VLBA ACQUISITION MEMO #264

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To: VLBA Data Acquisition Group

From: Alan E.E. Rogers

Subject: Theoretical Model for Head Flying

In VLBA Acquisition Memo #254 it was shown that we should not expect flying. However, the larger scale structure on the approach to the head and the initial head contour are now considered.

On the approach to the head there is air circulation which can be approximated by the analytic solution to the Navier-Stokes equations[1] given in VLBA Acquisition Memo #254. This air circulation produces a pressure P (see Figure 1)

$$P \sim \frac{6\mu V}{\phi^2 r} \tag{1}$$

ϕ	=	headstep approach angle ($\sim 5°$)
z	=	headstep height ($\sim 50\ \mu m$)

which acts over a distance longer than the characteristic bending length of the tape (~150 microns - see VLBA Acquisition Memo #141) to produce a change in angle of the tape at the entry point to the head bearing surface. Since the curvature of the tape is

$$\frac{d^2y}{dx^2} = P/T \tag{2}$$

the slope change is the integral

$$\alpha = \frac{dy}{dx} \sim \left(\frac{6\mu V}{T\phi^2}\right) ln\ (1 + B\phi/z) \tag{3}$$

B	=	length of headstep approach ($\sim 1250\ \mu m$)
z	=	headstep height ($\sim 50\ \mu m$)
T	=	tension per unit width (0.2 lbs. for 5" vacuum)

[1] This is a little known solution found by Michell in 1899 (this was pointed out to me by Prof. Ain Sonin of MIT). Note the typo in small angle approx. of memo #254 - factor should be 6.

Once entering the head bearing surface, the air flow develops into a thin film. The new profile formed by the tape over the head surface must simultaneously satisfy

1] Reynolds' equation (assuming the flow in unidirectional).
2] The boundary conditions of pressure.
3] The entry angle (derived above).
4] The bending equations (see VLBA Acquisition Memo #141).

We consider the solutions to Reynolds' equation given in Fluid film Lubrication by Gross et al and note the following:

1] An increasing pressure is accompanied by a decreasing film thickness. A constant film thickness gives constant pressure.
2] The maximum load is supported with thickness ratios 2-3 (see Figure 3-2.2 for example).
3] A taper-flat bearing supports the greatest load. Assume that a parabolic segment is approximately a taper-flat bearing with equal taper and flat segments.
4] For modest bearing numbers (< 100) the load supported is approximately one hundredth of the bearing number (see Figure 3-5.5).

If we consider the symmetrical film and pressure profile shown in Figure 2. A film thickness ratio of 2 occurs when the flying and head profiles differ by the central height h. In this case

$$L^2\left(\frac{1}{2R_h} - \frac{1}{2R_f}\right) = h \tag{4}$$

where

L	=	headstep length
R_h	=	radius of curvature of head
R_f	=	radius of curvature of flying profile

Using the relation (see memo #179)

$$R\Theta = L + l \tag{5}$$

where

R	=	radius of curvature of stable head contour
L	=	distance from gap to headstep (150 μm)
l	=	characteristic bending length (approximately 150 μm for 16 μm tape)
θ	=	wrap half-angle (5°)

$$h = L^2/(2L + 2l)\alpha \tag{6}$$

for the effective change in wrap angle α. Thus the flying height at the gap is

$$h \sim \left[L^2/(2L + 2l)\right]\left[\frac{6\mu V}{T\phi^2}\right] \ln(1 + B\phi/z) \tag{7}$$

$\sim$ 0.2μm at 320 IPS and T = 0.2 lbs (5" vacuum)

However for flying to actually occur the tape load $2T\theta$ must be supported by the film. This imposes a condition (from #4) that

$$\Lambda b/100 > 2T\theta/p_a \tag{8}$$

where

Λ = bearing number = $6\mu Vb/(h^2 p_a)$

and

b = bearing length = $2L$

or

$$h^1 = (12\mu VL^2/(100T\theta))^{1/2} \tag{9}$$

For very small flying heights the film may be more difficult to support on account of the effective reduction in viscosity such that

$$\mu \sim \mu_o/(1 + 6\lambda/h) \tag{10}$$

The model plotted in Figure 5 assumes that h is given by equation 7 unless this height cannot be supported ($h^1 < h$) in which case $h = h^1$ from equation 9 modified by equation 10.

The effect of head contour

Equation 4 assumes that the head has an equilibrium radius of curvature appropriate for that particular operating tension. However, R_h may not be the equilibrium curvature, in which case, we need to use Equation 5 to obtain a modified head curvature. Differentiating Equation 5 with respect to angle and tension (l varies as $T^{1/2}$)

$$h = \left(L^2/(2L + 2l)\right)\left(\alpha + F\theta l/(2L + 2l)\right) \tag{11}$$

where

F = fractional increase in tension for which the head was conditioned - valid for small changes.

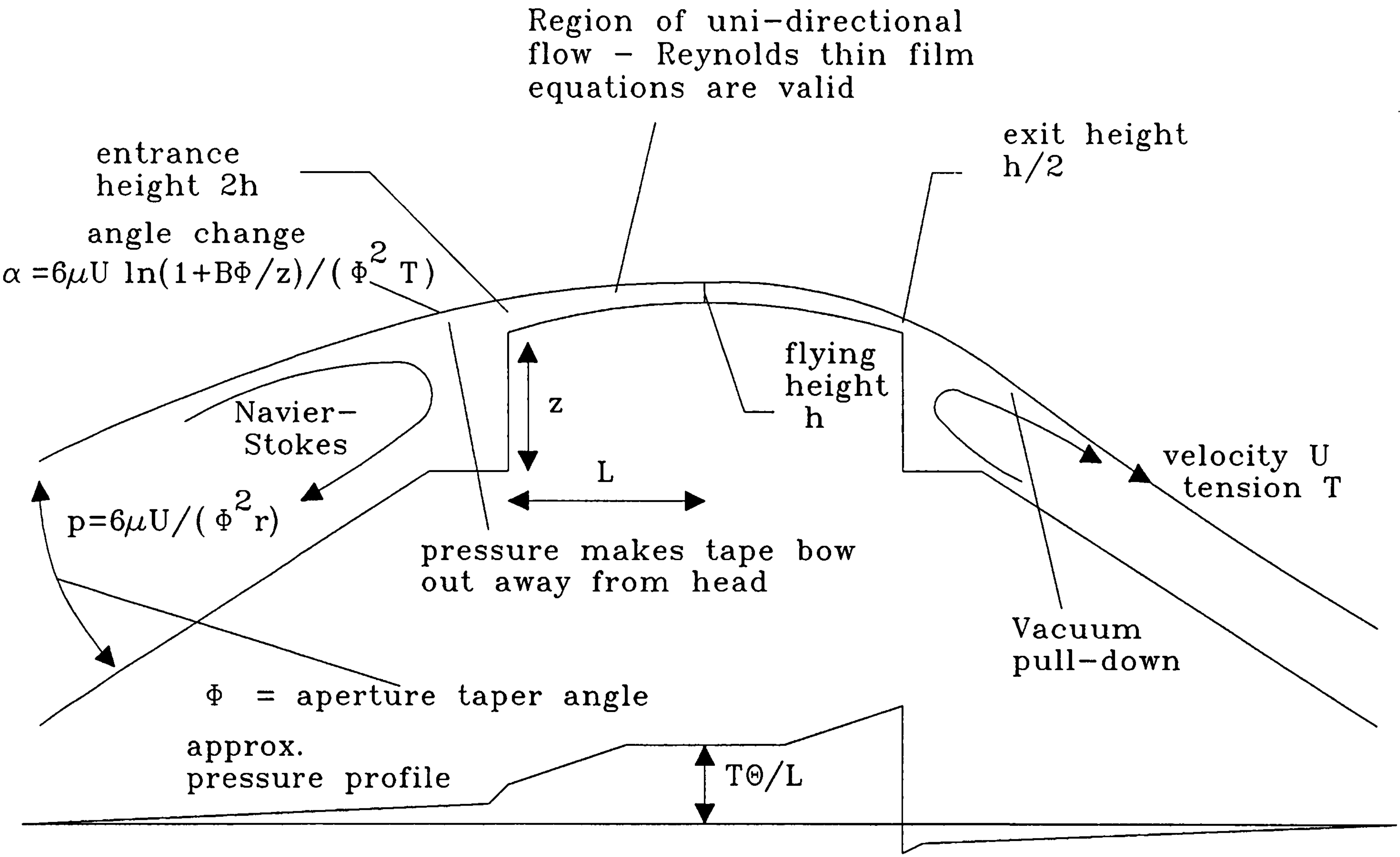
Figure 6 shows the calculated flying height based upon equations 9, 10, and 11 and a threshold (see below). The upper envelope represents the maximum supportable film thickness. However when h from equation 11 becomes much larger than h^1 the assumption of a thickness ratio in range 2-3 breaks down and another solution in which the air reverses before reaching the gap is possible at low velocities.

Threshold effect

So far, the model for tape profile (Equation 5) assumes that the pressure is constant along the headstep half-length L. However, the effective length of constant pressure is somewhat shorter. In this case, the equilibrium contour for a flying tape will be slightly sharper (smaller radius of curvature). This will have the effect of introducing a threshold value for h before flying will start. On the assumption that the parabolic film thickness is equivalent to a 50/50 taper-flat the effective length of constant pressure is 75%. However, when boundary layer slip is taken into account the pressure build-up is more rapid. Figure 6 assumes 90% effective length which leads to a 20% tension threshold.

Conclusions

The results of this analysis are surprising. For a stable profile the flying is not intrinsic to the head and headstep (with square corner) but is provoked by the larger scale structures leading up to the headstep. Most important is the 5° approach. Also of some importance is the inchworm housing that precedes the headstack in reverse direction (see Figure 3) and adds more lift making the flying worse in the reverse direction for the standard location of the VLBA headstack. The solution to the flying problem is simple, increase the approach angle or place air relief grooves (like on the IBM 3480 heads) in the approach. Other solutions are to reduce the headstep width or add air scrapers. Both alternate solutions have disadvantages. Reducing the headstep width will reduce head lifetime and air scrapers (like those used on the "triple cap" headstack) might produce other undesirable effects. This model has yet to be tested by measurements which are still in progress. Predictions of this model is an increase in the flying as the headstep wears down owing to the $ln(1 + B\phi/z)$ term. This memo only sketches the derivation of the model and will be augmented later with greater vigor if the basic assumptions and concepts prove to be adequate.



Air flow in regions around the head-to-tape interface

Figure 1

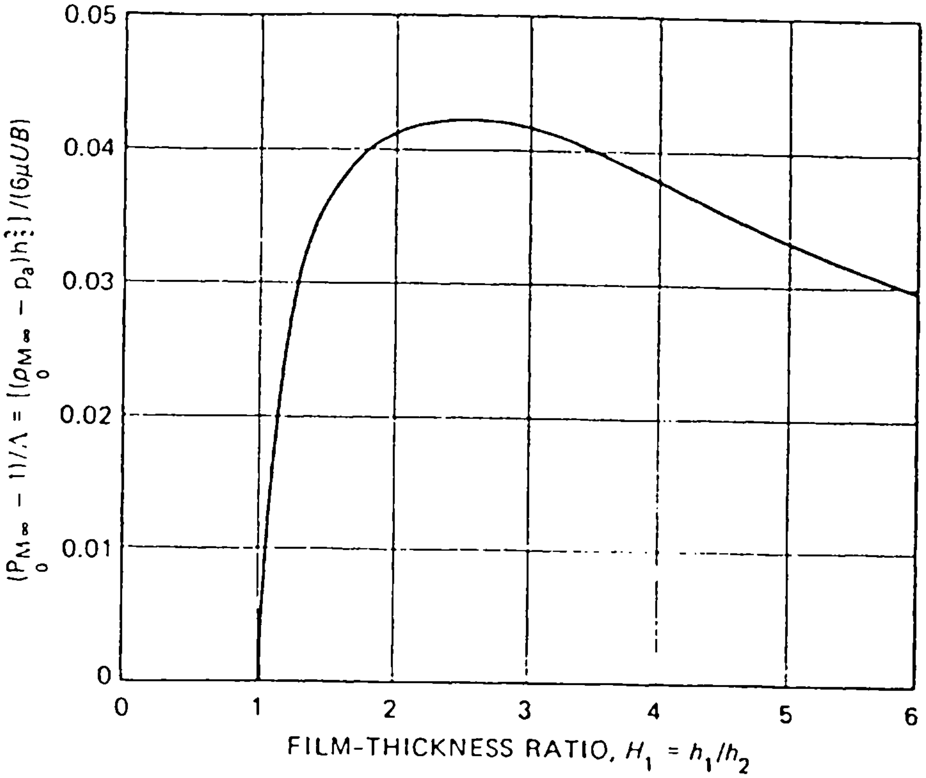


Fig. 3-2.2 Maximum pressure in incompressible plane-wedge slider-bearing film vs. film-thickness ratio, H_1.

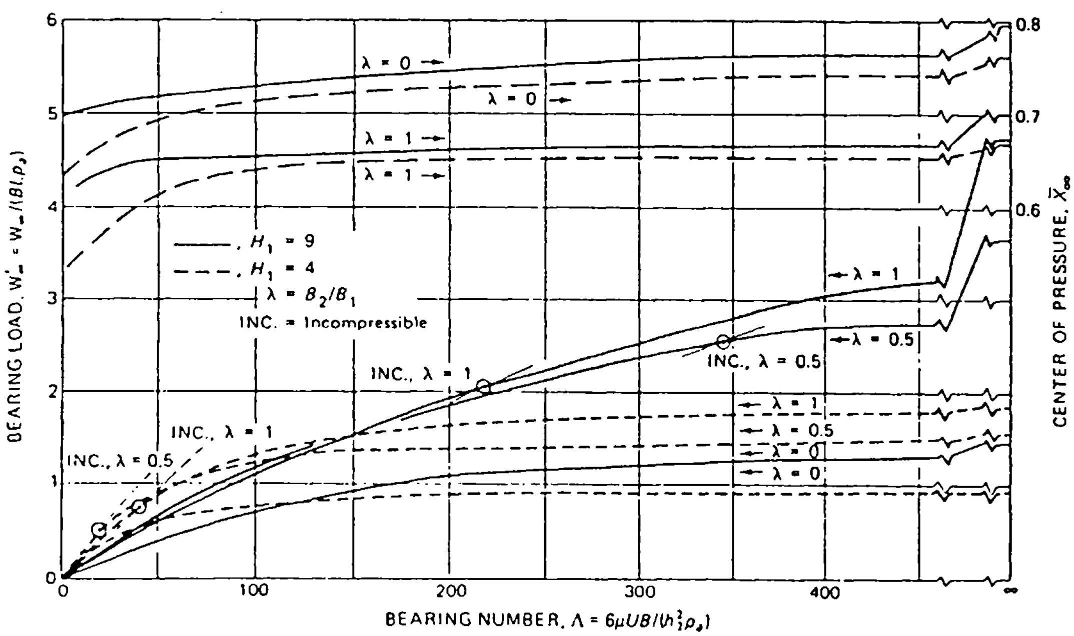
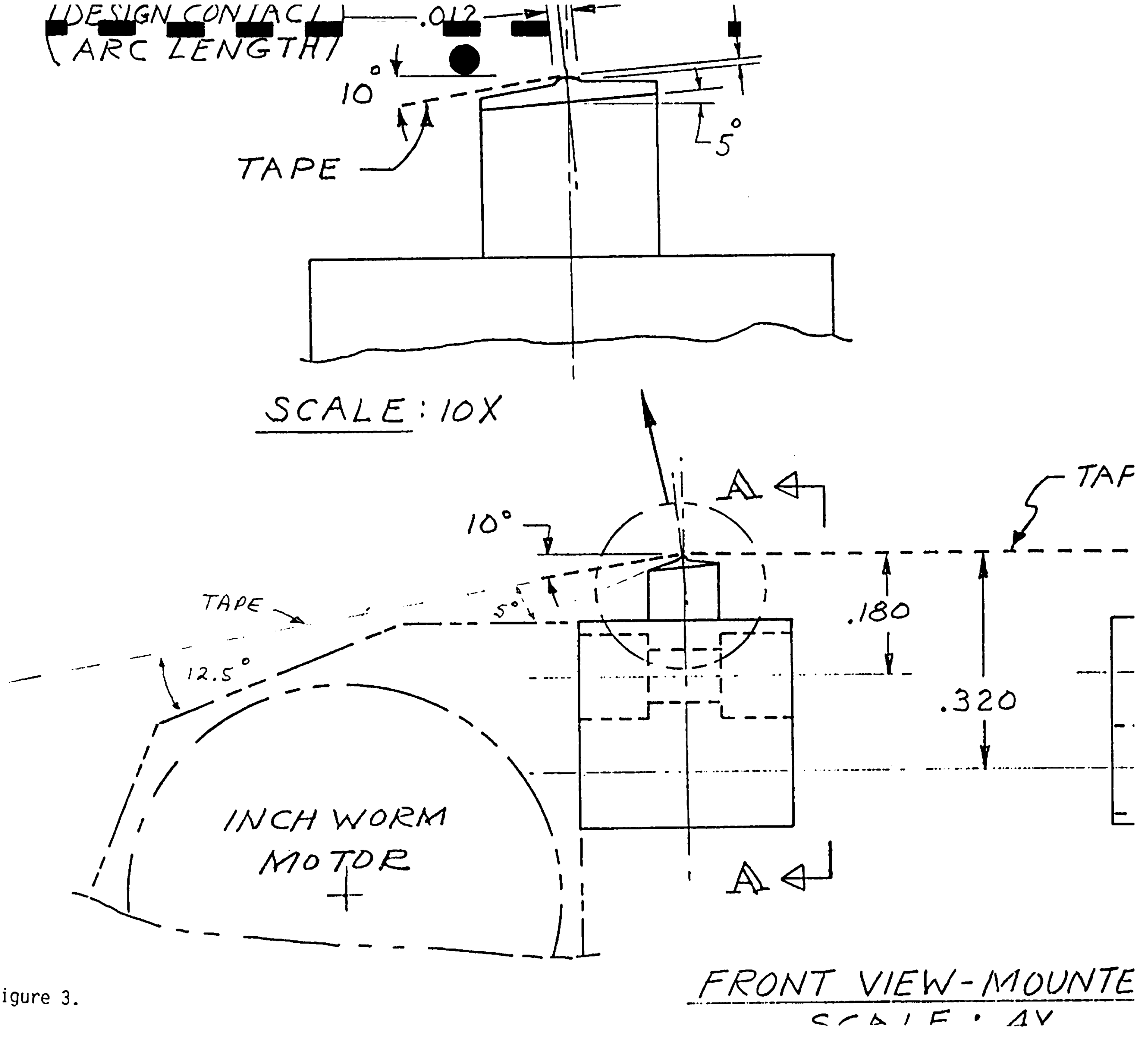


Fig. 3-5.5 Effect of bearing number on bearing load and center of pressure for infinitely long inclined-plane and taper-flat gas bearings. Intersect points designated Inc. refer to the incompressible case.

Figure 2. From "Fluid Film Lubrication", John Wiley Press



(DESIGN CONTACT
ARC LENGTH)
.012
10°
5°
TAPE
SCALE: 10X
10°
TAPE
5°
12.5°
.180
.320
INCH WORM
MOTOR
FRONT VIEW-MOUNTE

Figure 3.

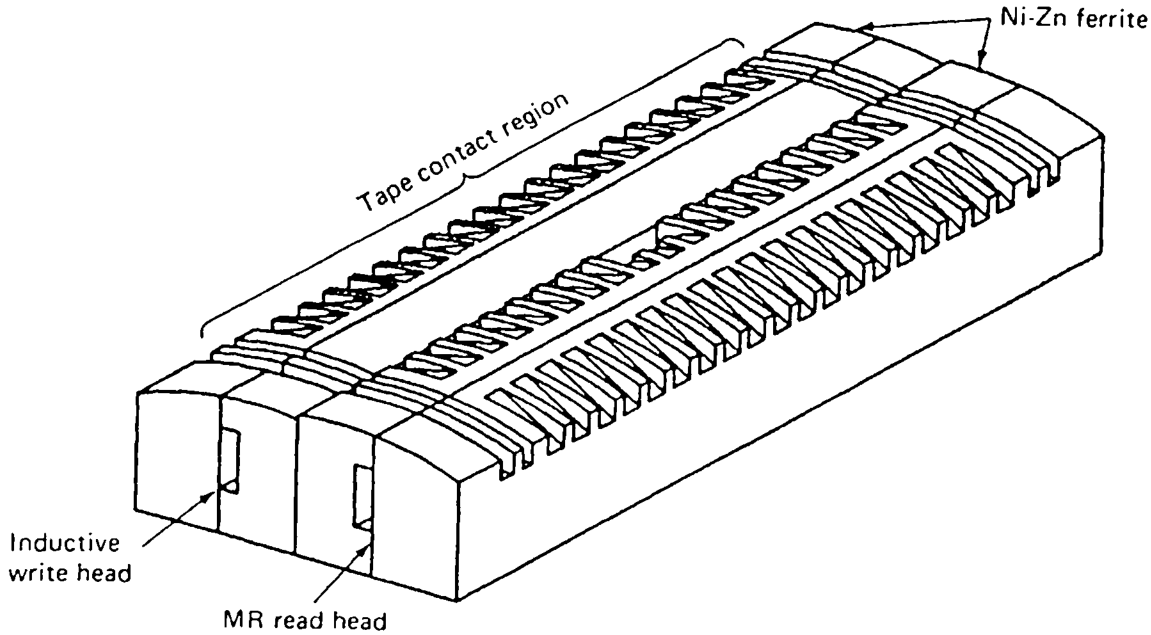


Fig. 1.15. Schematic of a magnetic-recording head for an IBM 3480 tape drive.

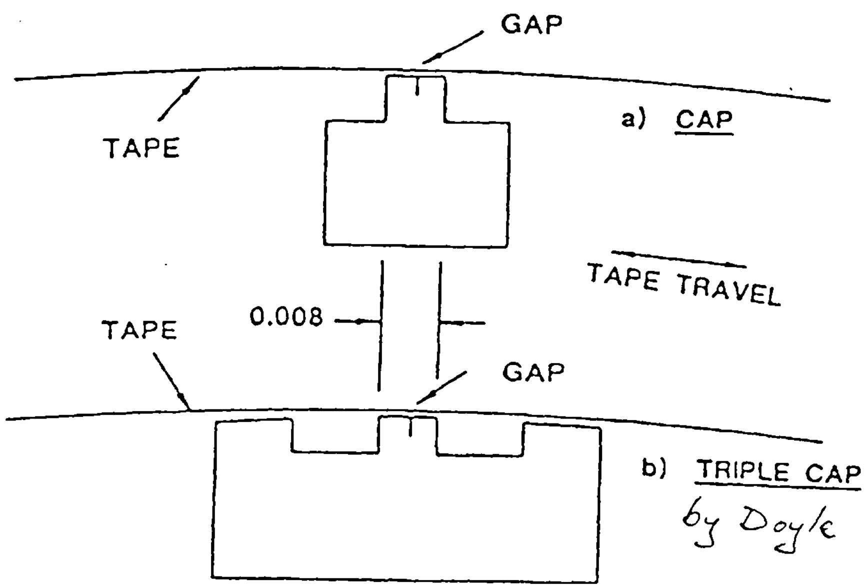


Figure 7. Two experimental head contours: a) the CAP; b) the Triple CAP. The dimensions are in inches.

A HIGH CAPACITY, HIGH PERFORMANCE, SMALL FORM FACTOR MAGNETIC TAPE STORAGE SYSTEM

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Figure 4.

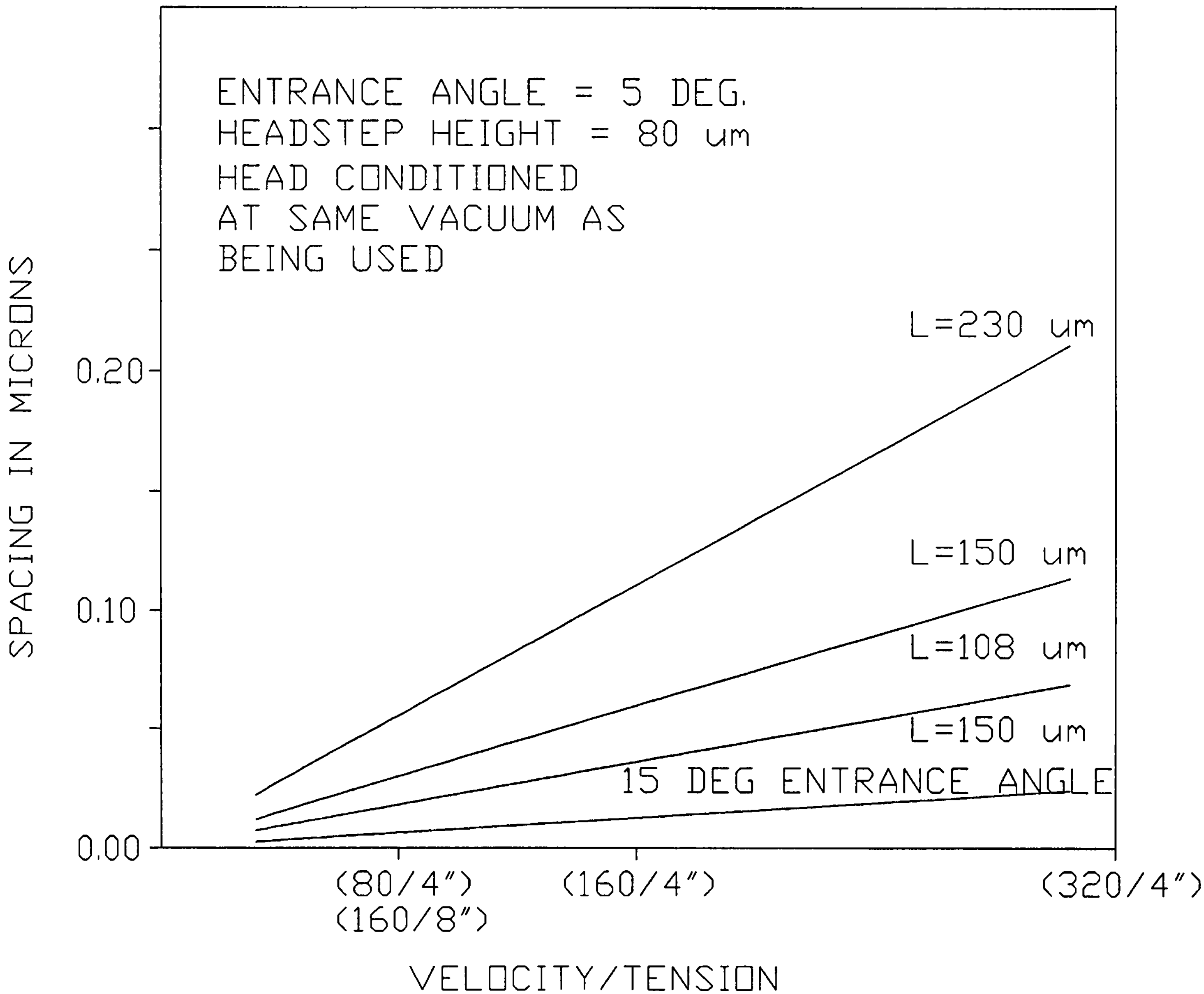

FIGURE 5 PLOT OF THEORETICAL MODEL FOR FLYING

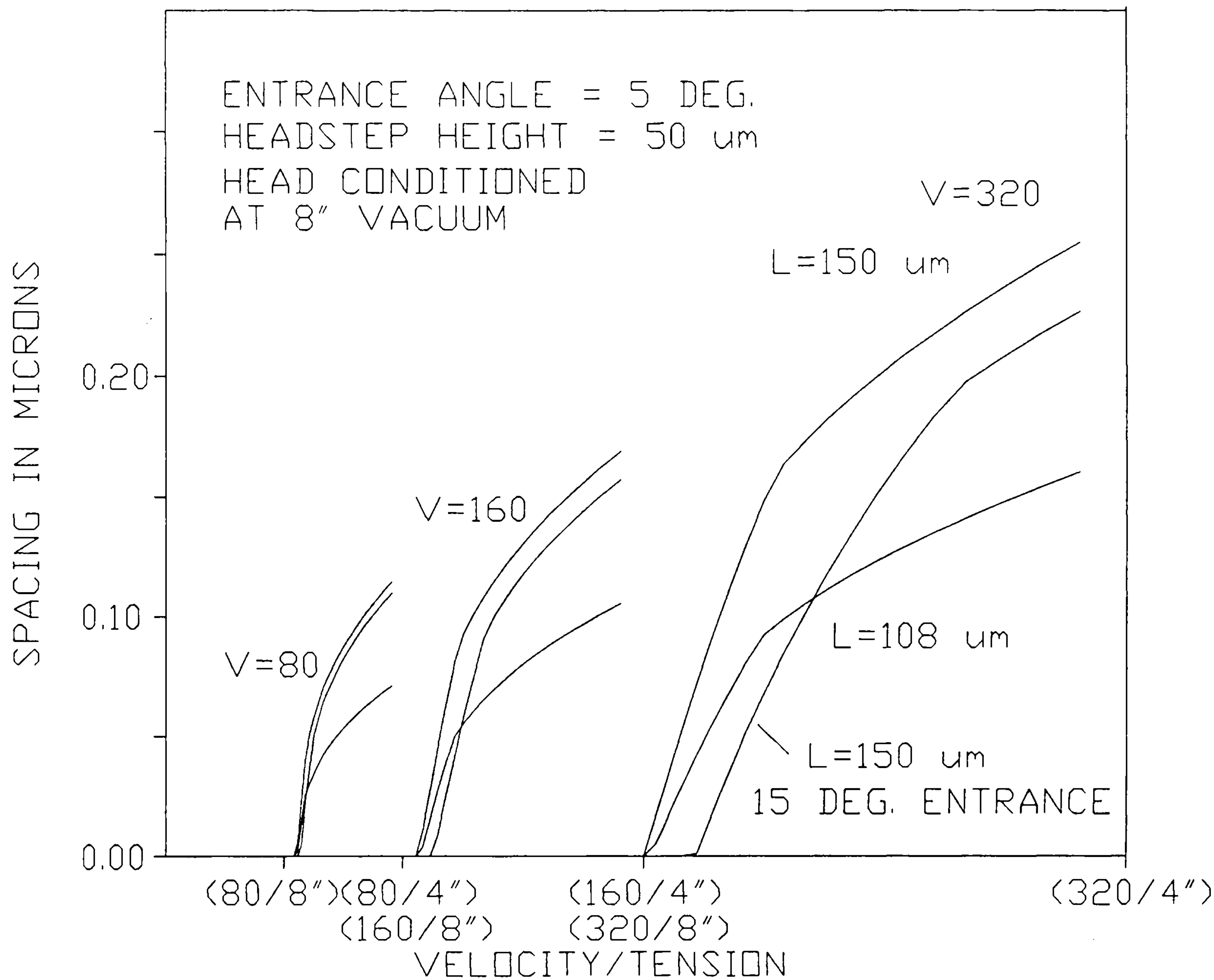

FIGURE 6 FLYING MODEL WITH HEAD CONDITIONED AT FIXED VACUUM