M.E. Ph.D. Qualifier Exam
FALL Semester 2001

GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - FALL Semester 2001

Bioengineering
EXAM AREA

Assigned Number **(DO NOT SIGN YOUR NAME)**

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

Problem I

The vascular endothelium resides at the interface between the arterial wall and flowing blood. As such it is exposed to a complex mechanical environment imposed by the hemodynamics of the vascular system.

A. Describe the endothelial cell from structural view point. What is the role of the membrane and its internal elements? Are there other factors important to this cell from a structural view point?

B. Describe the mechanical environment to which the endothelial cell is exposed? What are the different components of this different environment?

C. When cultured endothelial cells are exposed to flow, describe how these cells respond? What are possible mechanisms by which the presence of flow can be sensed by the cell?

Problem II

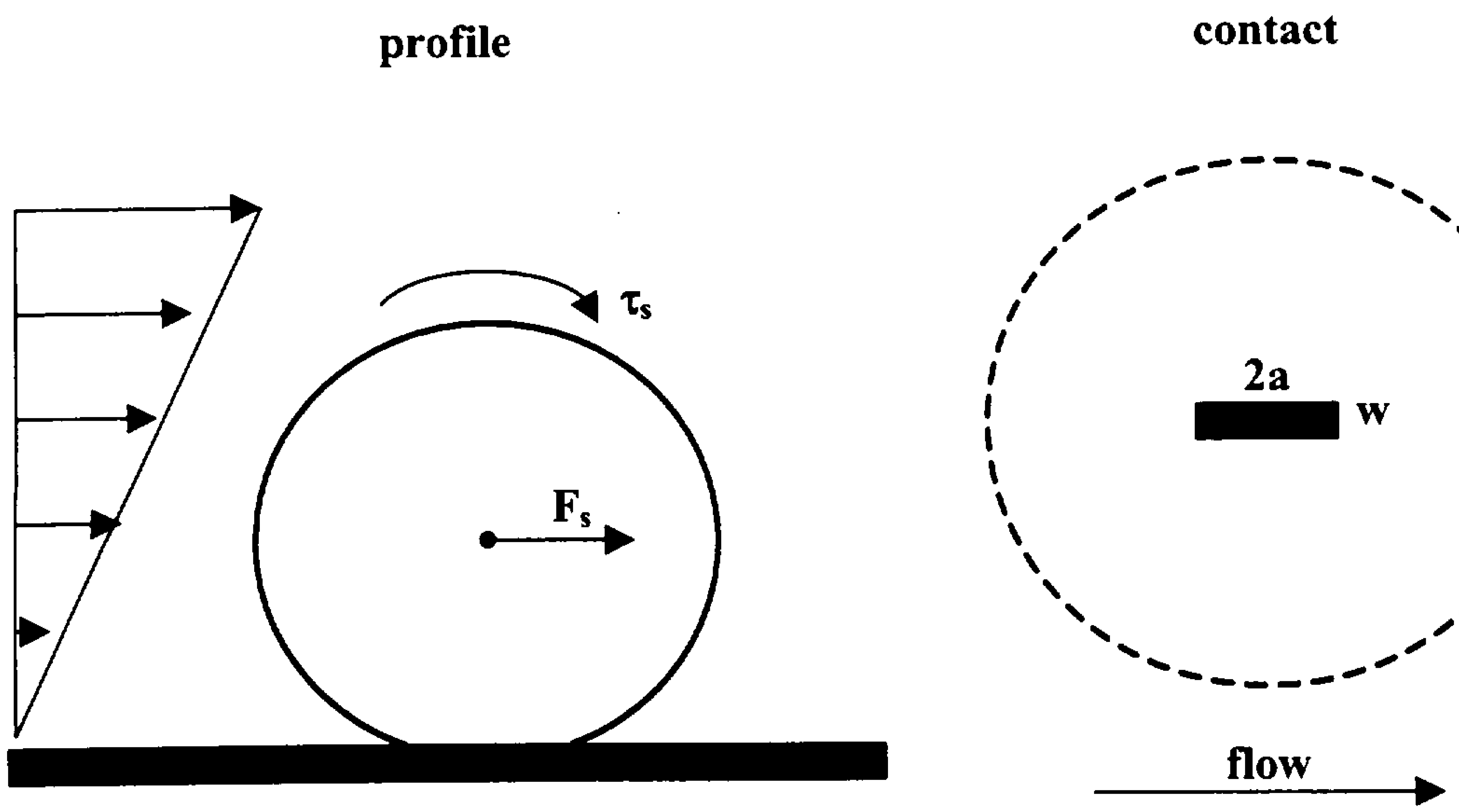
Consider a cell attached to a surface through receptor-ligand bonds. The cell is subjected to shear flow and the hydrodynamic flow produces a shear force F_s and moment τ_s on the cell. The cell-surface contact area is a rectangular region as depicted below. The ligand density at the surface is constant and equal to $[L]_o$.

A. Derive expressions for the rate of bond accumulation and bond number at steady state (B_{equil}) in the contact area (prior to the application of the hydrodynamic force).

B. Find expressions for the resultant horizontal and vertical surface and bond forces at the contact area in terms of the applied fluid forces. Clearly state your assumptions.

C. The hydrodynamic forces are increased until the cell detaches. At detachment, will the resultant vertical bond force be lower, equal, or higher than $f * B_{equil}$?
($f * B_{equil}$ = rupture force of 1 bond * number of bonds in contact area)
Explain your answer.

Additional information:
Cell radius = ρ (units μm)
Total number of receptors on cell surface = R_T (no units)
Forward bond rate = k_f (units $\mu m^2/s$)
Reverse bond rate = k_r (units s^{-1})
Rupture force of 1 bond = f (units pN)



Problem III

It is reasonable to hypothesize that the mechanical environment of the cell *in situ* is an important determinant of cell function. The determination of that environment represents a difficult challenge for engineers.

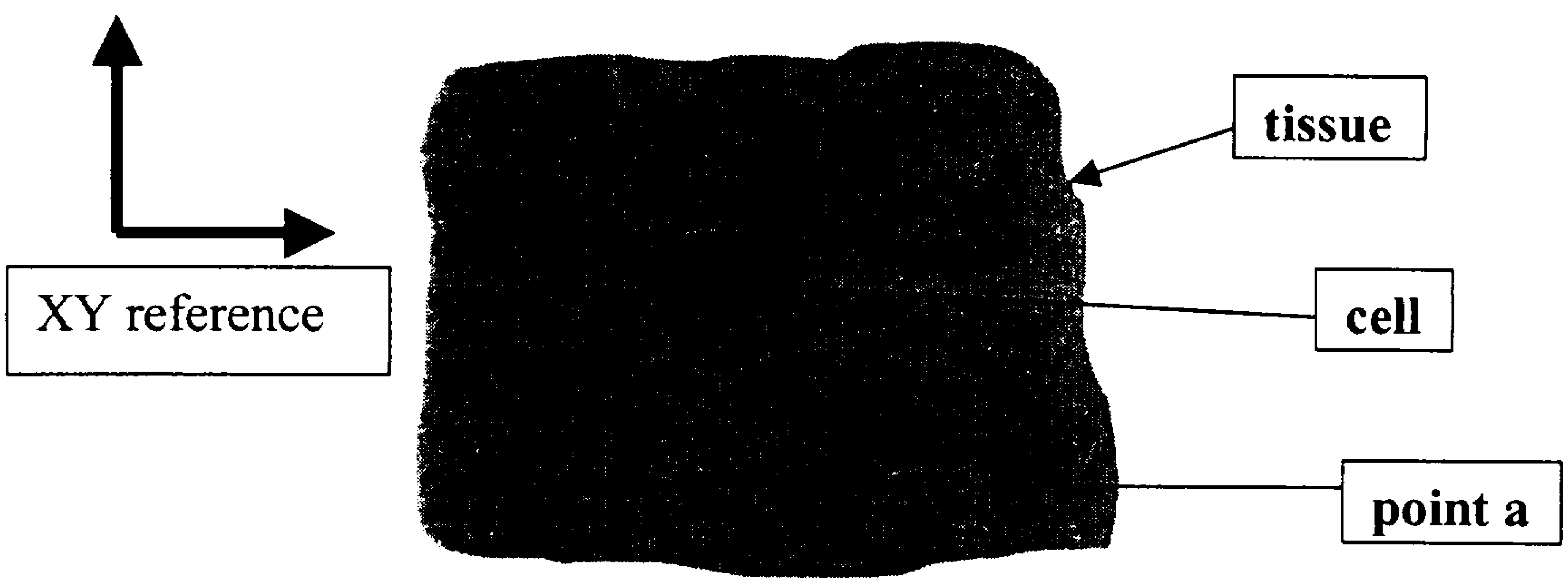
Shown below if an idealized *two dimensional* view of the region surrounding a more or less elliptical cell. The cell is shown embedded in a *homogeneous* elastic tissue which, we will assume, is loaded in the xy plane.

A. We would like to model this system. What basic information would you need to know in order to *estimate the surface tractions on the surface of the cell*? You will need to make assumptions in answering this question. Please state clearly what they are. A solution is NOT expected but a clear methodology for getting there is.

B. Suppose point (a), located by the arrow, is in the state of bi-axial tension relative to reference XY shown. Do you expect any shear strain on the cell surface? If so, is it zero at any point(s)? Be specific.

C. For the state of stress at point (a) described above, what simple analysis can you perform to estimate the average normal stresses in the cell?

D. If the tissue is NOT isotropic, does this affect the calculation you did in part c? If so, how?



Problem IV

A. Draw a diagram of the human arterial system listing the major branches from the heart to the knee.

B. What is the relevance of the Womersley parameter in describing the hemodynamics of the ascending aorta, the carotid artery, and a capillary.

C. Derive the Womersley parameter from Navier-Stokes or a dimensional similarity argument.

D. Define the important hemodynamic parameters necessary to describe whether a tissue engineered vascular graft was suitable for human implantation. Defend why this set of parameters are necessary and sufficient.