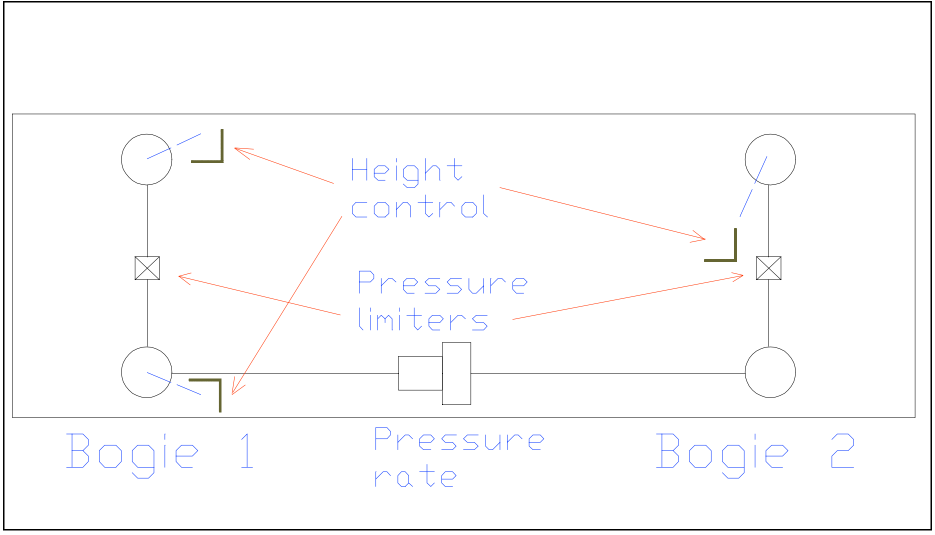


Figure 10: *Lay-out of three point control*

Some characteristics of this construction are:

- The longitudinal connection results in the absence of vertical wheel unloading due to twist in the track. This is only the case when the position of the centre of gravity (c.o.g.) in longitudinal direction and the pressure rate in the connection is well defined. If the position of the c.o.g. changes in longitudinal direction, initial wheel unloading will occur.
- A roll stabiliser is not necessary, because the lateral connection contains a pressure limiter and the airsprings can take up the rolling moment until the pressure limit is reached.

The response of such system will be investigated by means of an ADAMS/Rail model of a passenger coach.

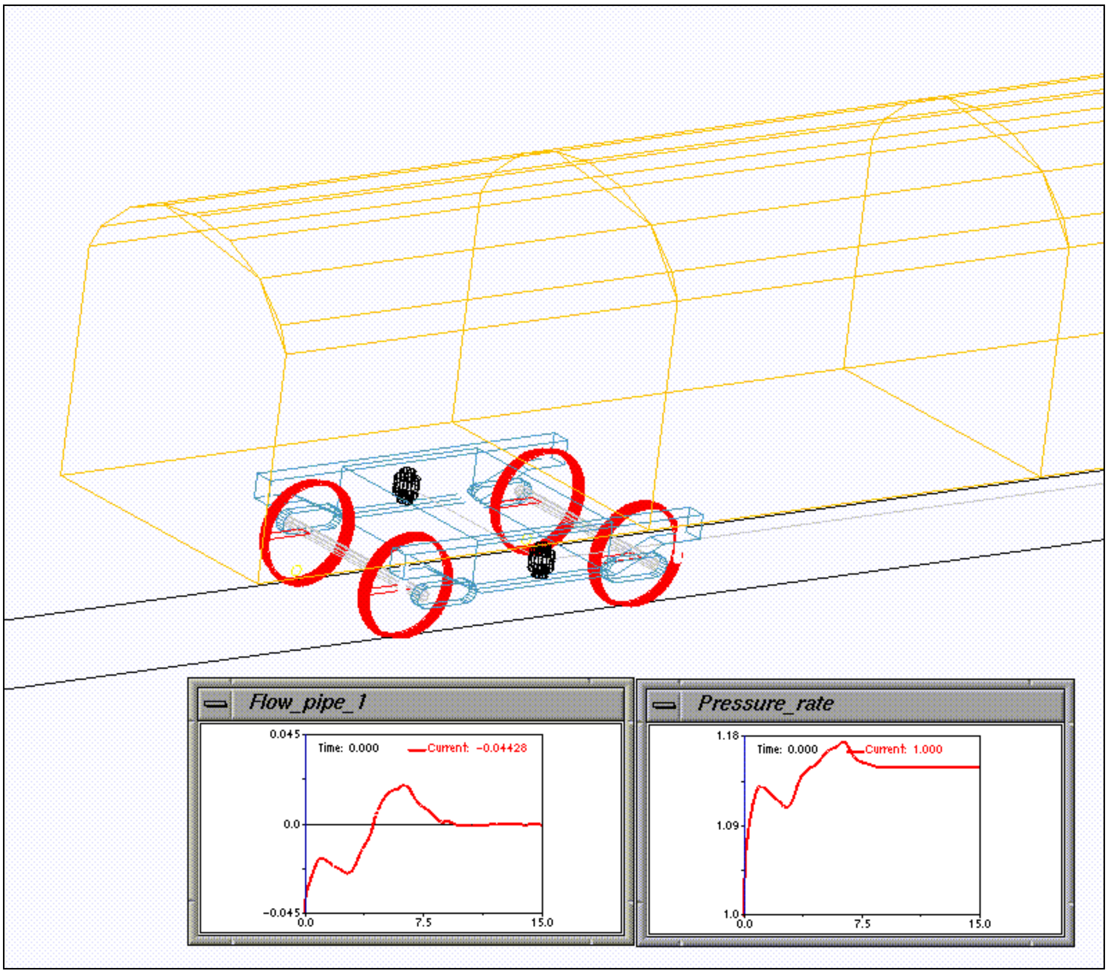


Figure 11: *ADAMS/Rail simulation using an airspring system*

Figure 11 shows the vehicle containing the described airspring. The vehicle runs with low velocity through a twisted track. This means that one rail moves down in vertical direction and the other rail remains on the same level. Two different cases will be discussed.

Case 1

In this case, the pressure rate in the longitudinal connection equals 1.0. The position of the c.o.g. in longitudinal direction is exactly between the two bogies. This means that different airspring forces are introduced between left and right side, which introduces wheel load differences. The airspring pressures are crossover equal. The results are shown in *Figure 12*.

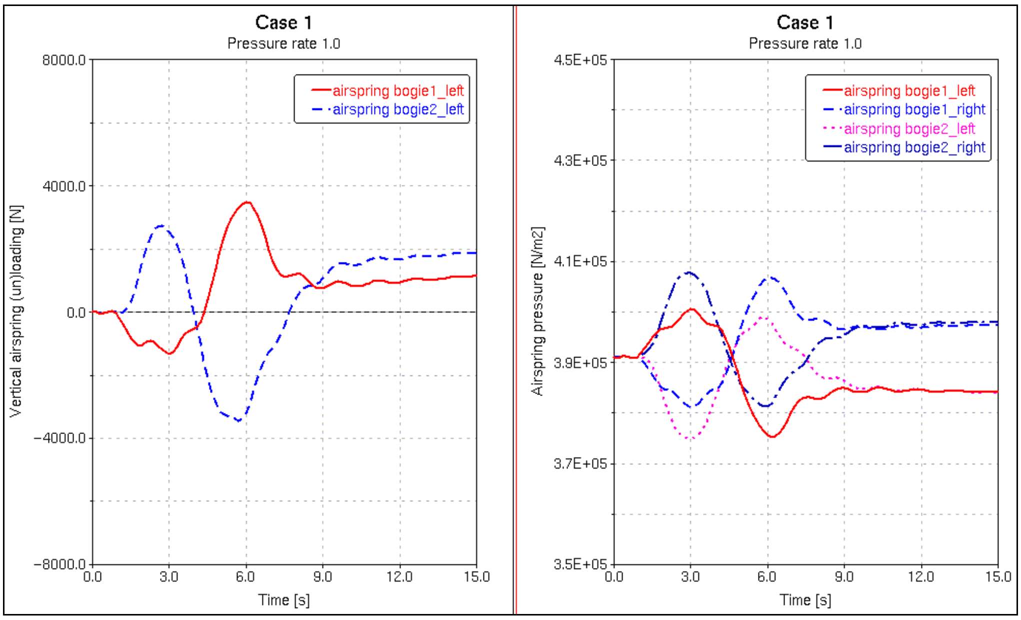


Figure 12: *Results of three point control system with pressure rate 1.0*

Case 2

In this case, the pressure rate in the longitudinal connection is changed to 1.15. This means that different airspring forces are introduced between left and right side, which introduce wheel load differences. The airspring pressures are crossover equal. The results are shown in *Figure 13*.

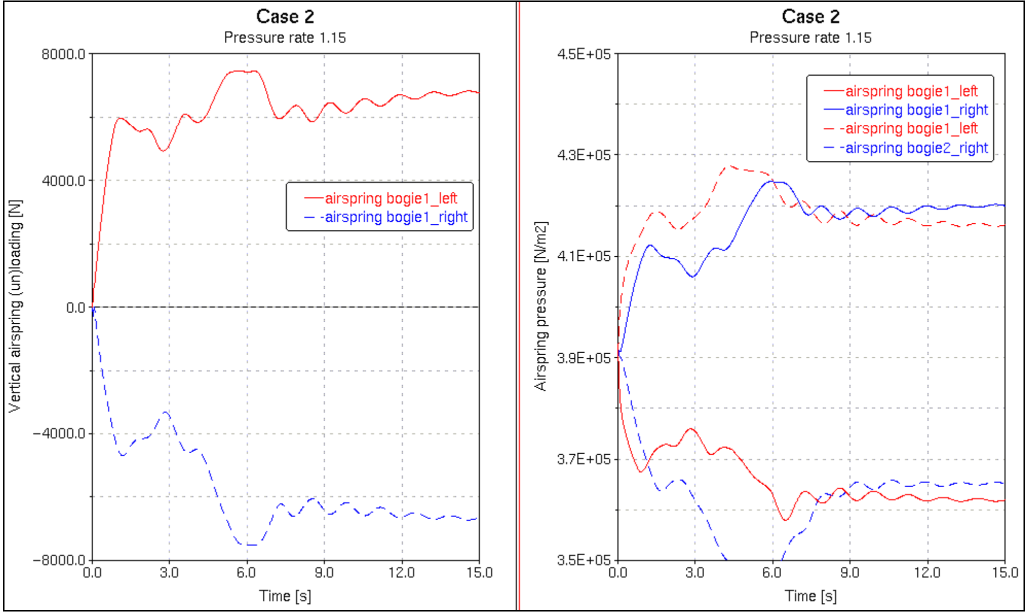


Figure 13: *Results of three point control system with pressure rate 1.15*

Through the pressure rate connection the vehicle body rests on the bogie on three imaginary points, in which the location of third point is defined by the chosen value of the pressure rate.

This tool enable optimisation of the airspring system and provides insight in the complex behaviour of coupled airspring systems.