THE AERODYNAMIC STABILIZATION OF VIDEO DISCS

Mahfuz Ahmed, Richard Brown and Adrianus Korpel
Zenith Radio Corporation
Chicago, Illinois 60639

SUMMARY

This paper describes the general principles behind the aerodynamic stabilization of flexible video discs as demonstrated by the Thomson-CSF stabilizer, and a modified version investigated by Zenith. It is shown that aerodynamic stabilization is a very nonlinear process and is governed by the stiffness of the air film between the disc and the stabilizer. For the stabilizers under discussion this stiffness is inversely proportional to the cube of the gap between the disc and stabilizer, which necessitates the use of a small gap. Depending on disc thickness and hence on disc stiffness, this gap may be 2-8 mils in excess of the disc thickness. In the modified version the lower CSF stabilizer is replaced by a flight deck. It is shown that the flight deck acts as a prestabilizer which produces a two-to-three fold improvement in stability for the same air gap. Experimental data and computer calculations are organized in a form which provides definite design criteria for the selection of an optimum system.

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The general principles involved in the playback of an optical video disc are well known and were discussed in some detail at the last Chicago Spring Conference of BTR. An important requirement of an optical playback scheme is the maintenance of a constant spacing between the reading lens and the disc for the entire duration of playback. This would not be a difficult problem if the disc were of uniform thickness and free from wrinkles, completely balanced, free of all internal stresses and of such a mass density that when rotated at 1800 rpm the centrifugal force exactly balances the gravitational pull. Such ideal conditions do not, however, exist in practice and current state-of-the-art replicated discs typically deviate from flatness by 1-2 mm (peak-to-peak value), possess an overall thickness variation of about 5%, and are neither balanced nor free from internal stresses. When rotated at 1800 rpm on a spindle they vibrate up and down by as much as 1 mm which is well beyond the depth of focus (~ 7 μm) of the reading lens. It therefore becomes necessary to use some device or technique for maintaining adequate focus during playback. Two methods are presently being investigated at various laboratories around the world. The first uses a servo to provide the required constant spacing between the lens and the disc, while the second employs a passive aerodynamic stabilizer used with a flexible disc. The passive aerodynamic system has the advantages of simplicity, reliability and lower cost resulting from the elimination of a disc surface position sensor, signal processing electronics and servo motor. On the other hand, it lacks the capability of playing discs of all thicknesses, and it is not fully automatic in the sense that it may require the viewer to manually focus once for every disc to be played.

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Maintaining a fixed distance between a rigid surface and a light object by means of an aerodynamic film is not a new idea. This concept has been used extensively in the computer industry where a slider bearing is used to keep a magnetic head a fixed distance from a rigid magnetic disc.[1] Systems have also been described in which the magnetic head is held rigid and a flexible disc is maintained at a fixed distance by aerodynamic forces.[2] The video disc aerodynamic stabilizer is very similar to the latter approach. Here, also, the lens is held stationary and aerodynamic forces act on a flexible disc. There is, however, an important difference. As shown in subsequent sections it is relatively easy to produce large aerodynamic forces by maintaining a small gap between the reader (signal sensor) and the disc. These forces decrease rapidly (they are inversely proportional to the square of the gap) as the gap is increased. To prolong life the disc must be made very flat, handled with care and mil-size dust particles which might scratch the disc must be filtered out from the circulating air. This is a matter of cost, not technology, and poses no problem for the computer industry which is not geared to the consumer market. The video disc system, however, has to be cost competitive. The creation of adequate aerodynamic forces with a large gap to protect a normally wavy disc from a normally dirty environment is the challenge. The designs described here satisfy this requirement to a large extent though not completely.

The passive stabilizers, which are most effective operate, in general, by creating a positive pressure on both sides of the disc. In the equilibrium condition the air film acts as a stiff spring and straightens out any deformation existing in the region of the disc to be read. The deformation may be due to internal stresses within the disc produced by inhomogeniety of the disc material and nonuniformity of the replication process. The radial component of this deformation is modified by aerodynamic and centrifugal forces acting on the spinning disc. This is clarified by Fig. 1, which shows a disc rotating at angular frequency ω in a fluid at rest. Due to friction, the disc imparts centrifugal force to the fluid in its immediate neighborhood thus causing the fluid to be cast off at the rim of the disc and drawn in around the hub region. A radial pressure gradient is thus generated along the disc. When a flexible disc is rotated over a surface, the conditions above and below the disc differ, and thus create a radial deformation normal to the surface along the radius of the disc, the extent of deformation being a function of the type of surface used, the disc stiffness and the hub height. A 4-12 mil thick PVC disc, flat to within 1 mm gliding over a 50 inch radius cylindrical surface deforms along the crest as shown

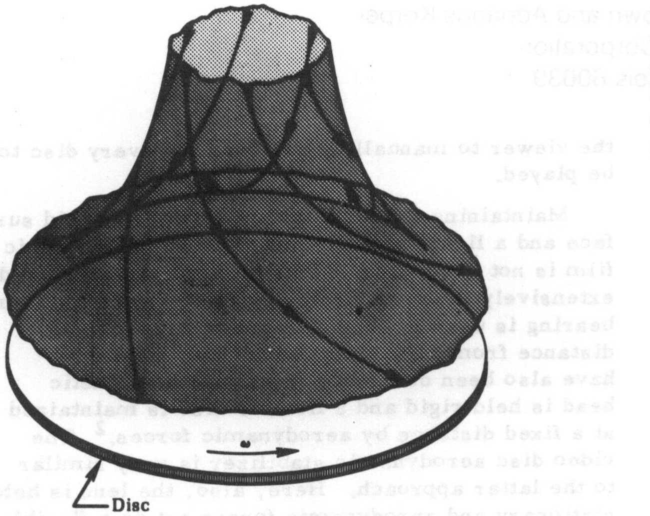

Fig. 1. Air flow pattern shown by arrows above the spinning disc.

in Fig. 2a. This shape can be modified by changes in the stiffness of the disc material, type and degree of disc flatness and hub height. The net radial deformation of a 10 mil thick 12 inch diameter PVC disc, rotating at 1800 rpm over a cylindrical surface is on the order of 100 μm over the outer 3 inches.

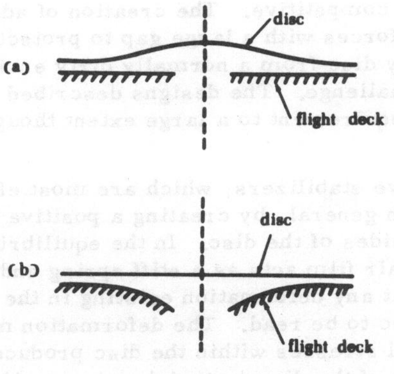

Fig. 2. (a) Shape, in the radial direction, of a flat disc spinning on a flat or cylindrical flight deck. (b) Shape of flight deck required to make spinning disc flat.

It is clear that stabilization can be considered to be effective only if the residual deformation of the stabilized section is less than the depth of focus of the reading lens -- about 7 μm. Several passive systems have been designed and tested in our laboratory. We shall, however, limit our discussion here to two which illustrate the general principles behind aerodynamic stabilization. The first is the Thomson-CSF stabilizer, shown in Fig. 3a which consists of two closely spaced and opposing aerodynamic surfaces operating on the disc in a manner analogous to the classic journal bearing. The second, designed at Zenith and shown in Fig. 3b, is a modification of the Thomson-CSF system and uses a large cylindrical surface over which the disc glides in place of the CSF lower stabilizer. This surface is slotted to accommodate hub travel, and depressed to maintain uniform disc position radially as shown in Fig. 2b. The degree of surface depression is on the same order as the deformation discussed above.

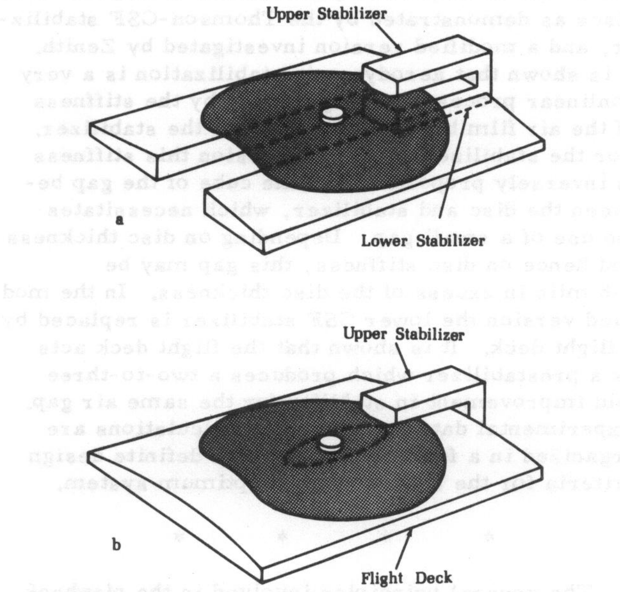

Fig. 3. (a) Thomson-CSF stabilizer with dihedral planes. (b) Zenith's cylindrical flight deck with CSF upper stabilizer.

DISC STABILITY

Typical measured values of disc stability (or residual deformation) obtained with the above-mentioned stabilizers are shown in Figs. 4 to 7. Two components of stability have to be considered. These we name the a. c. and the d. c. components. The a. c. component is the peak-to-peak temporal variation of the disc position at a given radius during one revolution (1/30 sec). This parameter includes the effect of thickness variation of the disc. The d. c. component is the relative change in the average position of the disc with radius, and this is greatly influenced by the flatness and stiffness of the disc. In these diagrams h_o is the gap height in excess of disc thickness at the point of closest approach between the stabilizers. A binary system is used to identify each disc. The first number refers to disc thickness in mils while the second number identifies the disc. Thus 10-3 is disc number 3 of a set of 10 mil discs. The following should be noted from Figs. 4-7.

1. The stability varies over a wide range.
2. Replacing the lower CSF stabilizer by a continuous surface improves the stability by approximately a factor 2.
3. The a. c. and d. c. stability in both systems is considerably degraded at the outer 1/2 inch of the

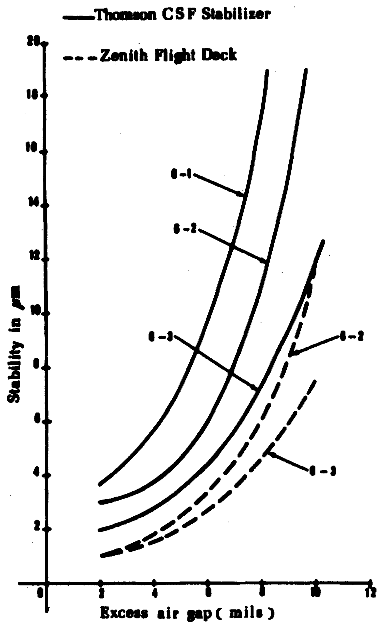

Fig. 4. A. c. stability (peak-to-peak value) of 6 mil, 10-5/8 inch diameter discs at a radius of 3. 5 inches. The dihedral angle of the Thomson-CSF system was 10°, and the radius of curvature of the Zenith flight deck was ≈ 10 inches.

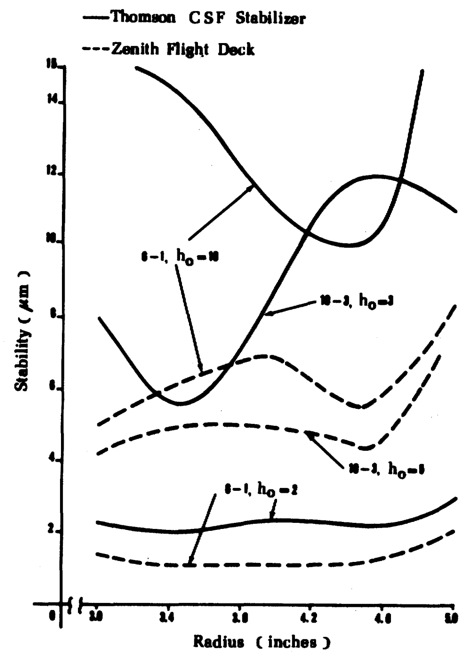

Fig. 6. Variation of a. c. stability with radius under conditions mentioned in Figs. 4 and 5.

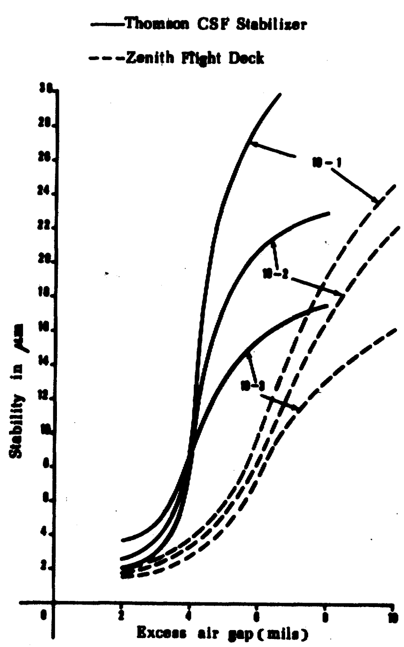

Fig. 5. A. c. stability of 10 mil, 10-5/8 inch diameter discs at a radius of 3. 5 inches. The dihedral angle of the Thomson-CSF system was 10°, and the radius of curvature of the Zenith flight deck was ≈ 25 inches.

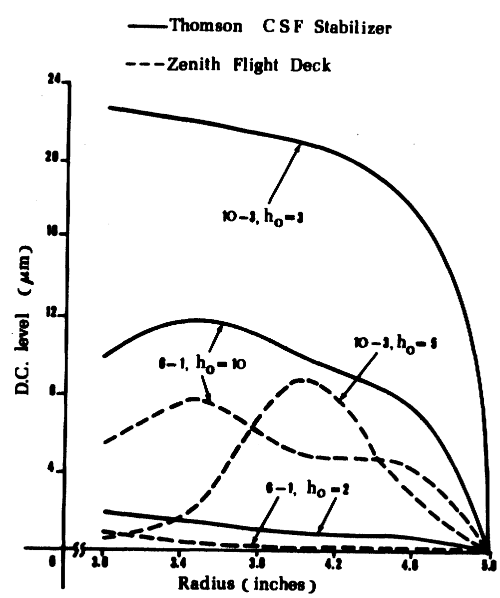

Fig. 7. Variation of d. c. level with radius under conditions mentioned in Figs. 4 and 5.

disc. Although not shown here, this is true for all discs irrespective of radius and is most likely the result of turbulence at the edge of the disc.

4. The stability deteriorates as the gap is increased, more so for thicker and hence stiffer discs than for thinner ones. This is due to a decrease in positive pressure acting on the disc with an increase in gap.

PRINCIPLES OF AERODYNAMIC STABILIZATION

As stated earlier, the stabilizer operates by creating aerodynamic forces which act on the disc. The Navier-Stokes[3] equations form the basis of the whole science of fluid mechanics. By neglecting inertial and body force terms in these equations one derives Reynolds' equation of lubrication[4] which describes the aerodynamic stabilization of a completely flexible disc. This equation is quite difficult to solve without the help of a computer. Numerical solutions were therefore obtained by using the procedure outlined by Michael.[5] Although Reynolds' equation neglects the stiffness of the disc, the computer generated values for pressure are in good agreement with experimental data obtained with 6 mil, 10-5/8 inch diameter discs. This would indicate that the stiffness of the 6 mil discs does not play a major role in the stabilization process.

Here, we shall derive Reynolds' equation very simply by using the conservation of mass law and the expression for velocity associated with viscous flow between parallel plates. Consider the CSF system shown schematically in Fig. 8. Let ΔV be an element

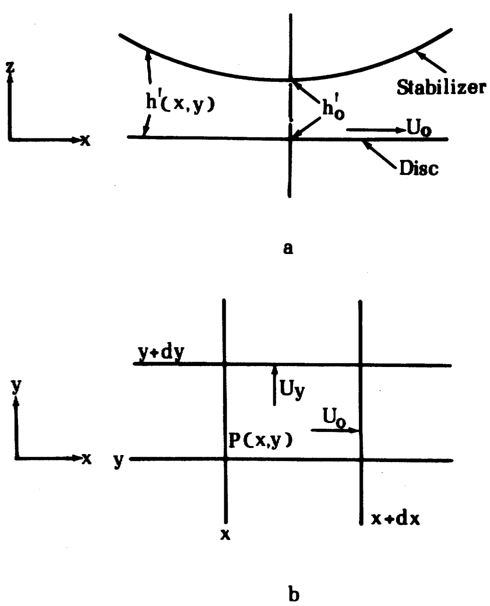

Fig. 8. (a) Schematic of stabilizer and disc.
(b) Elemental region under the stabilizer used to calculate pressure distribution.

of volume between the disc and the upper stabilizer bounded by the lines x, x + dx, y and y + dy and having a variable height $h'(x,y)$. Also, let U_o be the linear velocity of the disc in this region and let U_y represent the velocity of air leaking out (or being sucked in) from the sides due to the pressure $p(x,y)$ above (or below) atmospheric under the stabilizer. As a first approximation we shall neglect the effect of centrifugal forces created by the spinning disc on the air under the stabilizer and use the expression for U_y as that obtained for viscous flow between parallel plates;[6] we thus obtain

$$U_y = -\frac{1}{12}\,\frac{\Delta p\,(x,y)\,h^2\,(x,y)}{\mu\,\Delta y} = -\frac{h^2}{12\mu}\,\frac{\partial p}{\partial y} \tag{1}$$

In the above equation, μ is the viscosity of the fluid and the - sign takes into account the fact that pressure decreases as y increases. A similar equation may be written for a component U_x pertaining to the x- direction. If ρ is the mass density, $\frac{U_o}{2}$ the average velocity of the air driven by the disc through the stabilizer, then conservation of mass flow through the elemental volume ΔV dictates that

$$\frac{\partial}{\partial x}\left[\rho\,(x,y)\,U_x\,h(x,y)\,dy\right]dx\ +$$
$$\frac{\partial}{\partial y}\left[\rho\,(x,y)\,U_y\,h(x,y)\,dx\right]dy\ +$$
$$\frac{\partial}{\partial x}\left[\rho\,(x,y)\,h\,(x,y)\,\frac{U_o}{2}\right]dx = 0 \tag{2}$$

If we assume the flow to be incompressible, (2) takes the form

$$\frac{\partial}{\partial x}\left(h^3\frac{\partial p}{\partial x}\right) + \frac{\partial}{\partial y}\left(h^3\frac{\partial p}{\partial y}\right) = 6\mu\,\frac{\partial}{\partial x}\left(h\,U_o\right) \tag{3}$$

This is the Reynolds' equation of lubrication.

The Thomson-CSF stabilizer consists of a flat upper surface and a lower surface having a radius of curvature of approximately 20 cm. We shall assume the disc to fly in a manner so as to have approximately the same curvature relative to either surface viz. a radius of curvature $\sim$ 40 cm. We shall refer to this radius of curvature as R and use h'_o for the smallest gap between disc and stabilizer. Furthermore, we shall denote the length (x-direction) and width (y-direction) of the upper stabilizer by ℓ and a respectively. The computer program uses the boundary conditions $p = 0$ at $(x,y) = (\pm\frac{1}{2}a, \pm\frac{1}{2}\ell)$.

Taking R = 40 cm, h'_o = 0.0025 cm, $U_o = 1.9\times10^3$ cm/sec (at 4 inch radius with disc speed = 1800 rpm), a = 3.8cm and ℓ = 2.5 cm, we obtain a computer solution for the pressure distribution along the line y = 0 as shown in Fig. 9. It should be noted that the pressure distribution has a maximum within the leading half of the stabilizer, is zero at the center and has a minimum within the trailing half. The experimental values obtained with a 6 mil, 10-5/8 inch diameter disc are shown by triangles and are found to agree well with the

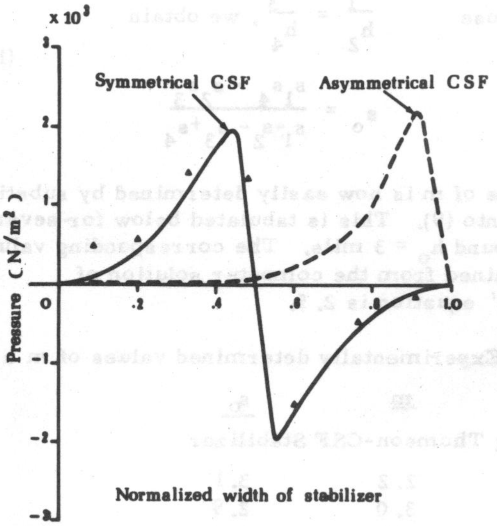

Fig. 9. Pressure distribution in the tangential (x-) direction along the center line (y = 0) of the upper stabilizer, with h_o = 2 mil and R = 16 inches, obtained through a computer solution of the Reynolds' equation. Experimental data obtained with a 6 mil, 10-5/8 inch diameter disc is shown by triangles. In both cases the center of the upper stabilizer was 4 inches from the hub.

computer predictions. The pressure distribution can be changed by tilting the stabilizer, thereby making the system asymmetrical. The distribution calculated by the computer for a stabilizer so tilted that the point of closest approach is pushed to the extreme trailing edge, is shown by the dotted lines.

The two-dimensional pressure distribution under a symmetrical CSF stabilizer with h'_o = 0.0025 cm, R = 40 cm, and the values of U_o, a and ℓ taken previously is shown in Fig. 10. The height of the curve represents the pressure, the magnitude of the maximum and minimum pressures being 2×10^3 N/m^2 (0.29 psi).

SPRING CONSTANT OF THE AIR FILM

The total force F on the disc is obtained by integrating the pressure p(x, y) over the entire surface of the stabilizer. Thus

$$F = \iint p(x,y)\, dx\, dy$$

It is clear from Fig. 9 that the net force is zero in a symmetrical Thomson-CSF system. Considering, therefore, an asymmetrical system(the leading half of the Thomson-CSF structure, but stretched to full length of the original), we find that the computer predicts a dependence of force on h'_o as shown in Fig. 11. If we assume that

$$F \propto \frac{1}{{h'_o}^{n}} \qquad (4)$$

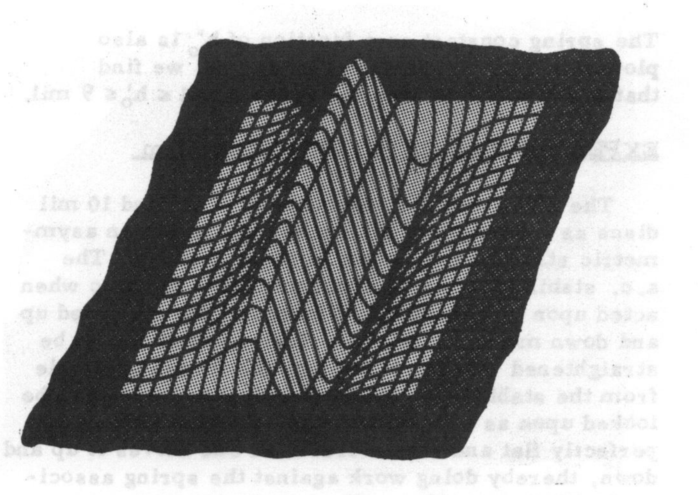

Fig. 10. Pressure distribution under the Thomson-CSF stabilizer. The height of the curve represents the pressure, the maximum and minimum values being 2×10^3 N/m^2 (0.29 psi).

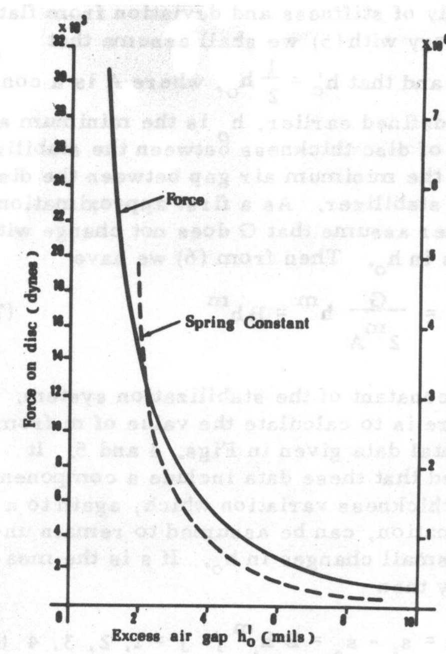

Fig. 11. Force on disc and spring constant of an asymmetrical Thomson-CSF stabilizer as a function of minimum air gap.

we find from Fig. 11 that n varies from 1.2 in the region of h'_o = 1 mil to n = 2.0 in the region of h'_o = 10 mil.

The stabilizer acts on both sides of the disc. The spring constant of the air film is, therefore, given by

$$K = \frac{2\, dF}{dh'_o} \propto \frac{-2\, n}{(h'_o)^{n+1}} \qquad (5)$$

The spring constant as a function of h_o' is also plotted in Fig. 11. If we let $(n+1) = m$, we find that $2.3 \leq m \leq 3.0$ over the range 2 mil $\leq h_o' \leq$ 9 mil.

EXPERIMENTAL DETERMINATION OF m

The measured a.c. stability of 6 mil and 10 mil discs as a function of the excess air gap in an asymmetric stabilizer is shown in Figs. 4 and 5. The a.c. stability is the residual motion of the disc when acted upon by aerodynamic forces. The observed up and down motion is due to wrinkles which cannot be straightened out any further by the forces available from the stabilizer. These residual wrinkles can be looked upon as a fictitious force G which acts on a perfectly flat and strain-free disc and moves it up and down, thereby doing work against the spring associated with the air film. The residual motion x is, therefore, given by

$$x = \frac{G}{K} \tag{6}$$

where K is the spring constant of the air film. It should be noted that G is a function of the disc parameters, mainly of stiffness and deviation from flatness. In analogy with (5) we shall assume that $K = A(h_o')^{-m}$, and that $h_o' = \frac{1}{2} h_o$, where A is a constant, and as defined earlier, h_o is the minimum air gap in excess of disc thickness between the stabilizers and h_o' is the minimum air gap between the disc and the upper stabilizer. As a first approximation we shall further assume that G does not change with small changes in h_o. Then from (6) we have

$$x = \frac{G}{2^m A} h^m = B h^m \tag{7}$$

where B is a constant of the stabilization system. Our object here is to calculate the value of m from the experimental data given in Figs. 4 and 5. It should be noted that these data include a component s_o related to thickness variation which, again to a first approximation, can be assumed to remain unchanged with small changes in h_o. If s is the measured stability then

$$x = s_j - s_o = B h_j^m; \quad j = 1, 2, 3, 4 \tag{8}$$

where s_j are the values of stability at the 4 points denoted by j = 1, 2, 3 and 4, and h_j are the gaps corresponding to them. Combining the first and last two equations in (8) we find that

$$\log \frac{s_1 - s_o}{s_2 - s_o} = m \log \frac{h_1}{h_2}$$

$$\text{and} \quad \log \frac{s_3 - s_o}{s_4 - s_o} = m \log \frac{h_3}{h_4} \tag{9}$$

If we choose $\frac{h_1}{h_2} = \frac{h_3}{h_4}$, we obtain

$$s_o = \frac{s_1 s_4 - s_2 s_3}{s_1 - s_2 - s_3 + s_4} \tag{10}$$

The value of m is now easily determined by substituting (10) into (9). This is tabulated below for several discs around h_o = 3 mils. The corresponding value of m obtained from the computer solution of Reynolds' equation is 2.5.

Table 1 Experimentally determined values of m & s_o

Disc	m	s_o
A) Using Thomson-CSF Stabilizer		
6-1	2.2	3.1
6-2	3.0	2.9
6-3	3.1	2.0
10-1	6.8	2.5
10-2	6.3	2.0
10-3	4.6	3.5
B) Using Zenith's Flight Deck		
6-2	3.1	1.0
6-3	3.4	1.0
10-1	3.1	1.8
10-2	3.3	1.5
10-3	4.1	1.5

Table 1 shows that the same disc has different values for s_o when stabilized by the CSF and Zenith systems. Since s_o was assumed to be associated with thickness variation, which is fixed at a given radius, one may wonder how it can change from one system to another. The explanation is that although thickness variation remains unchanged, the amount associated with the experimentally observed flutter can vary depending on the air gap above and below the disc and the radii of curvature of the disc relative to the stabilizing surfaces. This can be seen clearly if we consider a disc whose thickness has changed by an amount $(t_1 + t_2)$, and which is in equilibrium between the stabilizers. We assume that before the thickness change occurred the minimum gap above the disc was h_{10} and the gap below it was h_{20}. Let t_1 be the amount of thickness variation by which h_{10} is reduced. t_1 is, therefore, the observed change in thickness if the flutter of the upper surface is monitored. t_2 is the corresponding change in the gap h_{20} and is the amount by which the bottom surface would have been observed to move if it had been monitored. Using the expression for K given by (5),[7] it is clear that under equilibrium conditions the additional force F_a above the disc and F_b below it, resulting from thickness change, are given by

$$F_a = \frac{A(\mu, U_o, a, \ell)}{\left(h_{10}\right)^{n+1}} t_1 = F_b = \frac{A(\mu, U_o, a, \ell)}{\left(h_{20}\right)^{n+1}} t_2$$

or
$$t_1 = \left(\frac{h_{10}}{h_{20}}\right)^{n+1} t_2$$

where (n+1) can be as large as 3. If $h_{10} = h_{20}$, as assumed previously, then $t_1 = t_2$ and half the thickness variation is observed as flutter. On the other hand, if $h_{10} = 0.5\, h_{20}$ then using n+1 = 3, the observed thickness variation is only 13% of the actual thickness variation. The effect of thickness variation can therefore be minimized by making h_{10}/h_{20} very small.

OPERATION OF THE THOMSON-CSF STABILIZER

The operation of the asymmetrical CSF stabilizer is well understood. The pressure distribution under the stabilizer is shown in Fig. 9. Here, an upward motion of the disc is countered by a downward force and vice versa, which tends to maintain the disc a fixed distance from the lens.

It is, however, not quite clear how stabilization is achieved with the symmetrical Thomson-CSF Stabilizer. Figures 12 and 13 may provide some insight into its operation. Under equilibrium conditions the pressure above the disc must equal the

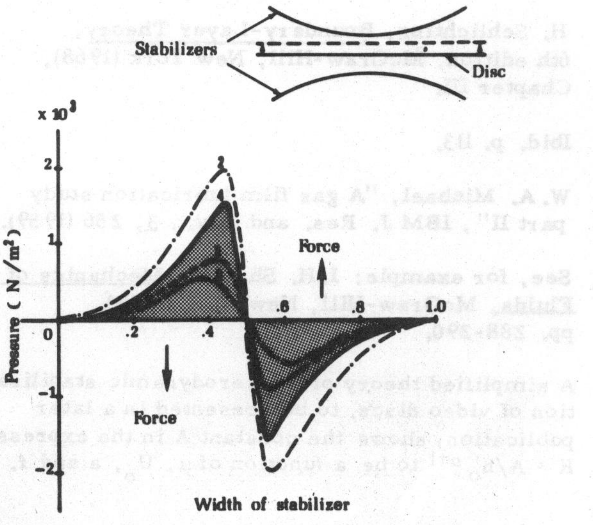

Fig. 12. Forces acting on the disc when it moves up. Curve 1 is the pressure distribution above and below the disc when it is in the middle of the stabilizer with h_o = 3 mil and R = 16 inches. Curves 2 and 3 are the pressure distributions above and below the disc when it is moved up by 1/2 mil. Curve 4 is the difference between 2 and 3, and the shaded areas represent the forces acting on the disc. The width of the stabilizer has been normalized.

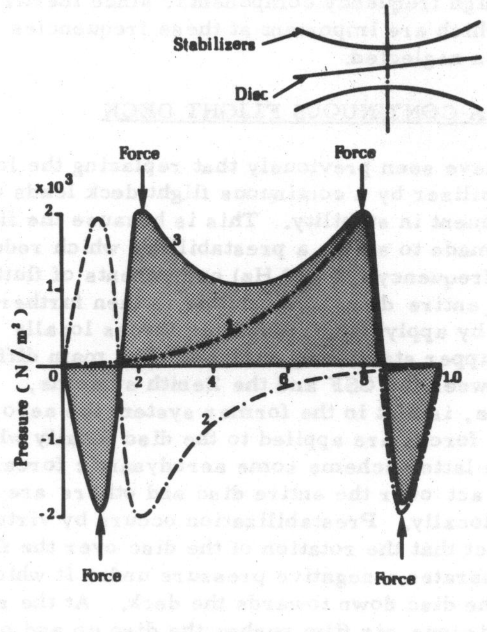

Fig. 13. Forces acting on the disc when it tilts but passes through the center of the gap. 1 and 2 are the pressure distributions above and below the disc, and 3 is the difference of 1 and 2. The shaded areas represent the forces acting on the disc.

pressure below it at every point within the stabilizer. If an upward force now pushes on the disc and we assume for the moment that it does not affect the disc curvature, then, as shown in Fig. 12, the disc experiences a moment which tends to rotate it in the counter-clockwise direction. The rotation, however, displaces the positions of zero and maximum pressure which results in a pressure distribution as shown in Fig. 13. It is clear that the disc no longer experiences a moment but a net downward force which opposes the original upward force. Thus the net effect of an upward force on the disc is a counter-clockwise pitch, the amount of which depends on the magnitude of the force. Similarly, a downward force results in a clockwise pitch. If the tilting occurs about a point which is exactly below the reading lens, then the distance between the lens and the point read on the disc always remains constant and perfect stability is achieved. On the other hand, tilting about some other point can produce large motions of the disc at the reading point. This explains why, in our experiments, the stability has been found to improve when the upper stabilizer is tilted so as to make the system asymmetrical to prevent pitching of the disc. The experimental plots shown in Figs. 4-7 were obtained with such an asymmetrical system. The amount of tilt needed to make the system asymmetrical is in the order of a few milliradians.

The operation of the CSF stabilizer has been studied, here, by freezing time and treating the forces acting on the disc as a problem in statics. Although this is valid for the low frequency components of vertical motion, it may not be so for the high frequency components, since inertial forces which are important at these frequencies have been neglected.

USE OF A CONTINUOUS FLIGHT DECK

We have seen previously that replacing the lower CSF stabilizer by a continuous flight deck leads to improvement in stability. This is because the flight deck is made to act as a prestabilizer which reduces the low frequency (30-120 Hz) components of flutter over the entire disc. The flutter is then further reduced by applying aerodynamic forces locally with an upper stabilizing surface. The main difference between the CSF and the Zenith systems, therefore, is that in the former system the aerodynamic forces are applied to the disc locally whereas in the latter scheme some aerodynamic forces initially act over the entire disc and others are then applied locally. Prestabilization occurs by virtue of the fact that the rotation of the disc over the flight deck generates a negative pressure under it which forces the disc down towards the deck. At the same time a viscous air film pushes the disc up and prevents it from touching the surface. The air film under the disc thus acts as a spring which, however, is not sufficient by itself to produce the required stability. A detailed analysis of the spring constant is in progress.

It is observed from Table 1 that $m \sim 3$ for all cases except when a 10 mil disc is stabilized by a CSF system. Since stabilization is basically a straightening out of wrinkles, this would indicate that the stiffness of low frequency wrinkles existing in (PVC) discs, thicker than 6 mils, introduces forces into the stabilization mechanism that are comparable to the localized aerodynamic forces of a CSF stabilizer. In terms of the quantities in (7), this means that for the 10 mil discs in a CSF system, G changes with small changes in h_o. The additional force generated by a flight deck counteracts the disc stiffness and reduces the low frequency components, thereby diminishing their effect under the local stabilizer.

DESIGN OF STABILIZER

The optimum design obviously depends upon the thickness or range of thicknesses of discs to be played, and on disc stiffness which is a function of disc material. In any case prestabilization by means of a flight deck and a tilted upper stabilizer which makes the system asymmetrical is always desirable. As shown in Figs. 4 to 7 the following designs have been found to give good results with PVC discs.

6 mil thick discs, 8-12 inches in diameter

Flight deck with radius of curvature $\sim$10 inches used in conjunction with an upper stabilizing surface. Adequate stabilization is obtained with total gap as large as 12-14 mils.

10 mil thick discs, 8-12 inches in diameter

Flight deck with radius of curvature $\sim$ 50 inches also used in conjunction with an upper stabilizer. This has recently been found to be superior to the 25 inch deck used to generate the data of Figs. 5-7. To obtain adequate stabilization the total gap should be no more than 15 mils.

ACKNOWLEDGMENT

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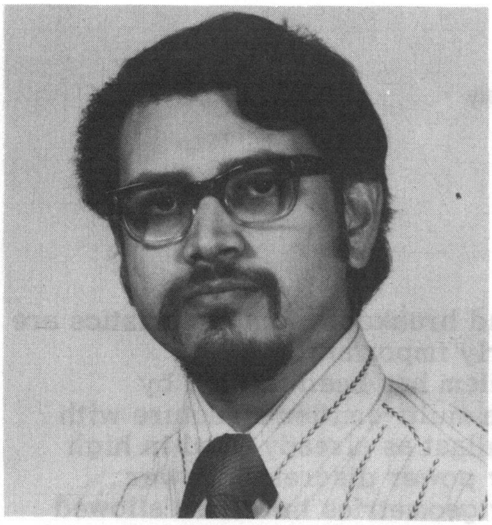
7. A simplified theory of the aerodynamic stabilization of video discs, to be presented in a later publication, shows the constant A in the expression $K = A/h_o'^{\,n+1}$ to be a function of μ, U_o, a and ℓ.

BIOGRAPHIES



Mahfuz Ahmed was born in Delhi, India, on July 8, 1941. He received the B. E. degree from the American University of Beirut, Beirut, Lebanon, the M. S. degree from Yale University, New Haven, Conn., and the Ph. D. degree from the University of California, Santa Barbara, Calif., all in Electrical Engineering, in 1964, 1967 and 1971, respectively. He was the recipient of a U. S. A. I. D. scholarship during 1960-1964, and a Yale University Fellowship during 1965-1967.

From 1964-1965 he was a lecturer at the N. E. D. Engineering College, Karachi, Pakistan. From 1967-1971 he was a teaching assistant in the Department of Electrical Engineering at the University of California, Santa Barbara, working in the field of e. m. theory, microwaves, physics and technology of solid state devices, holography and acoustic imaging. Since April 1971 he has been with the research department of Zenith Radio Corporation. His current research interests are: acoustic imaging, acousto-optic systems and devices, acoustical and optical holography, optical signal processing, video recording and playback systems and aerodynamics.

Dr. Ahmed is a member of Sigma Xi, Eta Kappa Nu and IEEE.

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Richard I. Brown was born in Utica, New York on October 4, 1945. He received his B. S. degree in Mechanical Engineering from Lowell Technological Institute in 1967 and his M. S. degree in Mechanical Engineering from Northwestern University in 1968. From 1968 to 1973 he was employed by Sandia Laboratories of Livermore, California where he worked in Thermal and Holographic NDT. He joined Zenith Radio Corporation in 1973 where he has worked in the area of the Aerodynamic Stabilization of Video Discs.

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Adrianus Korpel was born in Rotterdam, Holland on February 19, 1932. He received his M. S. degree in Electrical Engineering from the University of Delft, Holland in 1955, and his Ph. D. degree from the same university in 1969. The subject of his thesis was acoustic visualization by Bragg diffraction of light.

From 1956-1960 he was employed by the Research Laboratories of the Postmaster General's Department in Melbourne, Australia. His main activities were in the field of information and communication theory as applied to television and later in the field of parametric amplifiers.

He joined Zenith Radio Corporation, Chicago, in 1960 and since 1963 is Head of the Light-Modulation Group. The main activities of this group concerned image type applications of Lasers such as television display, sound visualization and acoustic holography. At present Dr. Korpel is in charge of the video disc research effort at Zenith.

Dr. Korpel is a member of the Royal Dutch Institute of Engineers, the Institution of Engineers of Australia, the Physical Society of America and the Institute of Electrical and Electronics Engineers.