2900-250-T

Report of Project MICHIGAN

DYNAMIC BALANCING OF SCANNER DRUM AND GYROSCOPIC EFFECT DURING MANEUVERS OF AIRCRAFT

W. L. BROWN
C. T. YANG

February 1961

Infrared Laboratory
Institute of Science and Technology
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan

NOTICES

Sponsorship. The work reported herein was conducted by the Institute of Science and Technology for the U. S. Army Signal Corps under Project MICHIGAN, Contract DA-36-039 SC-78801. Contracts and grants to The University of Michigan for the support of sponsored research by the Institute of Science and Technology are administered through the Office of the Vice-President for Research.

Distribution. Initial distribution is indicated at the end of this document. Distribution control of Project MICHIGAN documents has been delegated by the U. S. Army Signal Corps to the office named below. Please address correspondence concerning distribution of reports to:

U. S. Army Liaison Group
Project MICHIGAN
The University of Michigan
P. O. Box 618
Ann Arbor, Michigan

ASTIA Availability. Qualified requesters may obtain copies of this document from:

Armed Services Technical Information Agency
Arlington Hall Station
Arlington 12, Virginia

Final Disposition. After this document has served its purpose, it may be destroyed. Please do not return it to the Institute of Science and Technology.

PREFACE

Project MICHIGAN is a continuing research and development program for advancing the Army's long-range combat-surveillance and target-acquisition capabilities. The program is carried out by a full-time Institute of Science and Technology staff of specialists in the fields of physics, engineering, mathematics, and psychology, by members of the teaching faculty, by graduate students, and by other research groups and laboratories of The University of Michigan.

The emphasis of the Project is upon basic and applied research in radar, infrared, information processing and display, navigation and guidance for aerial platforms, and systems concepts. Particular attention is given to all-weather, long-range, high-resolution sensory and location techniques, and to evaluations of systems and equipments both through simulation and by means of laboratory and field tests.

Project MICHIGAN was established at The University of Michigan in 1953. It is sponsored by the U. S. Army Combat Surveillance Agency of the U. S. Army Signal Corps. The Project constitutes a major portion of the diversified program of research conducted by the Institute of Science and Technology in order to make available to government and industry the resources of The University of Michigan and to broaden the educational opportunities for students in the scientific and engineering disciplines.

Progress and results described in reports are continually reassessed by Project MICHIGAN. Comments and suggestions from readers are invited.

Robert L. Hess
Technical Director
Project MICHIGAN

CONTENTS

FIGURES

DYNAMIC BALANCING OF SCANNER DRUM AND GYROSCOPIC EFFECT DURING MANEUVERS OF AIRCRAFT

ABSTRACT

This report presents the equations for determining the dynamic balancing and gyroscopic effect of a rotating scanner drum assembly of the type used in the Project MICHIGAN wide-angle scanner. The parameters used in the numerical example are those of the wide-angle scanner, and the theoretical calculations of the dynamic balancing agree excellently with the actual mechanical dynamic balancing of the drum assembly. The calculations also indicate that gyroscopic forces in the drum are negligible even during maximum rate of turn and maximum rate of climb of the aircraft carrying the scanner.

1 INTRODUCTION

This report presents the equations for calculating, from a purely analytical viewpoint, the physical changes needed to balance a rotating mechanism. The Project MICHIGAN wide-angle scanner drum assembly was used in the numerical examples. The results obtained from a mathematical analysis were compared with the results of conventional mechanical measurements and a close agreement was found, indicating that such an analysis could be useful in reducing the amount of trial-and-error work required for dynamic balancing.

This report also discusses the gyroscopic effects on the balanced scanner during maneuvers of the transporting aircraft. It is shown that the gyroscopic forces which would be encountered in a rotating scanner during the most extreme maneuvers of conventional reconnaissance aircraft are negligible compared to the weight and centrifugal forces in the scanner.

2 EQUATIONS for the DYNAMIC BALANCING of a SCANNER DRUM

2.1. GENERAL THEORY

Equilibrium, whether static or dynamic, depends on the forces acting upon the system in question. A system is in equilibrium when

$$\sum \vec{F} = 0$$

and

$$\sum \vec{M} = 0$$

If the x-axis is the axis of rotation (Figure 1), the system is in equilibrium when

$$\sum F_x = F_x' + F_x'' = 0$$

$$\sum F_y = \iiint_V \rho\omega^2 y\, dV - \iiint_V \rho g\, dV + F_y' + F_y'' = 0$$

$$\sum F_z = \iiint_V \rho\omega^2 z\, dV + F_z' + F_z'' = 0$$

$$\sum M_x = \iiint_V \rho\omega^2 zy\, dV - \iiint_V \rho\omega^2 yz\, dV + \iiint_V \rho gz\, dV$$

$$+ F_y' c + F_y'' f - F_z' b - F_z'' e = 0$$

$$\sum M_y = \iiint_V \rho\omega^2 zx\, dV - F_z' a + F_z'' d = 0$$

and

$$\sum M_z = \iiint_V \rho\omega^2 yx\, dV - \iiint_V \rho gx\, dV - F_x' b - F_x'' e - F_y' a + F_y'' d = 0$$

where

ρ = density $\left(\frac{\text{pound-seconds}^2}{\text{inch}^4}\right)$

ω = angular velocity (radians/second)

g = acceleration of gravity (inches/second^2)

F', F'' = bearing forces (pounds)

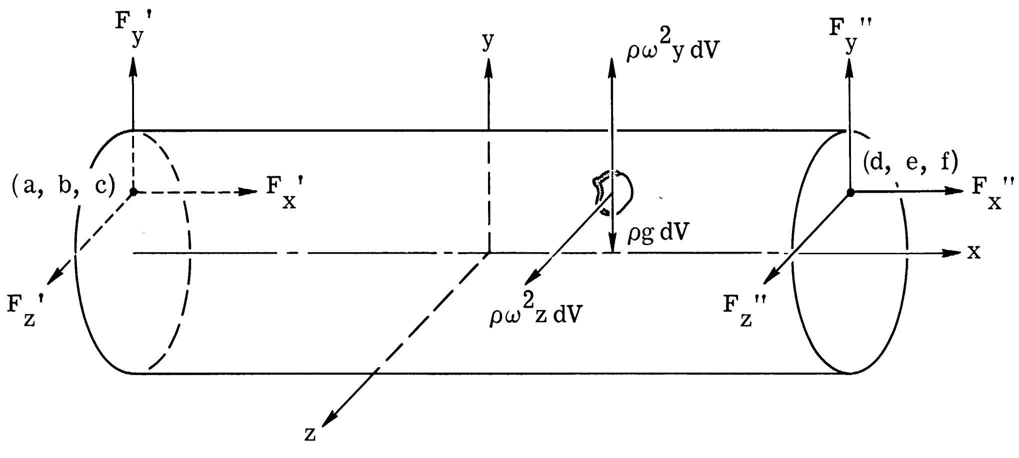

FIGURE 1. FORCES ACTING UPON A SCANNER DRUM

If the origin is located at the centroid, the system is in "static balance" and

$$\iiint_V \rho g x \, dV = \iiint_V \rho g y \, dV = \iiint_V \rho g z \, dV = 0$$

There are no x- or y-components of the bearing forces in the balanced drum, since "balance" implies that there is no bearing force other than that required to support the weight of the drum. Hence, for the dynamically balanced drum (neglecting gravity), where the axes are located at the centroid of the system and the x-axis is the axis of rotation,

$$F_x' = F_x'' = F_y' = F_y'' = F_z' = F_z'' = 0$$

$$\iiint_V \rho z x \, dV = 0$$

and

$$\iiint_V \rho y x \, dV = 0$$

The integrals

$$\iiint_V \rho z x \, dV \equiv I_{zx}$$

and

$$\iiint_V \rho y x \, dV \equiv I_{yx}$$

are known as the "products of inertia" of the system.

The drum assembly of the wide-angle scanner is an extremely complicated mechanism geometrically, and as a result it would be very difficult to evaluate the products of inertia for the entire drum at one time. However, if a body B_1 of density ρ_1 has a hollow region B_2 in its interior (Figure 2), then the products of inertia are

$$I_{ij} = \iiint_{B_1} \rho_1 ij \, dV - \iiint_{B_2} \rho_1 ij \, dV$$

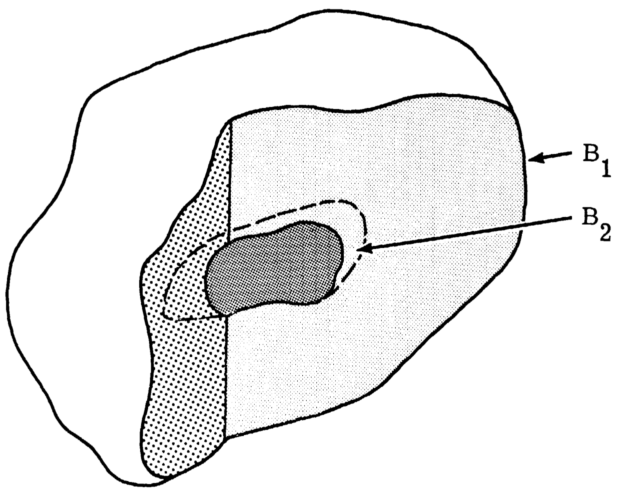

FIGURE 2. BODY WITH HOLLOW PORTION

Hence, as far as the products of inertia are concerned, a body of irregular shape may be thought of as a combination of regularly shaped bodies.

One further consideration may be made. If a body has a cross section which is independent of x, the products of inertia become

$$I_{yx} = \rho V \bar{y} \bar{x}$$

and

$$I_{zx} = \rho V \bar{z} \bar{x}$$

where $\bar{x}$, $\bar{y}$, and $\bar{z}$ are the coordinates of the centroid of the body. In many cases it is simpler to calculate the product of inertia in this fashion.

2.2. APPLICATION OF THEORY TO SCANNER DRUM ASSEMBLY

A scanner drum assembly is shown in Figure 3. Essentially, the drum is constructed by taking an aluminum cylinder and drilling two holes (of equal radii) through it, one axially and one normal to its longitudinal axis. The resulting member is cut along a 45° plane (Figure 4). The two halves are then separated sufficiently to allow an elliptical mirror and a mounting ring to be inserted in the 45° cut. Screws are placed longitudinally into the drum to hold the parts together (Figure 3). Finally, balancing is accomplished by mounting two 90° rings (whose thickness will be determined by the analysis) onto the drum shown in Figure 3.

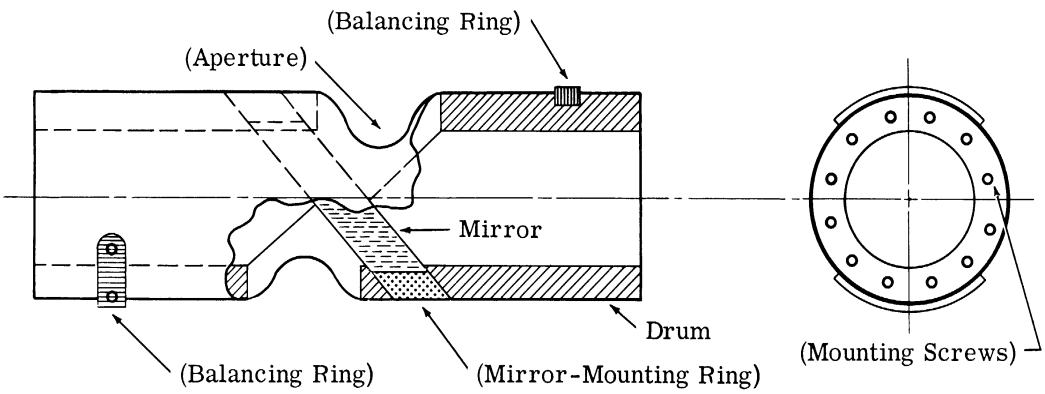

FIGURE 3. SCANNER DRUM ASSEMBLY

The yx products of inertia of several bodies follow. (The zx products all cancel or go to zero due to the symmetry of the drum assembly.)

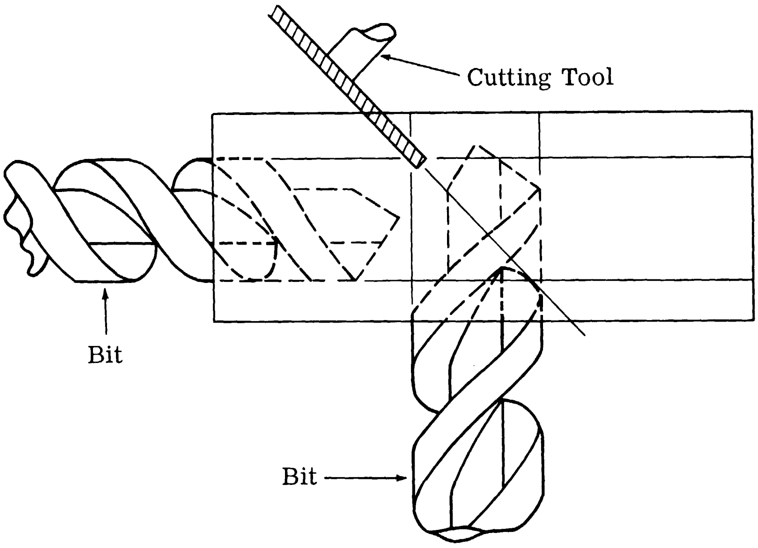

FIGURE 4. CONSTRUCTION OF SCANNER DRUM

(A) Cylinder. The longitudinal axis of the cylinder is parallel to the x-axis, and the centers of the two ends have the coordinates (x_0, y_0, z_0) and $(x_0 + L, y_0, z_0)$. The length of cylinder is L and its radius is r (Figure 5).

$$I_{yx} = \rho V \overline{y}\overline{x} = \rho \pi r^2 L \, (x_0 + L/2) \, (y_0)$$

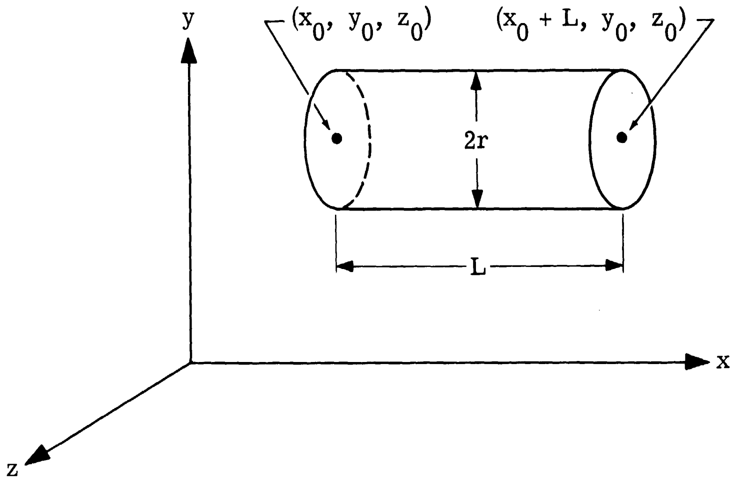

FIGURE 5. CYLINDER

(B) Ring (1). The ring is centered at the origin but makes a 45° angle with the yz-plane (Figure 6). Its inside radius is r_i, its outside radius is r_o, and its width is 2a.

$$I_{yx} = \int_0^{2\pi}\int_{r_i}^{r_o}\int_{-a-r\cos\theta}^{a-r\cos\theta} \rho(x)(r\cos\theta)\, r\, dx\, dr\, d\theta = -\frac{\pi a}{2}\left(r_o^{\ 4} - r_i^{\ 4}\right)\rho$$

(C) Ring (2). The ring is symmetric about the xy-plane and parallel to the yz-plane (Figure 7). Its inside radius is r_i, its outside radius is r_o, its width is 2b, and $\bar{x} = \ell$. The ring subtends an arc of 2α.

$$I_{yx} = \int_{-\alpha}^{\alpha}\int_{r_i}^{r_o}\int_{\ell-b}^{\ell+b} \rho(x)\,(r\cos\theta) r\, dx\, dr\, d\theta = \frac{4}{3} b\ell \left(r_o^{\ 3} - r_i^{\ 3}\right)(\sin\alpha)\rho$$

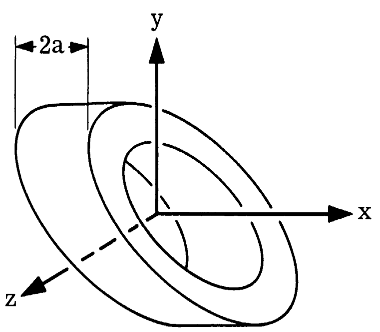

FIGURE 6. 45° RING

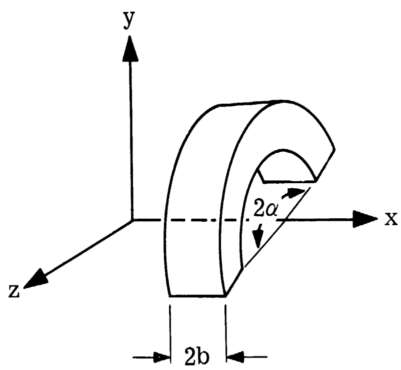

FIGURE 7. RING (2)

(D) Aperture Opening. The aperture opening is the intersection of three cylinders (Figures 3, 4, and 8). The aperture radius is r_i, and the outside radius of the tube is r_o, and $\bar{x} = a$.

$$I_{yx} = \int_{-r_i}^{r_i}\int_{+\sqrt{r_i^{\ 2}-z^2}}^{+\sqrt{r_o^{\ 2}-z^2}}\int_{-\sqrt{r_i^{\ 2}-z^2}}^{+\sqrt{r_i^{\ 2}-z^2}} \rho\,(x+a)(y)\, dx\, dy\, dz = \frac{a}{2}\left(r_o^{\ 2} - r_i^{\ 2}\right)\left(\pi r_i^{\ 2}\right)\rho$$

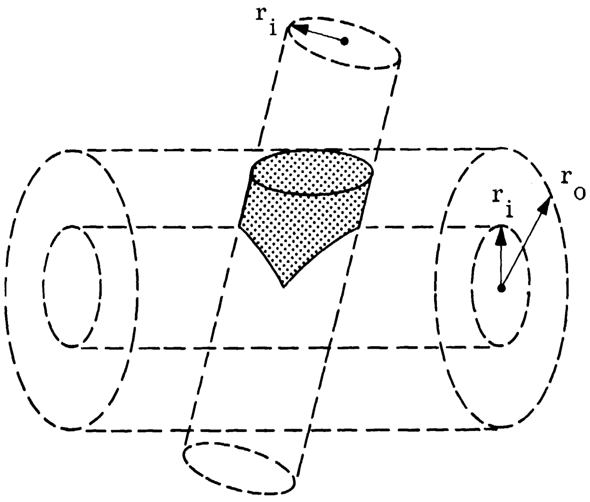

FIGURE 8. APERTURE OPENING

Each part of the scanner drum assembly in Figure 3 may be classed as one of the above bodies. All that remains is to put the proper numbers into the product of inertia expressions, add them up, and set the total equal to zero. The only unknown will be either ℓ, b, α, r_o, or r_i for the balancing ring.

For example, the balancing of the Project MICHIGAN wide-angle scanner drum assembly may be calculated as follows.

(a) Apertures (quantity = 2)—aluminum: $a = 9/16\sqrt{2}$ inch, $r_o = 3\ 15/16$ inches, $r_i = 3\ 1/16$ inches.

$$\text{Total } I_{yx} = -2\left[\frac{a}{2}\left(r_o^{\ 2} - r_i^{\ 2}\right)\left(\pi r_i^{\ 2}\right)\right]\rho$$

$$= -71.79(2.62 \times 10^{-4}) = -0.0188 \text{ inch-pound-second}^2$$

(b) Drum:

$$\text{Total } I_{yx} = 0$$

(c) 45^o cut in drum—aluminum: $a = 9/16\sqrt{2}$ inch, $r_o = 3\ 15/16$ inches, $r_i = 3\ 1/16$ inches.

$$I_{yx} = \frac{\pi a}{2}\left(r_o^{\ 4} - r_i^{\ 4}\right)\rho = 95.24(2.62 \times 10^{-4}) = 0.0250 \text{ inch-pound-second}^2$$

(d) Mirror-mounting ring—Invar: $a = 9/16\sqrt{2}$ inch, $r_o = 3\ 15/16$ inches, $r_i = 3\ 3/16$ inches.

$$I_{yx} = -\frac{\pi a}{2}\left(r_o^{\,4} - r_i^{\,4}\right)\rho = -85.70\ (7.63 \times 10^{-4}) = -0.0654 \text{ inch-pound-second}^2$$

(e) Mirror—quartz: $a = 9/16\sqrt{2}$ inch, $r_o = 3\ 3/16$ inches, $r_i = 0$.

$$I_{yx} = -\frac{\pi a}{2}\left(r_o^{\,4} - r_i^{\,4}\right)\rho = -64.51\ (2.07 \times 10^{-4}) = -0.0134 \text{ inch-pound-second}^2$$

(f) Slot for balancing rings (quantity = 2)—aluminum: $b = 1/2$ inch, $\alpha = \pi/4$, $\ell = 4$ inches, $r_o = 3\ 15/16$ inches, $r_i = 3\ 3/16$ inches.

$$\text{Total } I_{yx} = -2\left[\frac{4}{3} b\ell \left(r_o^{\,3} - r_i^{\,3}\right)\sin\alpha\right]\rho = -21.24\ \ (2.62 \times 10^{-4}) = -0.0041 \text{ inch-pound-second}^2$$

(g) Mounting screw holes— aluminum and Invar:

$$\text{Total } I_{yx} = 26.29(2.62 \times 10^{-4}) + 4.80(7.63 \times 10^{-4}) = 0.0106 \text{ inch-pound-second}^2$$

(h) Mounting screws—steel:

$$\text{Total } I_{yx} = -\ 10.40(7.50 \times 10^{-4}) = -\ 0.0078 \text{ inch-pound-second}^2$$

(i) Balancing rings— GE Hevimet: $b = 1/2$ inch, $\alpha = \pi/4$, $\ell = 4$ inches, $r_o = r_o$, $r_i = 3\ 13/16$ inches.

$$\text{Total } I_{yx} = 2\left[\frac{4}{3} b\ell \left(r_o^{\,3} - r_i^{\,3}\right)\sin\alpha\right]\rho = (3.77 r_o^{\,3} - 209.36)(16.00 \times 10^{-4})$$

$$= 0.0060 r_o^{\,3} - 0.3350 \text{ inch-pound-second}^2$$

Since the total product of inertia of the balanced drum should be zero,

$$\sum I_{yx} = 0$$

Adding up all the parts of the drum assembly, the result is

$$0.0060 r_o^{\,3} - 0.4089 = 0$$

or

$$r_o = (67.78)^{1/3} = 4.0775 \text{ inches}$$

Hence, the thickness of the ring is

$$r_o = r_i \; 4.0775 - 3.8125 = 0.2650 \text{ inch}$$

The thickness of the balancing weights used on the actual scanner assembly was determined experimentally to be slightly over 0.250 inch. Hence, the theoretical results agree very closely with the experimental results.

3
GYROSCOPIC EFFECTS on SCANNER DRUM during MANEUVERS of AIRCRAFT

The scanner is carried by an aircraft whose line of flight is parallel to the axis of rotation of the scanner drum. During maneuvers of the aircraft, the rotating drum assembly experiences a "precession" or rotation about an axis normal to the axis of rotation. A gyroscopic couple is produced in the scanner drum as shown in Figure 9. This couple produces forces in the bearings which support the drum.

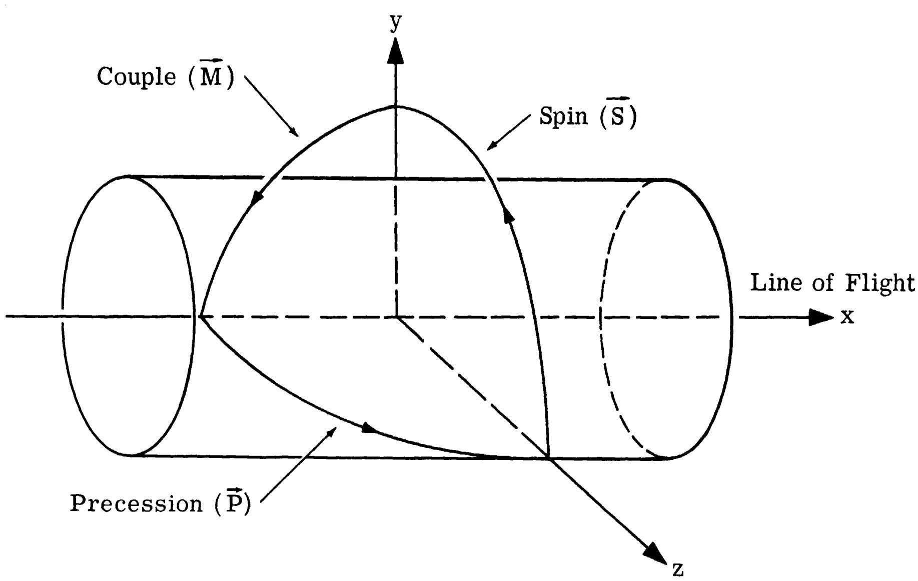

FIGURE 9. GYROSCOPIC EFFECT DURING TURN OF AIRCRAFT

The equation for the gyroscopic couple is

$$\vec{M} = I_{xx} (\vec{P} \times \vec{S}) = \begin{Bmatrix} I_{xx} PS\vec{k} & \text{(turn)} \\ I_{xx} PS\vec{j} & \text{(dive)} \end{Bmatrix}$$

where $\vec{M}$ = couple (inch-pounds)

I_{xx} = moment of inertia about x-axis (inch-pound-seconds^2)

$\vec{P}$ = precession vector (radians/second)

$\vec{S}$ = spin vector (radians/second)

$\vec{j}, \vec{k}$ = unit vectors in y, z directions,respectively

Again, the wide-angle scanner drum is used as an example. The moments of inertia of the components (see Section 2.2 for descriptions) may be evaluated as follows:

(A) Cylinder

$$I_{xx} = \frac{\pi L}{2} \left(r_o^{\,4} - r_i^{\,4}\right) \rho$$

(B) Ring (1)

$$I_{xx} = \pi a \left(r_o^{\,4} - r_i^{\,4}\right) \rho$$

(C) Ring (2)

$$I_{xx} = \alpha b \left(r_o^{\,4} - r_i^{\,4}\right) \rho$$

(D) Aperture Opening

$$\text{Volume} = V = \frac{4}{3} \left\{ r^2 R \left[K(k) + E(k)\right] - R^3 \left[K(k) - E(k)\right] - 2r^3 \right\}$$

where $k = r_i/r_o$ and E(k) and K(k) are elliptic functions.

$$I_{xx} \cong \rho V \left(\frac{r_o + r_i}{2}\right)^2$$

The calculations based on the dimensions of the wide-angle scanner follow.

(a) Apertures (quantity = 2)—aluminum:

$$\text{Total } I_{xx} = -2\rho V \left(\frac{r_o + r_i}{2}\right)^2 = -2\,(2.62 \times 10^{-4})\,(25.78)\left(\frac{49}{4}\right) = -0.1654 \text{ inch-pound-second}^2$$

(b) Drum—aluminum:

$$I_{xx} = \frac{\pi L}{2} \left(r_o^{\,4} - r_i^{\,4}\right) \rho = (2482)(2.62 \times 10^{-4}) = 0.6504 \text{ inch-pound-second}^2$$

(c) 45^{o} cut in drum — aluminum:

$$I_{xx} = -\pi a \left(r_o^4 - r_i^4\right)\rho = -(190.5)(2.62 \times 10^{-4}) = -0.0499 \text{ inch-pound-second}^2$$

(d) Mirror-mounting ring — Invar:

$$I_{xx} = \pi a \left(r_o^4 - r_i^4\right)\rho = (171.4)(7.63 \times 10^{-4}) = 0.1308 \text{ inch-pound-second}^2$$

(e) Mirror — quartz:

$$I_{xx} = \pi a \left(r_o^4 - r_i^4\right)\rho = (129.0)(2.07 \times 10^{-4}) = 0.0268 \text{ inch-pound-second}^2$$

(f) Slots for balancing rings (quantity = 2) — aluminum:

$$\text{Total } I_{xx} = -2\left[\alpha b\left(r_o^4 - r_i^4\right)\rho\right] = -(10.80)(2.62 \times 10^{-4}) = -0.0028 \text{ inch-pound-second}^2$$

(g) Mounting screw holes — aluminum and Invar:

$$\text{Total } I_{xx} = -0.0047 \text{ inch-pound-second}^2$$

(h) Mounting screws — steel:

$$\text{Total } I_{xx} = 0.0089 \text{ inch-pound-second}^2$$

(i) Balancing rings — GE Hevimet:

$$\text{Total } I_{xx} = 2\left[\alpha b\left(r_o^4 - r_i^4\right)\rho\right] = (35.10)(16.00 \times 10^{-4}) = 0.0561 \text{ inch-pound-second}^2$$

The total moment of inertia is the sum of the moments of inertia of the parts. Hence,

$$\text{Total } I_{xx} = \sum I_{xx} = 0.6502 \text{ inch-pound-second}^2$$

Since the drum rotates at 5000 rpm, the magnitude of the gyroscopic couple is

$$|\vec{M}| = I_{xx}PS = (0.6502)(P)\ \frac{5000 \cdot 2\pi}{60} = 342.6 \text{ P inch-pounds}$$

If the scanner is carried by an aircraft cruising at 150 mph, the maximum rate of precession about any axis is 360° per minute. Therefore, the maximum gyroscopic couple is

$$|\vec{M}|_{\text{maximum}} = 342.6\,|P|_{\text{maximum}} = (342.6)\left(\frac{2\pi}{60}\right) = 35.88 \text{ inch-pounds}$$

Since the distance between the bearings is 1 foot, the maximum bearing force is about 3 pounds.

PROJECT MICHIGAN DISTRIBUTION LIST 7
1 February 1961—Effective Date

Copy No.	Addressee
1	Army Research Office, ORCD, DA Washington 25, D. C. ATTN: Research Support Division
2-3	Commanding General U. S. Army Combat Surveillance Agency 1124 N. Highland Street Arlington 1, Virginia
4-40	Commanding Officer U. S. Army Signal Research & Development Laboratory Fort Monmouth, New Jersey ATTN: SIGRA/SL-ADT
41-42	Commanding General U. S. Army Electronic Proving Ground Fort Huachuca, Arizona ATTN: Technical Library
43	Chief, Human Factors Research Division Office of the Chief of Research & Development Department of the Army, Washington 25, D. C.
44-45	Commander, Army Rocket & Guided Missile Agency Redstone Arsenal, Alabama ATTN: Technical Library, ORDXR-OTL
46-47	Commanding Officer U. S. Army Transportation Research Command Fort Eustis, Virginia ATTN: Research Reference Center
48	Commanding General Army Medical Research & Development Command Main Navy Building, Washington 25, D. C. ATTN: Neuropsychiatry & Psychophysiology Research Branch
49	Commanding Officer, Ordnance Weapons Command Rock Island, Illinois ATTN: ORDOW-GN
50-53	Director, U. S. Army Engineer Research & Development Laboratories Fort Belvoir, Virginia
(50)	ATTN: Chief, Topographic Engineer Department
(51-52)	ATTN: Chief, Electrical Engineering Department
(53)	ATTN: Technical Documents Center
54	Commandant, U. S. Army War College Carlisle Barracks, Pennsylvania ATTN: Library
55	Commandant, U. S. Army Command & General Staff College Fort Leavenworth, Kansas ATTN: Archives
56	Commandant, U. S. Army Infantry School Fort Benning, Georgia ATTN: Combat Developments Office
57-58	Assistant Commandant U. S. Army Artillery & Missile School Fort Sill, Oklahoma
59	Assistant Commandant, U. S. Army Air Defense School Fort Bliss, Texas
60	Commandant, U. S. Army Engineer School Fort Belvoir, Virginia ATTN: ESSY-L
61	Commandant, U. S. Army Signal School Fort Monmouth, New Jersey ATTN: SIGFM/SC-DO
62	Commandant, U. S. Army Aviation School Fort Rucker, Alabama ATTN: CDO
63-64	President, U. S. Army Intelligence Board Fort Holabird, Baltimore 19, Maryland
65	Commanding Officer, U. S. Army Signal Electronic Research Unit, P. O. Box 205 Mountain View, California
66-69	Office of Naval Research, Department of the Navy 17th & Constitution Avenue, N. W. Washington 25, D. C.
(66-67)	ATTN: Code 463
(68-69)	ATTN: Code 461
70	The Hydrographer, U. S. Navy Hydrographic Office Washington 25, D. C. ATTN: Code 4100
71	Chief, Bureau of Ships Department of the Navy, Washington 25, D. C. ATTN: Code 690
72-73	Director, U. S. Naval Research Laboratory Washington 25, D. C. ATTN: Code 2027
74	Commanding Officer, U. S. Navy Ordnance Laboratory Corona, California ATTN: Library
75	Commanding Officer & Director U. S. Navy Electronics Laboratory San Diego 52, California ATTN: Library
76-77	Department of the Air Force, Headquarters, USAF Washington 25, D. C. ATTN: AFOIN-1B1
78	Commander in Chief, Headquarters Strategic Air Command, Offutt Air Force Base, Nebraska ATTN: DINC

Distribution List 7, 1 February 1961—Effective Date

Copy No.	Addressee
79	Aerospace Technical Intelligence Center U. S. Air Force Wright-Patterson AFB, Ohio ATTN: AFCIN-4B1a, Library
80-89	ASTIA (TIPCR) Arlington Hall Station, Arlington 12, Virginia
90-98	Commander, Wright Air Development Division Wright-Patterson AFB, Ohio (90-93) ATTN: WWDE (94) ATTN: WWAD-DIST (95) ATTN: WWRDLP-2 (96-98) ATTN: WWRNOO (Staff Physicist)
99-100	Commander, Rome Air Development Center Griffiss AFB, New York (99) ATTN: RCOIL-2 (100) ATTN: RCWIP-3
101-103	Commander, AF Command & Control Development Division Laurence G. Hanscom Field Bedford, Massachusetts ATTN: CCRHA-Stop 36
104	APGC(PGTRI) Eglin Air Force Base, Florida
105-108	Central Intelligence Agency 2430 E Street, N. W. Washington 25, D. C. ATTN: OCR Mail Room
109-114	National Aeronautics & Space Administration 1520 H Street, N. W. Washington 25, D. C.
115	Combat Surveillance Project Cornell Aeronautical Laboratory, Inc. Box 168, Arlington 10, Virginia ATTN: Technical Library
116	The RAND Corporation 1700 Main Street Santa Monica, California ATTN: Library
117-118	Cornell Aeronautical Laboratory, Inc. 4455 Genesee Street Buffalo 21, New York ATTN: Librarian VIA: Bureau of Naval Weapons Representative 4455 Genesee Street Buffalo 21, New York
119-120	Director, Human Resources Research Office The George Washington University P. O. Box 3596, Washington 7, D. C. ATTN: Library
121	Chief, U. S. Army Air Defense Human Research Unit Fort Bliss, Texas ATTN: Library
122	Chief, U. S. Army Armor Human Research Unit Fort Knox, Kentucky ATTN: Security Officer
123	Chief, U. S. Army Infantry Human Research Unit P. O. Box 2086 Fort Benning, Georgia
124	Chief, USA Leadership Human Research Unit P. O. Box 2086, Presidio of Monterey, California
125	Chief Scientist, Department of the Army Office of the Chief Signal Officer Research & Development Division, SIGRD-2 Washington 25, D. C.
126	Columbia University Electronics Research Laboratories 632 W. 125th Street New York 27, New York ATTN: Technical Library VIA: Commander, Rome Air Development Center Griffiss AFB, New York ATTN: RCKCS
127	Coordinated Science Laboratory University of Illinois, Urbana Illinois ATTN: Librarian VIA: ONR Resident Representative 605 S. Goodwin Avenue Urbana, Illinois
128	Polytechnic Institute of Brooklyn 55 Johnson Street Brooklyn 1, New York ATTN: Microwave Research Institute Library VIA: Air Force Office of Scientific Research Washington 25, D. C.
129	Visibility Laboratory Scripps Institution of Oceanography University of California, San Diego 52, California VIA: ONR Resident Representative, University of California Scripps Institution of Oceanography, Bldg. 349 La Jolla, California
130	U. S. Army Aviation, Human Research Unit U. S. Continental Army Command P. O. Box 428, Fort Rucker, Alabama
131	Commanding General Quartermaster Research & Engineering Command U. S. Army, Natick, Massachusetts
132	Cooley Electronics Laboratory University of Michigan Research Institute Ann Arbor, Michigan ATTN: Director
133	U. S. Continental Army Command Liaison Officer, Project MICHIGAN The University of Michigan P. O. Box 618, Ann Arbor, Michigan
134	Commanding Officer, U. S. Army Liaison Group, Project MICHIGAN The University of Michigan P. O. Box 618, Ann Arbor, Michigan

AD Div. 6/3

Institute of Science and Technology, U. of Michigan, Ann Arbor
DYNAMIC BALANCING OF SCANNER DRUM AND GYROSCOPIC EFFECT DURING MANEUVERS OF AIRCRAFT by W. L. Brown and C. T. Yang. Rept. of Proj. MICHIGAN. Feb 61. 12 p. incl. illus.
(Rept. no. 2900-250-T)
(Contract DA-36-039 SC-78801) Unclassified report

This report presents the equations for determining the dynamic balancing and gyroscopic effect of a rotating scanner drum assembly of the type used in the Project MICHIGAN wide-angle scanner. The parameters used in the numerical example are those of the wide-angle scanner, and the theoretical calculations of the dynamic balancing agree excellently with the actual mechanical dynamic balancing of the drum assembly. The calculations also indicate that gyroscopic forces in the drum are negligible even during maximum rate of turn and maximum rate of climb of the aircraft carrying the scanner.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Brown, W. L., Yang, C. T.
III. U. S. Army Signal Corps
IV. Contract DA-36-039 SC-78801

Armed Services Technical Information Agency
UNCLASSIFIED

AD Div. 6/3

Institute of Science and Technology, U. of Michigan, Ann Arbor
DYNAMIC BALANCING OF SCANNER DRUM AND GYROSCOPIC EFFECT DURING MANEUVERS OF AIRCRAFT by W. L. Brown and C. T. Yang. Rept. of Proj. MICHIGAN. Feb 61. 12 p. incl. illus.
(Rept. no. 2900-250-T)
(Contract DA-36-039 SC-78801) Unclassified report

This report presents the equations for determining the dynamic balancing and gyroscopic effect of a rotating scanner drum assembly of the type used in the Project MICHIGAN wide-angle scanner. The parameters used in the numerical example are those of the wide-angle scanner, and the theoretical calculations of the dynamic balancing agree excellently with the actual mechanical dynamic balancing of the drum assembly. The calculations also indicate that gyroscopic forces in the drum are negligible even during maximum rate of turn and maximum rate of climb of the aircraft carrying the scanner.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Brown, W. L., Yang, C. T.
III. U. S. Army Signal Corps
IV. Contract DA-36-039 SC-78801

Armed Services Technical Information Agency
UNCLASSIFIED

AD Div. 6/3

Institute of Science and Technology, U. of Michigan, Ann Arbor
DYNAMIC BALANCING OF SCANNER DRUM AND GYROSCOPIC EFFECT DURING MANEUVERS OF AIRCRAFT by W. L. Brown and C. T. Yang. Rept. of Proj. MICHIGAN. Feb 61. 12 p. incl. illus.
(Rept. no. 2900-250-T)
(Contract DA-36-039 SC-78801) Unclassified report

This report presents the equations for determining the dynamic balancing and gyroscopic effect of a rotating scanner drum assembly of the type used in the Project MICHIGAN wide-angle scanner. The parameters used in the numerical example are those of the wide-angle scanner, and the theoretical calculations of the dynamic balancing agree excellently with the actual mechanical dynamic balancing of the drum assembly. The calculations also indicate that gyroscopic forces in the drum are negligible even during maximum rate of turn and maximum rate of climb of the aircraft carrying the scanner.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Brown, W. L., Yang, C. T.
III. U. S. Army Signal Corps
IV. Contract DA-36-039 SC-78801

Armed Services Technical Information Agency
UNCLASSIFIED

AD Div. 6/3

Institute of Science and Technology, U. of Michigan, Ann Arbor
DYNAMIC BALANCING OF SCANNER DRUM AND GYROSCOPIC EFFECT DURING MANEUVERS OF AIRCRAFT by W. L. Brown and C. T. Yang. Rept. of Proj. MICHIGAN. Feb 61. 12 p. incl. illus.
(Rept. no. 2900-250-T)
(Contract DA-36-039 SC-78801) Unclassified report

This report presents the equations for determining the dynamic balancing and gyroscopic effect of a rotating scanner drum assembly of the type used in the Project MICHIGAN wide-angle scanner. The parameters used in the numerical example are those of the wide-angle scanner, and the theoretical calculations of the dynamic balancing agree excellently with the actual mechanical dynamic balancing of the drum assembly. The calculations also indicate that gyroscopic forces in the drum are negligible even during maximum rate of turn and maximum rate of climb of the aircraft carrying the scanner.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Brown, W. L., Yang, C. T.
III. U. S. Army Signal Corps
IV. Contract DA-36-039 SC-78801

Armed Services Technical Information Agency
UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Infrared detection
Infrared scanners
Mathematical analysis
Equations

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Infrared detection
Infrared scanners
Mathematical analysis
Equations

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Infrared detection
Infrared scanners
Mathematical analysis
Equations

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Infrared detection
Infrared scanners
Mathematical analysis
Equations

UNCLASSIFIED

AD Div. 6/3

Institute of Science and Technology, U. of Michigan, Ann Arbor
DYNAMIC BALANCING OF SCANNER DRUM AND GYROSCOPIC EFFECT DURING MANEUVERS OF AIRCRAFT by W. L. Brown and C. T. Yang. Rept. of Proj. MICHIGAN. Feb 61. 12 p. incl. illus.
(Rept. no. 2900-250-T)
(Contract DA-36-039 SC-78801) Unclassified report

This report presents the equations for determining the dynamic balancing and gyroscopic effect of a rotating scanner drum assembly of the type used in the Project MICHIGAN wide-angle scanner. The parameters used in the numerical example are those of the wide-angle scanner, and the theoretical calculations of the dynamic balancing agree excellently with the actual mechanical dynamic balancing of the drum assembly. The calculations also indicate that gyroscopic forces in the drum are negligible even during maximum rate of turn and maximum rate of climb of the aircraft carrying the scanner.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Brown, W. L., Yang, C. T.
III. U. S. Army Signal Corps
IV. Contract DA-36-039 SC-78801

Armed Services Technical Information Agency
UNCLASSIFIED

AD Div. 6/3

Institute of Science and Technology, U. of Michigan, Ann Arbor
DYNAMIC BALANCING OF SCANNER DRUM AND GYROSCOPIC EFFECT DURING MANEUVERS OF AIRCRAFT by W. L. Brown and C. T. Yang. Rept. of Proj. MICHIGAN. Feb 61. 12 p. incl. illus.
(Rept. no. 2900-250-T)
(Contract DA-36-039 SC-78801) Unclassified report

This report presents the equations for determining the dynamic balancing and gyroscopic effect of a rotating scanner drum assembly of the type used in the Project MICHIGAN wide-angle scanner. The parameters used in the numerical example are those of the wide-angle scanner, and the theoretical calculations of the dynamic balancing agree excellently with the actual mechanical dynamic balancing of the drum assembly. The calculations also indicate that gyroscopic forces in the drum are negligible even during maximum rate of turn and maximum rate of climb of the aircraft carrying the scanner.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Brown, W. L., Yang, C. T.
III. U. S. Army Signal Corps
IV. Contract DA-36-039 SC-78801

Armed Services Technical Information Agency
UNCLASSIFIED

AD Div. 6/3

Institute of Science and Technology, U. of Michigan, Ann Arbor
DYNAMIC BALANCING OF SCANNER DRUM AND GYROSCOPIC EFFECT DURING MANEUVERS OF AIRCRAFT by W. L. Brown and C. T. Yang. Rept. of Proj. MICHIGAN. Feb 61. 12 p. incl. illus.
(Rept. no. 2900-250-T)
(Contract DA-36-039 SC-78801) Unclassified report

This report presents the equations for determining the dynamic balancing and gyroscopic effect of a rotating scanner drum assembly of the type used in the Project MICHIGAN wide-angle scanner. The parameters used in the numerical example are those of the wide-angle scanner, and the theoretical calculations of the dynamic balancing agree excellently with the actual mechanical dynamic balancing of the drum assembly. The calculations also indicate that gyroscopic forces in the drum are negligible even during maximum rate of turn and maximum rate of climb of the aircraft carrying the scanner.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Brown, W. L., Yang, C. T.
III. U. S. Army Signal Corps
IV. Contract DA-36-039 SC-78801

Armed Services Technical Information Agency
UNCLASSIFIED

AD Div. 6/3

Institute of Science and Technology, U. of Michigan, Ann Arbor
DYNAMIC BALANCING OF SCANNER DRUM AND GYROSCOPIC EFFECT DURING MANEUVERS OF AIRCRAFT by W. L. Brown and C. T. Yang. Rept. of Proj. MICHIGAN. Feb 61. 12 p. incl. illus.
(Rept. no. 2900-250-T)
(Contract DA-36-039 SC-78801) Unclassified report

This report presents the equations for determining the dynamic balancing and gyroscopic effect of a rotating scanner drum assembly of the type used in the Project MICHIGAN wide-angle scanner. The parameters used in the numerical example are those of the wide-angle scanner, and the theoretical calculations of the dynamic balancing agree excellently with the actual mechanical dynamic balancing of the drum assembly. The calculations also indicate that gyroscopic forces in the drum are negligible even during maximum rate of turn and maximum rate of climb of the aircraft carrying the scanner.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Brown, W. L., Yang, C. T.
III. U. S. Army Signal Corps
IV. Contract DA-36-039 SC-78801

Armed Services Technical Information Agency
UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Infrared detection
Infrared scanners
Mathematical analysis
Equations

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Infrared detection
Infrared scanners
Mathematical analysis
Equations

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Infrared detection
Infrared scanners
Mathematical analysis
Equations

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Infrared detection
Infrared scanners
Mathematical analysis
Equations

UNCLASSIFIED