GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Semester 2000

Design
EXAM AREA

Assigned Number (DO NOT SIGN YOUR NAME)

- **Please sign your name on the back of this page—**

George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology

DESIGN QUALIFING EXAM

Fall 2000

We are interested in learning what you know and your ability to reason in the formulation and solution of design problems. If you find any question or part of this exam confusing, please adjust the question, explicitly rephrase it, and state your assumptions.

Read the entire exam first. Allocate your time carefully so that you cover all three parts of the exam: Realizability, Analysis, and Methods.

ORALS
We will conduct the oral exam by first giving you the opportunity to state how design fits into your research activities. If you do not do an adequate job on this written exam, we may ask you to discuss it during the oral exam.

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1 – Opening and Closing a Stadium Roof

The centerpiece of the Sydney 2000 Olympic Games is also the largest outdoor venue in Olympic history. The Olympic Stadium has a capacity of 110,000, and four Boeing 747s would fit side-by-side under the span of the main arches of the grandstands.

The stadium has already hosted a number of major sporting events. These include a rugby league double header that drew a crowd of 104,583 in March 1999, two international football (soccer) events, and an American NFL pre-season game between the San Diego Chargers and the Denver Broncos. The rugby union Bledisloe Cup match played there on 28 August 1999, between the Australian Wallabies and the New Zealand All Blacks, attracted a crowd of 107,042 — a world record for a rugby union match.

For the Games, a continuous lower seating bowl surrounds the athletics track, flanked on both sides by two permanent roofed grandstands and by temporary open grandstands at the ends. After the Olympic Games are over, the stadium will be reconfigured to seat 80,000.

Suspended from a huge arch structure and three hectares (30,000 square meters) in area, the roof is constructed from translucent polycarbonate to minimize the shadows and patches of direct sunlight on the playing area. This will create ideal conditions for TV presentations and for spectators.

Problem Statement: Your task is to design a way to open and close the roof of the Sydney Olympic Stadium (for example, a dome covering the stadium that can open and close). You should use a variety of design tools to *develop specifications for this enclosure, determine a variety of alternatives and then rate those alternatives*.

We are interested in the process that you are following in coming up with your design, but we also like to know your insight in the feasibility and, therefore, we would like to see your decisions backed-up by simple, but realistic (as far as it is possible), calculations regarding weight, power, strength, geometry and any other properties you feel necessary to determine the proper design.

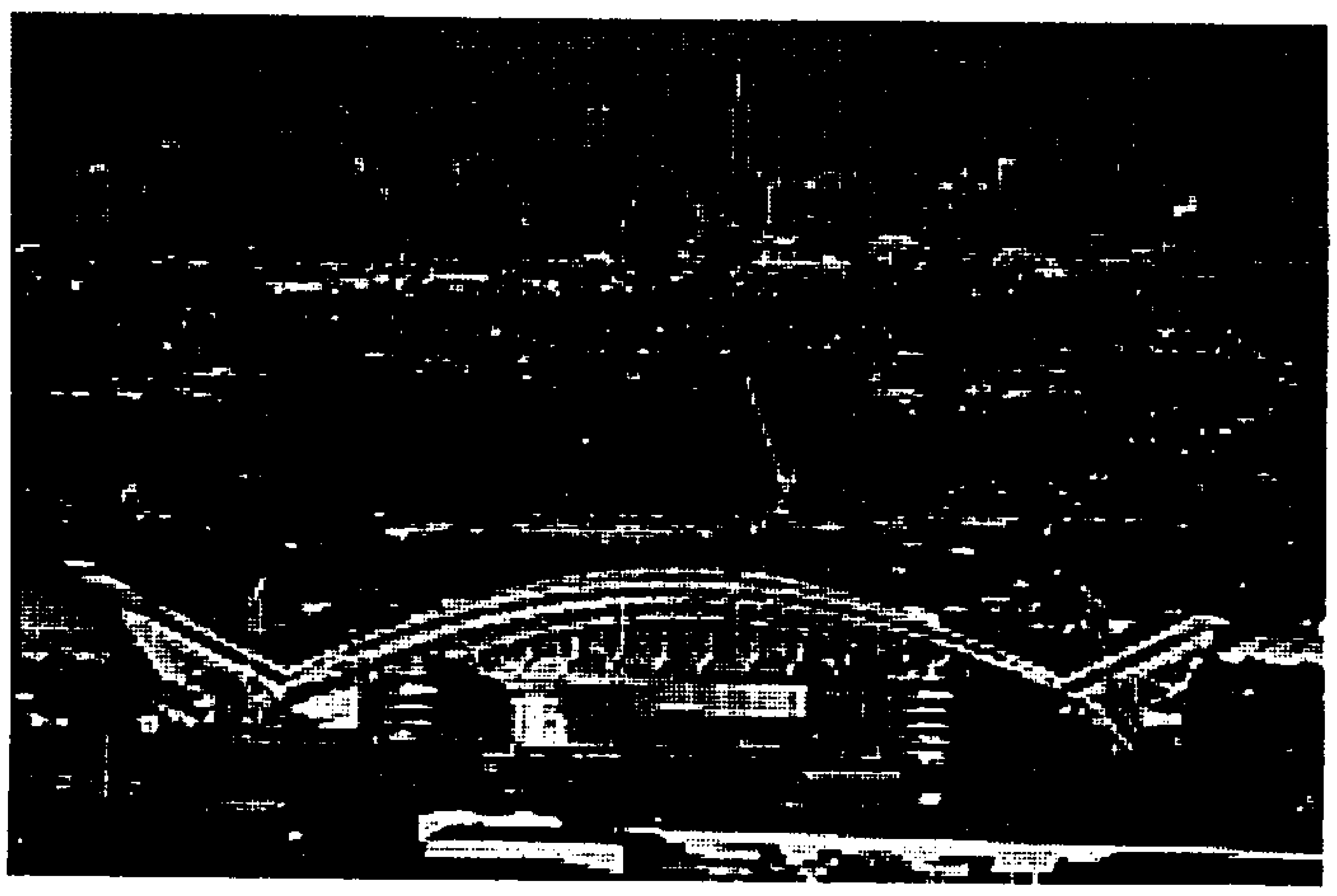

Figure 1. The Olympic Stadium in Sydney Australia.

Please write neatly, and be to the point in your discussions, text, supporting figures and calculations.

2 - Steam Engine Analysis

In Figure 1, a cross-sectional drawing of a two-cylinder steam engine is given (it was taken from a Dutch publication). The two pistons drive a crankshaft through the connecting rods. In Figure 2, a detailed drawing is given of the connecting rods connection to the crankshaft. <u>ALL DIMENSIONS ARE IN MILLIMETERS (mm).</u>

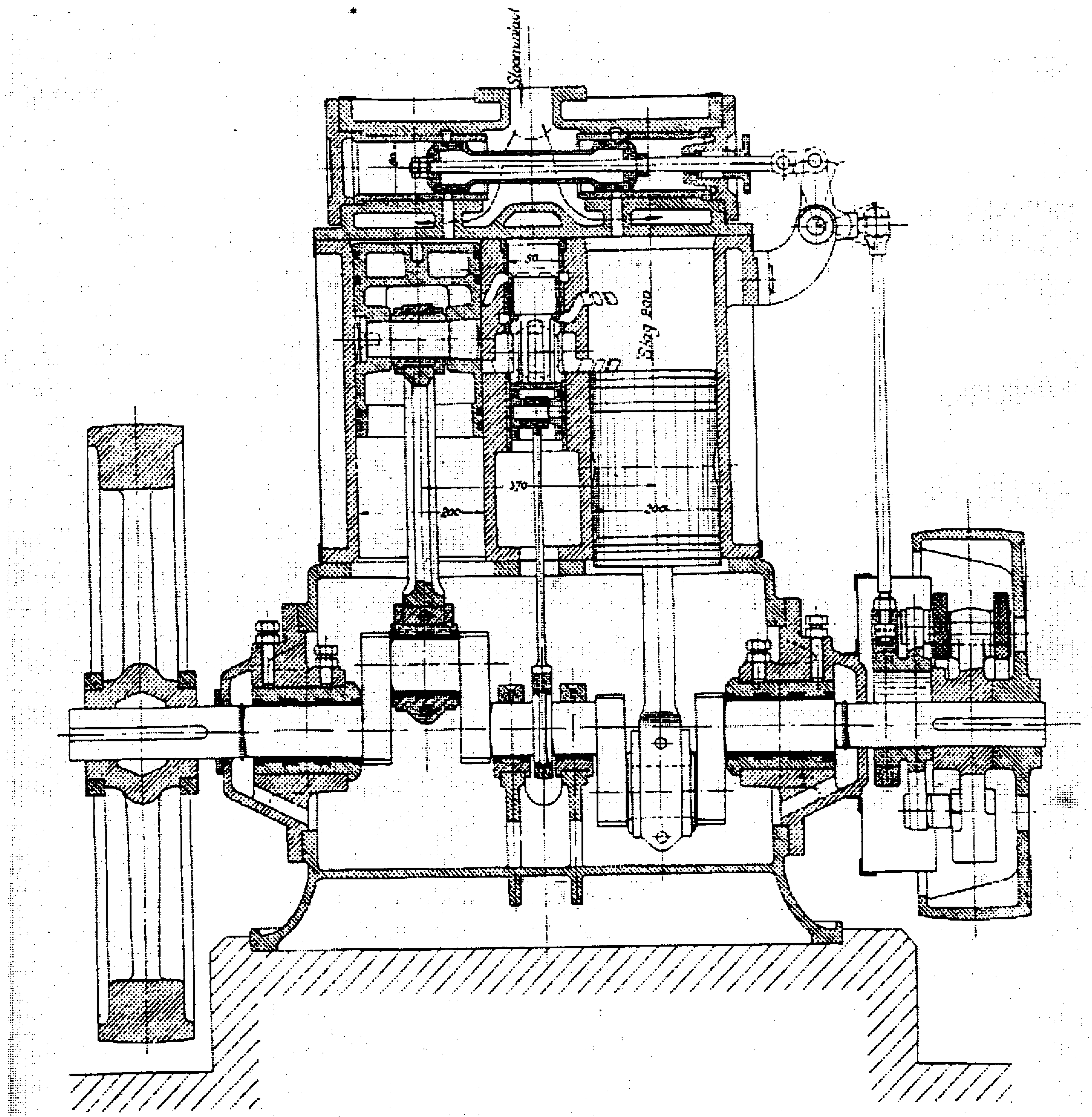

Figure 1 - Two Cylinder Steam Engine.

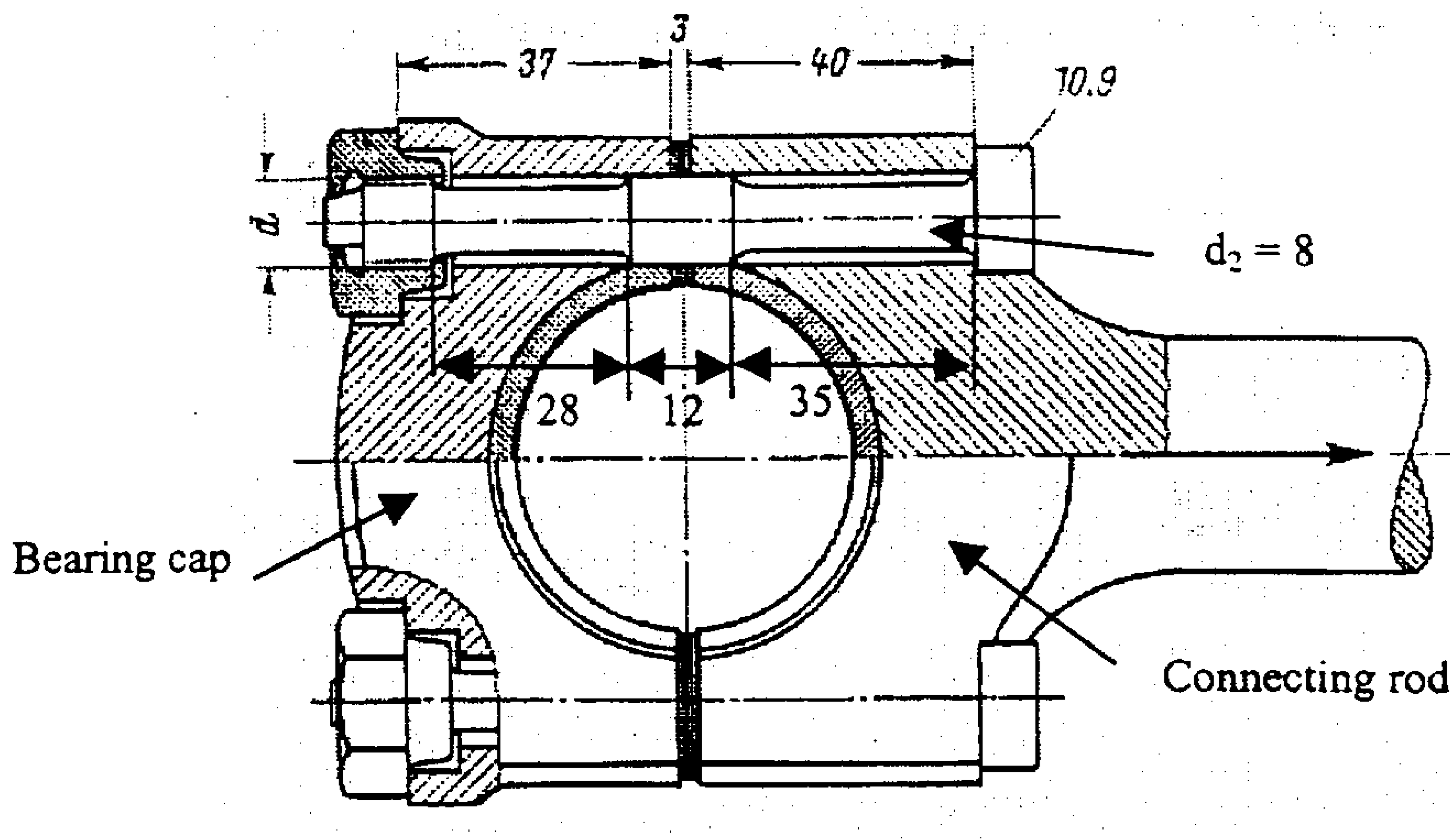

Figure 2 – Connecting Rod Drawing and Dimensions

As you see in Figure 2, two bolts connect the bearing cap to the connecting rod. Your concern is the bolt-nut combination used for clamping the bearing cap on the connecting rod in Figure 2. M10 coarse pitch bolts grade 10.9 are used with a proof strength of 830 Mpa and a thread tensile stress area of 58.0 mm^2. The diameter (d) of the bolt hole is 10 mm - the same as the outer diameter of the bolt shank at its thickest point. As shown in Figure 2, the bolts have two slender areas where the shank diameter d_2 is 8 mm.

The bearing cap is made of gray cast iron, whereas the connecting rod is made out of carbon steel. The modulus of elasticity E for carbon steel is 207 GPa. The modulus of elasticity E for cast iron is 100 GPa.

Assume that a tensile load is induced on the bearing cap and bolt nut combination through the crankshaft. Assume that the minimum load is zero and that the maximum tensile load on the bearing cap occurs when the maximum pressure in a cylinder is reached, which is 50×10^5 Pascal. The cylinder is 84 mm in diameter.

a) Calculate the stiffness of the bolt in Figure 2.

b) Narratively, explain how you would go about calculating the stiffness of the members. What assumptions would you make?

Assume a joint constant of C = 0.25 for the next two questions.

c) What is the minimum required torque to avoid joint separation?

d) What is the maximum allowable bolt pre-load before bolt failure would occur? Assume static loading for simplicity.

e) Why would you not recommend reusing the nuts for the connecting rod after, say, an engine overhaul has taken place?

f) The shape of the nuts used in Figure 2 is different than regular nuts that you typically see. Can you explain what the purpose (or intended purpose) of these special nuts is?

g) What are some (more than one) advantages and disadvantages of using journal bearings for the crankshaft?

It has been decided to add a transmission to the crankshaft and the designers want to use an epicyclical (or planetary) gear system as depicted in Figure 4.

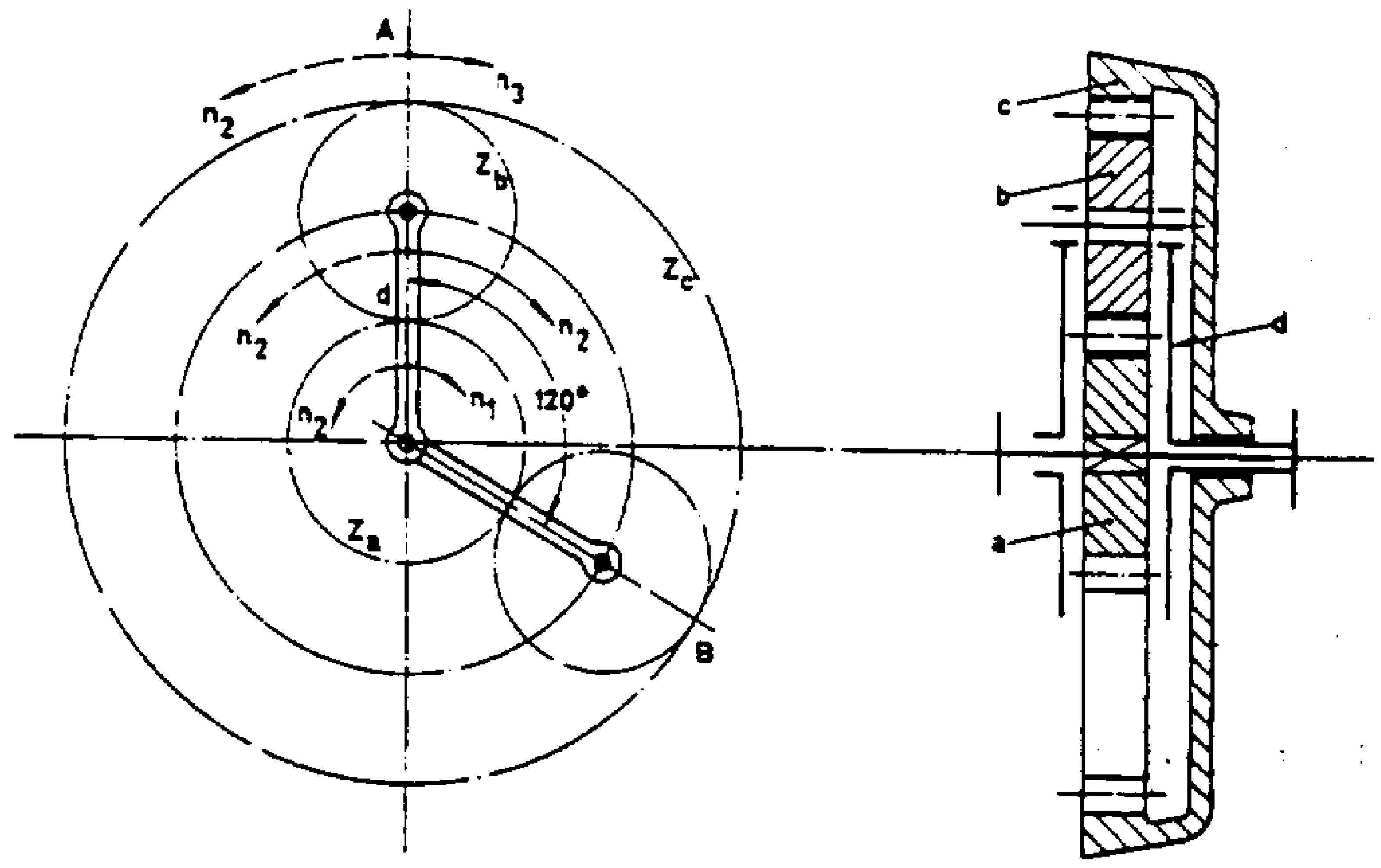

Figure 3 - Epicyclical Gear System

h) What are two reasons why epicyclical gear systems are often preferred over regular gear systems?

i) How many degrees of freedom does an epicyclical gear system have? Please explain clearly what you mean.

j) How many teeth has the internal ring gear c of the system in Figure 4, if the number of teeth on gear wheel a (sun wheel), Za = 25, and the number of teeth on gear wheel b (planet wheel), Zb = 20?