CS515 Project Fall 2001
Final Report

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2 Background Research

The starting point for the research was a series of articles in a game development magazine describing a basic rigid body physics simulation [Hec96a], [Hec96b], [Hec97a], [Hec97b]. The course content in CS515 eventually caught up to and passed these articles in terms of depth, but

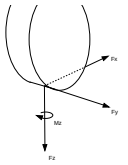


Figure 1: Forces and moments acting on tire. The x axis is called the tire's *heading*, and is the *longitudinal* direction, while the y axis is the *lateral* direction.

tire from slipping laterally and allows the car to turn. There may also be an aligning moment M_z which acts to align the wheel with the movement of the car, in situations where the wheel's heading is not the same as the car's heading. These are shown in Figure 3.

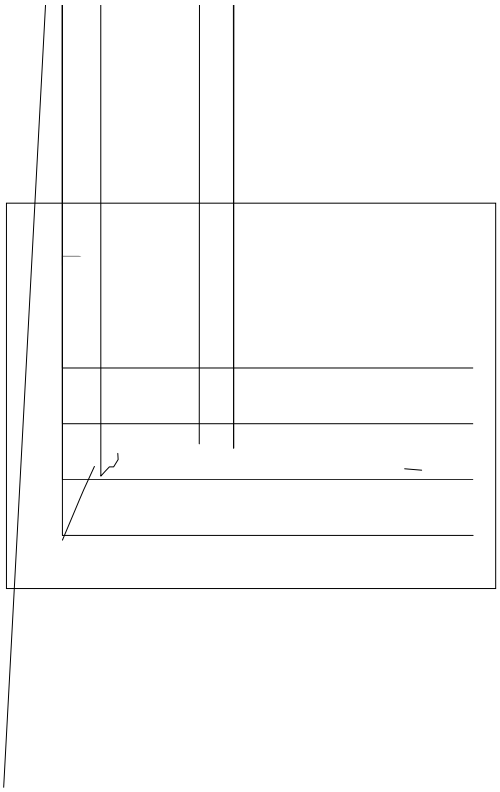
There are a number of tire models which can be used to determine these forces and moments, the most common being the Pacejka magic formula. Most such models require the same four inputs: vert7cal loadF_z, longitudinal slip , lateral slip angle and camber (or inclination angle) . For our tires, we used Zuvich's data for the longitudinal forces and Pacejka magic formulas for the lateral forces. The full equations associated with these and other forces are given in Appendix B. We have ignored and assumed that the camber , the rotation of the wheel about the

longitudinal force in a 1970 Chevelle as a function of the vehicle's velocity and the operating gear. We used a second-degree polynomial to t this data.

This approach depends upon the soundness of Zuvich's data, which is questionable. From examining the notes in his spreadsheet, it appears that he based his data on only two published statistics: peak power (450 hp at 5600 RPM) and peak torque (500 lb ft at 3500 RPM). Using these two data points, he appears to have invented data for other velocities. The shape of Zuvich's curves generally matches the form of curves from other vehicles, but does so only roughly.

Zuvich also makes some major simpli cations in the tire model, assuming that output torque

Figure 2: De nition of-387 01 0 0l eangle



4 Physics

Substantial e ort was invested in the physics engine itself, and unfortunately much of that work had to be discarded in the end.

4.1 Initial Approach

As described in the interim report, the initial approach to the physics involved a set of rigid frames and rigid bodies, which interacted with wrenches applied in an appropriate coordinate frame. The simulation employed the screw theory concepts seen in CPSC515, such as coordinate frame independent twists and wrenches. At the time of the interim report, some initial demos appeared to be working correctly, but no serious testing had been done.

Suppose that body A has a twist ^{W} = $(0; 0; 1; 0; \ 3; 0)^{T}$. Expressed with respect to frame A

on the children. Hierarchical culling provides a fast way for eliminating large portions of the world from being processed by the renderer.

The same nested bounding volumes support collision detection. If the bounding volume of the

6 Implementation

6.3 The Scene Graph

6.3.1 Updating the Scene Graph

```
{
    if ( A.BV does not intesect B.BV )
        return false;

    if ( IsLeaf( A ) )
        if ( IsLeaf( B ) )
        {
            if ( GeometryStoredAtNode( A ) intersects
                 GeometryStoredAtNode( B ) )
                return true;
        }
        else
        {
            for ( each B.Child )
                return BoundingVolumeTreesCollide(A, B.Child);
        }
    }

    for ( each A.Child )
        return BoundingVolumeTreesCollide(A.Child, B);
}
```

At SIGGRAPH 96, Gottschalk et al.[GLM96] presentea11.9Td[(rets(8-)27ert)-424calltea11.9T\OBBTre:
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thea1251(casea12525ofa1251(ob8-55(jsects12525moA)28vline)250(aet)251(highe)250(s08-)28eede6,)268(ita12
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where $_i = j1j$. Each test requires computing the signed distances

$$N \quad \forall \quad d = (N \quad C \quad d) + \ _0a_0dN \quad A_0 + \ _1a_1N \quad A_1 + \ _2a_2N \quad A_2: \qquad (3)$$

The four dot prodcts are computed once, each dot product using three multiplications and

References

A Physics equations

Following the derivation given by Bara , the state vector $Y(t)$ for each rigid body is de ned as

$$Y(t) = \begin{pmatrix} x(t) \\ \end{pmatrix}$$

B Vehicle model equations

B.1 Physical constants

Symbol	Description	Value
g	gravity	9:81 m=s^2
	density of air	1:29 kg=

Symbol	Description	Value
M_{kd}	mass	1765 kg
d_f	distance from centre-of-mass to front axle	1:22 m
d_b	distance from centre-of-mass to back axle	1:62 m
d_{wb}	wheel base (axle separation)	2:84 m
d_{tw}	track width (lateral wheel separation)	1:52 m
d_l	length	5:01 m [from musclecarclub.com]
d_w	width	1:6 m [invented based on wheelbase]
d_h	height	1:43 m
d_{cmh}	height of centre-of-mass above ground	0:6 m [from Zuvich, but dubious]
d_{td}	tire diameter	0:7112 m
A	frontal area of vehicle	2:2 m^2
k_{rr1}	rolling resistance coe cient 1	0:01
k_{rr2}	rolling resistance coe cient 2	0:0225
k_d	drag coe cient	0:45
k_l	lift coe cient	0:5
$_{max}$	maximum steering angle	$_{max}$

Using Zuvich's data, assuming rear-wheel drive, and using a simplistic linear scaling by throttle, the longitudinal forces on front and back tires are given by

$$F_x^{fl} = F_x^{fr} = 0$$
$$F_x^{bl} = F_x^{br} = \frac{F_e(i_g; \mathrm{v}_x) i_t}{4}$$

The velocity of tire *i*

Constant	Value	Constant	Value

C E2544u2116.458 -15

C Program Usage

What follows is a partial list of available console commands. Tokens appearing in bold are

C.1.1 Aliasing

alias[*newString stringToAlias*]

alias commands with other strings. If no arguments are speci ed, current aliases are listed.

unalias *stringToUnalias*

unalias an aliased string.

C.1.2 Key Bindings

bind *key < +j > string*

attach a command to a key. + denotes key-down event, - denotes key-up.

bindings

unaliasi014.516 0j0(Aliasing)]TJ 4.981 -18.389 T cvarNamenotes

hunk

display hunk usage.

checkhunk

run hunk consistency test.

zone

display zone usage.

checkzone

run zone consistency test.

C.1.5 Simulation Control

changeCam

cycle through available cameras.

reset

reset the simulation.

toggleSim

pause/unpause the simulation.

C.2 Console Variables

bgmvolume

CD audio volume. Default: 1.0.

cam_damp

tracking camera damping constant. Default: 2.0.

cam_dist

distance from tracking camera to target. Default: 40.0.

cam_spring

tracking camera spring constant. Default: 10.0.

cmd_log

if 1, log incomming console commands to le. Default: 0.

con_log

if 1, log all console activity to le. Default: 0.

_notifycmd

mem *size*

specify total memory availble to program, in KB. Default: 8192K (8MB).

nocdaudio

do not use CD audio.

nomouse

do not use mouse.

opengldriver

dumps OpenGL driver info (vendor, version, and supported extensions) to `log.txt`.

zone *size*

specify zone size, in KB. The zone is used for quick dynamic allocations. Default zone size is 256K.

C.3.1 Linux-specific

cddev *path*

specify location of CDROM device. Default: /dev/cdrom.

C.3.2 Windows-Specific

nodinput

do not use DirectInput.