Problem 1.1 –failure modes

(a) Helical gear/shaft set

1. Fatigue of the gear teeth at the root of the gear teeth.
2. Failure by excess wear of the teeth face.
3. Static ductile or brittle fracture of the gear teeth due to a high overload.
4. Excess deformation of the gear teeth or the shaft causing greater noise, stress, and shorter life.
5. Fatigue failure of the shaft due to combined bending and torsion of the shaft.
6. Fretting fatigue between the gear and the shaft.
7. If a pin holds the gear to the shaft, then the pin, gear, or shaft could fail in fatigue at this location.

(b) Ship propeller

1. Excess corrosion.
2. Cavitation fatigue of the blades.
3. Corrosion fatigue of the blades due to multiaxial loading and corrosion environment.
4. Excess deformation or fracture from hitting a foreign object.

(c) Handlebar on a mountain bike

1. Excess deformation or fracture from an overload such as hitting a foreign object or wiping out.
2. Fatigue failure at the gooseneck interface. Could be corrosion fatigue too.
3. Esthetic failure from corrosion.

(d) Airplane landing gear

1. Excess deformation or fracture from a severe impact landing.
2. Fatigue of various parts due to cyclic landing/taxi/takeoff. Could be corrosion fatigue too.
3. Wear or fretting at shaft /bearing/pin interfaces.

(e) Automotive engine connecting rod

1. Fatigue failure at connections or geometrical changes.
2. Wear at the sleeve bearing region.

(f) Door key

1. Excess deformation or fracture due to overload during turning.
2. Fatigue failure due to repeated use.
3. Damage by excess deformation from external loads such as dropping the key.
4. Wear of the key due to repeated use.

Problem 1.2- component examples and failure modes.

(a) Simple and inexpensive
1. Bar stool: leg buckling, fatigue, excess deformation from leaning back.
2. Car door handle: fatigue, excess deformation from overload.
3. Hammer: fatigue of the handle, wood handle rotting, chipping of the hammer metal head from pounding, wood handle chipped away from poor striking.

(b) Complex and expensive
1. Automotive transmission: gear or shaft fatigue or wear failures, excess deformation or fracture from improper shifting causing damage from fatigue or hitting external objects.
2. Indy 500 race tire: excess wear, fatigue of the case, foreign object damage.
3. Giant coal mining bucket: corrosion fatigue of connections, excess deformation, wear of edges.

Problem 1.3- failure mode examples

(a) Brittle fracture- S.S. Schenectady T-2 tanker liberty ship fractured while in dock, 1943.
(b) Ductile fracture- continuous rotation of a paper clip until fracture.
(c) Excess deformation- crushing a beer or soda can.
(d) Creep rupture- old locomotive steam engine boiler/pressure vessel.
(e) Wear- automobile wheel bearing.
(f) Stress corrosion cracking- Point Pleasant bridge in West Virginia, 1967.
(g) Esthetic failure- corrosion of a steel chrome plated auto bumper or tire wheel.
(h) Fatigue- automobile engine crank shaft from years of cyclic loading.

Problem 1.4 – bicycle failure modes

1. Excess deformation or fracture of the handle bar, frame, or wheels during an impact accident.
2. Wear of the chain, chain sprocket, shifting mechanism, wheel bearings, and seat.
3. Fatigue failures of all welded connections, pedal shaft and bolted connections, shock absorber connections.
4. Esthetic failure due to paint chipping and subsequent corrosion.
5. Fretting fatigue at the handle bar/goose neck connection.

Problem 1.5- three synergistic failure modes

1. Corrosion and fatigue interaction.
2. High temperature creep/fatigue interaction.
3. Low temperature embrittlement and corrosion and fatigue

Problem 1.6- four actual failures involved with.

Depends upon the student experience and therefore no general answer.

Problem 1.7- one page paper on cost of failure in the USA.

Depends on the student, but could include the following ideas:

Increase cost of failures due to more mechanical systems in use, more technical sophistication needed, high legal payments/costs in products liability litigation, more drug/alcohol use, inflation, higher effeciency desired, lower safety factors, others.

Decrease in cost of failures due to better emphasis on safety and products liability, better standards/codes, OSHA, CPSC, FAA, NTSB etc., improved digital prototyping, improved testing capabilities, improved instructions/warnings, federal government recalls and regulations, higher quality materials/manufacturing/inspection, others.

Problem 1.8- write paper on one of the references

Depends upon student and reference chosen and therefore no general answer .

Problem 2.1- automobile safety critical parts.

(a) Fail-safe: independent acting brakes at four wheels, leak before burst radiator, multiple wheel nuts, some body frames with multiple path loading, exhaust system, multiple spark plugs/fuel injectors, dual headlights, shock absorbers.
(b) Safe-life: wheel bearings, axles/spindles both front and rear, steering system, some frames without multiple path loading, tires, wheels, and others.

It would be difficult to make most safe-life parts fail-safe, since redundancy, multiple load paths, crack stoppers or inspection would have to be added. The cost could be prohibited in most cases. It may not be needed in many situations, but in some it is desirable.

Problem 2.2- damage-tolerant design in automotive field

Because the added cost of redundancy, multiple load paths, crack stoppers and non-destructive inspection, and much less catastrophic in nature. There is much less NDI capability in the auto industry due to cost. Less control on maintenance/inspection.

Problem 2.3 – fatigue design considerations for stretch versions.

(a) commercial jet

1. New load magnitudes and history within the inserted section and outside the inserted section will alter fatigue resistance of frame, skin, and mechanical systems.
2. New connections are needed that often are prime fatigue failures.
3. New hydraulics and fittings may be needed that could be fatigue failures.
4. Landing gear systems, wings, fuselage will have different stresses and alteration of fatigue resistance.
5. Different inspection may be needed.
6. Different engines may be needed.
7. Many others

(b)limousine

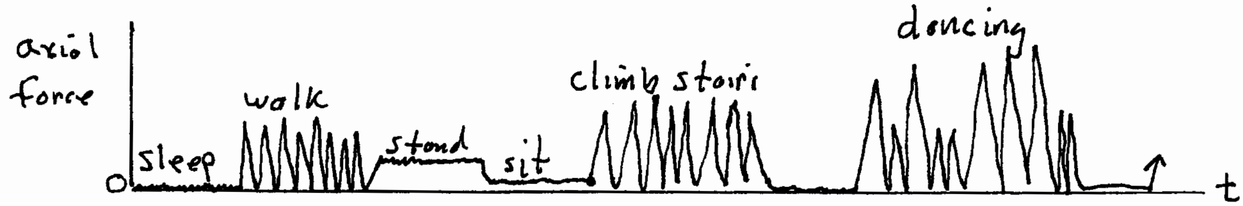
1. same as 1 to 3 above.

Problem 2.4 – loading modes

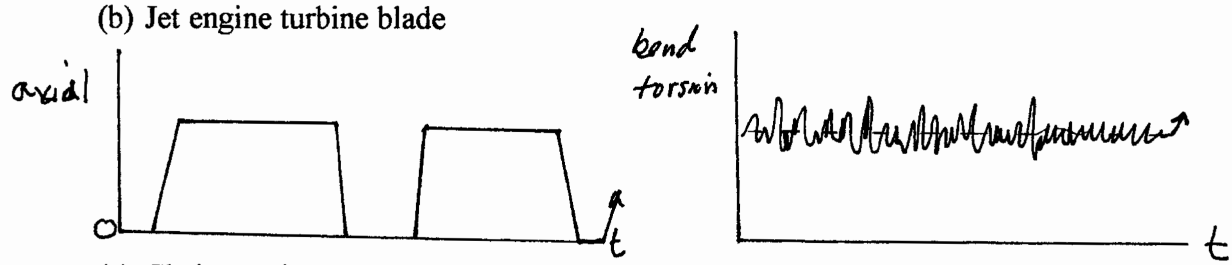
(a) Hip replacement prosthesis: axial, shear, combined bending/torsion.
(b) Jet engine turbine blade: centrifugal force, flow pressure, vibration and hence axial, shear, combined bending/torsion, pressure.
(c) Chair rear leg: axial, bending, torsion, shear.
(d) Motorcycle front axle: combined bending/torsion, shear.
(e) Alaska pipeline: internal pressure, bending, shear, axial

Problem 2.5- load spectra for prob.2.4, and how to determine.

(a) Hip prosthesis



(b) Jet engine turbine blade



(c) Chair rear leg

(d) Motorcycle front axle

(e) Alaska pipeline

Service load spectra would be obtained through various load, torque, displacement transducers or accelerometers placed on prototypes, previous models, or through computational dynamics programs such as DADS or ADAMS. The specific techniques would differ for each component. For example, the hip prosthesis spectrum could be obtained from special "walking" platforms that measure forces through scales or other transducers. Strain gages could be attached to turbine blades and the chair leg and calibrated to forces. Rotary transducers could be used on the motorcycle axle while strain gages and pressure gages could be used on the pipeline.

Problem 2.6- for prob 2.4 how to integrate analysis and testing and what testing.

(a) Hip prosthesis: analysis could include FEM plus significant inclusion of available literature and standards. Test using servohydraulic test systems in conjunction with ASTM standards.
(b) Turbine blade: analysis using FEM, previous calculations/experimental results, literature inclusion and standards. Test using actual engines in test stands, along with individual blade tests and standards.
(c) Chair leg: analysis using calculations with mechanics of materials, FEM and standards. Test using external axial and bending loads applied to fixed chairs and standards.
(d) Motorcycle axle: analysis using FEM, mechanics of materials, DADS/ADAMS. Test using servohydraulic simulator, test track driving, standards.
(e) Alaska pipeline: analysis using mechanics of materials calculations, FEM, leak-before- break, ASME pressure vessel standards. Test using servohydraulic test systems, proof testing, standards.

Problem 2.7- for prob 2.4 what design criteria.

(a) Hip prosthesis: safe-life based on analysis, standards, and tests.
(b) Turbine blade: safe-life based on analysis, standards, and tests.
(c) Chair leg: safe-life based on analysis, standards, and tests.
(d) Motorcycle axle: safe-life based on analysis, standards, and tests.
(e) Alaska pipeline: fail-safe with leak- before-break and safe-life based on analysis, standards, and tests.

Safe-life was chosen for a-d because of complexity/cost of considering fail-safe.

Problem 2.8- what fatigue life model.

(a) auto axle without stress concentrations: S-N or ε-N, since inspection is not reasonable.
(b) gear with periodic overloads: S-N or ε-N, since inspection is not reasonable.
(c) plate with edge crack: da/dN-ΔK since all fatigue crack growth.
(d) Riveted airplane wing plate: S-N based on joint test data, and da/dN-ΔK, or two stage, since inspection is applicable

Problem 2.9- NDI paper

Depends on student choice. Therefore no general solutions applicable.