

FILM THICKNESSES IN LUBRICATED HERTZIAN CONTACTS. PART 2: POINT CONTACTS

1. NOTATION AND UNITS

The International System of units is given in this Item. Any other coherent system of units may be used.

C	geometry parameter for determining radius ratio	m^{-1}
E	modulus of elasticity	N m^{-2}
E_1, E_2	moduli of elasticity for materials at surfaces in contact	N m^{-2}
E'	effective modulus of the contact defined by $\frac{1}{E'} = \frac{1}{2} \left\{ \frac{(1-\nu_1^2)}{E_1} + \frac{(1-\nu_2^2)}{E_2} \right\}$	N m^{-2}
F	factor for calculation of p_0 (see Section 3.3)	—
G	material parameter = $\alpha E'$	—
$h_{\min}$	minimum lubricant film thickness	m
H_k	non-dimensional lubricant film thickness = $h_{\min}/[R(UG)^{2/3}]$	—
k	thermal conductivity of lubricant	$\text{W m}^{-1}\text{K}^{-1}$
p	pressure of lubricant	N m^{-2}
p_0	maximum Hertzian pressure	N m^{-2}
P	pressure parameter = αp_0	—
R	effective radius of curvature (see Section 3.1)	m
R'	radius ratio (see Section 3.1)	—
R'_{calc}	ratio used in calculation of radius ratio (see Section 3.1)	—
R_{x1}, R_{y1}	principal radii of curvature [†] at contact point for body 1	m
R_{x2}, R_{y2}	principal radii of curvature [†] at contact point for body 2	m
R_q	RMS (root mean square) roughness of a surface	m
R_{q1}, R_{q2}	RMS (root mean square) roughnesses of two contacting surfaces	m

For footnote see end of Notation.

R_{qt}	composite surface roughness of mating surfaces = $(R_{q1}^2 + R_{q2}^2)^{1/2}$	m
S	speed parameter = $GU^{1/4}$	–
u	magnitude of lubricant entrainment velocity vector	m s^{-1}
u_1, u_2	surface velocities relative to contact point	m s^{-1}
$\underline{u}$	lubricant entrainment velocity vector	m s^{-1}
$\underline{u}_1, \underline{u}_2$	surface velocity vectors relative to contact point	m s^{-1}
U	lubricant entrainment parameter = $\eta_0 u / (E'R)$	–
w	load applied to contact	N
X, Y, Z	body axes (see Section 3.1)	
X_1, Y_1, Z	principal axes for body 1 (see Section 3.1) [†]	
X_2, Y_2, Z	principal axes for body 2 (see Section 3.1) [†]	
α	pressure exponent of lubricating viscosity	$\text{m}^2 \text{N}^{-1}$
η	dynamic viscosity	N s m^{-2}
η_0	lubricant dynamic viscosity at atmospheric pressure and at operating temperature (see Section 3.4)	N s m^{-2}
θ	absolute temperature	K
γ	direction of lubricant entrainment velocity vector relative to X-axis of equivalent principal axes	rad
λ	specific film thickness (see Section 4.2)	–
ν	Poisson's ratio	–
ν_1, ν_2	Poisson's ratio for materials at surfaces in contact	–
ϕ	angle between corresponding axes of principal axes	rad
ψ	orientation angle of contact ellipse (see Section 3.1)	rad

[†] The principal axes of a body for a given point on its surface are the two mutually perpendicular axes, passing through the point and being tangential to the surface, such that the local radius of curvature of the surface in the direction of one axis is greater, and in the direction of the other axis is less, than for any other tangential axis passing through that point. The maximum and minimum local radii of curvature so defined are called the principal radii.

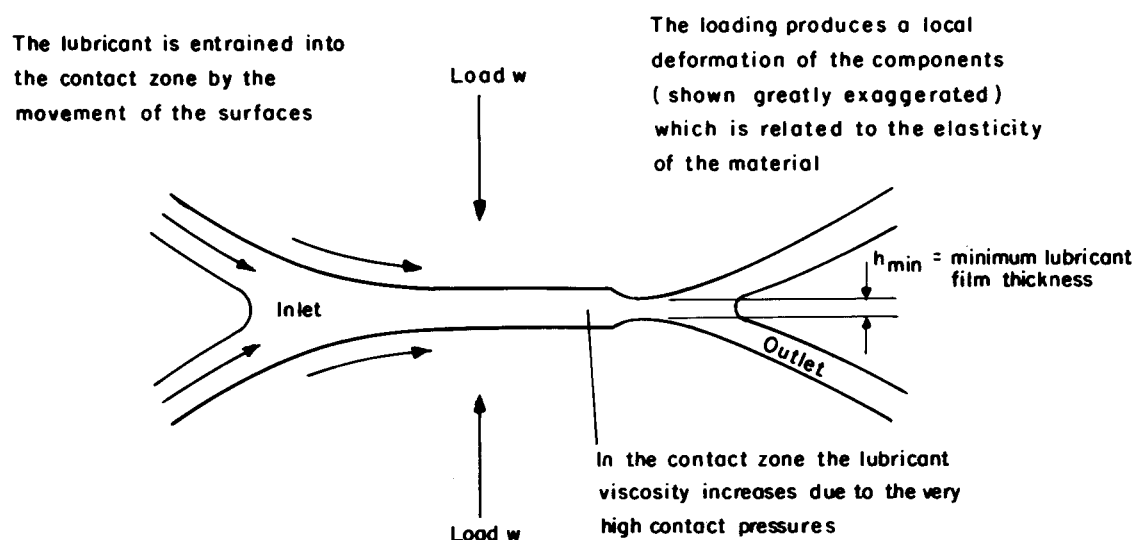
2. INTRODUCTION

This Item provides charts and calculation methods for determining the minimum lubricant film thickness in concentrated contacts that occur, for example, in rolling element bearings and gears. In such contacts, often called Hertzian contacts, the contact area increases with applied load.

For the purpose of calculating the lubricant film thickness, Hertzian contacts are regarded as either two-dimensional, with line contact, or three-dimensional, with point contact. Line contact occurs in, for example, roller bearings, roller followers on cams and spur gears while three-dimensional contacts occur in, for example, ball bearings, certain roller bearings (at roller-rib contacts), variable speed traction drives and many types of gears. The charts and calculation methods presented in this Item apply to three-dimensional contacts. Two-dimensional contacts are dealt with in Reference 1.

2.1 Description of Contact Phenomena

The formation of a lubricated Hertzian contact depends upon a viscous lubricant being drawn into the contact zone by the movement of the surfaces as shown in Sketch 2.1. In a typical contact the fluid pressures generated within the entrained lubricant can be a thousand times greater than those occurring in hydrodynamic journal and thrust bearings and, as a consequence of these high pressures[†], changes in the viscosity of the lubricant and elastic deformation of the components in contact may both be highly significant.



Sketch 2.1 A typical lubricated Hertzian contact

In point contacts, the lubricant film is often of a uniform thickness over much of the contact but is, typically, constricted towards the rear and the sides of the contact. The minimum thickness may be located either at the centre of this exit constriction or in the side lobes. A knowledge of this film thickness, which can be two orders of magnitude smaller than those occurring in hydrodynamic journal and thrust bearings, is required in order to assess the likelihood of wear and surface distress.

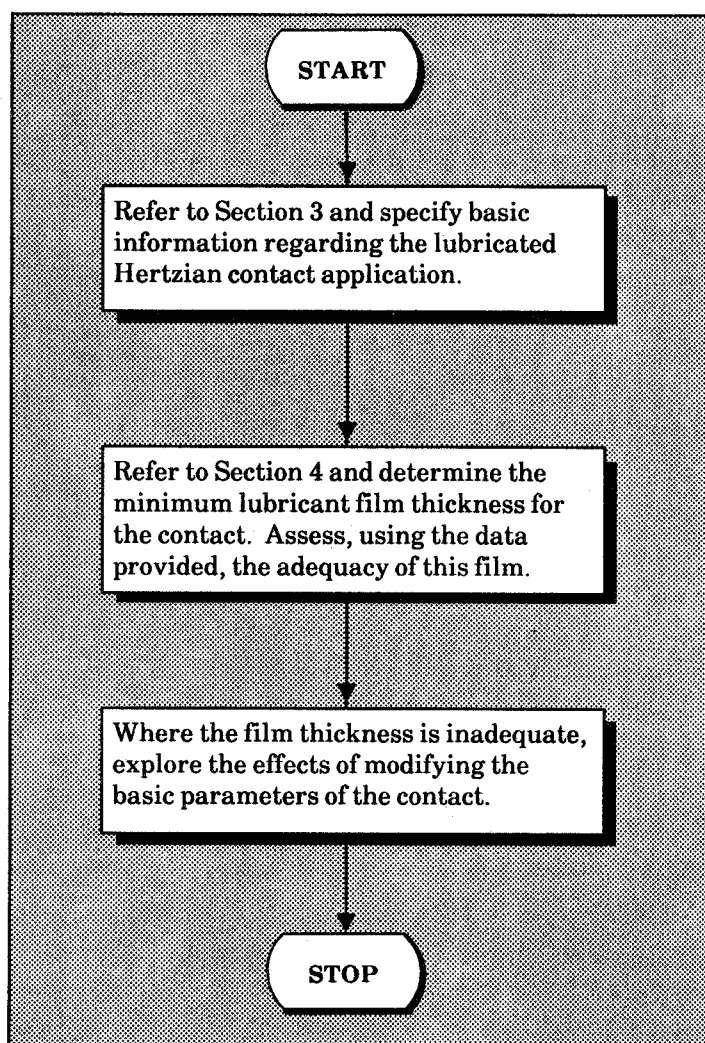
[†] The strength and integrity of the surfaces of the contacting bodies should, of course, be carefully considered (see References 2 and 3).

2.2 Guide to The Use of This Item

In order to use this Data Item to determine the lubricant film thickness in a Hertzian contact you should have available the following information.

- (i) The radii of curvature of the contacting surfaces.
- (ii) The surface velocities at the point of contact.
- (iii) The material properties of the contacting surfaces and the load.
- (iv) The properties of the lubricant.

In order to then determine the adequacy of this film thickness you should also have given consideration to the surface finish of the contacting bodies. Sketch 2.2 provides a flowchart of the design process.

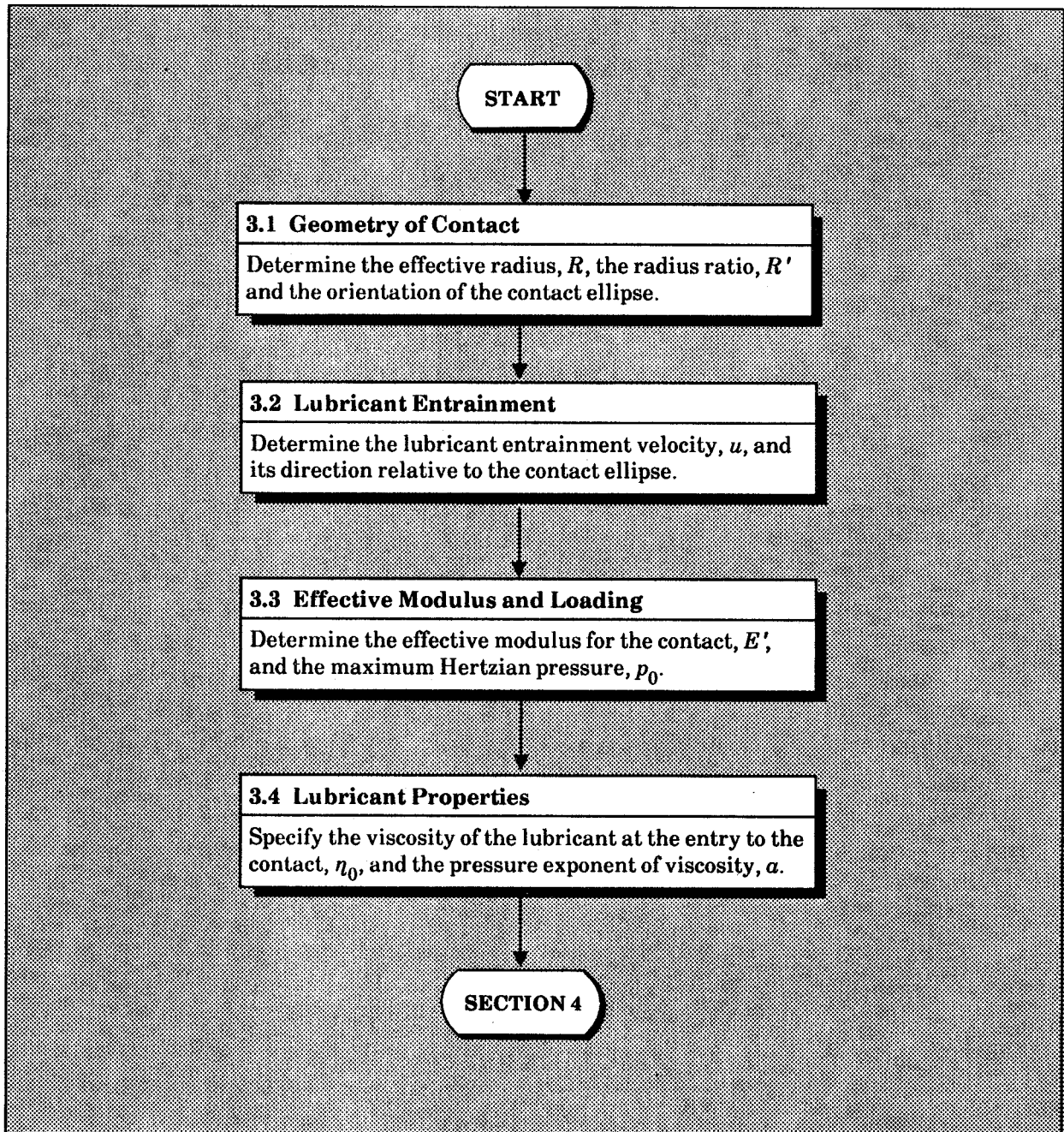


Sketch 2.2 Flowchart of design process

Three worked examples illustrating the use of this Item are presented in Section 5.

3. SPECIFICATION OF APPLICATION

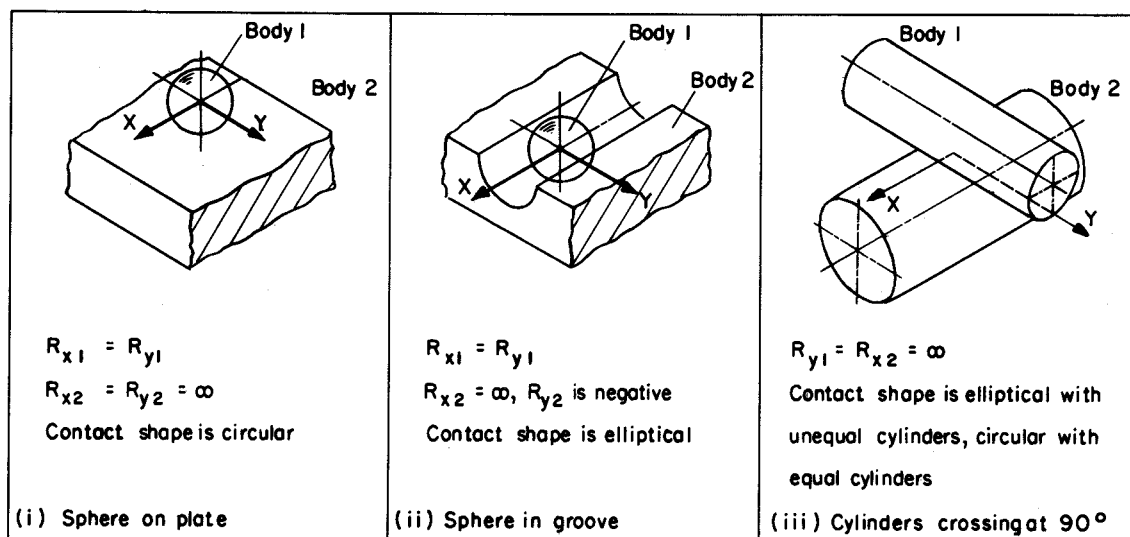
In this section basic information regarding the intended application is specified, which includes the geometry and entrainment conditions at the contact, the loading and the elastic properties of the contacting bodies and the lubricant properties. The procedure is summarised in Sketch 3.1.



Sketch 3.1 Specification

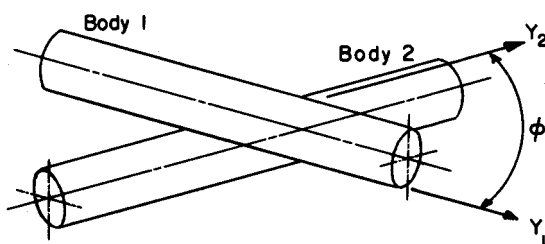
3.1 Geometry of Contact

Non-conforming machine parts, when loaded together, contact at an approximately elliptical contact area. In many practical contacts the major and minor axes of this contact ellipse are aligned with the principal radii of curvature of the contacting bodies (see Sketch 3.2) and determination of the equivalent radius, R , and the radius, R' , which are required in subsequent calculations, is relatively straightforward as shown by the procedure of Sketch 3.4.



Sketch 3.2 Some combinations of bodies with aligned principal axes

Where there is no such alignment of principal axes (see Sketch 3.3), determination of the radius ratio is more complicated and involves first determining the orientation angle of the contact ellipse, a procedure for which is given in Sketch 3.5.

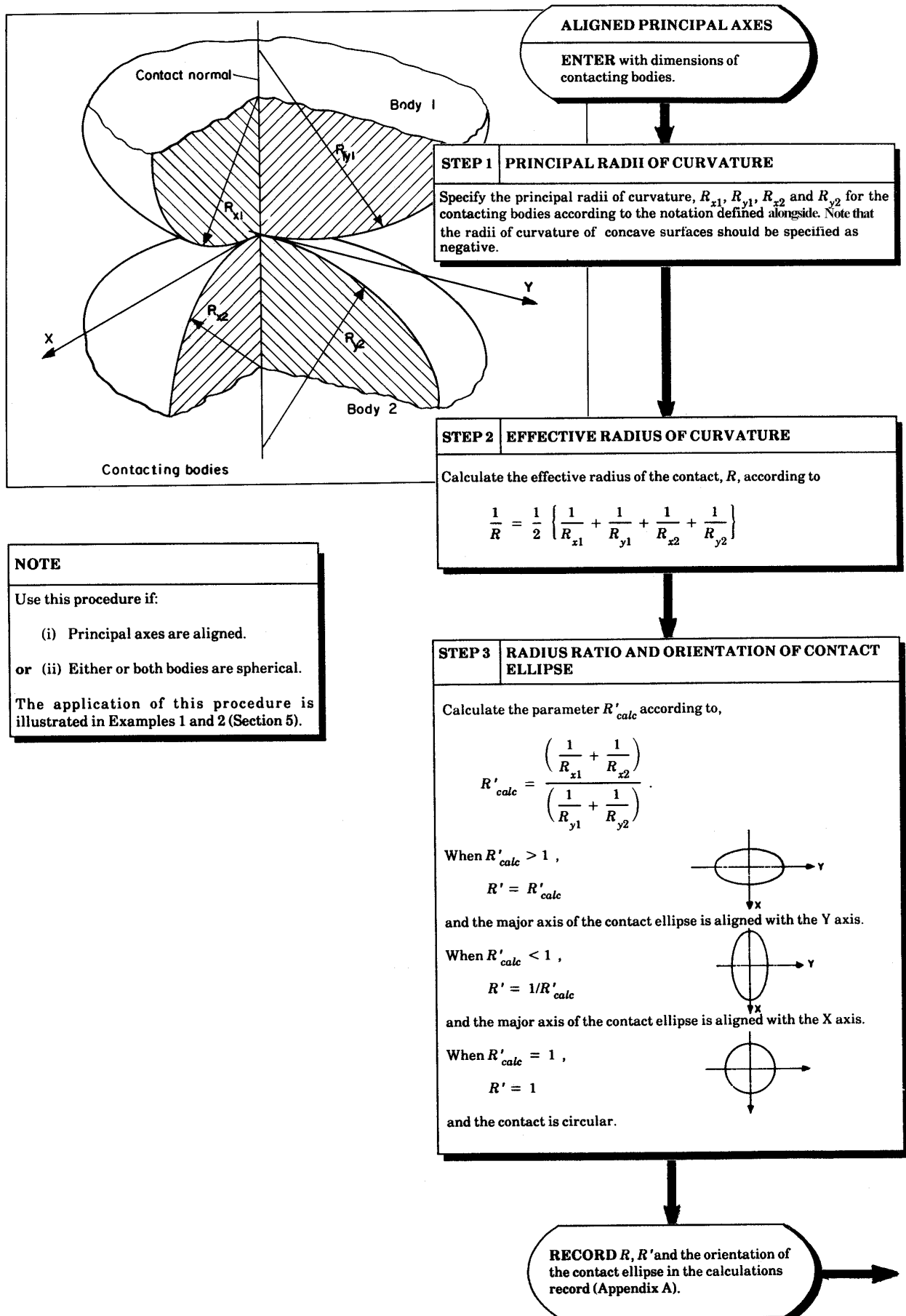


$$R_{y1} = R_{y2} = \infty, \quad 0^\circ < \phi < 90^\circ$$

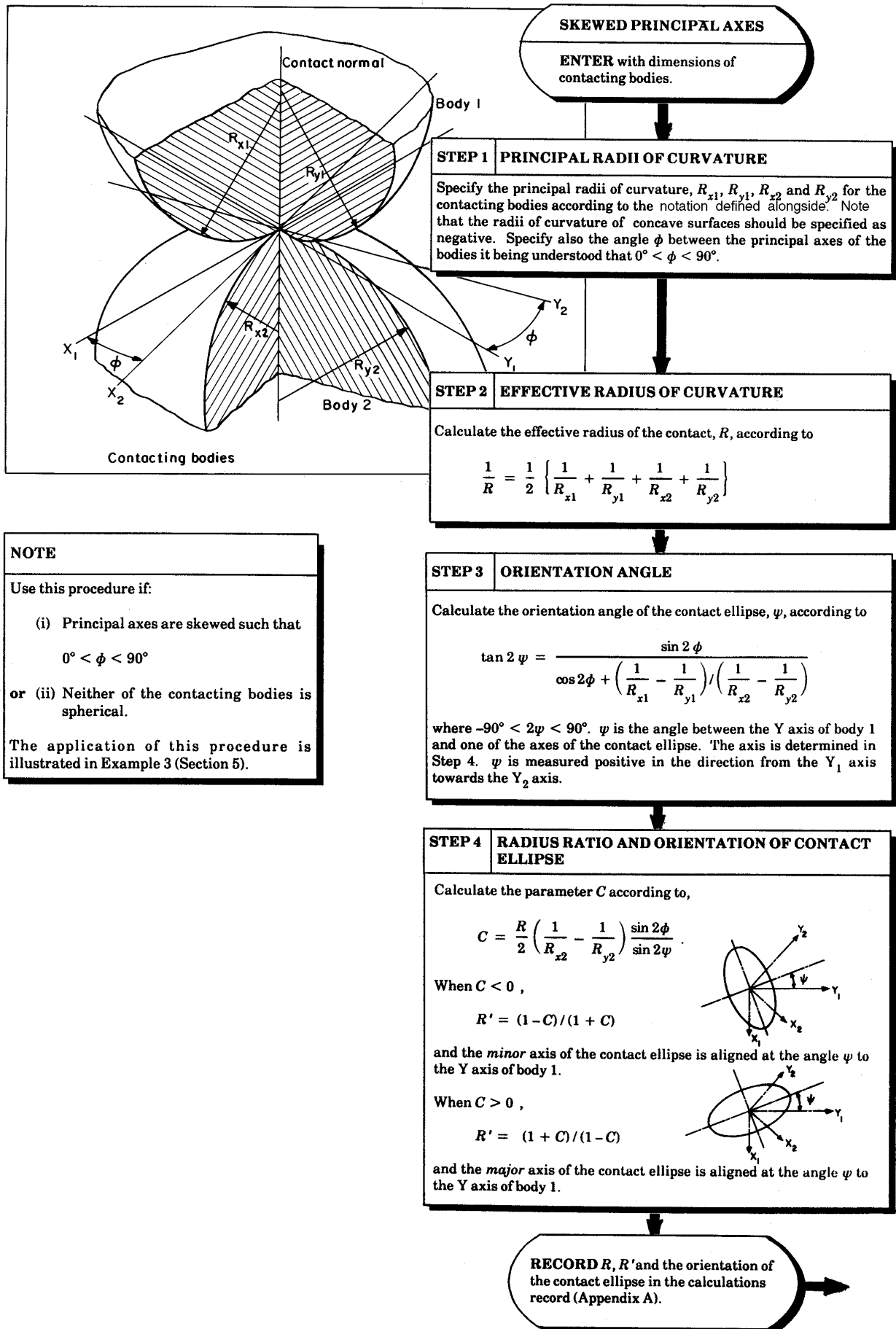
Contact shape is elliptical

Crossed cylinders

Sketch 3.3 A combination of bodies with skewed principal axes



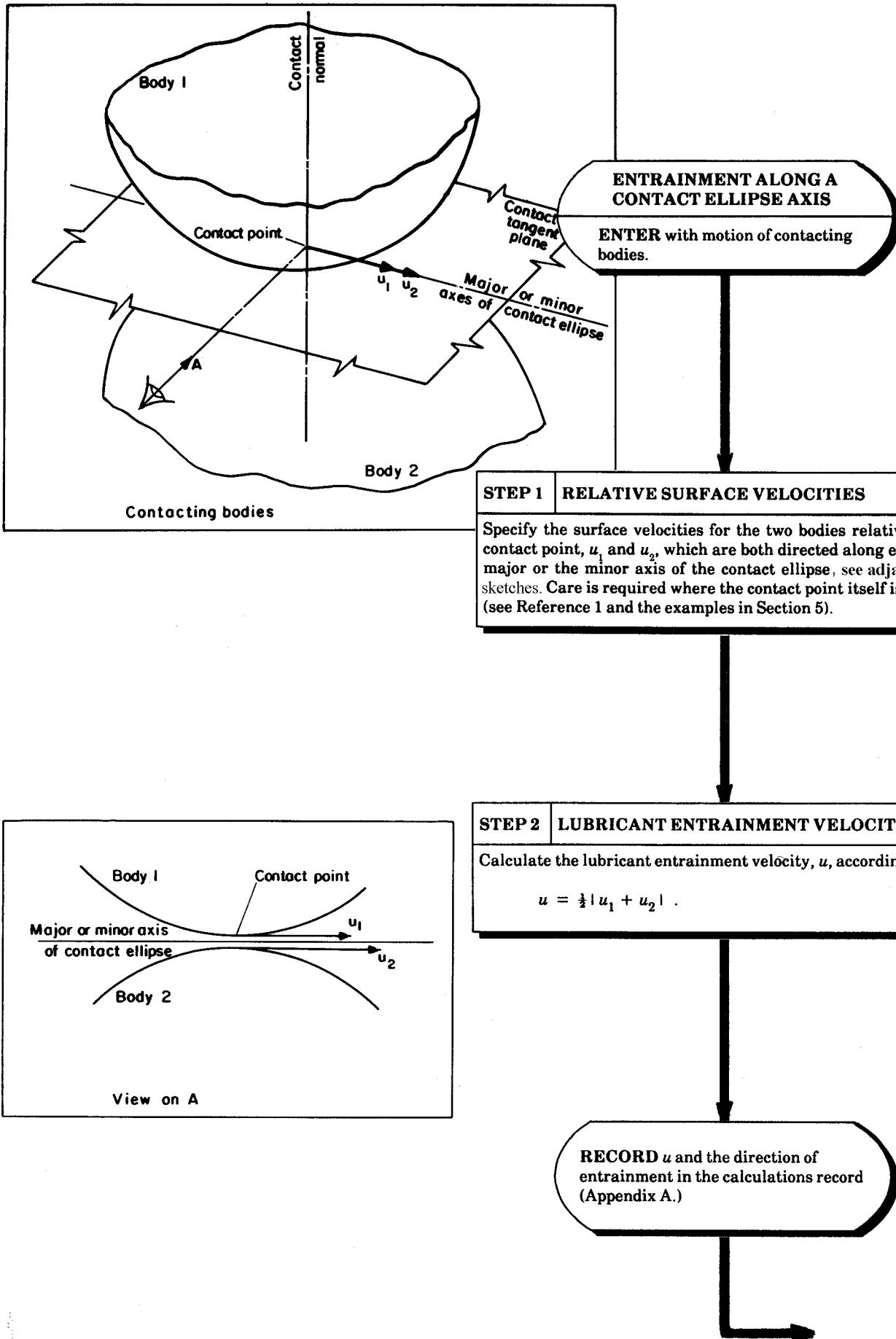
Sketch 3.4 Geometry for aligned principal axes



Sketch 3.5 Geometry for skewed principal axes

3.2 Lubricant Entrainment

The lubricant is entrained into the elliptical contact area, the orientation of which has been established in Section 3.1, by the motion of the surfaces of the contacting bodies. In many practical contacts the relative surface velocities of both bodies are directed along a single axis (either the major or the minor) of the contact ellipse and the resulting lubricant entrainment velocity is, consequently, directed along the same axis. In such contacts, determination of this entrainment velocity is relatively straightforward as shown by Sketch 3.6, entitled “Entrainment along a contact ellipse axis”. However, in some contacts, such as those in crossed axis gears and in parallel axis helical gears with special profiles, the lubricant is entrained at some angle to the contact ellipse axis and it is then advisable to consider a vector diagram of the surface velocities of the contacting bodies as in Sketch 3.7, entitled “Entrainment at an angle”.



Sketch 3.6 Entrainment along a contact ellipse axis