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Brake Calculation Software for Commercial Vehicles

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Brake Calculation Software for Commercial Vehicles

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by

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Sammanfattning
Abstract

To ensure that a commercial vehicle has sufficient braking performance, properties as friction utilization, braking rate and braking distances are examined. Calculating the brake performance is, though not matematically difficult, very time consuming. Using modular concepts of vehicle design, a vast number of configurations regarding dimensions, weight and braking equipment adds further to the time and energy laid on brake related calculations.

The natural solution to the problem is to seek aid from computers. However, computerized brake calculations, in order to be efficient, needs highly specialized software. Presented, is a program explicitly designed to calculate braking performance for commercial vehicles.

Design emphasis is laid upon user frendliness, and modularity providing for easy upgrading of the program for dealing with future products.

The modular vehicle model used, tailored to computer aided braking performance calculation, is presented also.

Nyckelord
Keywords Commercial vehicle, Brake performance calculation, Software

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Preface

This thesis is the final report to a Masters degree in Mechanical Engineering at the Linköping Institute of Technology (Linköpings Tekniska Högskola, LiTH). The work was conducted at Scania CV AB in Södertälje between June and November 1998.

Acknowledgments

I would like to thank all the people at Scania CV and LiTH who have helped me through this work.

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Thanks also to Peter Engelke for proof reading and valuable feedback, and to all the people at the Brake, Suspension & General Vehicle Systems Department for their support.

Contents

Nomenclature

Symbols		
D	Distance	$[m]$
F	Force	$[N]$
L	Load	$[N]$
M	Moment	$[Nm]$
H	Height	$[m]$
W	Weight	$[kg]$
l	Length	$[m]$
g	Gravity constant	$9.82[m/s^2]$
η	Mechanical efficiency	[-]
P	Point	-
p	Pressure	[bar]
C	Constant	-

Indices	
F	Front
R	Rear
F|R	Front OR Rear
n	Normal (force)
b	Brake (force)
eff	Effective

Chapter 1

Introduction

This chapter describes the background and the purpose of this thesis work. A description of the disposition of this report is included to help the reader in navigating this document.

1.1 Background

Brake calculations are performed to determine stopping distances, braking rate and friction utilization for a vehicle. These properties are needed for determination of what braking system components, in terms of brake cylinders, brake levers and load sensing valves the vehicle should be equipped with, and to show that a vehicle of a certain configuration can meet requirements imposed by law.

At Scania, module concepts of design offer a high level of freedom for the customer to specify the overall configuration of the vehicle when ordering. This results in manufacturing a wide variety of vehicle specifications, from two to five axles, with a number of different axle distances. Other properties affecting brake performance is the customers choice of tires, ground clearance and inter-axle load distribution. Additionally, there are also differences in legal requirements on brakes between different parts of the world.

Whenever a new vehicle configuration or model is introduced, a brake calculation must be performed. In earlier days, engineers at Scania performed these calculations by hand, and later with the aid of computers.

The software tools in use today are custom-made, small programs and spreadsheet macros, written by consultants, and in many cases by the engineers themselves. There is no uniformity in the different tools, and calculation methods are often obscure to everyone but the tool designer. Often, this is inadequate, and the calculation has to be performed in a semi-manual way, or by combining an existing tool with own assumptions. This make brake calculations consume a lot of effort and time, in addition to increasing the hazard of miscalculation

1.2 Purpose

The purpose of this thesis work is to develop a user-friendly and powerful tool for calculating the impact on braking properties from a vehicles braking system, collecting the theories and methods into one program, with a consistent user interface.

1.3 Literature Survey

To get an understanding of commercial vehicles braking, a brief literature survey was performed at the Scania library. Older manually performed braking calculations were examined for algorithms and formulas to use in the program.

1.4 Disposition

To aid in reading this report, a short description of each chapter is provided, presenting the thread leading from one chapter to the next.

Chapter 2: Problem Description gives a specific description of the problem, as introduced in Chapter 1, in terms of calculation difficulties and the requirements for a tool used in these calculations.

Chapter 3: Brake Calculation Software presents the chosen solution, for the problem defined in Chapter 2. Thoughts behind the design, as well as tools used in the development process are discussed. The way calculated results are presented to the user is also discussed here. Finally, an example of how the program is to be used is provided.

Note that this section is *not* intended to serve as a user manual.

Chapter 4: Model and Calculation Methods describes the vehicle model used in the program introduced in Chapter 3, gives a description of how the parts interact during calculation of different properties, and shows calculation algorithm, using the model.

Chapter 5: Discussion and Future Work The resulting program, calculation results, users opinions and acceptance of the program is discussed. Included are suggestions where to emphasize future development, plus some possible extensions of the program.

Chapter 2

Problem Description

2.1 Brake Calculations

Calculations on properties of the brakes of a vehicle are not theoretically difficult to accomplish, providing that you have a proper calculation basis. Properties such as braking distances, braking ratio and distribution of braking effort among a vehicles axles can easily, though time-consuming, be calculated by hand, using carefully balanced approximations.

The reason for interest in the braking properties varies. A commercial vehicles brake performance is of course always vital, but it is especially important when a vehicle manufacturer needs to show that his product fulfills the requirements imposed by laws and regulations.

Considering the fact that Scania sells vehicles in numerous countries, with different regulations and demands are put on the product, in combination with the fact that the vehicles are sold in a wide variety of configurations, it's easy to realize that the calculations are numerous.

The properties of special interest here are the *braking rate* and the *friction utilization* (see Section 4.2). Occasions for examining these can be:

- When certifying new vehicle types
- When the marketing department is submitting an offer
- Introducing a vehicle on a new market
- Specializing a vehicle for a certain task
- Impact study on new developments

The ordering instance of a brake calculation might not have all the parameters on a vehicle. The basis for the calculation must therefor introduce a number of approximations, weighings and qualified guesses of vehicle parameters. It is vital

Figure 2.1: Eight-wheeled vehicle with two front axles

to understand that reasonable results can be achieved anyway, while the accuracy of the results is a matter of discussion.

Another reason for simplifying the calculation basis is reducing the information quantity that goes into a calculation, in order to minimize the total time from brake calculation order to actual result. Reusing vehicle parameters, by saving them for use at other calculations, where large configuration parts are the same allows for somewhat more refined calculations, without having to input a large amount of vehicle data.

At the same time, a mathematical model must not be too simple. If one regards the vehicle in Figure 2.1, it becomes obvious that a stiff body model is not adequate for calculating e.g the reaction forces from ground on wheels. The importance grows with the impact of brake pitching on the ground reactions.

Summarized, this will form the requirements set upon a tool to use for brake calculations.

2.2 Software Requirements

From previous attempts of making a specialized application for brake calculations some conclusions can be drawn:

User friendliness is important. A lot of time can be wasted if the function of some part of the program is misunderstood. Also, credibility of the calculation can get questioned if an incorrect calculation is presented to e.g certification authorities.

Prepare for easy upgrading. Documentation of the inner structure of the program provides for code reusage, and is a requirement for adding functionality to an existing program.

Stability. Few things are as annoying as having to redo work just because the tool crashed. If it, for some reason, is impossible for a program to continue executing, it should at least be possible to save partial work.

Platform independence. Since computer evolution is rapid, software turns unusable simply because the machine or operating system it executes on is replaced. Preparing the source code for compilation on other architectures is a good strategic move.

Krister Lindström, a former employee at the TCTSB department and extensive user of a brake calculation program developed for MS-DOS$^{(R)}$ in 1990-1993 drafted a set of requirements based on his experience:

- A new program should be written in a stable and well-known language
- Simple and nice-looking user interface
- Clear and self-instructing
- Nice-looking and legible result printouts
- Printout results in both tabular and plot form
- Should be able to calculate using different types of brakes
- Should be able to calculate for various national regulations

Lindström also emphasizes modularity and upgradability.

Further demands regarding the vehicle component parameters storing were also presented by Nils-Gunnar Vågstedt:

Data consistency. The parameters for a vehicle component should be continuously updated to avoid deviation from reality. Some form of fully or partly automated updating of parameters regarding e.g geometry of a bogie, to avoid erroneous results caused by use of inactual data.

Automated calculations. Using already-present vehicle data e.g in an existing database, the calculation should be performable without having to separately specify these parameters through the user interface of the program.

Chapter 3

Brake Calculation Software

3.1 The WBrake Program

This section describes an implementation of software aided brake calculations, the wbrake program. It is an application built to serve one purpose: brake calculations for commercial vehicles.

3.1.1 Design Philosophy

The internal structure of the program was built with two major concerns: modularity and object orientation. Figure 3.1 shows the main modules, events and

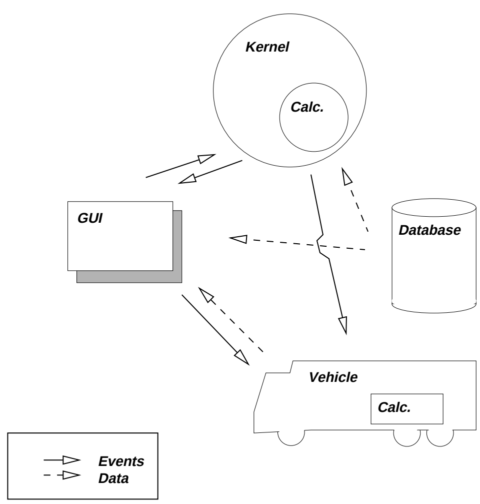


Figure 3.1: Application internal structure

dataflows within the program. Events trigger actions in a module, e.g causing a window to redraw, or a recalculation of internal parameters. Only a module sending events to another need knowledge of internal structures of the receiver. Data flows (e.g objects and parameters) are pulled by the receiver. In theory, a module could be changed completely, without having to change a module fetching data from it, as long as the data interface is kept the same. Using this scheme provides possibility to replace (some) modules without having to change others.

The modules in the WBrake program are:

Graphical User Interface. As Figure 3.1 imposes, it can be replaced without having to change the implementation of the vehicle model and parts database.

Kernel. This is where the work is done in the program. It controls calculation through the vehicle model and forms user output shown in the GUI and on paper printouts. This module can be changed without updating the vehicle model and parts database.

Vehicle Model. This module implements the mathematical vehicle model described in 4.1.

Components Database. This module stores vehicle components and brake regulation data. See Section 3.1.3.

3.1.2 Graphical User Interface

The GUI is what the user of the application sees, and through which the user interacts with the program. Guidelines when designing this user interface were:

- Use computer memory rather than human. Present all information that is needed simultaneously in one view, to avoid tiring the users mind.
- Place similar functions together. If functions, used for the same thing are scattered over a wide area, the user wastes time and energy refocusing attention.
- Use pictures and symbols wisely. A graphic can help the user get an overview of a substantial amount of data, but unnecessary use of symbols instead of text can cause great confusion.
- Input in any order. The basis for the calculation might come with vehicle data in any order. For first time users, 'any order' input can be confusing, but to slightly experienced users, fixed order input is an annoying constraint.

The user interface was built with the wxWindows library (see Appendix B and [4]).

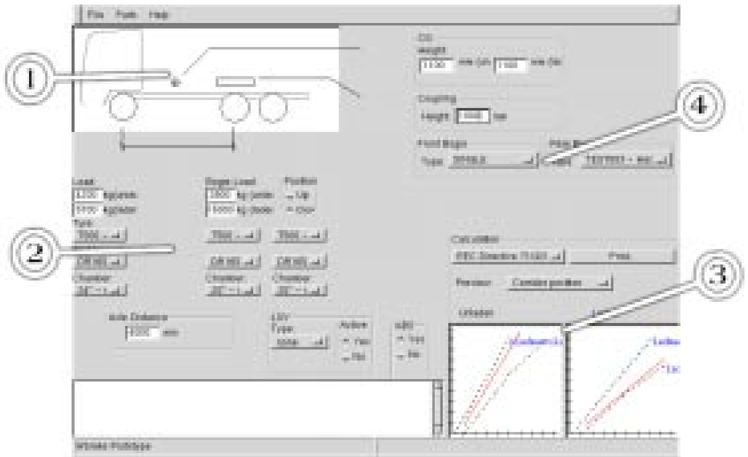


Figure 3.2: Graphical User Interface (Main window)

The main window of the user interface (see Fig 3.2) contains controls for all user configureable parts of the vehicle model and calculation. These are: bogie controls (labelled 4), brake equipment controls (labelled 2), a display showing the overall configuration (labelled 1) and a calculation result display (labelled 3).

3.1.3 Component Database

The component database stores information about vehicle components, as e.g the geometry for a bogie, in accordance with the requirements set in Section 2.1.

The database is loaded by the program upon startup, so defining the vehicle model properties is really done by selecting components, using the GUI controls. As a result of this, calculating the brake properties for a vehicle, though the model contains hundreds of parameters, is done in a matter of seconds.

Storing paramaters in a database also minimizes the hazard of miscalculation because of faulty parameters, providing, of course, that the parameters stored for a component is correct.

Ideal would be, if there was a company database, containing all the components available for building vehicles, to extract data from. That way, the data used for calculations would always be consistent with reality. No such database is available at Scania at this point, however, but the modularity of the wbrake program provides for an implementation change of the components database to include such functionality.

The storage method chosen here is plain text files, with a program module acting as a database manager (DBMS), receiving queries and returning component data. This scheme opens the possibility to incorporate a commercial standard database, should it be needed for performance reasons. The reason for not doing so in the current implementation is simplicity, plus avoiding platform dependance, which would be the case with a commercial database where source code usually is not supplied.

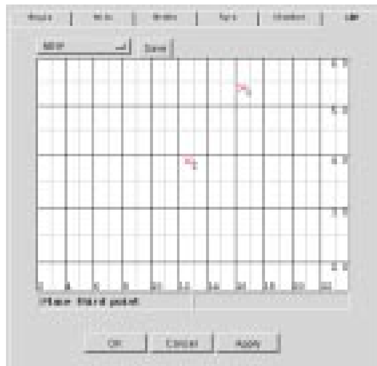


Figure 3.3: GUI for defining load sensing valve characteristics

Defining components for storage in the database is done either by simply adding the parameters to the plain text files, or in the case of more obscure components, through the graphical user interface, as shown in Figure 3.3.

3.1.4 Output

Results from the calculations with the WBrake program are ground reaction forces and brake forces for each axle. These results are processed in various ways to present the sought properties, first in preview plots, see Figure 3.2, and then on a two-page printout, see Figure 3.4.

On the result printouts, the vehicle is described in forms of overall configuration (labelled 1 in Figure 3.4), and information about braking equipment (labelled 2 and 3). The processed calculation results are presented as graphs (labelled 4) and tables (labelled 5 and 6).

The tables (5 and 6) provide essentially the same information as the plots (4), so the page layout is chosen so that all information is available on page 1, and printing page 2 is optional.

Authentic printouts are provided in Appendix E.

3.1.5 Development Tools

The tools used for the development of the WBrake program had to fulfill very specific requirements about cross-platform compability and performance.

The C++ compiler had to be available on all the intended platforms[1]and be able to generate working, debuggable programs from ANSI C++ code. The only

[1]Linux, IRIX, AIX and Win32

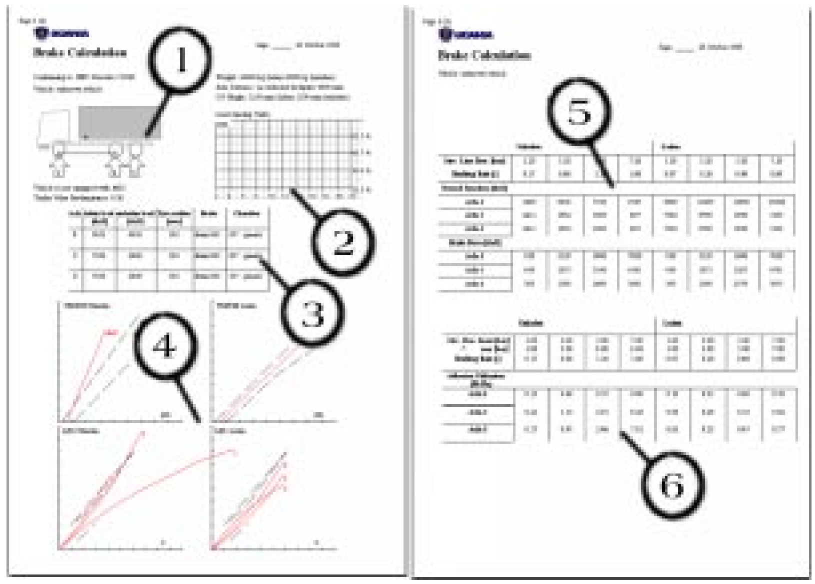


Figure 3.4: Result printouts

viable choice was the EGCS compiler from the GNU project (see [5]), which works on virtually all computer operating systems used today.

Likewise, the GUI library had to be multi-platform capable, though in theory, the GUI could be separately written for each platform. It also had to have proper C++ bindings, to avoid having to revert to C[2], for certain parts of the program.

The source code editor of choice was GNU Emacs, with an exception for the IRIX platform, where XEmacs was used. Emacs has the basic features of a source code editor, e.g syntax indentation and highlighting, and it is, similar to EGCS, available on all the used platforms.

Debugging the program was done using the GNU debugger, gdb, which worked on all platforms except AIX, for unknown reasons. If development, other than compiling already debugged source code, is to be performed on AIX, the debugging issue has to be resolved.

A complete list of the used development software, including version information, is available in Appendix B.

3.2 Use Example

Using the program to calculate brake properties for a vehicle is done in a few simple steps, once the components used are stored in the database.

[2] C is the de-facto standard binding for GUI toolkits

	Front Bogie	Rear Bogie	
Unladen Load [ton]	5.0	4.9	
Laden Load [ton]	8.2	16.0	
Bogie Type	Single axle	Leaf spring suspended balance bogie	
	Axle 1	Axle 2	Axle 3
Tire	14.00 - 20	14.00 - 20	14.00 - 20
Brake	drum brake	drum brake	drum brake
Brake Cylinder Size	30	20	16
Load Sensing Valve	none		
Axle Distance [mm]	4000		
Trailer Valve Pred. [bar]	0.2		
	Unladen		Laden
CG Height [mm]	1100		1550

Table 3.1: Example Vehicle Configuration

For finding out the trailer compability (braking rate characteristics) for a vehicle with configuration as table 3.1, the walkthrough looks like:

1. Create the vehicle by selecting 'new->truck' from the file menu. The GUI shows a tractor (Figure 3.5) without wheels.
2. Select type of bogie for front and rear, respectively. Controls for per-axle configuration appears.
3. Fill in the values for CG height and axle distance.
4. For each axle of the vehicle, select tire, brake and chamber (Figure 3.6).
5. Select load sensing valve type and trailer valve predominance value.
6. Select regulations, and preview case (corridor position).
7. Fill out the loads for front and rear bogie. The program calculates the braking rate and shows preview plots (Figure 3.7).
8. To get a paper hardcopy of the results, select 'print' from the file menu. A print preview of page 1 is shown in Figure 3.8.

Conforming to the guidelines set in 3.1.2, step 3 to 7, above, can be performed in any order. The paper printout from step 8 is provided in appendix E.

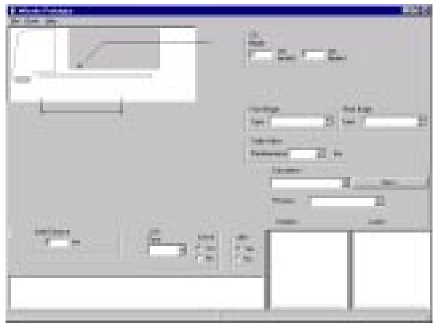


Figure 3.5: Main window after creating new vehicle

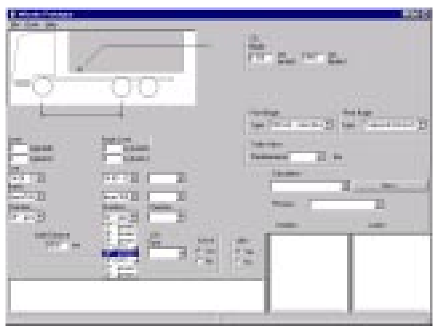


Figure 3.6: Main window while selecting brake equipment

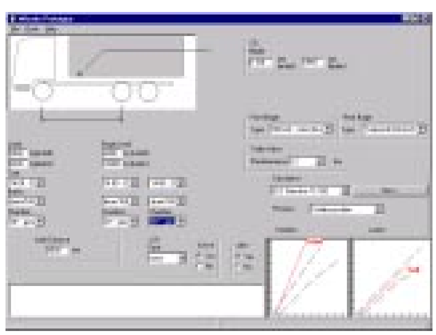


Figure 3.7: Main window when calculation is complete

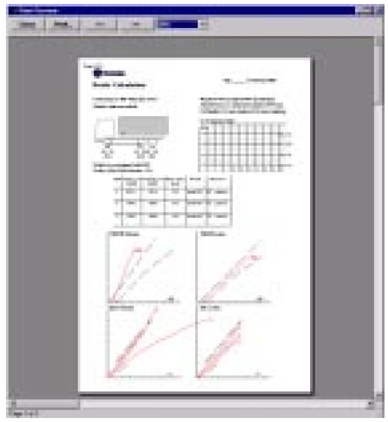


Figure 3.8: Print preview window

Chapter 4

Model and Calculation Methods

4.1 Vehicle and Brake System Model

This section describes a mathematical model of a vehicle, tailored to the specific calculation objectives used in the program (see Section 4.2). Mathematical correctness of the model, and adherence to 'the reality', is constrained, either by the need to fulfill algorithms defined in braking regulations, or by the strive for implementation simplicity.

Since most equations used are linear, and many of the input values are somewhat arbitrary, the accuracy of the results would not benefit from a complex model, either. Instead, reasonable approximations are made where possible. Where at Scania accepted algorithms exist, those have been used, even if their accuracy may deviate somewhat from the model's general level.

The model is also created under the assumption that iteration is preferred over other mathematical solving techniques. The reason for this is that it is meant to be easy to transform into C++ program code. While most desktop computers has computing power enough to iterate a formula several thousand times in fractions of a second, a programmer needs several hours to implement any kind of 'smart' solving routine.

To provide for modularity, an object oriented approach is used throughout the model. Model parts are generalized as far as possible to form objects with consistent interfaces.

A prerequisite for this is that model components need no knowledge of the intrinsics of components attached to it, they can only observe their behavior in forms of outputs. This is also known as a 'black box' view. A component using another, typically, supplies inputs, e.g for a brake using a brake chamber, the control pressure, and observes and uses the output, in this case a force. Figure 4.1 shows the dependency tree for the whole vehicle model.

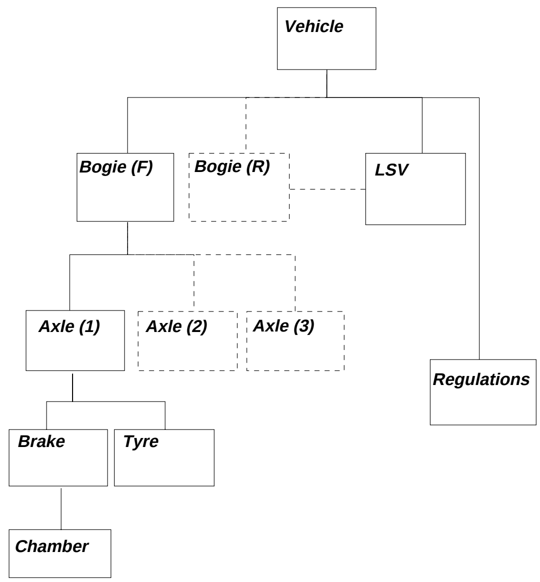


Figure 4.1: Vehicle Model Components (tree view)

4.1.1 Vehicle

The vehicle model, preferably a tractor or truck, contains four or more wheels, certain dimensions and a mass. Since the concept of time is not at all used in any of the calculation objectives, there is no need for moments of inertia or other dynamic properties.

It is also assumed that deflection of parts other than suspension is not of great importance for the results. Hence, the model does not rely upon information about the physical structure of the vehicle it is modeling.

Consequently, the model part referred to as the 'Vehicle' is, from the programs point of view, a 'black box' into which is put a weight, distributed over two suspension points (bogies), a distance between these suspension points [1] at rest, a center of gravity height, and an air pressure, which represents the control pressure from the foot valve (see Appendix C).

The output consists of a retardation value (actually the ratio between braking force and weight) plus, for each axle on the vehicle, a ratio between the brake force and the normal force, the *adhesion utilization* (see Section 4.2.2).

Transferring the inputs to outputs is done using two *Bogie* components. Each of them are given a control pressure, which it transforms to a brake force. This information, along with the one supplied, is used to decide the resulting load distribution through equations 4.1 - 4.2. For symbols, see Figure 4.2.

[1] This property is given as an axle distance, defined as *the distance between the frontmost axle of the vehicle, and the first driven axle in the rear bogie.*

$$L_R * D_A - F_b * H_{CG} = 0 \tag{4.1}$$

$$L_R + L_F - W * g = 0 \tag{4.2}$$

If the vehicle is equipped with a *load sensing valve* (see Section 4.1.7), the control pressure given to the rear bogie depends on the load distributed to it, which calls for iteration, since the brake force, in fact, becomes dependant of the retardation.

As a response to the loads, the bogie components also react with a deflection, from which the pitching angle of the vehicle is derived, through eqn. 4.3. The need for this is explained in section 4.1.2.

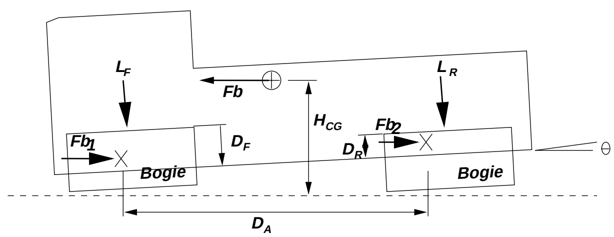


Figure 4.2: Vehicle - Bogie interaction

$$\Theta = \arcsin\left(\frac{D_F - D_R}{D_A}\right) \tag{4.3}$$

Regulations (see Appendix D) state how the center of gravity height should be approximated. In general, the exact height of CG is not known, and often not derivable from supplied data either. This is unfortunate, since the impact on weight distribution calculation is directly proportional, as can be seen in eqn. 4.1.

The suspension point distance (axle distance when dealing with two-axle vehicles) in eqn. 4.1 is also affected by the output of the bogies. It is important to understand that this change does not come from any deflection of the vehicle. It is simply a way to accommodate for the fact that the bogie can create a pitching moment, as well as a normal force.

A summary of inputs and outputs for this component is given in Appendix A.

4.1.2 Bogie

A bogie in its usual meaning, is a constellation of two or more axles mounted close to eachother on a vehicle, more or less acting as a unit. In some cases a mechanism for balancing load, on uneven surfaces, between the axles is present. This is usually a mechanical link system for leaf spring suspended bogies, or a bellow pressure transfer device, of some sort, for air suspended bogies.

This makes the bogie the far most complex part of the vehicle model. It consists of one to three *axles*, together with a set of functions to translate a load, a pitch angle and an air pressure, to forces and deflections that apply to the vehicle as a whole, and to forces that apply to each axle. To do this, it needs to be able to make qualified predictions about things like e.g spring constants for the suspension.

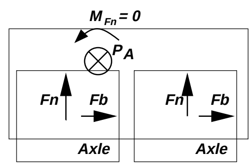


Figure 4.3: Bogie - Axle interaction

Given an air pressure, the bogie calculates the total braking force from its axles by summarizing their brake forces, respectively, and passes this value to the vehicle it is attached to. Calculated is also the normal force for each axle, with respect to the bogie geometry, the pitching angle and the total load. The *point of attachment*, ($P_A$in Figure 4.2) which is used to calculate the dynamic axle distance (see Section 4.1.1) is the point in the bogie, around which the moment from normal forces is equal to zero.

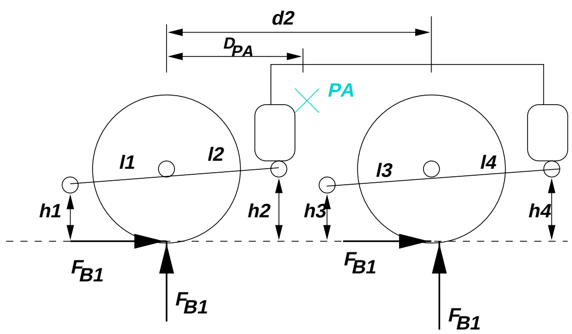


Figure 4.4: Example bogie.

Exemplifying an air suspended two-axle bogie with direct pressure transfer, and bellows of equal size, as shown in Fig. 4.4, this model renders equations 4.4 to 4.6 for the forces transfered to the vehicle, and eqn. 4.7 for the deflection.

$$F_{N1}\frac{l_1}{l_1+l_2} + F_{B1}\frac{h1}{l_1+l_2} = F_{N2}\frac{l_3}{l_3+l_4} + F_{B2}\frac{h3}{l_3+l_4} \tag{4.4}$$

$$F_{N1} + F_{N2} = L \cdot g \tag{4.5}$$

$$D_{PA} = \frac{F_{N2} \cdot d_2}{F_{N1} + F_{N2}} \tag{4.6}$$

$$D_{F|B} = C_B \frac{\frac{l_1}{l_1+l_2} + \frac{l_3}{l_3+l_4}}{2} \cdot \left(\frac{\frac{F_{N1} \cdot l_1 + F_{B1} \cdot h_1}{l_1+l_2} + \frac{F_{N2} \cdot l_3 + F_{B2} \cdot h_3}{l_3+l_4}}{L_{rest} \cdot g \cdot \left(\frac{l_1}{2(l_1+l_2)} + \frac{l_3}{2(l_3+l_4)} \right)} - 1 \right) \tag{4.7}$$

$D_{PA}$is the distance from the first axle in the bogie to the *point of attachment* on the vehicle. C_B approximates the air bellow spring constant. Note that the real spring constant for any air suspension is dependant on L_{rest}, the load at rest, because it effectively decides the air pressure in the bellow.

The difference in bogie behavior needs equations corresponding to eqn. 4.4 - 4.7 to be set up for each bogie type, and ultimately coded in C++. That is not ideal, but generalizing all bogie types to a fixed set of equations is virtually impossible with the chosen approach.

A summary of all component inputs and outputs can be seen in Appendix A.

4.1.3 Axle

An axle is simply a stiff rod, laterally connecting two wheels. It can also provide housing for transmission, and/or steering, but that is of very little interest in this case.

The axles role in the vehicle model is merely to work as an attachment point for brakes and tires. The control pressure given to it by the bogie is passed on to the brake attached, and the resulting brake moment is divided by the dynamic rolling radius of the tire, thus giving a brake force, which is passed back to the bogie.

4.1.4 Brake

Using friction, a mechanical brake transfers energy in the form of motion into energy in the form of heat. Typically a pad is pressed against a rotating disc or drum, creating a braking moment. The size of this braking moment can be calculated, with knowledge of how force (input) is transfered to the brake pad.

The brake cylinder force acts on a lever, which turns a cam, pressing the pad against the rotating disc or drum. This is true for both the disc brake in Fig. 4.5, and the drum brake (see schematic in Fig. 4.6).

Equations 4.8 - 4.9 show how this model component transfers chamber force (F_{cyl}) to braking moment. Note that the 'servo factor', C in Eqn. 4.8 is 0.8 for a disc brake (roughly the number of pads times the friction coefficient), while it is 1.9 for a drum brake, because of the self-amplifying geometry (the leading shoe gets pressed towards the drum).

$$M_b = \frac{M_{cam} \cdot C \cdot R_{eff} \cdot \eta}{R_{cam}} \tag{4.8}$$

$$M_{cam} = l_{lever} \cdot (F_{cyl} - F_{thr}) \tag{4.9}$$

Figure 4.5: Disc brake with brake cylinder

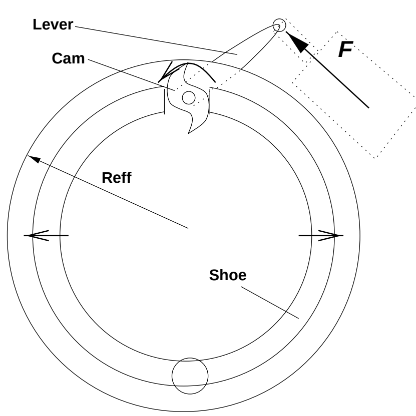


Figure 4.6: Drum brake schematic

Since the pads (disc brake) and shoes (drum brake) are springloaded, a threshold force is subtracted from the cylinder force. This threshold force is dependant on the brakes configuration, and is given to the model component as a constant.

A summary of inputs and outputs of this component is provided in Appendix A.

4.1.5 Tire

The tire creates friction against the ground for braking, acceleration and cornering of the vehicle. It also deflects under load and provides for a somewhat smoother ride.

From the WBrake model's point of view, however, it is only treated as a lever from the brake center to the ground, transferring braking moment to a force braking the vehicle. The only important property is consequently its dynamic rolling radius, or the distance from its center to the ground, mounted on a vehicle.

4.1.6 Brake Cylinder

A brake cylinder contains a chamber, transforming air pressure into force. It consists of a spring-loaded diaphragm inside a cylinder, to which a pushrod is attached. The chamber is mounted near the brake, and actuates its force on a lever mounted on the brake. See Figure 4.7 and schematic in Figure 4.8.

Figure 4.7: Brake cylinder fitted on vehicle (drum brake)

The mathematical model of this component is very simple. Air pressure (input) transforms to a force (output) through Eqn. 4.10.

$$F = C * P_m - F_{thr} \tag{4.10}$$

The chamber diaphragm, on which the air pressure is applied is springloaded, which gives a threshold force, F_{thr}, being subtracted from the output force.

The chamber constant, C, in Eqn. 4.10 is a property proportional to the chamber diaphragm area, and is here chosen so that Eqn. 4.10 is true for a chamber at 60% of its stroke.

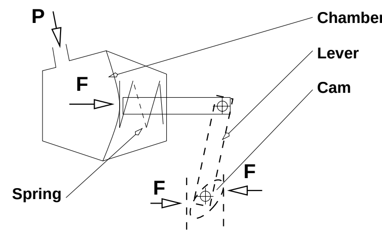


Figure 4.8: Brake cylinder schematic

4.1.7 Load Sensing Valve

For vehicles without electronic control of brake pressure, there is need to vary the control pressure for different load conditions. This in order to avoid the instability that would occur if wheels lock (start skidding) in an unsuitable order. (See also Section 4.2.2).

This device is called a *Load Sensing Valve.*

For leaf spring suspended vehicles, there is a linkage, transferring the spring deflection from load to a mechanical pressure limiter. Air suspended vehicles, however has no deflection, hence, the load is messaged to the valve through the air pressure in one or more of the air suspension bellows.

The valve is usually located at the rear of the vehicle, reducing control pressure to the brakes in the rear bogie. See Figure 4.9.

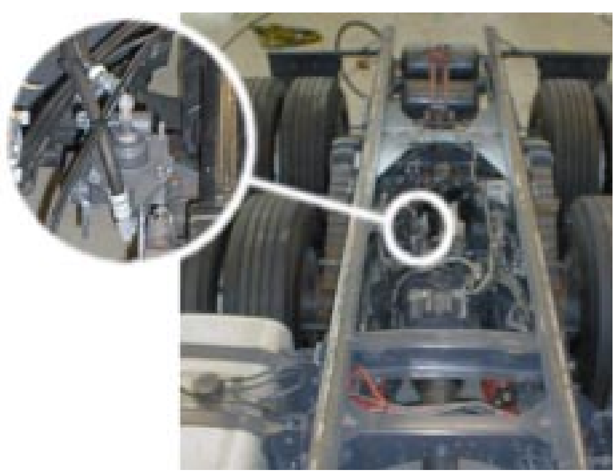


Figure 4.9: Load Sensing Valve (encircled)

Modeling this device is not entirely trivial. A glass box view of this component would require knowledge about both the characteristics of the valve itself, as well as about the deflection (or pressure raise) that comes from a load. That information cannot be easily obtained. Instead a function, by the author empirically found fittable to most load sensing valve characteristics is used. See curve fit Eqn. 4.11.

$$P_2 = P_1 \cdot (1 - \frac{1}{C_1 \cdot \ln(1 + C_2)} \cdot \ln(1 + C_2(C_3 \cdot (L_{max} - L))) \tag{4.11}$$

$$C_3 = \frac{e^{\left(\frac{P_1 - P_2}{P_1} \cdot C_1 \cdot \ln(1+C_2)\right)}}{C_2(L_{max} - L)} \tag{4.12}$$

Since the combined characteristics of a load sensing valve mounted on a vehicle is known[2], constants $C_1 - C_3$ can be defined by insertion of three values of pressure and load into Eqn. 4.11 - 4.12.

To avoid having to manually calculate these constants, a program module is provided, see Section 3.1.3. A comparison between sample characteristics and model approximation is provided in Appendix F.

Inputs and outputs of this model component is provided in Appendix A.

4.1.8 Putting it Together

Given that we want to find the brake forces and normal reactions of the wheels of a truck with the following configuration:

- 3 axles, 1 front and 2 rear axles, of which both rear axles are driven
- Front suspension is leaf springs
- Rear (bogie) suspension is air, as in 4.1.2
- A given brake configuration
- Given loads, as front axle load and rear bogie load, for laden and unladen condition
- A given control pressure
- Given load sensing valve characteristics
- Given heights of center of gravity for laden and unladen condition.

The calculation algorithm, using the model components defined in this chapter would be as follows:

1. Find the retardation
   (a) Sum the retarding forces from both bogies[3]
      i. For each bogie, sum the retarding force from the axles mounted on it

[2]The combined characteristics is the actual behaviour of the pressure reduction for different load conditions

A. for each axle connected to the bogie, find its brake force by dividing the braking moment from the brakes connected to it, by the rolling radius of the tires.
The control pressure given, transfers to a force using the chamber components. The force transfers to braking moment using the brake components (Eqn. 4.8 and 4.9)

(b) Divide the retarding forces with the vehicle mass.

2. Find the reaction force from ground on tires

   (a) Find load transfer from rear to front suspension due to the retardation gotten in step 1. (Eqn. 4.1 and 4.2)

   (b) Find the pitch angle of the vehicle.

      i. Using the bogie components, find their deflection due to load and brake force (Eqn. 4.4 to 4.7)

   (c) Using pitch angle[4] , brake force and load, find ground reaction force for each axle.

      i. For each bogie, evaluate Eqn. 4.4 to 4.7.

3. If the ground forces fall within the active area of the load sensing valve, reduce control pressure for the brakes it affects and go to step 1.

Steps 1-3 is iterated until some criteria is fulfilled, and the calculation has converged.

From step 1(a)iA, the brake forces can be extracted. Step 2(c)i gives the reaction forces, and the retardation of the vehicle is the result of step 1.

4.2 Calculation Objectives

This section describes how, and for what reason the calculation results from the vehicle model defined in Section 4.1 is used. Intuition tells that brake performance of a vehicle is of vital interest. Especially when regarding that the vehicle brakes can be used to decelerate masses of up to 100,000kg, moving at a speed in the magnitude of 25 m/s, to complete standstill.

4.2.1 Braking Rate

The braking rate of a vehicle is, put simply, its retarding force divided by the vehicle's mass. This, plotted against the control pressure creating the braking force (see Figure 4.10), defines a behavior, to which a trailer towed by the vehicle must adhere. If it doesn't, either the brakes on the trailer or the brakes on the

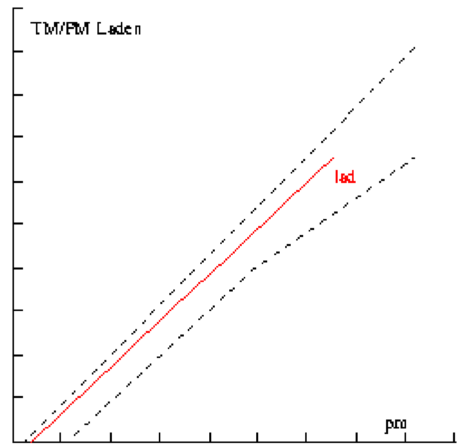


Figure 4.10: Braking rate with tolerance acc. to 71/320/EEC

vehicle is retarding the whole vehicle, which leads to brake overheat, uneven pad wear, and in some cases instability of the braking vehicle - trailer combination.

Brake regulations, as 71/320/EEC (see Appendix D) define allowed values for braking rates, and how the braking rate for different vehicles should be calculated.

In the case of 71/320/EEC, the braking rate is defined as TM/PM, where TM is the *sum of braking forces at the periphery of wheels,* and PM the *total normal static reaction of road surface on wheels.* The control pressure p_m, against which the braking rate is plotted is defined as the *pressure at coupling head of control line*, i.e the pressure that is fed to a trailer connected to the vehicle. This is not the same pressure as the brake cylinders of the vehicle experience, but instead that pressure offset with typically 0.0 to 1.0 *bar*.

Using the model defined in 4.1 to get values suiteable for plotting a diagram as in Fig. 4.10 is fairly straightforward. Just input a control pressure , read the sum of braking forces for all wheels, and divide it by the vehicle gross weight. If the vehicle is a tractor, however, or the vehicle is equipped with a load sensing valve, there are load issues to be considered.

In the case of an unladen tractor[5], the EEC rules state that the semitrailers effect on the vehicle during braking (see Figure 4.11) is to be assumed as a static mass of 15% of the payload[6]mounted at the 5:th wheel coupling of the tractive unit. This effects the total mass to be retarded by the vehicles brakes, as well as the height of the center of gravity.

A similar, but somewhat more complicated scheme is used in 71/320/EEC for a tractor with laden semitrailer, to calculate the total weight and the center of

[3]the single front axle is regarded as a bogie
[4]The pitch angle (if it is small) does not effect the bogies chosen for this vehicle
[5]tractive unit + unladen semitrailer
[6]here the weight difference between an unladen and a laden vehicle

Figure 4.11: Tractor unit and semitrailer

gravity height (see Appendix D). The correctness of these approximations could of course be a matter of discussion, but that is beyond the scope of this thesis work.

4.2.2 Friction Utilization

What here is referred to as the *friction utilization* is the ratio between the braking force at the rim of a wheel, and the static reaction of road surface on that wheel. The reason for examining this property is mainly stability of a braked vehicle. If, for instance, wheel locking occur on rear tires of a vehicle at a braking rate where front vehicles still are rolling, or if trailer wheels lock before the towing unit's, the vehicle or vehicle combination acts as 'a dart thrown backwards'.

The way of examining this property here is plotting the adhesion used by the tires on each axle on the vehicle, against the braking rate of the vehicle as a whole. Figure 4.12 shows a plot for a three-axle vehicle (axle two and three have the exact same friction utilization here) where instability would occur at braking rates above 0.2.

Calculating the friction utilization for each axle is done using Eqn. 4.13, where

$$f_i = \frac{F_{B_i} \cdot L \cdot g}{F_{n_i} \cdot \sum_1^j F_{B_i}} \tag{4.13}$$

the brake forces for each axle (F_B) and the normal reaction (F_n) is retrieved using the vehicle model from 4.1 at different control pressures. Eqn. 4.2.2 is derived from item 3.1.3 in the 71/320/EEC regulations, see appendix D.

The exact legal requirements on the friction utilization in terms of absolute and relative positions of plotted curves such as in Figure 4.12 can be seen in Appendix D.

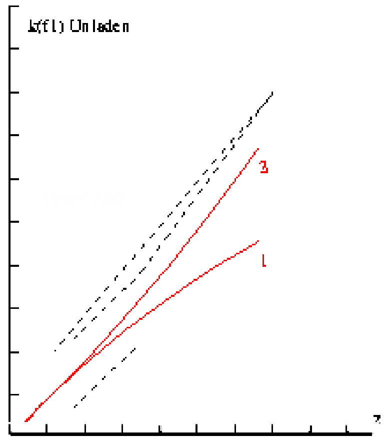


Figure 4.12: Friction utilization plot with 71/320/EEC tolerance drawn (dashed)

Chapter 5

Discussion and Future Work

The WBrake program is in moderate use at time of writing, and after adding all components used in vehicles at present to its database, it should be able to fully replace its MS-DOS$^{(R)}$-based predecessor.

For verification, a number of vehicles should be calculated simultaneously using both programs and examined for deviations other than those originating from obvious differences in the vehicle models used.

Another point for future work is the stability of the WBrake program. Normal use does not cause program execution errors, but for user acceptance, the program should also handle user induced errors nicely.

5.1 Database Refinement

Keeping the vehicle component database in accordance to reality is a hard task, requiring both information search for properties that have changed, and manual updating of the database. By researching other database resources at Scania, perhaps a solution for automatic updating of the database could be found.

A first step could be adding a dependancy scheme, which could check for updated products, and scan for property changes that affect the calculation values of components stored in the database.

5.2 User Feedback

Though user acceptance of the WBrake program is much higher than of its predecessor, there are still areas of improvement. Collecting and evaluating feedback from users of the program would be a natural step to take, and modify the user interface accordingly. If features are to be added, how should they preferably be integrated into the user interface?

5.3 Model Verification

The vehicle model, though simple, introduces a not formally verified way to calculate the impact from pitch on ground reaction. A reasonable next step would be to verify that the result, especially for vehicles with four or more axles, is a good approximation of reality.

The choice of representation of load sensing valves in the model is also a matter of discussion. Can acceptable results really be achieved, without modeling the intrinsics of the valve?

Bibliography

[1] Commercial Vehicle Braking – Newcomb & Spurr, 1979, ISBN: 0-408-00362-6

[2] Brake Design and Safety – Limpert, 1992, ISBN: 1-560-091261-8

[3] Brake Regulations, ECE R13 and 71/320/EEC – INTEREUROPE, 1997

[4] wxWindows website – http://web.ukonline.co.uk/julian.smart/wxwin/

[5] The GNU Project website – http://www.gnu.org/

List of Figures

Appendix A

Model Component Interface

Vehicle

Methods:

getType() returns the vehicle type, e.g tractor or truck

getAxleType() returns the type of an axle connected to the vehicle

getTotalWeight() returns the total weight of the vehicle

getTotalBForce() returns the total braking force for a given control pressure

getTotalBogieLoad() returns the load acting on a bogie connected to the vehicle

SetLoads() sets the loads on all bogies connected to the vehicle

SetCG() sets the centre of gravity height

SetAxleDist() sets the axle distance

SetBogie() connects a bogie to the vehicle

LiftAxle() sets a (tag) axle's lifted status

SaveOnFile() saves the vehicle on file

ReadFromFile() reads a vehicle from file

IsValid() validates the vehicle

Properties: trailer valve predominance, ABS present/not present

Bogie

Methods:

SetAxles() connects axles to a bogie

GetAxles() returns axles connected to the bogie

getTotalBForce() returns the sum of braking forces exerted by axles connected to this bogie at a given control pressure

LiftAxle() sets a (tag) axle's lifted status

GetDeflection() routine used in main calculation. Returns deflection, individual brake forces and ground reactions for each axle in the bogie

Properties: bogie geometry parameters

Axle

Methods:

getBForce() returns the brake force for an axle at a given control pressure

Properties: lifted status

Tire

Methods: none

Properties: tire radius

Brake

Methods:

getBMoment() returns the braking moment for a given control pressure

Properties: lever length, effective diameter, cam radius, threshold force, mechanical efficiency

Chamber

Methods:

getForce() returns pushrod force at a given control pressure

Properties: treshold pressure, control pressure/force ratio

Regulations

Methods:

ForceRatioToAxis() converts brake/reaction force ratio to plot scaled value

ManPressureToAxis() converts control pressure to plot scaled value

Properties: regulated min/max values, plot labels

LSValve

Methods:

Reduce() returns reduced control pressure

Properties: curve fit function constants

Appendix B

Development Tools

Linux:

	Name	Version
Operating System	Linux	2.1.108
C++ Compiler	EGCS	1.1b
Debugger	GDB	4.17
Source Editor	GNU Emacs	20.2
GUI Library	wxGTK	1.95

IRIX:

	Name	Version
Operating System	IRIX	6.2
C++ Compiler	EGCS	1.1b
Debugger	GDB	4.17
Source Editor	XEmacs	20.4
GUI Library	wxGTK	1.95

Windows NT:

	Name	Version
Operating System	MS Windows NT	4.0
C++ Compiler	EGCS	1.0.2 (MingW)
Debugger	GDB	4.16 (gnu-win32-B19)
Source Editor	GNU Emacs	19.34
GUI Library	wxWindows	2.0 alpha 14

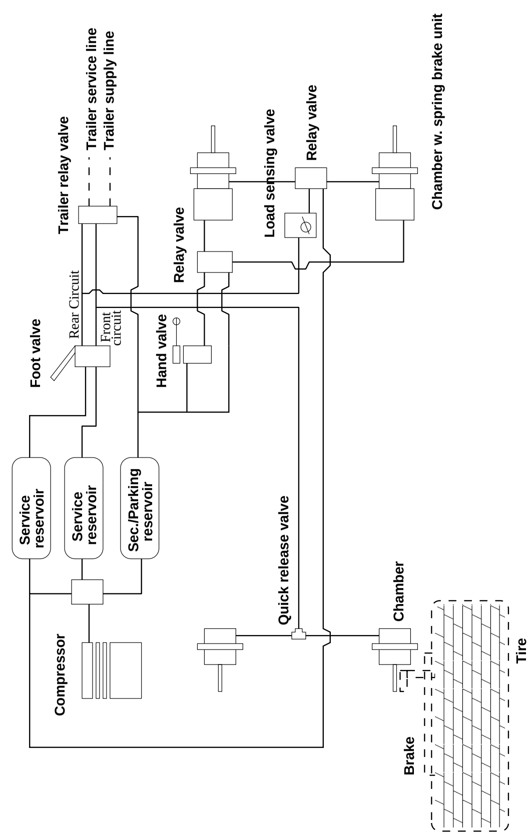
AIX:

	Name	Version
Operating System	AIX	4.3.1
C++ Compiler	EGCS	1.1b
Debugger	-	-
Source Editor	GNU Emacs	20.4
GUI Library	wxGTK	1.94

Appendix C

Pneumatic Brake System

Brake system schematic:



Appendix D

Regulations

Vehicles discussed are categorized by EEC Directive 71/320 as:

Category N_3**:** Vehicles used for carriage of goods and having a maximum weight exceeding 12 metric tons.

The following is a transcript of the rules that are of special interest here. From 71/320/EEC of 1997, Annex II-Appendix:

Symbols	
i	axle index (i = 1, front axle;i = 2, second axle; etc.)
P_i	normal reaction of road surface on axle i under static condition
N_i	normal reaction of road surface on axle i under braking
T_i	force exerted by the brakes on axle i under normal braking conditions on the road
f_i	T_i/N_i, adhesion utilized by axle i
J	deceleration of the vehicle
g	acceleration due to gravity
z	braking rate of vehicle = J/g
P	mass of vehicle
h	height above ground of centre of gravity
k	Theoretical coefficient of adhesion between tyre and road
TM	sum of braking forces at the periphery of wheels of towing vehicles
PM	total normal static reaction of road surface on wheels of towing vehicles
p_m	pressure at coupling head of control line
...	...

...

3.1.1 For all cathegories of vehicles for k values between 0.2and 0.8:

$z \geq 0.1 + 0.85(k - 0.2)$

For all states of load of the vehicle, the adhesion utilization curve shall be situated above that for the rear axle

...
- for all braking rates of between 0.15 and 0.30

3.1.3 In order to verify the requirements of item 3.1.1., the manufacturer should provide the adhesion utilization curves for the front and rear axles calculated by the formulae:

$$f_1 = \frac{T_1}{N_1} = \frac{T_1}{P_1 + z\frac{h}{E}P} \; ; \; f_2 = \frac{T_2}{N_2} = \frac{T_2}{P_2 + z\frac{h}{E}P}$$

The graphs shall be plotted for both the following load conditions:

- unladen, in running order with the driver on board.

In the case of vehicle presented as a bare chassis-cab, a supplementary load mey be added to simulate the mass of the body, not exceeding the minimum mass declared by the manufacturer in Annex IX.

- laden

Where provision is made for several possibilities of load distribution, the one whereby the front axle is the most heavily laden shall be the one taken into consideration.

3.1.4. Towing vehicles other than tractive units for semi-trailers.

3.1.4.1. In the case of a motor vehicle authorised to tow trailers of cathegory O_3or O_4fitted with compressed air braking systems, the permissable relationship between the braking rate TM/PM and the pressure $p_m$shall be within the areas shown in diagram 2.

3.1.5. Tractive units for semi-trailers

3.1.5.1 Tractive units with unladen semi-trailer

An unladen articulated combination is considered to be a tractive unit in running order, with the driver on board, coupled to an unladen semi-trailer. The dynamic load of semi-trailer on the tractive unit shall be represented by a static mass mounted at the fifth wheel coupling equal to 15% of the maximum mass on the coupling. The braking forces must continue to be regulated between the state of the tractive unit with semi-trailer (unladen) and that of the solo tractive unit; the braking forces relating to the solo tracive unit shall be verified.

3.1.5.2 Tractive units with laden semi-trailer

A laden articulated combination is considered to be a tractive unit in running order with the driver on board coupled to a laden semi-trailer. The dynamic load of the semi-trailer on the tractive unit shall be represented by a static mass $P_s$mounted at the fifth wheel coupling equal to:

$$P_s = P_{SO}(1 + 0.45z)$$

where P_{SO} represents the difference between the maximum laden mass of the tractive unit and its unladen mass.

For h the following value should be taken: $h = \frac{h_o P_o + h_s P_s}{P}$

where: $h_o$is the height of the centre of gravity of the tractive unit
h_s is the height of the coupling on which the semi-trailer rests
P_o is the unladen mass of the solo tractive unit

$$P = P_o + P_s = P_1 + P_2$$

3.1.5.3. In the case of a vehicle fitted with a compressed-air braking system, the permissable relationship between the braking rate TM/PM and the pressure $p_m$shall be within the areas shown in diagram 3.

3.2. Vehicles with more than two axles

The requirements of item 3.1. shall apply to vehicles with more than two axles. The requirements of item 3.1.1. with respect to wheel-lock sequence shall be considered to be met, if, in the case of braking rates between 0.15 and 0.30, the adhesion used by at least one of the front axles is greater than that used by at least one of the rear axles.

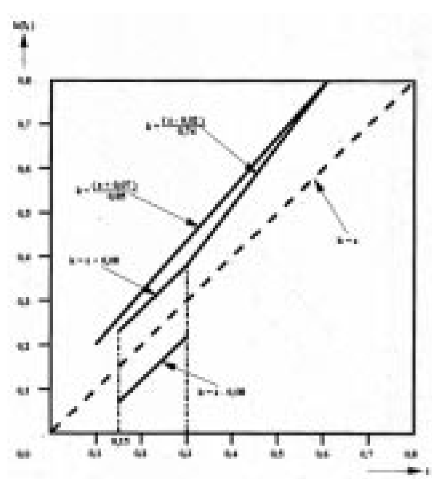


Diagram 1B

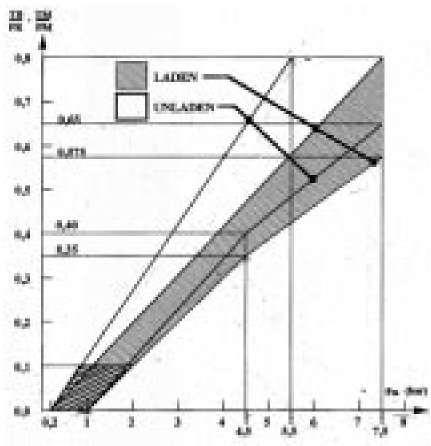


Diagram 2

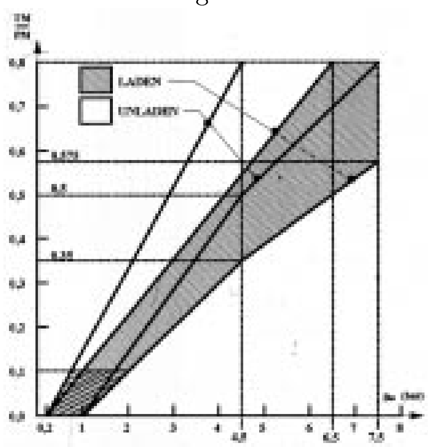


Diagram 3

Appendix E

Sample Output

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Brake Calculation

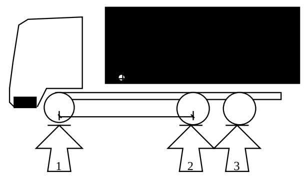
Conforming to: EEC Directive 71/320

Vehicle: Example truck

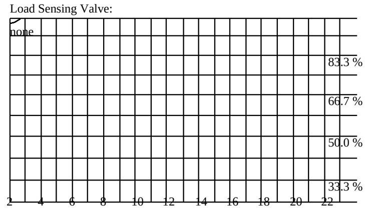
Weight: 24200 kg (laden) 9900 kg (unladen)

Axle Distance: (as indicated in figure) 4000 mm

CG Height: 1550 mm (laden) 1100 mm (unladen)



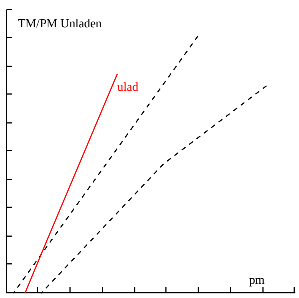
Load Sensing Valve:

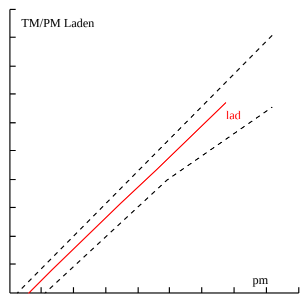


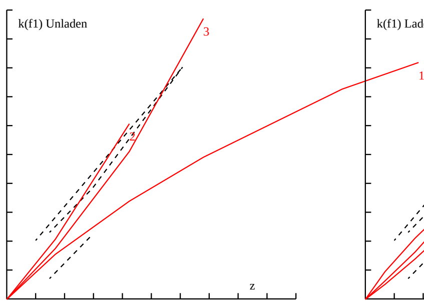
Vehicle is not equipped with ABS

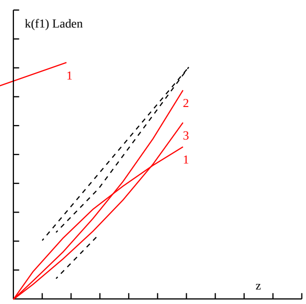
Trailer Valve Predominance: 0.20

Axle	laden load [daN]	unladen load [daN]	Tyre radius [mm]	Brake	Chamber
1	8052	4910	595	drum/165	30" - generic
2	7856	2406	595	drum/165	20" - generic
3	7856	2406	595	drum/165	16" - generic









SCANIA

Sign: ______ 5 November 1998

Brake Calculation

Vehicle: Example truck

	Unladen				Laden			
Serv. Line Pres. [bar]	1.20	3.20	5.20	7.20	1.20	3.20	5.20	7.20
Braking Rate [-]	0.17	0.68	1.16	1.68	0.07	0.28	0.49	0.69
Normal Reaction [daN]								
Axle 1	5299	6458	7556	8727	8600	10233	11866	13499
Axle 2	2211	1632	1083	497	7582	6766	5949	5133
Axle 3	2211	1632	1083	497	7582	6766	5949	5133
Brake Force [daN]								
Axle 1	819	3159	5498	7838	819	3159	5498	7838
Axle 2	459	1873	3148	4591	459	1873	3287	4701
Axle 3	383	1580	2660	3881	383	1580	2778	3975

	Unladen				Laden			
Circ. Pres. front [bar]	1.00	3.00	5.00	7.00	1.00	3.00	5.00	7.00
-"- rear [bar]	1.00	3.00	4.80	6.84	1.00	3.00	5.00	7.00
Braking Rate [-]	0.17	0.68	1.16	1.68	0.07	0.28	0.49	0.69
Adhesion Utilization (Fb/Fn)								
Axle 1	0.15	0.49	0.73	0.90	0.10	0.31	0.46	0.58
Axle 2	0.21	1.15	2.91	9.23	0.06	0.28	0.55	0.92
Axle 3	0.17	0.97	2.46	7.81	0.05	0.23	0.47	0.77

Appendix F

LSV Model Comparison

Sample Characteristics:

Load Sensing Valve 302 360		
Sample	Load [ton]	P2 [bar]
1	5.7	2.0
2	9.5	3.0
3	12.0	4.4
4	14.0	6.0

LSV Model Constants (curve autofitted by WBrake program):

C1	C2	C3
5.75	0.59	0.98

Comparative Plot: