Multibody Dynamics A - wb1310

Lecture 1, course 2014-2015

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TU Delft, 3mE/BmechE

www.bicycle.tudelft.nl/schwab/wb1310fall2014/index.htm

Multibody Dynamics A
wb1310
(fall 2014, Q2)

Instructor: Arend L. Schwab

Delft University of Technology

Description: Multibody Dynamics A is an introductory course in applied dynamics of mechanical systems. The emphasis is on the usage of multibody dynamics software. We want you to learn enough about dynamics in 3D that you will be able to use a standard multibody dynamics software package correctly, appreciate the limitations, and say some sensible things about the model at hand.

In the course you will learn about the fundamentals of Multibody Dynamics: the description of the orientation of a rigid body in space, the Newton-Euler equations of motion for a 3D rigid body, how to add constraints to the equations of motion, and how to solve such a system of coupled equations. You will spend most of the time (80%) in doing the lab assignments. These assignment consists of a number of practical problems that have to be worked out with the software package ADAMS. Your findings are to be put down in a Lab Report.

Goal: By the end of the course you be able to make a complex model of realistic 3D mechanical system and draw some conclusions from the dynamical analysis.

Grading: The written exam is of the open book type and has the form of a questionnaire about the findings as written down in your lab report. The report serves as reference material for your exam. At the end of the exam the questionnaire together with the Lab Report are to be handed over, The final grading is 50% on the report and 50% on the written exam.

News

Hand-Outs
- The course Contents.
- The Laboratory Assignments.
- A short Introduction to ADAMS (1,169 KB).
- Tire and Road files for assignment#5: 16r26_new.tir, 18r38_new.tir, FlatRoad.rdf.

Office Hours
Instructor: Arend L. Schwab, a.l.schwab@tudelft.nl, Monday, 15-17 h., room F-0-010, phone: 015 278 2701.
TA: Sten Ponsioen, s.l.ponsioen@student.tudelft.nl, Monday, 13-17 h. IO-PC hall 3 (SHIFT).

Course Outline

Lecture	Contents	Assignment
1th	Introduction, team-up. Newton-Euler eqn's of motion for a 3D rigid body.	1-Pendulum
2nd	Chris Verheul shows some nice examples of the usage of ADAMS	2-Wheel
3rd	Modelling of Mechanical Systems.	3-Crane
4th	How-to describe the Orientation of a Rigid Body in Space.	4-Governer
5th	Coupled Differential and Algebraic equations, opening ADAMS.	5-Tractor/Bicycle
6th	Overview.	5-Tractor/Bicycle

Time Management

Section	hours
Lectures	7*2
Assignments, guided	7*4
Assignments, free	7*4
Preparation	7*1
? Written Exam !	7
Total (3 ECTS):	84

Questions?

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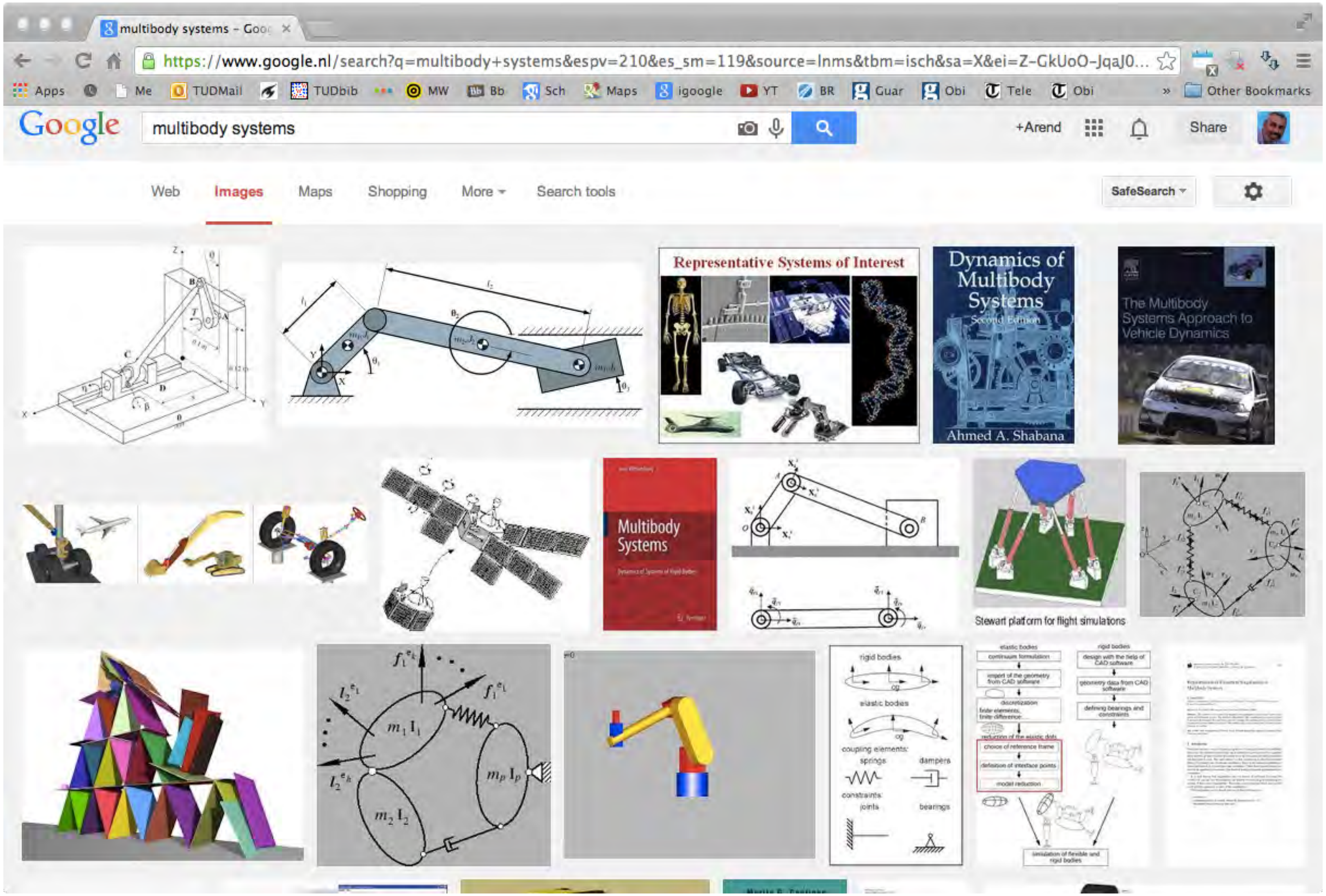
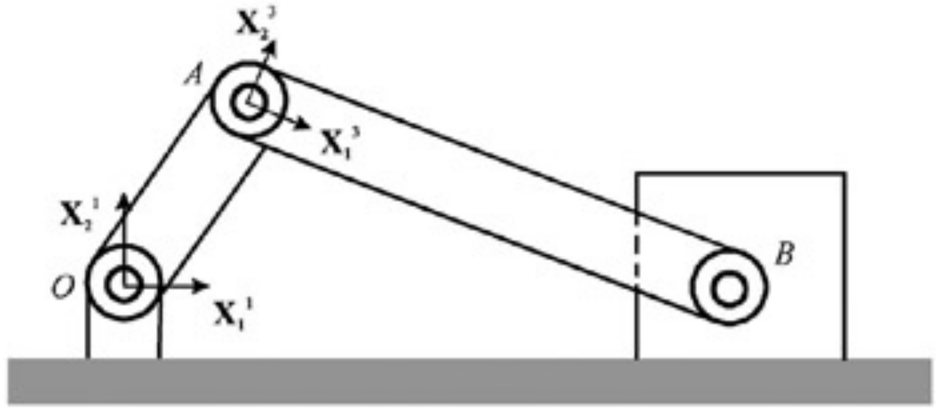
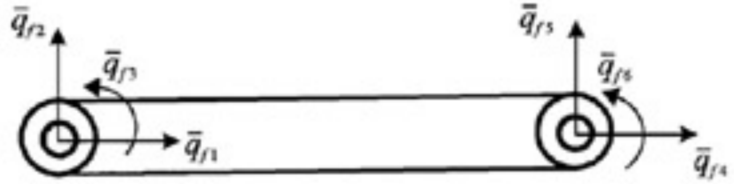
Multibody Systems



Multibody Systems

Rigid bodies with constraints

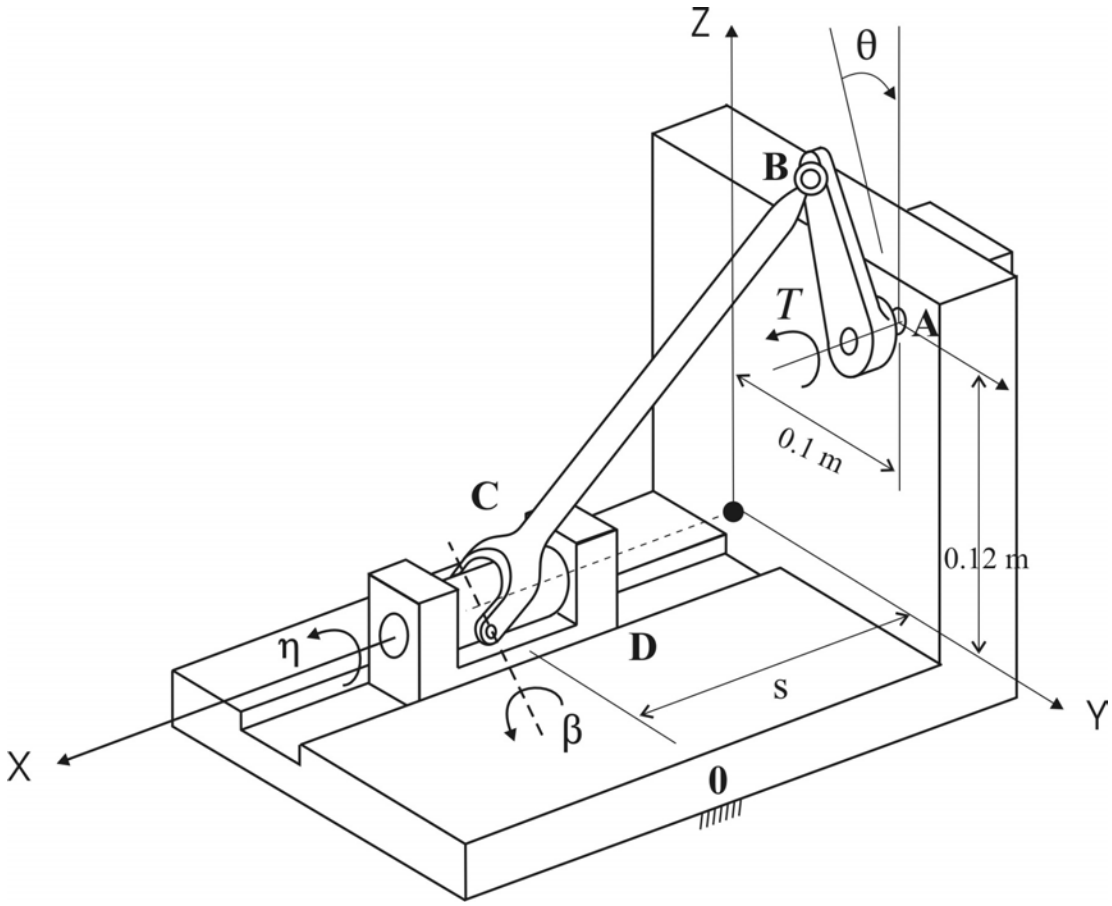




<u>2 Dimensional</u>
3 rigid bodies: +3*3
3 rev joints: -3*2
1 slide joint: -1*2
Dof: (9-8)=+1

Multibody Systems

Rigid bodies with constraints



3 Dimensional

4 rigid bodies: +4*6

3 rev joints: -3*5

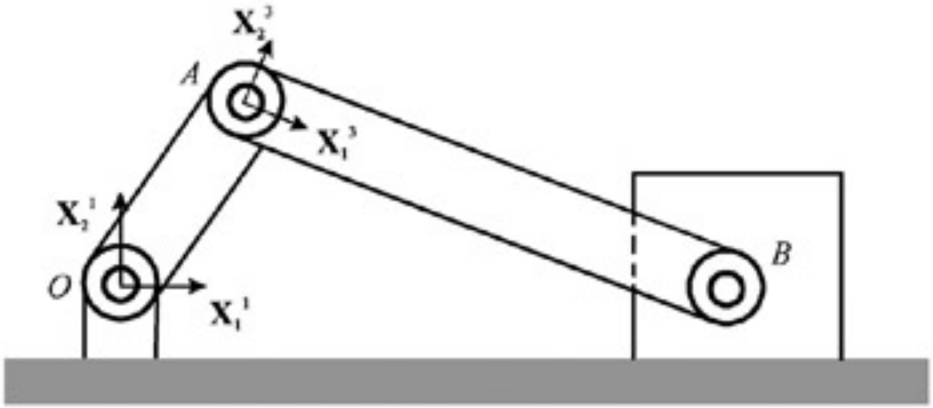
1 ball joint: -1*3

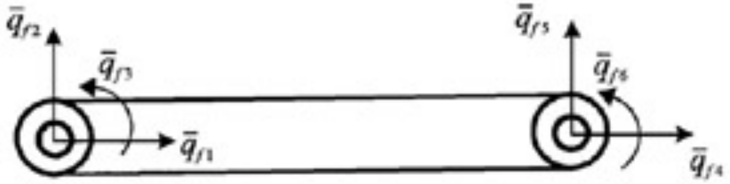
1 slide joint: -1*5

Dof: (24-23)=+1

Multibody Systems

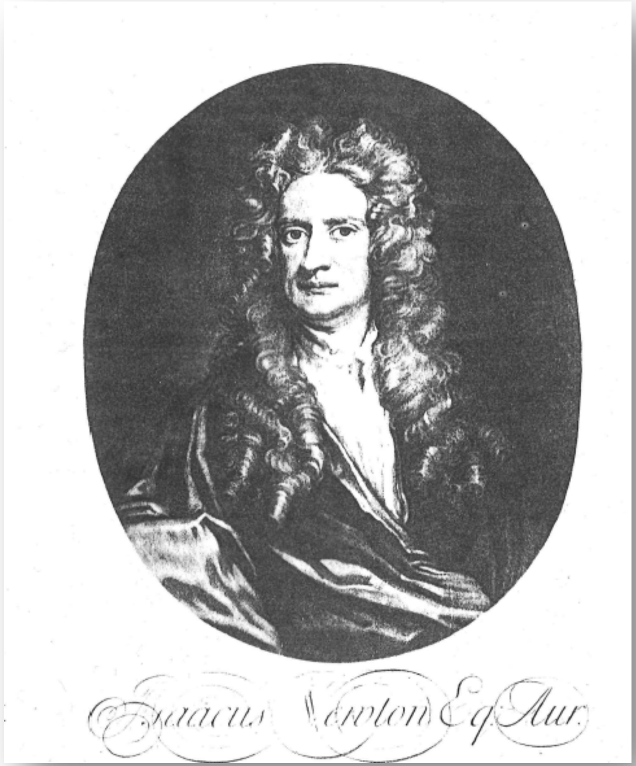
Rigid bodies with constraints





<u>3 Dimensional</u>
3 rigid bodies: +3*6
3 rev joints: -3*5
1 slide joint: -1*5
Dof: (18-20)=-2

Newton-Euler eqn’s for a rigid body

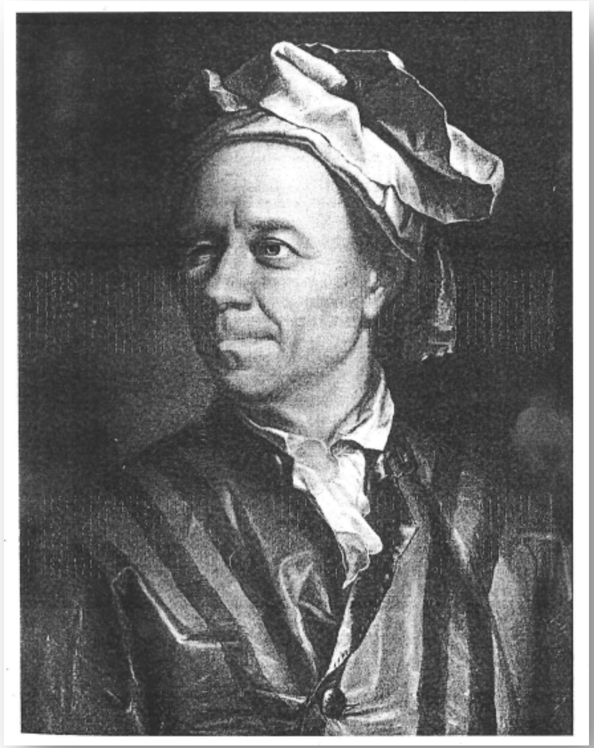


Isaac Newton
1643-1727
Woolsthorpe-Kensington

1664?

$$\sum f = m \cdot a$$

Newton-Euler eqn’s for a rigid body

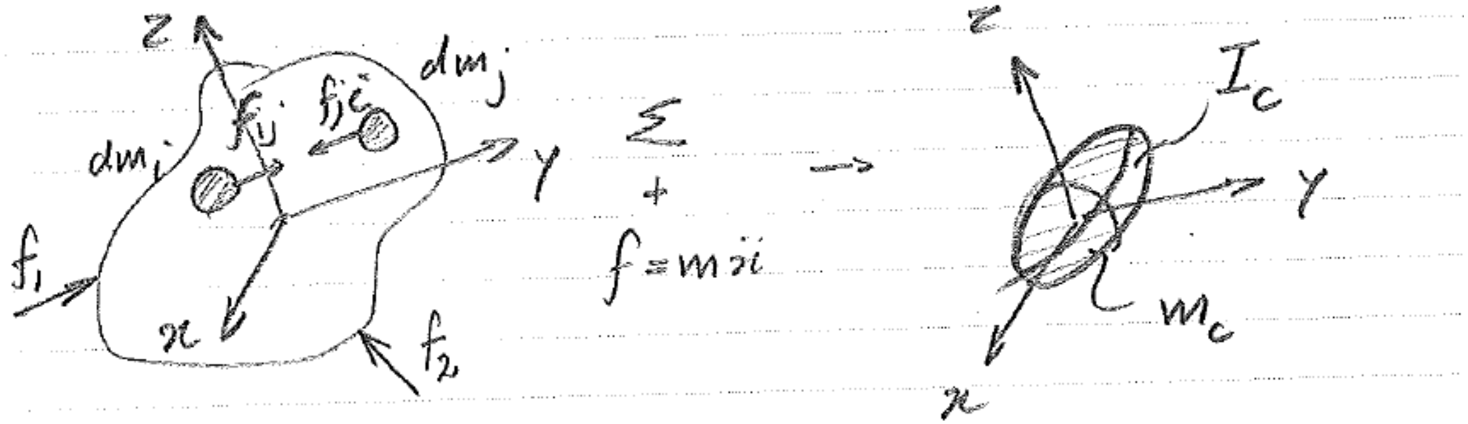


Leonhard Euler
1707-1783
Basel-StPetersburg

1727?

$$\Sigma \underline{M}_c = I_c \cdot \dot{\underline{\omega}}_c + \underline{\omega}_c \times (I_c \cdot \underline{\omega}_c)$$

Newton-Euler eqn's for a rigid body



$\Sigma f_c = m_c \cdot \ddot{x}_c$ Newton

$\Sigma M_c = I_c \cdot \dot{\omega}_c + \omega_c \times (I_c \cdot \omega_c)$ Euler

met $I_c = \begin{pmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{pmatrix}$

klopt niet!

~~ω_c totale, meebewegende hoeksnelheden~~

~~M_c totale, meebewegende momenten.~~

en $\omega_c = (\omega_x, \omega_y, \omega_z)$

$I_{xx} = \int_V (y^2+z^2)\,dm$ cycl. Zie bv. Meriam & Kraige (H7)

$I_{xy} = -\int_V xy\,dm$

Assignment 2

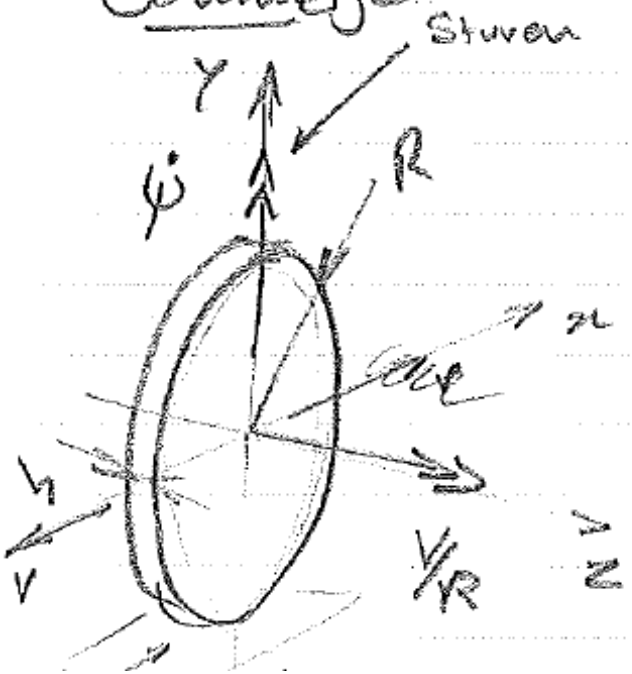
Assignment 2

In order to examine the steering forces and moments of a bicycle in motion, the front wheel of a bike is put to a further test. The model of this front wheel consists of a thin hoop with a mass of $m = 2.7$ [kg] and a diameter of $d = 700$ mm, which can rotate around its own axle, ϕ. It is assumed that the mass is concentrated along the perimeter of the wheel. Perpendicular to this axis of rotation, a second hinge has been attached in order to be able to rotate the ϕ-axle, the so-called steering, around an angle ψ.

1. Make an estimate, by means of the Euler equation of motion for a rigid body, $\mathbf{M} = \mathbf{I}\dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \times (\mathbf{I}\boldsymbol{\omega})$, of the size and direction of the moment $\mathbf{M}_1$ that is exerted on the wheel in the first hinge at a constant riding speed of $v = 20$ [km/hour] and a constant steering angular velocity of $\dot{\psi} = 60$ [°/sec].
2. Make a model of the steering front wheel in ADAMS. Remember that there is a body between the two hinges, namely the fork. For the sake of simplicity, the fork offset (trail) and head angle are assumed to be zero. Simulate the motion for some time with the initial conditions from above. Plot the moments in the hinge of the wheel axle as a function of time and compare this with your estimate of $\mathbf{M}_1$. By generating a Measure you will be able to follow the rotating hinge moment during simulation.

Assignment 2

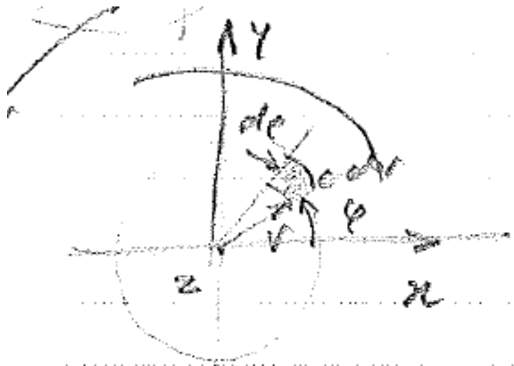
Sommetje



$$\underline{\omega} = \begin{pmatrix} 0 \\ \dot{\psi} \\ V/R \end{pmatrix}_{\text{caskel}} \rightarrow \dot{\underline{\omega}} = \begin{pmatrix} 0 \\ 0 \\ c \end{pmatrix}$$

$$\underline{I} = \Bigg(\begin{matrix} ? & \\ & ? \end{matrix}$$

Assignment 2



$$I_{zz} = \int_V (x^2+y^2)\,dm$$

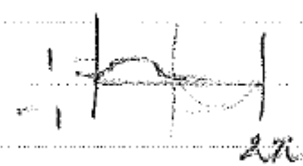
$$dm = \rho h \cdot dA = \rho \cdot h\, r\, d\varphi\, dr$$

$$I_{zz} = \int_0^R \int_0^{2\pi} r^2 \rho h r\, d\varphi\, dr = \frac{1}{4} 2\pi \rho h r^4$$

$$m = \rho h \pi R^2 \qquad I_{zz} = \frac{1}{2} m R^2$$

$$I_{xx} (= I_{yy}) = \int (y^2+z^2)\,dm \simeq \int y^2\, dm$$

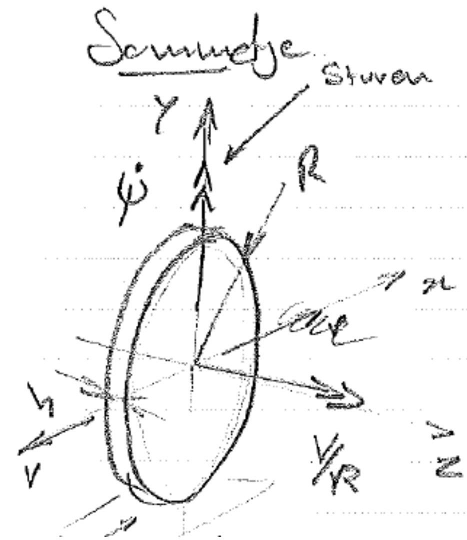
$$= \int (r\sin\varphi)^2 \rho h r\, dr\, d\varphi \qquad \int_0^{2\pi} \sin^2\varphi\, d\varphi = \pi$$



$$= \frac{1}{4} \pi \rho h r^4$$

$$= \frac{1}{4} m R^2$$

Assignment 2



$$\underline{\omega} = \begin{pmatrix} 0 \\ \dot\psi \\ V/R \end{pmatrix}_{\text{constant}} \longrightarrow \dot{\underline{\omega}} = \begin{pmatrix} 0 \\ 0 \\ c \end{pmatrix}$$

$$\underline{I} = \begin{pmatrix} ? & & \\ & ? & \\ & & ? \end{pmatrix}$$

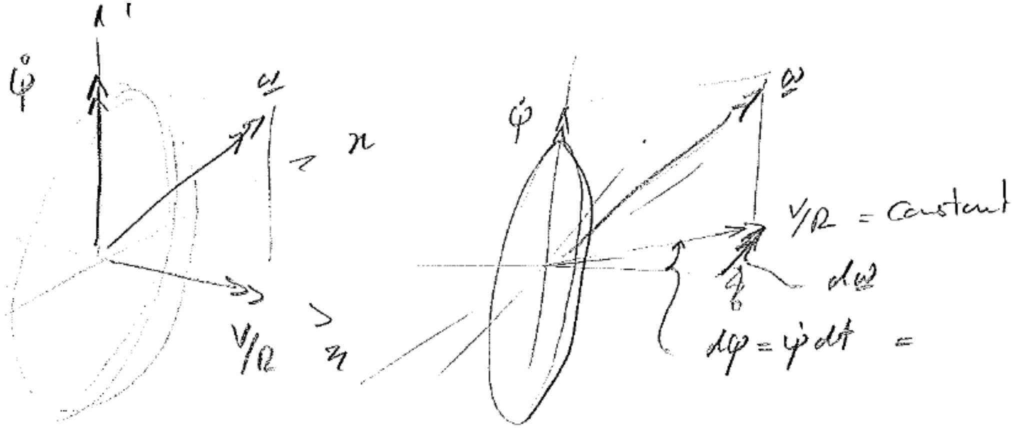
$$\begin{pmatrix} M_x \\ M_y \\ M_z \end{pmatrix} = \underline{I} \cdot \begin{pmatrix} 0 \\ 0 \\ c \end{pmatrix} + \begin{pmatrix} 0 \\ \dot\psi \\ V/R \end{pmatrix} \times mR^2 \begin{pmatrix} 1/4 & & \\ & 1/4 & \\ & & 1/2 \end{pmatrix} \begin{pmatrix} 0 \\ \dot\psi \\ V/R \end{pmatrix} =$$

$$mR^2 \begin{pmatrix} 0 \\ \dot\psi \\ V/R \end{pmatrix} \times \begin{pmatrix} 0 \\ \dot\psi/4 \\ V/2R \end{pmatrix} = \cancel{mR^2 \begin{pmatrix} \frac{1}{4}\dot\psi V/R \\ 0 \\ 0 \end{pmatrix}}$$

Wrong!

Check?

Assignment 2



$$\boxed{\dot{\underline{\omega}} \neq \underline{0}}$$

$$d\underline{\omega} = V/R \cdot d\varphi \cdot \underline{e}_x$$

$$\frac{d\underline{\omega}}{dt} = \frac{V}{R} \cdot \frac{d\varphi}{dt}\, \underline{e}_x$$

$$\dot{\underline{\omega}} = \begin{pmatrix} V/R\, \dot\varphi \\ 0 \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} M_x \\ M_y \\ M_z \end{pmatrix} = \frac{1}{4} m r^2 \begin{pmatrix} V/R\, \dot\varphi \\ 0 \\ 0 \end{pmatrix} + m R \begin{pmatrix} 1/4\, \dot\varphi\, V/R \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 1/2\, m r^2\, \dot\varphi\, V/R \\ 0 \\ 0 \end{pmatrix}$$

Correct!

Newton-Euler eqn's for a rigid body

From linear and angular momentum change

Lineaire Impuls $\underline{p} = m \cdot \underline{v}$ (Huygens Energie!)

Impuls Moment $\underline{H} = \underline{I} \cdot \underline{\omega}$

Impuls Moment Stelling!

$\Sigma \underline{F} = \dot{\underline{p}}$ Som krachten is Verandering impuls

$\Sigma \underline{M} = \dot{\underline{H}}$ Sommomenten is " ImpulsMoment.

(NB geen Punt Sommen $m = \text{constant}$)

Newton-Euler eqn's for a rigid body

From linear and angular momentum change

Hulpstelling :

$$\frac{d}{dt}(\text{iets})_{VAST} = \frac{d}{dt}(\text{iets})_{BEWEGEND} + \underline{\Omega}_{BEW} \times (\text{iets})$$

vector:

$$\underset{\text{comp.}}{X_i = x_j}\ \underset{\text{basisvectoren}}{e_{ji}} \qquad e_{1i} = \begin{pmatrix}1\\0\\0\end{pmatrix} \quad e_{2i} = \begin{pmatrix}0\\1\\0\end{pmatrix} \quad e_{3i} = \begin{pmatrix}0\\0\\1\end{pmatrix}$$

$$\dot{X}_i = \dot{x}_j e_{ji} + x_j \dot{e}_{ji}$$

Componenten Verandering   Verandering BasisVectoren

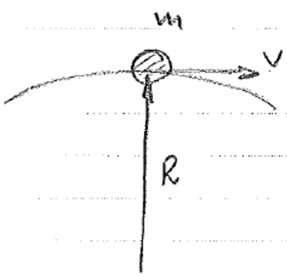
$$\dot{e}_{ji} = ? \qquad \dot{\underline{e}}_j = \underline{\Omega} \times \underline{e}_j$$

Dus !

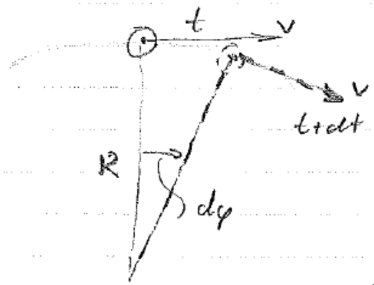
$$\Sigma \underline{f} = m \dot{\underline{v}} \quad \text{en} \quad \Sigma \underline{M} = \underline{I}\,\dot{\underline{\omega}} + \underline{\omega} \times (\underline{I}\,\underline{\omega})$$

Examples, 2D circular motion

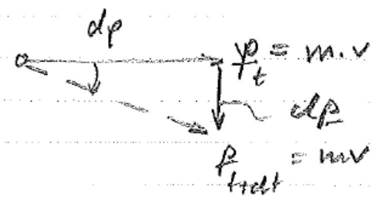
From linear and angular momentum change



Geef de krachten op m

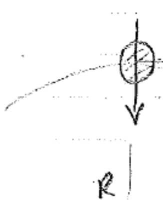


Alleen Verandering van Richting!



$$d\varphi = \frac{v}{R} \cdot dt$$

$$dp = p \cdot d\varphi = m \cdot v \cdot \frac{v}{R} \cdot dt \qquad \frac{dp}{dt} = \dot{p} = m \frac{v^2}{R}$$



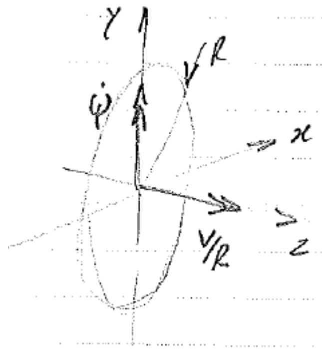
$$F = \dot{p} = m \frac{v^2}{R}$$

met $\omega = v/R$

$$= m \omega^2 \cdot R$$

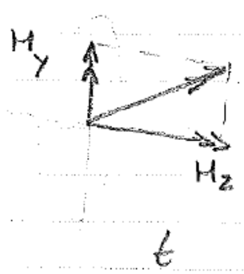
Examples, Assignment 2

From linear and angular momentum change

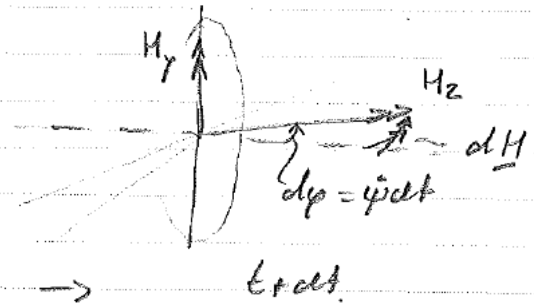


$$\underline{I} = mR^2 \begin{pmatrix} 1/4 & & \\ & 1/4 & \\ & & 1/2 \end{pmatrix} \qquad \underline{\omega} = \begin{pmatrix} 0 \\ \dot\varphi \\ V/R \end{pmatrix}$$

$$\underline{H} = \begin{pmatrix} 0 \\ \frac{1}{4} mR^2 \dot\varphi \\ \frac{1}{2} mR^2 V/R \end{pmatrix}$$



$\longrightarrow$



$$d\underline{H} = \begin{pmatrix} H_z \cdot d\varphi \\ 0 \\ 0 \end{pmatrix}$$

$$\Sigma \underline{M} = \underline{\dot H} = \begin{pmatrix} H_z \cdot \dot\varphi \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} \frac{1}{2} mR^2 V/R\, \dot\varphi \\ 0 \\ 0 \end{pmatrix}$$

Next week…

Chris Verheul from Sayfield International will show some nice examples of the usage of the ADAMS software.