Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie

School of Engineering
Skool vir Ingenieurswese

Department of Mechanical and Aeronautical Engineering
Departement van Meganiese en Lugvaartkundige Ingenieurswese

Vehicle Engineering MVE420
Voertuigingenieurswese MVE420

Prof PS Els
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Vehicle Engineering MVE 420 (2017)

OVERVIEW AND APPROACH

The aim of the *Vehicle Engineering 420* course is to establish a technical foundation for prospective vehicle engineers. Basic scientific principles, as well as vehicle specific engineering knowledge areas are applied to describe, analyze and design vehicles. Specific knowledge of tyres, vehicle performance, suspension systems, ride comfort and handling is applied to analyse and evaluate vehicle systems.

To understand, analyse and design vehicles, you must be able to:

- Formulate *dynamic models* of a typical vehicle (single and multi-degree of freedom systems).
- Formulate the *governing equations* for typical inputs.
- Find *solutions* for the equations
- *Interpret* and use results for design purposes.
- *Specify* sensible *experiments* to determine vehicle behaviour, based on sufficient understanding of the measuring process.

In all engineering disciplines the ability to work in groups is of paramount importance. Therefore, as a secondary purpose with this module, we want to contribute and develop your ability in this regard.

The module further serves to prepare you for the *Vehicle Dynamics MVI 780* postgraduate module.

This study guide is a crucial part of the general study guide of the Department. In the study guide of the Department, information is given on the mission and vision of the department, general administration and regulations (professionalism and integrity, course related information and formal communication, workshop use and safety, plagiarism, class representative duties, sick test and sick exam guidelines, vacation work, university regulations, frequently asked questions), ECSA outcomes and ECSA exit level outcomes, ECSA knowledge area, CDIO, new curriculum and assessment of cognitive levels. It is expected that you are very familiar with the content of the Departmental Study Guide. The study guide is available on the Department’s website.

http://www.up.ac.za/media/shared/120/Noticeboard/2017/departmental-studyguide-eng-2017_version27may2017.zp119960.pdf

Take note of the specific instructions in the above study guide on:

a) Safety, b) Plagiarism, c) What to do if you were sick (very important)? and d)the appeal process on the adjustment of marks

ORGANISATIONAL COMPONENT

LECTURERS

Module coordinator & Lecturer: Dr C Kat
Tel: 012 420 3205
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Lecturer: Prof PS Els
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Consulting hours:
By appointment. You may arrange appointments via e-mail or directly after lectures.

Post-box:
All assignments and practical reports must be handed in during the lectures.

STUDY MATERIAL

Textbooks:

The textbook prescribed for the course is: **Gillespie, TD.** *Fundamentals of Vehicle Dynamics*, 1992, SAE. Extensive literature is available in the Academic Information Centre and students are encouraged to study additional literature in addition to the lecture notes and the prescribed textbook.

The following books can also be recommended:

- **Reimpel, J. & Stoll, H.,** *The Automotive Chassis: Engineering Principles*, Arnold, 1996.
- *Automotive Handbook*, Bosch, SAE Society of Automotive Engineers.
- **Milliken, W.F. & Milliken, D.L.,** *Race Car Vehicle Dynamics*, SAE, 1995.
- **Dixon, J.,** *The Shock Absorber Handbook*, SAE, 1999.

Additional lecture notes and information may be distributed.

Study guide:
This guide has been carefully compiled to assist you to work independently and structured. The study guide is intended as a guideline to the student to study independently and prepare for lectures in advance. The course covers a very wide spectrum of work that cannot be treated in detail during lectures. Self-study will be required to master all the aspects involved.

The lecturer acts as a guide as to what knowledge should be mastered by the student. The document is subject to change by announcement in class.

LEARNING ACTIVITIES

Lectures:
3 Lectures per week for 12 weeks. Through the semester you are expected to spend about 4 hours of your own time per lecture on this module. You are further expected to attend lectures regularly and be ready to participate in class discussions at any time.

Group work:
Modern teaching in engineering emphasises the ability of students to function in groups. For this module you will be grouped in groups of maximum 4 people. These groups will work together in the practical as well as in certain assignments. For all group work only one consolidated report must be submitted. To prevent particular students from taking a free ride, each student will do an independent evaluation of each group member's contribution to the group effort.

Computer work:
Much of the work in this module requires simulation using computer programmes. Since one cannot develop a good feel for this subject without doing the computations, convenient access to a computer is necessary. You are expected to have a working knowledge of MATLAB (or similar e.g. Octave or Python). The MATLAB version, which comes with *The student edition of MATLAB*, is sufficient for this module.

Problems:
Apart from the official assignments, example problems in the textbook are of the utmost importance to get to grips with this work. You are expected to study the example problems in your own time. **You are encouraged to discuss the problems and solutions with your group members**.

Practicals :
There are two practicals in the course. The first is vehicle testing at the Gerotek Test Facilities and the second is a multi-body dynamics exercise in the computer laboratories. A comprehensive consolidated group report must be submitted on each practical. The *content* and *presentation* of the report will be evaluated. See p.13 for further information on the practicals.

Assignments:
Homework assignments will be given during lectures. These assignments must usually be handed in within a week, unless otherwise agreed upon during handout. The assignments must be submitted strictly according to the specified due date. Late assignments will not be accepted.

Tests and examinations:
Two semester tests will be written according to the schedule published by the Mechanical and Aeronautical Engineering Department. The final examination will be during November 2017. The specific dates and times will be announced during the course.

Marks:
Semester marks are calculated as follows:
Semester Tests 50 %
Assignments 40 %

Practicals 10 %

The final mark is calculated as follows:
Semester mark 50 %
Examination mark 50 %

To pass this module, the candidate must obtain a final mark of at least 50%, attend the practicals and obtain a sub minimum of a 50% mark for the practicals.

STUDY COMPONENT

MODULE STRUCTURE

The module is comprised of the following study themes:

Study theme	Mode of instruction	Notional hours	Contact sessions
1. Tyres	Lectures, assignments	26	6
2. Vehicle aerodynamics	Lectures, assignments	14	3
3. Performance	Lectures, assignments	34	8
4. Ride comfort	Lectures, assignments	14	3
5. Handling	Lectures, assignments	26	6
6. Suspension & steering systems	Lectures, assignments	18	4
7. Roll-over	Lectures, assignments	10	2
8. Simulation	Lectures, assignments	18	4
	Total	**160**	**36**

Note: *The notional hours include the contact time, as well as the estimated time to be allocated for self-study, practicals, preparation of assignments and preparation for tests and examination*

Fundamental concepts:
For each study unit *fundamental concepts* are identified. You must be able to explain each of these concepts properly and illustrate where applicable.

Learning outcomes:
For each study unit *learning outcomes* are identified. Use these outcomes to manage your learning process. You will be assessed on these outcomes.

STUDY THEME 1: TYRES

6 lectures

Theme	Source
Tyre construction	Gillespie Ch 10
Size and load rating	Gillespie Ch 10
Terminology and axis system	Gillespie Ch 10
Mechanics of force generation	Gillespie Ch 10
Tractive properties	Gillespie Ch 10
Cornering properties	Gillespie Ch 10
Camber thrust	Gillespie Ch 10
Aligning moment	Gillespie Ch 10
Combined braking and cornering	Gillespie Ch 10
Conicity and ply steer	Gillespie Ch 10
Durability Forces	Gillespie Ch 10
Tyre vibrations	Gillespie Ch 10
Tyre characteristics on soft soil	Class notes

Background:
The tyres on a vehicle represent the only physical contact between the vehicle and the road. All the forces between the vehicle and road (traction, braking, steering and vertical forces) are therefore controlled and limited by the tyres. In the lecture unit, tyre construction and characteristics are discussed, as well as the performance of tyres on soft surfaces (e.g. sand, mud, gravel).

Fundamental concepts:
Cross-ply tyre, radial ply tyre, force generation, traction, slip, surface friction coefficient, slip angle, pneumatic trail, cornering stiffness, camber, aligning moment, friction circle, terramechanics, soil mechanics, contact patch, contact pressure, mean maximum pressure.

Learning outcomes:
1. Describe and explain the different types of tyre construction
2. Interpret the tyre size and load rating
3. Know tyre terminology and axis system
4. Describe the mechanics of force generation
5. Describe the different tyre characteristics e.g. rolling resistance, tyre stiffness, generation of side force etc.
6. Describe and explain the effect of tyre construction on tyre characteristics such as rolling resistance, tyre stiffness, generation of side force etc.
7. Give a graphical representation of the characteristics and explain the influence of these characteristics on vehicle performance, handling and ride comfort.
8. Calculate and describe the influence of combined tyre forces, e.g. the effect of braking on side force generation for a tyre.
9. Analyse a specific tyre with regards to performance on different surfaces and estimate properties such as maximum traction, slip and rolling resistance on these surfaces.

Problems:
Homework assignments will be handed out in class.

STUDY THEME 2: VEHICLE AERODYNAMICS

3 lectures

Theme	**Source**
Coefficient of drag	Gillespie Ch 4
Coefficient of lift	Gillespie Ch 4
Side wind stability	Gillespie Ch 4
Pressure distribution	Gillespie Ch 4
Spoilers and wings	Gillespie Ch 4

Background:
Vehicle aerodynamics are important for the calculation of top speed and acceleration, as well as handling at high speed. It also has a significant effect on the choice of gear ratios and influences vehicle fuel consumption.

Fundamental concepts:
Coefficient of drag, frontal area, coefficient of lift, side wind stability, pressure distribution, soiling, spoilers, wings.

Learning outcomes:
After completion of this lecture unit, the student must master the following study goals:
1. Calculate the aerodynamic resistance of a vehicle
2. Calculate the aerodynamic lift force
3. Qualitatively describe the effects of pressure distribution, spoilers and wings on vehicle aerodynamics
4. Qualitatively describe the influence of vehicle design parameters on side wind stability
5. Develop a feeling for typical drag coefficients and frontal areas for different types of vehicle.

Problems: Homework assignments will be handed out in class.

STUDY THEME 3: PERFORMANCE

8 lectures

Theme	**Source**
Introduction to vehicle dynamics	Gillespie Ch 1
Fundamental approach to modeling	Gillespie Ch 1
Newton’s second law	Gillespie Ch 1
Equations of motion for a vehicle	Gillespie Ch 1
Dynamic axle loads	Gillespie Ch 1
Engine characteristics	Gillespie Ch 2
Traction limited acceleration	Gillespie Ch 2
Braking performance	Gillespie Ch 3
Aerodynamics	Gillespie Ch 4
Rolling resistance	Gillespie Ch 4
Total road loads	Gillespie Ch 4
Prediction of vehicle performance	Gillespie Ch 4

Background:
Vehicle performance (e.g. maximum speed, acceleration and fuel consumption) is determined by the drive train design as well as resistance forces (e.g. rolling resistance and aerodynamic drag). The concept of supply (propulsion forces) and demand (resistance forces) is applied in order to calculate several vehicle performance parameters.

Fundamental concepts:
Lumped mass, Newton’s second law, engine power and torque curves, power train, mass factor, drive train efficiency, automatic transmissions, torque converter, specific fuel consumption, traction limit, brake proportioning, anti-lock brake systems (ABS), coefficient of drag, frontal area, rolling resistance, fuel economy.

Learning outcomes:
After completion of this lecture unit, the student must master the following study goals:
1. Calculate the resistance forces on a vehicle.
2. Calculate the propulsion forces supplied by the vehicle drive train.
3. Present propulsion and resistance forces graphically on the ride diagram and use the diagram to analyse and evaluate vehicle performance.
4. Calculate the maximum speed, acceleration, gradient ability, and fuel consumption etc. of a vehicle.
5. Calculate the maximum traction force that a vehicle can exert as well as the maximum gradient a vehicle can negotiate, based on the maximum attainable traction force.
6. Calculate and explain the effect of drive train characteristics (e.g. gear ratios, tyre size, differential ratio) on vehicle performance.
7. Describe the working principles of fluid couplings and torque converters.
8. Explain and calculate the influence of fluid couplings and torque converters on vehicle performance.
9. Describe and explain vehicle braking as well as the factors that influence braking.
10. Calculate the stopping distance and ideal brake force distribution for a vehicle.

Problems: Homework assignments will be handed out in class.

STUDY THEME 4: RIDE COMFORT

3 lectures

Theme	**Source**
Excitation sources	Gillespie Ch 5
Vehicle response properties	Gillespie Ch 5
Springs	Class notes
Dampers	Class notes
Human response to whole body vibration	Gillespie Ch 5 & class notes

Background:
The ride comfort lectures establish the basic principles required when specifying, designing and evaluating a vehicle to obtain the best possible ride comfort for the occupants.

Fundamental concepts:
Road roughness, excitation sources, sprung mass, unsprung mass, isolation, natural frequency, stiffness, damping, equations of motion, amplitude ratio, wheel hop, pitch, bounce, wheelbase filtering, perception of ride, human response to whole-body vibration.

Learning outcomes:
After completion of this lecture unit, the student must master the following study goals:
1. Describe the main sources of vibration excitation on a vehicle
2. Describe the different types of springs used on vehicles
3. Describe, using figures, the characteristics of the different spring types
4. Describe the different types of dampers used on vehicles as well as their working principles
5. Describe, using figures, the characteristics of the different damper types
6. Derive the equations of motion for a ¼ car model from first principles
7. Calculate the natural frequencies of a ¼ car vehicle suspension system
8. Describe the effect of damping on the transfer function of a ¼ car vehicle suspension system
9. Motivate why the choice of suspension characteristics always involve a compromise.

Problems:
Homework assignments will be handed out in class.

STUDY THEME 5: HANDLING

6 lectures

Theme	Source
Low speed turning	Gillespie Ch 6
High speed cornering	Gillespie Ch 6
Suspension effects on cornering	Gillespie Ch 6
Steady state handling	Gillespie Ch 6
Dynamic handling	Class notes
Handling tests	Gillespie Ch 6
Dynamic simulation of handling	Gillespie Ch 6

Background:
The handling lectures establish the basic principles required when specifying, designing and evaluating a vehicle to obtain the best possible vehicle handling.

Fundamental concepts:
Ackerman steering, bicycle model, understeer gradient, neutral steer, oversteer, understeer, characteristic speed, critical speed, constant radius test, constant speed test.

Learning outcomes:
After completion of this lecture unit, the student must master the following study goals:

1. Describe and calculate the Ackerman steering geometry
2. Evaluate the handling response of a simplified vehicle model by calculating the understeer coefficient
3. Describe the terms oversteer and understeer
4. Describe the different handling tests as well as the vehicle handling parameters evaluated by each test
5. List the suspension parameters which is most important during the dynamic simulation of vehicle handling
6. Calculate the sliding vs. rollover stability of a vehicle
7. Describe the effect of the centre of gravity on the sliding and rollover stability of a vehicle.

Problems:
Homework assignments will be handed out in class.

STUDY THEME 6: SUSPENSION AND STEERING SYSTEMS

4 lectures

Theme	Source
Terminology	Gillespie Ch 7
Solid axles	Gillespie Ch 7
Independent suspensions	Gillespie Ch 7
Anti-squat and anti-pitch suspension geometry	Gillespie Ch 7
Anti-dive suspension geometry	Gillespie Ch 7
Roll center analysis	Gillespie Ch 7
Active suspensions	Gillespie Ch 7
Steering systems	Gillespie Ch 8
Steering geometry errors	Gillespie Ch 8
Steering system forces and moments	Gillespie Ch 8
Four wheel steering	Gillespie Ch 8

Background:
The two lectures on suspension and steering systems give the student an overview of the different systems that is in frequent use on vehicles today. The geometry and kinematics of each suspension and steering system is also described. The advantages and limitations of the different concepts, as applied to modern vehicles, are investigated.

Fundamental concepts:
Solid axles, independent suspensions, trailing arm, double wishbone, McPherson, multi-link, semi-trailing arm, swing axle, anti-squat, anti-pitch, anti-dive, roll center, semi-active suspension, active suspension, toe-in, roll steer, camber, caster, aligning moment, four wheel steer

Learning outcomes:
After completion of this lecture unit, the student must master the following study goals:

1. Describe the different suspension concepts using sketches.
2. Explain the advantages and limitations of each suspension concept.
3. Determine the roll center of the suspension concepts graphically.
4. Explain the effect of suspension movement on the track width, roll center, roll axis, camber angle and kingpin inclination.
5. Analyse anti-pitch, anti-squat and anti-dive geometry graphically
6. Describe the effect of anti-pitch, anti-squat and anti-dive on the dynamics of the vehicle during acceleration, braking or when crossing an obstacle.
7. Describe the different types of steering systems used on vehicles
8. Describe the effect of steering system kinematics on roll steer, bump steer, slip angle and pneumatic trail

Problems:
Homework assignments will be handed out in class.

STUDY THEME 7: ROLLOVER

2 lectures

Theme	**Source**
Static stability factor	Class notes
Quasi-static rollover	Gillespie Ch 9
Transient rollover	Gillespie Ch 9
Rollover propensity testing	Class notes
Banked roads	Class notes

Background:
Rollover accidents are a major cause of deaths worldwide. It is therefore important to understand the fundamental vehicle design parameters that influence rollover propensity.

Fundamental concepts:
Static stability factor, static rollover, transient rollover, rollover testing, rollover simulation

Learning outcomes:
After completion of this lecture unit, the student must master the following study goals:
1. Calculate the static stability factor for a vehicle
2. Determine whether a vehicle will roll or slide first
3. Calculate the effect of road bank angle on rollover
4. Describe the various test procedures used to quantify rollover propensity

Problems:
Homework assignments will be handed out in class.

STUDY THEME 8: SIMULATION

4 lectures

Theme	**Source**
Kinematics	Class notes
Dynamics	Class notes
¼ car models	Class notes
Simulation pitfalls	Class notes

Background:
The design of modern vehicles is so complex that simulation is increasingly used early in the design stages. This means that vehicle sub-systems or even complete vehicles are modeled mathematically in great detail to optimize performance and to reduce the development time.

Fundamental concepts:
Kinematics, dynamics, models, problems, challenges.

Learning outcomes:
After completion of this lecture unit, the student must master the following study goals:
1. Master a basic modeling capability in ADAMS
2. Understand the pitfalls e.g. redundancy, degrees of freedom, effect of solvers etc.
3. Use ADAMS to design a ¼ car suspension system taking both kinematics and dynamics into account.

Problems:
Homework assignments will be handed out in class.

GENERAL ARRANGEMENTS FOR PRACTICALS

General
a) The first practical will take place at the Gerotek Test Facilities West of Pretoria.
b) Every student must attend the practicals.
c) A sub minimum of 50% for the practicals is required for entrance into the exam.
d) No student will be exempted from practicals.

Reports
a) Document your findings thoroughly. Your report must typically include the following:
- Purpose (detailed)
- Instrumentation / measurements / simulations
- Approach
- Results
- Conclusion and evaluation (Particularly important! Devote sufficient attention to the critical discussion and evaluation of your results.)

b) Hand in a *group report* on the date arranged in class.

PRACTICAL 1: VEHICLE TESTING

Purpose:
To familiarise you with basic vehicle test methods, the use of measuring equipment and the interpretation of test data. The practical will include:
1. General test methodology
2. Measuring turning circle (Ackerman steering angles)
3. Steady state handling test
4. Dynamic handling test
5. Ride comfort measurement
6. Vehicle dynamics on wet surfaces (skid pan)

Arrangements:
a) The practical will take a full day from 08:00 until 16:00. The date and other specific arrangements will be announced in class.
b) Students must supply their own transport and preferably come in their own cars for the skid pad session.
c) Students will be required to sign an indemnity form.
d) A large degree of self-working and initiative is expected.

PRACTICAL 2: MULTI-BODY DYNAMICS SIMULATION

Purpose:
To analyse and compare different vehicle designs, as well as simulation of vehicle performance. The practical will include:

1. Suspension kinematics
2. Spring-mass-damper systems
3. Handling analysis
4. Ride analysis

Arrangements:

a. The practical will take place during lecture times in the computer laboratories. Specific dates and details will be announced later.
b. A large degree of self-working and initiative is expected.