NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 208

DETERMINATION OF TURNING CHARACTERISTICS OF AN AIRSHIP BY MEANS OF A CAMERA OBSCURA

By J. W. CROWLEY, Jr., and R. G. FREEMAN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1925

AERONAUTICAL SYMBOLS.

1. FUNDAMENTAL AND DERIVED UNITS.

	Symbol.	Metric.		English.	
		Unit.	Symbol.	Unit.	Symbol.
Length	l	meter	m.	foot (or mile)	ft. (or mi.).
Time	t	second	sec.	second (or hour)	sec. (or hr.).
Force	F	weight of one kilogram	kg.	weight of one pound	lb.
Power	P	kg.m/sec		horsepower	HP
Speed		m/sec	m. p. s.	mi/hr	M. P. H.

2. GENERAL SYMBOLS, ETC.

Weight, $W=mg$.

Standard acceleration of gravity, $g=9.806\text{m/sec.}^2=32.172\text{ft/sec.}^2$

Mass, $m=\frac{W}{g}$

Density (mass per unit volume), ρ

Standard density of dry air, 0.1247 (kg.-m.-sec.) at 15.6°C. and 760 mm. = 0.00237 (lb.-ft.-sec.)

Specific weight of "standard" air, 1.223 kg/m.^{3} = 0.07635 lb/ft.^{3}

Moment of inertia, mk^2 (indicate axis of the radius of gyration, k, by proper subscript).

Area, S; wing area, S_w, etc.

Gap, G

Span, b; chord length, c.

Aspect ratio $=b/c$

Distance from $c.\ g.$ to elevator hinge, f.

Coefficient of viscosity, μ.

3. AERODYNAMICAL SYMBOLS.

True airspeed, V

Dynamic (or impact) pressure, $q=\frac{1}{2}\rho V^2$

Lift, L; absolute coefficient $C_L=\frac{L}{qS}$

Drag, D; absolute coefficient $C_D=\frac{D}{qS}$.

Cross-wind force, C; absolute coefficient $C_c=\frac{C}{qS}$.

Resultant force, R

(Note that these coefficients are twice as large as the old coefficients L_c, D_c.)

Angle of setting of wings (relative to thrust line), i_w

Angle of stabilizer setting with reference to thrust line i_t

Dihedral angle, γ

Reynolds Number $=\rho\frac{Vl}{\mu}$, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi/hr., normal pressure, 0°C: 255,000 and at 15.6°C, 230,000;

or for a model of 10 cm. chord, 40 m/sec., corresponding numbers are 299,000 and 270,000.

Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length), C_p.

Angle of stabilizer setting with reference to lower wing. $(i_t-i_w)=\beta$

Angle of attack, α

Angle of downwash, ϵ

REPORT No. 208

DETERMINATION OF TURNING CHARACTERISTICS OF AN AIRSHIP BY MEANS OF A CAMERA OBSCURA

By J. W. CROWLEY, Jr., and R. G. FREEMAN
Langley Memorial Aeronautical Laboratory

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
10 CENTS PER COPY

REPORT No. 208

DETERMINATION OF TURNING CHARACTERISTICS OF AN AIRSHIP BY MEANS OF A CAMERA OBSCURA

By J. W. Crowley, Jr., and R. G. Freeman

SUMMARY

This investigation was carried out by the National Advisory Committee for Aeronautics at Langley Field for the purpose of determining the adaptability of the camera obscura to the securing of turning characteristics of airships, and also of obtaining some of those characteristics of the C–7 airship. The method consisted in flying the airship in circling flight over a camera obscura and photographing it at known time intervals. The results show that the method used is highly satisfactory and that for the particular maneuver employed the turning diameter is 1,240 feet, corresponding to a turning coefficient of 6.4, and that the position of zero angle of yaw is at the nose of the airship.

INTRODUCTION

At the present time there are apparently no data taken in flight of the turning characteristics of a nonrigid airship. However, there are data available on rigid airships but acquisition of the same was by methods admittedly deficient in accuracy. It was with the view of establishing a simple but precise method of obtaining the necessary data that the present investigation was made.

REFERENCES

R. & M. No. 537.—A Flight in Rigid Airship R–26. By J. R. Pannell.

R. & M. No. 668.—Experiments on Rigid Airship R–33. By J. R. Pannell and R. A. Frazer.

R. & M. No. 812.—Experiments on Rigid Airship R–32, Part II: Controllability and Turning Trials. By J. R. Pannell, R. A. Frazer, and H. Bateman.

R. & M. No. 716.—The Application of the Results of Experiments on Model Airships to Full-Scale Turning. By R. Jones.

R. & M. No. 675.—Experiments on Rigid Airship R–39. By J. R. Pannell and A. H. Bell.

METHODS AND APPARATUS

The Navy C–7 airship, stationed at the Naval Air Station, Hampton Roads, was flown to Langley Field for these tests.

The apparatus used was a camera obscura with a special automatic shutter. The camera consisted of a light-tight upper-story room with an opening in the ceiling to accommodate a 48-inch focal-length lens. An object passing over the lens threw an image on a table below, which was covered with overlapping strips of photographic film. (Fig. 1.)

The shutter (Fig. 2) consisted of a 15-inch diameter circular wooden frame *A* with a 5-inch circular opening *B* eccentrically located, two flat metal disks, 15-inch diameter, coaxial with *A* (one shown at *C*), and a constant-speed motor *D*. The constant-speed motor, mounted on the top of the wooden frame, drove, through worm and gearing, the two metal disks which were

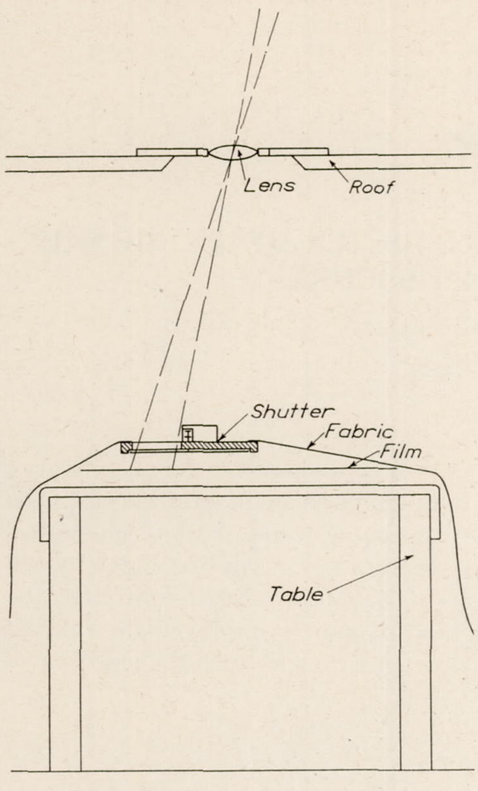


FIG. 1.—A vertical section through the camera obscura

mounted on the lower side of the frame. A rim on the circumference of the frame and projecting below it protected the revolving disks. The upper disk was provided with a radial slit *E*, which, traveling across the opening *B* in the frame, gave the requisite shutter action and made an exposure of about 0.01 second duration. In order to prevent excessive overlapping of pictures it was necessary to make an exposure at not more than every fourth revolution of the slit. This was accomplished by means of the lower disk (not shown in Fig. 2), in which a 60° sector was cut away. It was driven in the same direction, but at one-fourth the speed of the upper disk, and consequently the openings in the two came together at every fourth revolution of the slit. In this manner exposures of 0.01 second were obtained every 3.64 seconds.

In use the shutter was provided with a light-tight fabric attached as shown in Figure 2. It was placed flat on the table and the fabric loosely spread so as to completely envelop the table top and film. The lens was uncovered and the shutter moved so as to catch and keep the image in the circular opening.

In accordance with prearranged procedure the airship made a preliminary low-speed run across the camera obscura for focusing purposes. This accomplished, two duplicate circling flights were made over the camera, from which the data were obtained. The camera was approached from up-wind at a constant barometric altitude of approximately 3,000 feet with engines turning at 1,000 revolutions per minute. Just before entering the camera field the rudder was thrown hard over to starboard and the ship turned to the right, across wind and over the camera. On each run photographs were made for approximately a 90° turn.

Before the first run an altitude-velocity chart was obtained by means of pilot balloons and a theodolite. A wind velocity of 14.3 miles per hour, northwest, was indicated at 3,000 feet.

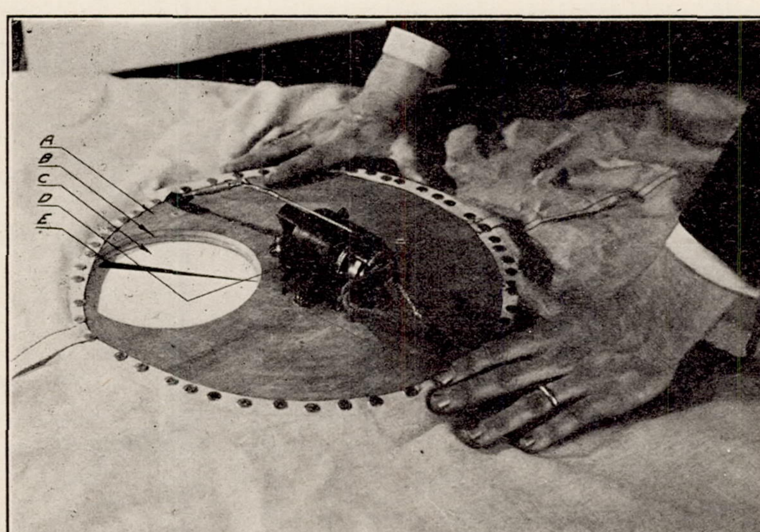


FIG. 2.—Automatic shutter for camera obscura

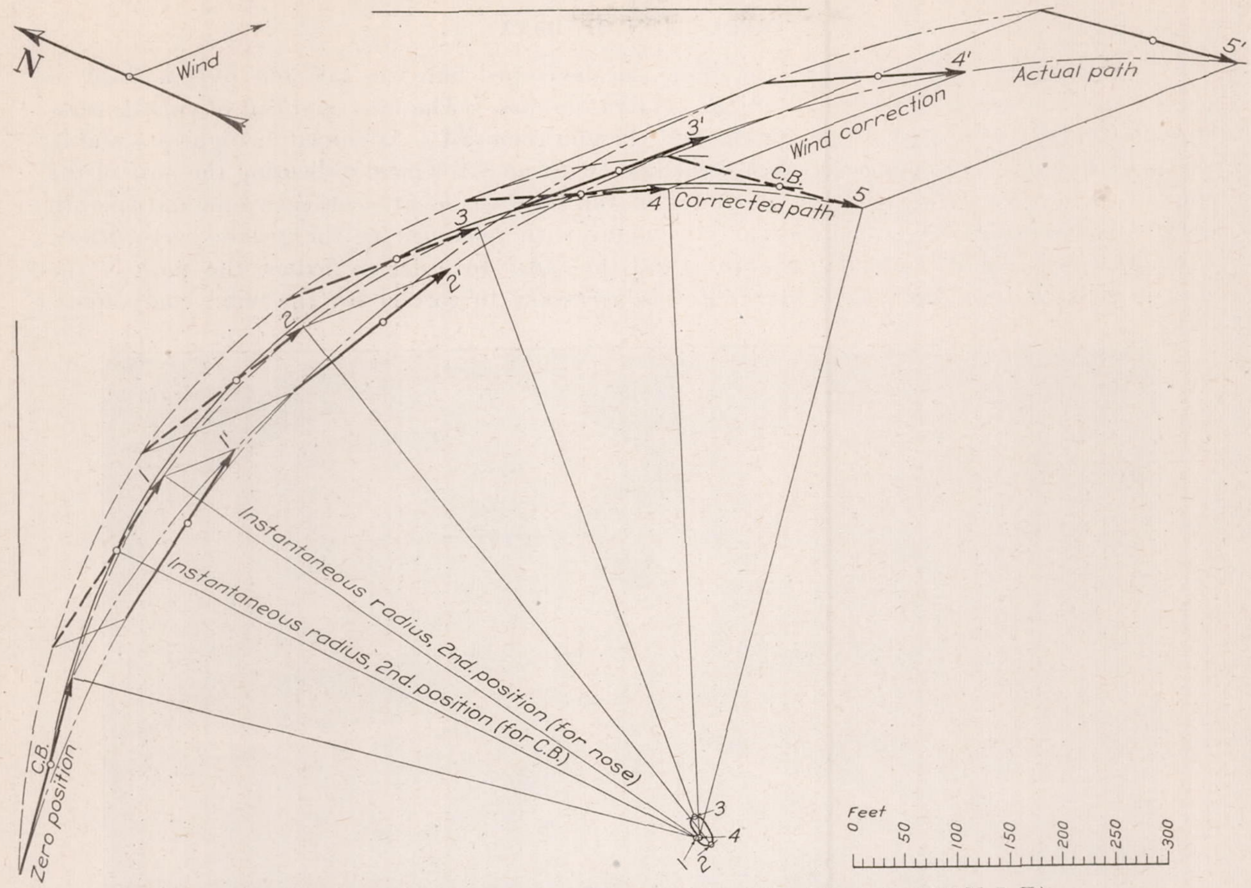


FIG. 5.—(Wind correction per exposure is 76.56 ft., corresponding to the wind velocity of 14.3 M. P. H.)

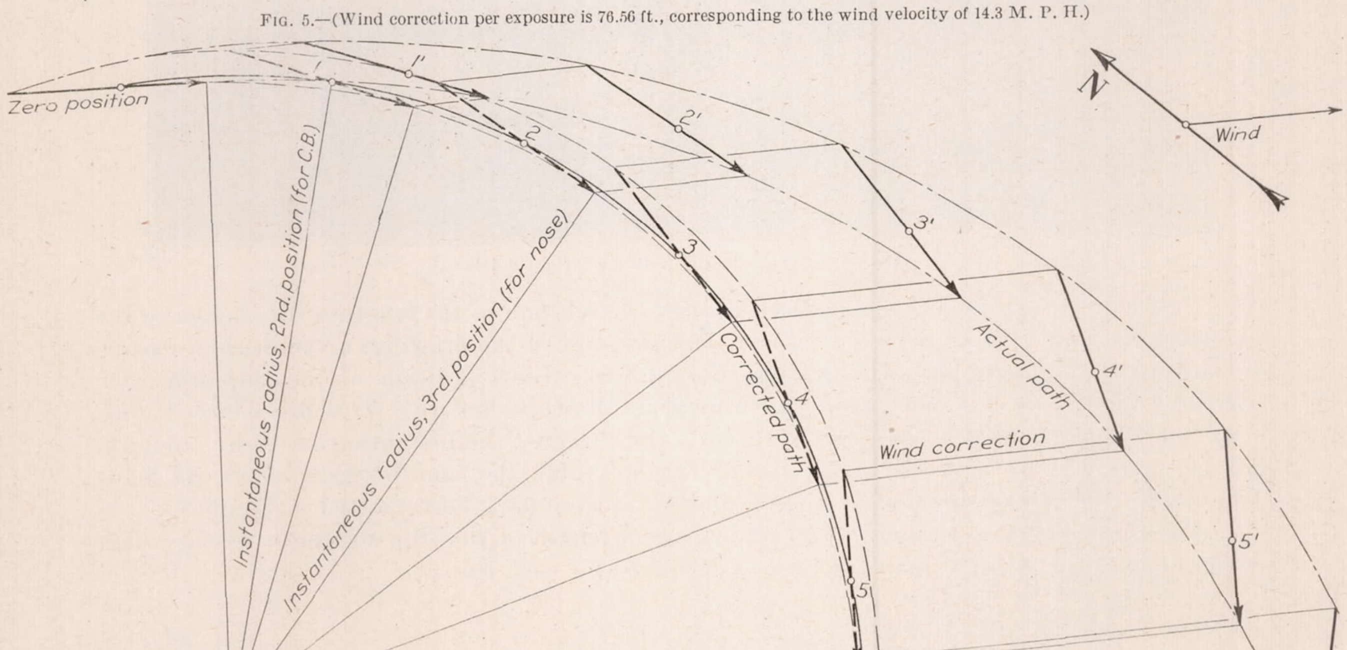


FIG. 6.—(Wind correction per exposure is 76.56 ft., corresponding to the wind velocity of 14.3 M. P. H.)

REDUCTION OF DATA

For the purpose of working up the data, the developed film was laid out over a sheet of paper, and the strips arranged as in the camera obscura. The nose and tail of each successive position were located by pin pricks and the film removed. As shown in Figures 5 and 6, the prick points were connected by a solid line, with an arrowhead indicating the nose of the ship in each case. The center of buoyancy of the ship was located on each line and smooth curves representing the actual path of the points with reference to the ground were drawn through the center of buoyancy, the nose, and the tail. In order to deduce the path of the ship in still air from the above curves it was necessary to correct for the wind component.

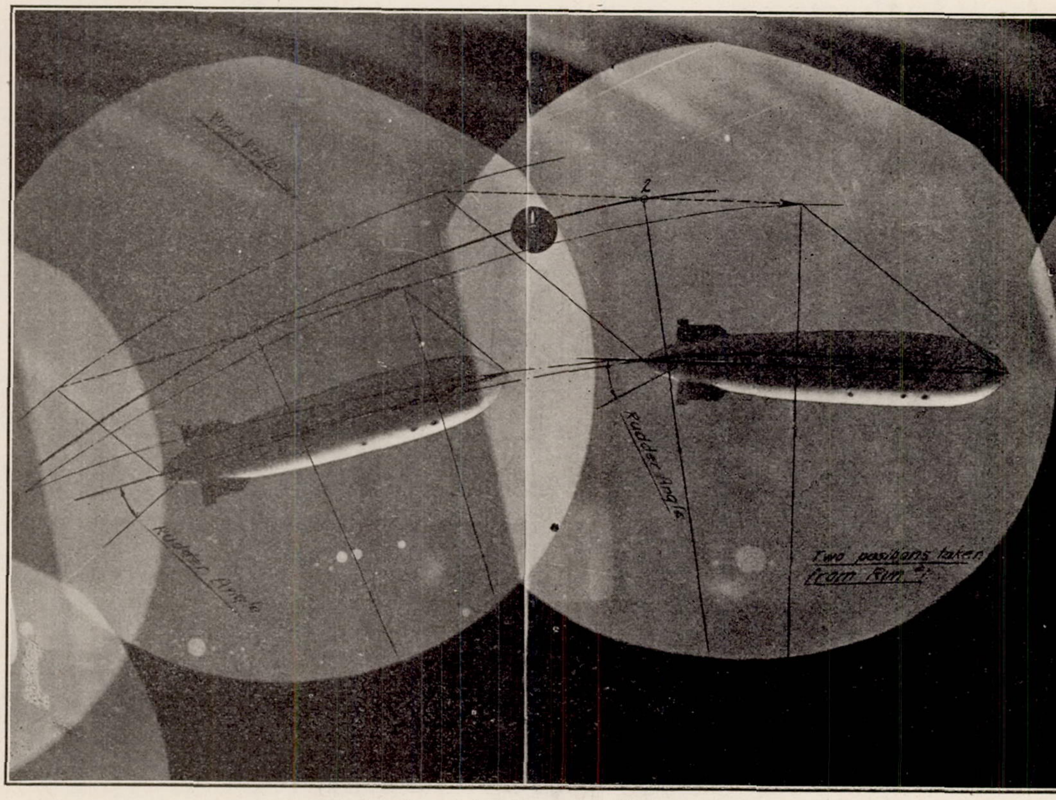


FIG. 4.—Diagram showing method of laying out data

The scale of the drawing was determined through the relation of the length of the image to the length of the ship. From the wind velocity and the scale of the drawings a vector representing the wind displacement per exposure was determined. Each position of the ship was then corrected for the wind displacement and the curves drawn as before. This procedure is illustrated in Figure 4. From these latter curves were obtained the instantaneous radii, the position of zero angle of yaw, the angle turned through, and, the time between exposures being known, the velocity of the airship (Figs. 5 and 6). These have been plotted in Figure 7.

The focal length of the lens and the relation of length of the ship to length of the image being known, the geometric altitude was determined for each run.

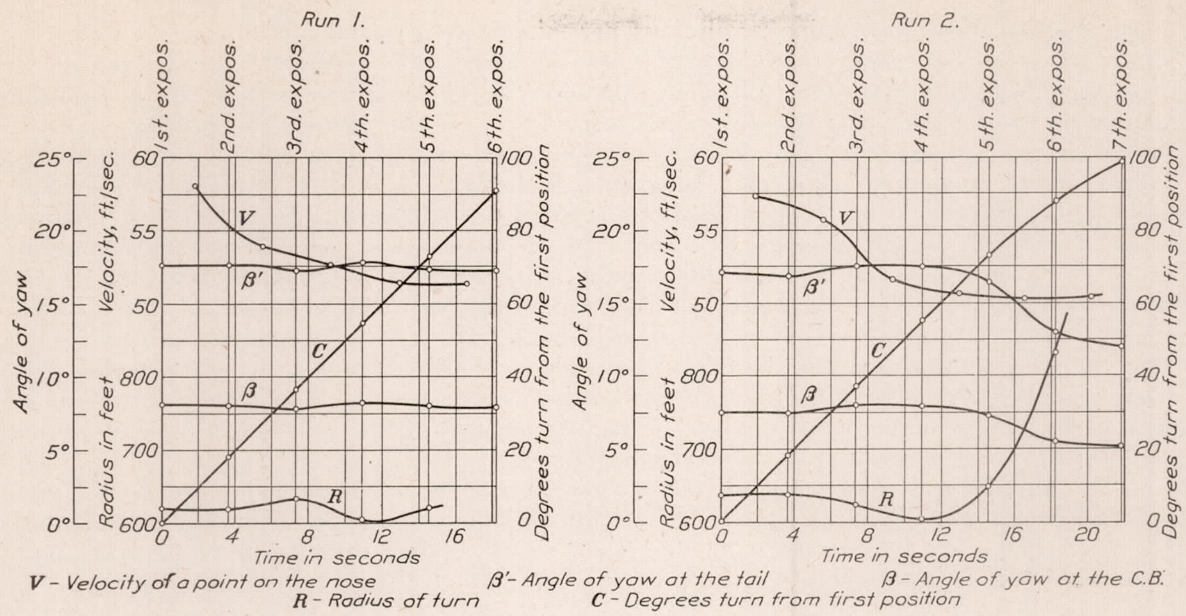


FIG. 7

RESULTS

The results of the two circling flights are contained in Table II and Figure 7. It is evident that exposure No. 6 in Run 2 (Fig. 7) was obtained when the airship was coming out of a turn and for that reason the instantaneous radius of that position was not used in computing the diameter of the turning circle. The turning diameter for the first run was 1,240 feet, corresponding to a turning coefficient $\left(\frac{\text{diameter of circle}}{\text{length of airship}}\right)$ of 6.4, and for the second run was 1,275 feet, corresponding to 6.5. Both turns were very steady, the maximum variation in radius being 41 feet in Run 2. The steadiness of the turn is indicated very well by the loci of the instantaneous centers in Figures 5 and 6.

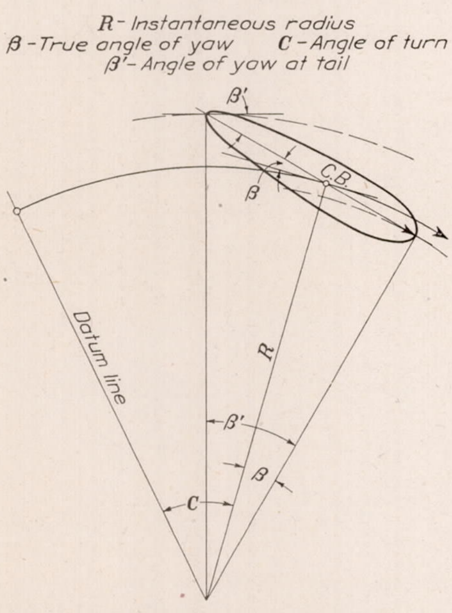


FIG. 3.—Diagram showing angles measured

The outstanding feature of the investigation was the determination that the position of zero angle of yaw was at the nose of the airship in all cases; i. e., the axis of the airship was tangent to the path at the nose. The distance between the center of buoyancy and the position of zero angle of yaw is R sine β (Fig. 3) and for small values of β, such as encountered here, is $R\beta$. This point coming at the nose in all cases seems to indicate that the product $R\beta=$constant and agrees in this respect with results previously determined.[1] However, this may be considered as a check on the previous work only to a very limited extent, inasmuch as the turns investigated here were so similar in nature that no general conclusions can be drawn from them.

CONCLUSIONS

This method is a very accurate and simple means of determining turning characteristics of an airship. The advantages over the method previously used, that of obtaining the data from the ship itself, are obvious. The data are all recorded simultaneously with the exception

[1] R. & M. No. 716.

of the rudder angle and engine revolutions per minute, and readings of the latter, taken in flight, can easily be synchronized with the data obtained on the ground. In this particular experiment the rudder position was shown on some of the photographs, but, due to lighting conditions and the fact that there was no contrast between the color of the envelope and the rudder, it was not shown in all cases. For further work of this nature the lower edge of the rudder should be painted some color contrasting with that of the body. If it were desired to maintain a constant rudder angle at all times it could be accomplished by means of a Telautograph instrument, which measures the angles of a control surface and electrically communicates the values to a visible indicating instrument in the cockpit. By manipulating the rudder wheel to keep this reading constant a constant rudder setting would be obtained.

It would be of great advantage in future tests to have radio communication between the ship and the ground in order to direct the operation of the airship and to synchronize data. A narrow-angle lens was used in these experiments but one with a wide field would be preferable. This would enable complete turns to be recorded without flying at excessive altitudes or requiring elaborate piloting of the ship over a certain point.

This method has proved so satisfactory that it is recommended that more work of the same nature in the form of a complete investigation of the turning characteristics of an airship be undertaken. With a few slight modifications in the shutter the method is adaptable also to investigating maneuverability of an airplane.

TABLE I

OBSERVED DATA

	Run 1	Run 2
Engine revolutions per minute	1,000	1,000.
Barometric altitude	2,900 feet	3,000 feet.
Wind velocity	14.3 miles per hour	14.3 miles per hour.
Focal length of lens	48 inches	48 inches.
Time between exposures	3. 64 seconds	3.64 seconds.
Length of image	3.25 inches	3.12 inches.
Length of airship	195 feet	195 feet.
Location of C. B. from nose	85 feet	85 feet.

COMPUTED DATA

	Run 1	Run 2
Geometric altitude	$\frac{195 \times 48}{3.25}=2,880$ feet	$\frac{195 \times 48}{3.12}=3,000$ feet.
Scale of displacement drawing	$\frac{195}{1.11}=1$ inch $=175$ feet	$\frac{195}{1.03}=1$ inch $=191$ feet.
Wind component (per exposure)	$14.3\times\frac{88}{60}\times3.64=76.4$ feet	76.4 feet.

TABLE II

RESULTS—RUN 1

Position	0	1	2	3	4	5
Instantaneous radius (feet)	626	626	641	611	629	629
Angle of yaw at tail (degrees)	17. 5	17. 5	17. 2	17. 8	17. 3	17. 2
Angle of yaw at C. B. (degrees)	8	8	7. 8	8. 1	7. 9	7. 8
Angle of turn (degrees)	0	18	37	55	73	91
Length of arc between successive positions (degrees)		211. 8	196	191. 4	186	186. 6
Velocity (mean), between successive positions (foot/sec.)		58. 1	53. 8	52. 6	51. 2	51. 2

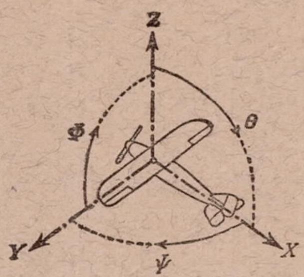
$$\text{Turning coefficients}=\frac{\text{mean diameter of turning circle}}{\text{length of airship}}=6.4 \text{ for Run 1.}$$

RESULTS—RUN 2

	0	1	2	3	4	5	6
Instantaneous radius (feet)	643	644	618	612	663	841	
Angle of yaw at tail (degrees)	17	16. 8	17. 5	17. 5	16. 4	13	12
Angle of yaw at C. B. (degrees)	7. 5	7. 45	8	8	7. 4	5. 6	5. 1
Angle of turn (degrees)	0	19. 5	36. 5	56	72	88	99
Length of arc between successive positions (degrees)		208. 5	202	187	185	184	184
Velocity (mean), between successive positions (foot/sec.)		57. 3	55. 7	51. 6	50. 7	50. 5	50. 5

$$\text{Turning coefficients}=\frac{\text{mean diameter of turning circle}}{\text{length of airship}}=6.5 \text{ for Run 2.}$$

○



Positive directions of axes and angles (forces and moments) are shown by arrows.

Axis.		Force (parallel to axis) symbol.	Moment about axis.			Angle.		Velocities.	
Designation.	Symbol.		Designation.	Symbol.	Positive direction.	Designation.	Symbol.	Linear (component along axis).	Angular.
Longitudinal....	X	X	rolling.....	L	$Y \longrightarrow Z$	roll.....	Φ	u	p
Lateral..........	Y	Y	pitching...	M	$Z \longrightarrow X$	pitch....	Θ	v	q
Normal..........	Z	Z	yawing.....	N	$X \longrightarrow Y$	yaw.....	Ψ	w	r

Absolute coefficients of moment

$$C_l = \frac{L}{q\,b\,S} \quad C_m = \frac{M}{q\,c\,S} \quad C_n = \frac{N}{q\,f\,S}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS.

Diameter, D
Pitch (a) Aerodynamic pitch, p_a
(b) Effective pitch, p_e
(c) Mean geometric pitch, p_g
(d) Virtual pitch, p_v
(e) Standard pitch, p_s
Pitch ratio, p/D
Inflow velocity, V'
Slipstream velocity, V_s

Thrust, T
Torque, Q
Power, P
(If "coefficients" are introduced all units used must be consistent.)
Efficiency $\eta = T\,V/P$
Revolutions per sec., n; per min., N
Effective helix angle $\Phi = \tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS.

1 HP = 76.04 kg. m/sec. = 550 lb. ft/sec.
1 kg. m/sec. = 0.01315 HP
1 mi/hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi/hr.

1 lb. = 0.45359 kg.
1 kg. = 2.20462 lb.
1 mi. = 1609.35 m. = 5280 ft.
1 m. = 3.28083 ft.