UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Engineering, Built Environment and Information Technology

DEPARTMENT OF MECHANICAL AND AERONAUTICAL ENGINEERING

STUDY MANUAL

DYNAMICS MSD210

2017

Compiled by:
Prof NJ Theron
Dr C Kat
Dr HM Inglis
Dr TR Botha

Date of last revision: 1 February 2017

Copyright reserved

TABLE OF CONTENTS

Page

ORGANISATIONAL COMPONENT

1. GENERAL PREMISE AND EDUCATIONAL APPROACH

MSD210 Dynamics deals with the dynamic behaviour of systems of particles. In order to predict this dynamic behaviour, the physics of the dynamic problem is modelled mathematically, after which the mathematical problem thus posed is solved. This means that insight into the dynamics problem and its modelling as well as the ability to apply the tools of mathematics to this is essential to achieve success in this module. The material is therefore presented with an emphasis on understanding modelling and the mathematics applied. See also section 1.1 of the Study Component of this document.

The most important player in this module is each individual student. She/he needs to maximize her/his own understanding of the material and this can only be done if she/he takes personal responsibility for this. The lecturers will be available to assist the students in reaching this goal, but only to assist, because they are incapable of doing anything more. The primary responsibility lies with the student.

This module carries a weighting of 16 credits, indicating that on average a student should spend some 160 hours to master the required skills (including time for preparation for tests and examinations). The average student should therefore spend about ten hours per week (including contact sessions) on this module.

There is a significant emphasis on enabling and encouraging the student to solve problems similar to the ones done in class by the lecturer. It is much more important for the student to do a few problems thoroughly and correctly and to understand in detail their solutions rather than doing and understanding a large number of problems only superficially. To this end, it is equally important to understand the theory presented in the module rather than memorising it. It is only when the theory is fully understood that it can be applied successfully to solve problems.

2. LECTURERS, VENUES AND CONSULTING HOURS

	Name	**Room No. and Building**	**Telephone No. and E-mail Address**
Lecturers			
Module Manager	Dr HM Inglis	Room 10-21, Eng I	012-420 3125, *helen.inglis@up.ac.za*
Lecturers English Group	Prof NJ Theron	Room 10-5, Eng I	012-420 3309, *nico.theron@up.ac.za*
	Dr TR Botha	Room 1-6, Eng II	012-420 3289, *trbotha@tuks.co.za*
Lecturer Afrikaans Group	Dr C Kat	Room 1-2, Eng II	012-420 3205, *cor-jacques.kat@up.ac.za*
Lecturer Tutorials	Dr HM Inglis	Room 10-21, Eng I	012-420 3125, *helen.inglis@up.ac.za*
Teaching Assistants	To be announced later		
Secretary	Ms I Meyer	Room 9-20, Eng I	012-420 3105, *ilka.meyer@up.ac.za*

As manager of the module, Dr Inglis deals with all administrative issues and problems with marks.

Location of the Notice Board: The official notice board of the module is the course web site, on ClickUP.

Consulting hours: Hours for consultation of lecturers will be announced at the beginning of the semester, and will also be displayed on ClickUP. Students may consult lecturers only during the consulting hours as indicated, or by appointment. Students should consult the lecturer responsible for her/his own group (as indicated in the table on page 3) and the part of the module in question.

A duty timetable for consulting hours for the teaching assistants will be available on the course web site and will be updated from time to time. Any teaching assistant on duty may be consulted, i.e., this is not bound by groups.

3. STUDY MATERIALS AND PURCHASES

The following textbook is prescribed:

Meriam JL, Kraige LG & Bolton, JN : Engineering Mechanics: Dynamics, 8th edition, SI version, 2016, John Wiley, ISBN 978-1-119-04481-9.

(Students may use the 7th SI edition of the textbook, but are responsible for reconciling the problem numbers and page numbers that will be given from the 8th SI edition.)

A set of *supplementary* notes is available as a pdf-file on the module web page, for students to download and print.

Both the book and the supplementary notes will be used extensively and it is **thus compulsory for each student to obtain a copy of both**.

Solutions to some of the problems done in class and other relevant study material will be made available on the web site.

4. LEARNING ACTIVITIES

4.1 Contact time

Number of formal contact sessions per week: five (5): three (3) teaching and two (2) tutorial classes. The teaching classes are referred to by this name, not because the lecturer is necessarily teaching the students, but because general teaching takes place during these sessions, often through student-to-student teaching. During the tutorial classes, on the other hand, the emphasis is more on students doing problems on an individual basis.

4.2 Teaching classes

The lecturing style differs from lecturer to lecturer. In the teaching classes, however, significant emphasis is placed on students discussing the theory and doing example problems in class. To enable students to participate, a preparatory reading assignment is issued before each teaching class. This reading assignment must be completed and a survey (quiz) then needs to be answered on ClickUP by 04h00 on the morning of the class. The purpose of this survey is to give the lecturer some feedback on the students' understanding of the reading material. Students' participation in the reading assignment and their filling in of the survey will be assessed and will be taken into account for about 10% of the semester mark, (see "Calculation of the semester mark" in section 5). In this assessment, the emphasis will be on participation and effort as well as on correct answers.

The bulk of the material that the student must master to pass MSD 210 Dynamics will not be lectured in the teaching classes. It is the students' responsibility, primarily, to master this material and this is not achieved by the lecturer presenting the material in class. Available time during the teaching classes will be focussed towards those areas where students are found to experience problems. In this whole process of the students mastering the material, the lecturer is available to assist and guide.

Students are advised not to take comprehensive notes during contact sessions. The time should rather be used more effectively by concentrating on active participation in discussions. All the relevant study material is adequately referenced and is available in the textbook, the supplementary notes, the study manual and on the module web site.

4.3 Homework assignments

During discussion of the various themes of the course, the lecturers will identify problems that the student has to solve at home in preparation for the tutorial sessions of the following week. These problems will be available on ClickUP by the Tuesday one week before the tutorial sessions. The final answers to about half the homework problems are available in the text book and the final answer to the other problems will be made available at the beginning of the tutorial class. **If students are unsuccessful in obtaining the correct answer, it is of paramount importance that they consult the lecturer or a teaching assistant during the tutorial class or consultation hours.**

Cooperation in the groups (see section 4.5) is encouraged with respect to the homework assignments. This cooperation must be understood as that the group members discuss the problem and its solution, but that each group member then generates on her/his own solution on paper.

Students' solutions to homework problems are neither marked nor taken into consideration in determining the semester mark.

4.4 Tutorial classes

Completion of the assignment at home is followed by attending a tutorial class during which a lecturer and teaching assistants will offer further assistance and teaching in a more informal manner. Special attention will be given to the understanding of difficult concepts and their application to problems with which the student is experiencing difficulty. Additional exercises will also, where necessary, be done under supervision.

Some tutorial classes will be concluded with a tutorial test in which students will be tested on the relevant theme. Having mastered the homework assignments is an excellent preparation for these tests. Tutorial tests will consist of a problem or problems similar to those solved in the homework assignment. As these are tests, each student is expected to do her/his own work. Students suspected of copying will receive zero for the test.

The tutorial tests will be marked in one of two methods:

- In tutorial, via a peer marking process, or
- By the teaching assistants.

The mark allocated to a student for a tutorial test will be taken into account in the calculation of the semester mark, only if this is higher than the student's average mark for the two semester tests. This is explained in greater detail in section 5 below. When a peer marking method is used, the accuracy of marking will also contribute to the semester mark. Students have the right to appeal against the marks awarded, see "Appeals on marks" in section 5 below. The marked tutorial tests will be returned to the students as soon as possible, usually at the following tutorial class. The model answer of each tutorial test will be made available on the module web page after the test.

The tutorial tests are open book in nature, but students are allowed to consult only the prescribed textbook and the supplementary notes mentioned in section 3 above. If a student uses any other material during a tutorial test, this will be construed as academic dishonesty that may lead to disciplinary action against the student. Additionally, the teaching assistants or the lecturer may confiscate this material. Each student must bring her/his **own copy** of the textbook and supplementary notes to the tutorial tests. If a student neglects to bring her/his own copy to the tutorial test, this will be a closed book test for that student.

4.5 Unannounced class quizzes

Small unannounced quizzes may be given in class. These will contribute to the semester mark as explained in Section 5 below.

4.6 Project

A project will be completed during the semester. The project will be completed in groups of up to 5 students, which will be determined at the beginning of the semester. Although formal group work only occurs for the project, students are encouraged to work together as groups during tutorial classes and when studying, to discuss the homework assignments and the class material.

As part of the group project, students will be asked to perform a peer evaluation of each group member to the collective group effort. This buddy rating will be taken into account in the distribution of marks for the project.

The project will make up 10% of the semester mark in the same way as the tutorial tests (see Calculation of the semester mark).

5. RULES OF ASSESSMENT

See also the examination regulations in the EBIT Yearbook, available at the following link: Yearbooks of the University of Pretoria (or http://web.up.ac.za/ > English > New Students > Study Information > Yearbook Information).

Pass requirements In order to pass the module a student must
1. obtain a final mark of at least 50%
and
2. obtain an examination mark of at least 40%.

Admission to the examination In order to be admitted to the examination a student must obtain a semester mark of at least 40%.

Calculation of the final mark The final mark is calculated as follows:

Semester mark:	50%
Examination mark:	50% (The final examination takes three hours.)

Semester tests Two tests of 90 minutes each will be written during the scheduled test weeks of the School of Engineering:

First test week:	11 to 18 March 2017
Second test week:	6 to 13 May 2017

For the dates, times and venues, students should consult the appropriate test timetable when it becomes available.

Absence with excuse Refer to the Departmental Study Guide.

Appeals on marks Please refer to the Departmental Study Guide for the appeal process on the adjustment and correction of marks.

Calculation of the semester mark The semester mark is compiled as follows:

Semester Test 1	30%
Semester Test 2	30%
Class work	40%.

The class work mark is made up of the marks for tutorial tests, unannounced class quizzes, reading assignments and the project.

- Define the Semester Test Average (STA) as the student's average mark for the two semester tests.
- For each tutorial test for which a student obtains a mark lower than her/his STA, the student will instead receive the STA. In other words, the tutorial test marks will only count if they help you.
- The unannounced class quizzes will together count the equivalent of one tutorial.
- The contribution to peer marking will count the equivalent of one tutorial
- The reading assignments before teaching classes (see section 4.2) will be assessed using ClickUP and the combined mark awarded for this, covering the whole semester, will contribute 10% of the semester mark.
- The Project will contribute 10% of the semester mark. Notice that the project is voluntary, and cannot lower the semester mark. Students who do not complete the project, or who earn a mark lower than their STA, will be awarded their STA for this component.

Supplementary examination Please refer to the year book of the University of Pretoria for the instances for which a supplementary examination is granted. The year book also gives information on how the final mark is calculated in the event that a supplementary examination has been granted.

6. GENERAL

6.1 Use of pocket calculators during tests and the examination

Students are allowed to use pocket calculators during tests and examinations on condition that all memory of such calculators is cleared before the test/examination is written. Failure to do so may be construed as academic dishonesty that may lead to disciplinary action against the student.

6.2 Inspection of examination scripts

After the examination the marked scripts will be made available, together with a model answer sheet, for inspection under supervision at a time and place that will be announced on the module web page. Especially students who failed the examination but qualified for a supplementary examination are encouraged to inspect their scripts in preparation for this examination.

The marked scripts of the supplementary examination will also be available for inspection at a time and place that shall be announced later.

6.3. Departmental study guide

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.zp107056.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)?
d. Appeal process on the adjustment of marks

STUDY COMPONENT

1. MODULE OBJECTIVES AND ARTICULATION

1.1 Statement of Objective

MSD 210 Dynamics is an introductory module intended for students from all disciplines in engineering, dealing with the dynamic behaviour of systems of particles with the emphasis on special cases of rigid bodies and mechanisms. Essentially, it entails the formulation and solution of mathematical models of physically dynamic systems. In setting up the model, principles of mechanics together with applicable physical and mathematical approximations are used to formulate the equations of motion of the system. In the solution, geometry, trigonometry, scalar and vector algebra and calculus are used. This gives meaning to the mathematical tools the student already has at his/her disposal. Finally, the relevance of the model is evaluated through the physical interpretation of the solution of the equations of motion. This synthesis of modelling, solution and interpretation represents a disciplined problem-solving approach, which has universal application and is therefore of value to engineering students from all disciplines. Since dynamics falls within the experience of all engineering students, it is the ideal vehicle through which this disciplined methodology can be conveyed to the student. In this way, the course has a very important formative function.

1.2 Prerequisite learning

Before admission to this module, a student must have passed the following modules: Physics FSK 116 and Mechanics SWK 122. It is not possible to pass MSD 210 Dynamics without a proper understanding of the material covered in these two modules. Many of the problems students experience with Dynamics can be traced back to not having fully mastered the theory presented in these two modules, even if these were passed. Time spent on revision of this material will therefore prove to be a good investment. In addition to the two prerequisite modules mentioned above, the module Differential Equations WTW 256 is a concurrent registration prerequisite for MSD 210 Dynamics, as the solution to differential equations plays a very important role in the latter part of this module. When Study Theme 4 is treated, it is assumed that the student is proficient in the solution of linear second order differential equations.

1.3 Articulation with other modules in the programme

MSD 210 Dynamics does not articulate directly with more advanced modules in the various engineering curricula, with the exception of that of Mechanical Engineering. However, due to the very nature of this module, in that it is aimed at the development of a disciplined problem-solving approach, it has an indirect articulation with a large number of later modules in all the engineering curricula of which it also forms a part.

In Mechanical Engineering, the study of Dynamics lays the foundation for many subsequent modules, such as MOW 227 Structural Design, MOW 312 Machine Design and MOW 323 Simulation-based Design, MVR 320 Vibrations and Noise, and MBB 410 Control Systems. Principles studied in Dynamics also play an important role in MTV 420 Thermal and Fluid Machines.

2. MODULE STRUCTURE

Study theme and Study units	Mode of instruction	Notional hours	Contact sessions
1. Plane Kinematics of Rigid Bodies 1.1 Fixed-axis Rotation 1.2 Relative Velocity 1.3 Relative Acceleration	Lectures, examples done in class, tutorial classes	40	14
2. Dynamics of Systems of Particles 2.1 Generalisation of Newton's Second Law 2.2 Principle of Work-Energy 2.3 Principle of Impulse-Momentum 2.4 Conservation of Energy and Momentum 2.5 Steady Mass Flow	Lectures, examples done in class, tutorial classes	44	20
3. Plane Kinetics of Rigid Bodies 3.1 General Equations of Motion 3.2 General Plane Motion 3.3 Translation 3.4 Fixed-axis rotation 3.5 Work and Energy	Lectures, examples done in class, tutorial classes	48	16
4 Vibration of Single Degree of Freedom Systems 4.1 Free Vibration of Particles 4.2 Forced Vibration of Particles 4.3 Vibration of Rigid Bodies	Lectures, examples done in class, tutorial classes	17	7
5. Moments of Inertia and Products of Inertia 5.1 Moments of Inertia around an Axis 5.2 Products of Inertia	Lectures, examples done in class, Tutorial classes	11	3
	Total	**160**	**60**

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

3. STUDY THEME DESCRIPTIONS

In the description that follows no mention is made of the introductory section of each chapter of the textbook. This is because the introduction does not constitute a study unit. The introduction is, however, important in all cases and forms an integral part of the module.

The prescribed module textbook by Meriam and Kraige is referred to by the abbreviation "M&K" and the Supplementary Notes by "SN" in the rest of this document.

3.1 STUDY THEME 1: Plane Kinematics of Rigid Bodies

3.1.1 Learning outcomes

At the end of this study theme, the student will be able to:
- **reason** logically about the cause and effect in, and illustrate understanding of the kinematics of rigid bodies
- **describe** the kinematics of a rigid body moving in a plane
- **express** the velocity and the acceleration of any point on the body in terms of the position, velocity and acceleration of other points on the body
- **calculate** the values of the magnitudes if sufficient information is furnished.

3.1.2 Study units

Fixed Axis Rotation
M&K §5/2 & SN

Relative Velocity
M&K §5/4 & SN

Relative Acceleration
M&K §5/6 & SN

3.1.3 Criteria of assessment

At the end of this study theme, a student will be able to:
- **define** the concepts: "kinematics", "kinetics" and "rigid body"
- **list** the four types of rigid-body plane motion and explain each type with a sketch
- **prove** that the angular velocity is the same on any point on a rigid body

(Fixed-axis Rotation)
- **calculate** the velocity and acceleration of any point on a rigid body which rotates around a fixed point in terms of the angular velocity and angular acceleration of the body
- **write** down the vector equations for the velocity and acceleration of a rigid body rotating around a fixed axis
- **explain** what each term in the equation represents

(Relative Velocity)
- **derive** the equation for the velocity of a point A by using the concept of relative velocity
- **explain** how the velocity of point A can be calculated by means of a velocity diagram
- **apply** the principle of relative velocity in solving problems

(Relative Acceleration)
- **derive** the equation for relative acceleration
- **explain** the meaning of each term in the expression
- **use** the equation in solving relevant problems

3.2 STUDY THEME 2: Dynamics of Systems of Particles

3.2.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **reason** logically about the cause and effect in, and **illustrate** understanding of the dynamics of a system of discrete particles
- **analyse** the kinematics and kinetics of a system of particles in space.
- **calculate** the velocity and accelerations of a system for given force inputs and/or initial values.
- **analyse** the dynamics of a stream of particles flowing under steady conditions and calculate the forces affecting them.

3.2.2 Study units

Generalisation of Newton's Second Law
M&K §4/2 & SN

Principle of Work-Energy
M&K §4/3 & SN

Principle of Impulse-Momentum
M&K §4/4 & SN

Conservation of Energy and Momentum
M&K §4/5

Steady Mass Flow
M&K §4/6 & SN

3.2.3 Criteria of assessment

At the end of this study theme, a student will be able to:

(Generalisation of Newton's Second Law)

- **derive** the general form of Newton's second law as applicable to a system of particles
- **solve** for the acceleration of a system of particles by using Newton's generalised second law

(Principle of Work-Energy)

- **define** the work done by the internal and external forces on a system of particles
- **write** down the work-energy equation
- **explain** what each term in the work-energy equation means
- **derive** an expression for the kinetic energy of a system of particles
- **calculate** the position and velocity of a system of particles after known external forces have acted on them for a given time interval

(Principle of Impulse-Momentum)

- **define** the linear momentum of a system of particles
- **prove** that the linear momentum of a system of particles is given by multiplying the total mass with the velocity of the centre of mass
- **define** the angular momentum of a system of particles
- **derive** equations for the angular momentum of a system of particles about the centre of mass G, a fixed point O and any arbitrary point P
- **derive** the impulse-momentum, and angular impulse angular momentum equations
- **solve** problems by means of the impulse-momentum principle

(Conservation of Energy and Momentum)

- **define** and explain the concept of a conservative mechanical system
- **defend** the principle of conservation of mechanical energy in such a system
- **use** the principle to solve appropriate problems
- **derive** the principle of conservation of momentum
- **solve** problems by means of the principle of conservation of momentum

(Steady Mass Flow)

- **define** a steady mass flow system
- **derive** the relevant forces and moment balance equations

- **solve** practical engineering problems by means of this theory.

3.3 STUDY THEME 3: Plane Kinetics of Rigid Bodies

3.3.1 Learning outcomes

At the end of this study theme, the student will be able to:
- **reason** logically about the cause and effect in, and illustrate understanding of the kinetics of rigid bodies
- **calculate** the forces acting on rigid bodies to effect certain accelerations and vice versa
- **calculate** the kinetic energy and momentum of rigid bodies
- **based** on calculated kinetic energy, accelerations, velocities or displacements, predict how the body will respond in a subsequent sequence of events.

3.3.2 Study units

General Equations of Motion
M&K §6/2 & SN

General Plane Motion
M&K §6/5

Translation
M&K §6/3

Fixed axis rotation
M&K §6/4 & SN

Work and Energy
M&K §6/6

3.3.3 Criteria of assessment

At the end of this study theme, a student will be able to:

(General Equations of Motion)
- **write** down the general equations of motion with which one may solve for the rotational and translational motion of a rigid body
- **derive** expressions that relate the moment of all external forces about the centre of mass *G*, a fixed point *O* and any other point *P* of a rigid body in terms of the moment of inertia of the body about *G* or *O*, its angular acceleration and the moment of mass times acceleration of *G* about *G*
- **discuss** the effect of internal forces on the kinetics of coupled rigid bodies

(General Plane Motion)
- **use** translation and rotation equations of motion to solve for the motion of a rigid body

(Translation)
- **solve** translation problems

(Fixed-axis rotation)
- **solve** problems with the equation

(Work and Energy)
- **derive** expressions for the kinetic energy of a rigid body
- **write** down the work energy equation explaining all variables
- **explain** what conservation of energy is and under which circumstances it applies
- **solve** problems with work energy equations

3.4 STUDY THEME 4: Vibration of Single Degree of Freedom Systems

3.4.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **reason** logically about the cause and effect in, and illustrate understanding of the vibration of single degree of freedom systems
- **calculate** the transient behaviour of single degree of freedom vibratory systems
- **determine** the total response due to harmonic excitation.

3.4.2 Study units

Free Vibration of Particles
M&K §8/2 & SN

Forced Vibration of Particles
M&K §8/3 & SN

Vibration of Rigid Bodies
M&K §8/4

3.4.3 Criteria of assessment

At the end of this study theme, a student will be able to:

(Free Vibration of Particles)

- **write** down the equation of motion of a damped system and explain the variables
- **solve** the response for given initial conditions
- **calculate** the natural frequency and damping ratio of a vibrating system with known mass, stiffness and damping constant
- **explain** what logarithmic decrement is and indicate what it is used for
- **solve** free-vibration problems

(Forced Vibration of Particles)

- **derive** the equation for the calculation of the amplification factor and indicate what it is used for
- **sketch** graphs of phase angle and amplification factor against force frequency and indicate the effect damping, rigidity and mass have on the response
- **write** down an expression for the total response of a forced single degree of freedom system
- **solve** problems for forced systems.

(Vibration of Rigid Bodies)

- **write** down the equation of motion describing the vibration of a rigid body
- **solve** problems for the free and forced vibration of rigid bodies.

3.5 STUDY THEME 5: Moments of Inertia and Products of Inertia

3.5.1 Learning outcomes

At the end of this study theme, the student will be able to:

- **reason** logically about and **illustrate** understanding of the moments of inertia of rigid bodies
- **calculate** the moments of inertia of rigid bodies in any set of axes.

3.5.2 Study units

Moments of Inertia around an Axis
M&K §B/1 & SN

3.5.3 Criteria of assessment

At the end of this study theme, a student will be able to:

(Moments of Inertia around an Axis)

- **proof** and **apply** the thin plate theorem
- **calculate** the radius of gyration about any axis for a rigid body
- **calculate** the moment of inertia of a rigid body composed of two or more different components

(Products of Inertia)

- **define** the product of inertia mathematically
- **identify** the product of inertia of a rigid body with respect to a pair of axes of which one is an axis of symmetry as being zero
- **state** the parallel axis theorem for products of inertia
- **identify** without proof all cases in which it is possible to apply the theory of Plane Kinetics of Rigid Bodies (study theme 3) and thus also identify all cases in which this theory may not be applied.