Lecture 1.
Course Syllabus
MAE 311
Machines and Mechanisms I
Spring 2003

Instructor:

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Course Web Page: TBA

Course Prerequisites:

EAS 209 and MAE 381. You should not take this course unless you have passed EAS 209 or its equivalent. A working knowledge of solid mechanics and stress analysis will be especially useful. If you haven’t taken MAE 381, please see Prof. Soom.
Textbook:


**Grading**

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homework Assignments</td>
<td>15%</td>
</tr>
<tr>
<td>Two tests</td>
<td>20-25% each</td>
</tr>
<tr>
<td>Final exam</td>
<td>35%</td>
</tr>
<tr>
<td>One/two mini-projects?</td>
<td>0–5% each</td>
</tr>
</tbody>
</table>

*Approximate cut offs for final grades are A/B 85, B/C 70, C/D 55, and D/F 45. Plus/minus grades will be used.*
What is Mechanical Design?

Formulation for plans for the physical realization of machines, devices, systems, instruments, products...to fulfil a need.

Design Process

Statement of need
Specification
Conceptual/preliminary design
Detailed design, analysis, optimization
Testing and evaluation
Manufacturing
Sales and service
Eventual disposal

Modern concurrent or integrated design considers all aspects "simultaneously."
Some Features of Design

- No unique solutions
- Constraints
  (time, cost, weight, size, etc.)
- Many variables
- Many factors, aspects are included

Some key factors

- Strength (avoid fracture, failure: static or fatigue, wear)
  *This will be the main emphasis in this course*
- Shape, rigidity, deflection, compliance
- Cost
- Reliability, quality
- Ease of manufacturing
- Weight, size
- Energy consumption
- Environmental impact
- Life cycle considerations
- Maintenance and service
- Noise and vibration
Design hierarchy

1. System, machine, vehicle, assembly product...
2. Subsystem, subassembly, module
3. Sub subsystem...
4. ....
5. Component, part, element

Elements, parts, components:

Shafts, axles...
Brackets, frames, housings...
Fasteners, bolts, machine screws, rivets...
Welds, brazes, solder joints, bonds...
Springs
Bearings, journal, rolling element
Gears, couplings
Brakes, clutches, pulleys

Covered in Chapters 8-17 in text
We will consider

...how the elements work

...basis for design or selection

...detailed design or selection

Generally we will assume that overall loading is known from static or dynamic considerations

Examples

- #1: Standard transmission
- #2: Engine and suspension
- #3: Engine and transmission
Blueprint for Gear Oils
The MINI has MacPherson struts at the front and a multilink system at the rear.

polished alloys. Both versions of the MINI have a hood that incorporates the front fenders and headlamps. The doors have frameless electric windows. The car's A-pillars are concealed behind a black, high-gloss plastic panel, and the B- and C-pillars are “hidden” behind glass, giving the impression of a continuous window extending around the car.

The original Mini had its speedometer placed centrally, and so has the new MINI. A rev counter is positioned above the steering column. The speedometer contains fuel-level, coolant-temperature, and tire-pressure warning indicators. An optional trip computer can be incorporated within the speedometer. If a satellite navigation system is specified, the speedometer is positioned next to the rev counter. In fact, the interior of the new MINI is very different from that of the minimalist—even stark—1959 Mini. Dashboard trim includes a wood option, and the steering wheel can incorporate a multifunction facility with stereo and cruise control functions. The Steptronic CVT can also be controlled from the steering wheel. The original Mini had toggle switches—so has the new MINI, but they are caged for safety. Unlike the original, the switches are sprung to return to a central position after operation. Sports seats, lumbar control, and two-level seat heating are other options that would have been unthinkable 42 years ago. Rear seats are bucket-shaped, and the car's high, level roofline aids headroom. The rear seats are divided 50:50; with them lowered, luggage space expands from a very modest 150 to 670 L (5.3 to 23.7 ft³).

Stuart Birch

Interesting? Circle 99
Fast interesting? Circle 36

ael AUGUST 2001 12
The Vortec 6000 engine is linked to a new Hydra-Matic 4L80-E HD (heavy-duty) four-speed automatic transmission. The heavy-duty version of the 4L80-E in the Vortec 5300-equipped Escalade was upgraded to handle the larger engine's greater power and torque. Compared to the 4L80-E, it has five pinions in the input and reaction gear sets for 20% more torque capacity. New aluminum-construction bushings in the stator shaft and an extra clutch plate (7 vs. 6) in the third and fourth gear clutch provide higher torque capacity. For improved durability, a new induction heat-treating process is used for the turbine shaft and strength is improved at the lubrication points. In addition, there are larger diameter clutch rollers in the low/ reverse roller clutch assembly and induction-hardened splines on the stator shaft.

The Escalade's Vortec 6000 engine is linked to a new Hydra-Matic 4L80-E HD (heavy-duty) four-speed automatic transmission upgraded to handle the engine's greater power and torque.

The Escalade's full-time, all-wheel drive system's torque split is 38/62% front/rear for balanced handling characteristics in normal operation. However, a viscous coupling transfer case can continuously adjust the torque to the wheels when slip is detected. The system automatically transfers torque to the wheels with better grip and restores the 38/62% ratio when full traction is regained. The transfer case is constructed of magnesium and has a "pancake-style" differential.

The Escalade's axles were upgraded, with synthetic fluid reduc-
Lecture 2

But first we will cover:

Ch 1. Introduction...you should read. Includes general discussion, codes and standards, strength and stress, factors of safety, economics, units

Ch 2-3 Stresses and deflections (mostly stresses some topics will be introduced as needed later in the course) Simple tension-compression, bending, shear, torsion, thick-walled cylinders, stress concentrations, contact stresses, combined stresses, principal stresses

Ch 5 Material properties
Ultimate strength, Yield strength, Shear strength, brittle vs. ductile materials, notch sensitivity

Ch 6 Static failure
Ch 7 Fatigue failure
STRESS and STRENGTH

Strength: Material Property or obtained from material property

\[ \sigma_u \rightarrow \text{Ultimate Strength} \]
\[ \sigma_y \rightarrow \text{Yield Strength} \]

Stress: Force (Applied) per unit area, \( \text{lb/in}^2 \)

FACTOR of SAFETY

\[ n = \frac{\sigma}{\sigma_{\text{appropriate}}} \]
where \( \sigma \) is stress, \( \sigma_{\text{appropriate}} \) is appropriate strength

\( n \geq 1 \) to account for variability (maximum stress + unknown effects)
ALLOWABLE STRESSES

Sometimes we will combine Factor of Safety and Strength ... many codes do this ... to get an allowable stress,” $\sigma_{all}$, which is not to be exceeded

$$\sigma_{all} = \frac{\sigma}{n} \geq \sigma_{max}$$

This is specified

This is implied
BASIC STRESS CALCS

I Tension & Compression

\[ \sigma = \frac{F}{A} \]

Stress is Uniform

Section B-B
II Simple Shear

\[ \tau = \frac{F}{A} \]  

(ignore moment due to \( F_b \))

**Stress is uniform... harder to achieve than uniform tension**

III Torsion

\[ \tau = \frac{T r}{I} \]  

polar of inertia (polar 2nd moment)

\[ T_{\text{max}} = \frac{T r}{J} \]

**TABLE A18**
Bending (Pure)

\[ \sigma = \frac{My}{I} \quad \text{or} \quad \sigma_{\text{max}} = \frac{Mc}{I} \quad \text{tension or comp.} \]

Area moment of inertia Table A-18

\[ \Theta = \frac{My}{I} \quad \text{distance from neutral axis} \]

Bending moment

\[ m \]
Bending and Shear

\[ R_1 = R_2 = \frac{F}{2} \quad V_{AB} = R_1 \]

\[ V_{AB} = R_1 \quad V_{BC} = -R_2 \]

\[ M_{AB} = \frac{Fx}{2} \quad M_{BC} = \frac{F}{2}(l - x) \]

\[ y_{AB} = \frac{Fx}{48EI}(4x^2 - 3l^2) \]

\[ y_{\text{max}} = -\frac{FL^3}{48EI} \]

Example from Table A-9

\[ M \text{ develops tension and compression as in pure bending} \]

\[ \sigma = \frac{My}{I} \]
$V$ develops shear stresses
- must be zero at top and bottom fibers
- maximum at neutral axis

\textit{e.g.}

\begin{center}
\begin{tabular}{c}
\textbf{See table} \\
2-4 for other shapes and $T_{\max}$
\end{tabular}
\end{center}

\textit{V} can be ignored except for very short beams. Stresses due to $M$ dominate
Example

Ground cantilever

Neutral axis for $F_y$
Neutral axis for $F_3$

$F$ applied at arbitrary angle

Components $F_x, F_y, F_3$

Element A - on top surface

$\sigma_{FF} \rightarrow \sigma$ due to $F_y$

$\sigma_F + \sigma_F = 0$

$\tau_{F_3}$
Principal Stresses

General state of stress on an element

3-D

2-D

Clockwise shear is +ve
First consider 2-0

\[ \sigma = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2} \cos 2\phi + \tau_{xy} \sin 2\phi \]

\[ \tau = \frac{\sigma_x - \sigma_y}{2} \sin 2\phi + \tau_{xy} \cos 2\phi \]

Equilibrium requires

for any \( \phi \neq \frac{\pi}{2} \)

\[ \sum F_x = 0 \quad \sum M = 0 \]

\[ \sum F_y = 0 \]
Principal Stresses

I

$\sigma_1, \sigma_2$ are stresses on \( \text{(angles)} \) angular face where shear stress is zero.

II

$\sigma_1$ and $\sigma_2$ are the max and min normal (tension, compression) stresses on the element.

III

Maximum shear stress occurs on element at 45° to planes of $\sigma_1, \sigma_2$

$$\tau_{\text{max}} = |\sigma_1 - \sigma_2|$$
Typically,

1. Obtain $\sigma_x, \sigma_y, \tau_{yx}, \tau_{xy}$ from stress calc.

2. Determine $\sigma_1, \sigma_2$, principal stresses & max shear stress $\tau_{\text{max}}$.
USING EQ'S

\[ \sigma_1, \sigma_2 = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} \]

\[ \frac{\Delta \sigma}{\sigma_{\text{max}}} = |\sigma_1 - \sigma_2|^{1/2} \]

ANGLE \( \phi_p \) determined from:

\[ \tau = \frac{\sigma_x - \sigma_y}{2} \sin 2\phi_p + \tau_{xy} \cos 2\phi_p \]

\[ = 0 \]

\[ \therefore \tan 2\phi_p = \frac{2\tau_{xy}}{\sigma_x - \sigma_y} \] ... (2-4)

Compression -ve
Tension +ve
READ OVER EXAMPLE 2-1

ANOTHER EXAMPLE

- VERTICAL FORCE, $F_2$
- LEVER LIES IN X-Y PLANE
- FIND BOTH PRINCIPAL STRESSES + MAX SHEAR
VIEW FROM ABOVE

ELEMENT "A" (LIKELY LOCATION OF MAX STRESS)

\[ F \text{ causes bending moment at } A \]

\[ M = F \frac{L}{2} \]

max tensile stress due to bending

\[ \sigma_x = \frac{Mc}{I} = \frac{M(d/2)}{\frac{\pi d^4}{64}} = \frac{32M}{\pi d^3} \]

assume \( \sigma_x = 60 \text{ MPa} \)
VIEW FROM "END"

\[ T = F_k b \]

\[ T_{xy} = \frac{T (d/2)}{J} \]

\[ T_{xy} = \frac{16T}{\pi d^3} \implies \text{TORSION} \]

F_k places torque on rod resulting in shear stress, \( T_{xy} \)

Assume:

\[ T_{xy} = 40 \text{ MPa} \]