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NOTES ON MAXIMUM AIRPLANE ANGULAR VELOCITIES

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CONFIDENTIAL BULLETIN

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INTRODUCTION

Considerable interest has been expressed recently in obtaining data regarding the maximum angular velocities to which aircraft are subjected in flight. A consideration of information of this nature is particularly important in designing high-speed rotating machinery carried by the airplane, since this machinery must be constructed to withstand the gyroscopic couple created by the combined angular velocities of the rotating parts of the machinery and of the airplane - provided, of course, that the respective planes of rotation do not coincide.

Designers of propellers and turbosuperchargers are especially interested in having accurate data on maximum airplane angular velocities, since the high rates of rotation of these components, together with any considerable angular motion of the airplane, result in rather large gyroscopic loads. In addition to these major airplane components, numerous small electric motors and gears must be designed to withstand the forces created by pitching, rolling, or yawing of the airplane.

VARIATION BETWEEN DESIGN VALUES

The need for additional information on this subject is indicated by the fact that different design values of maximum angular velocity are used by various organizations in the aviation industry. One large manufacturer uses a design value of 4 radians per second while another uses a value of 6 radians per second (these figures include a safety factor of 1.5). Other groups use still lower design values. As a result of the above condition, some organizations are apprehensive that their specification may be too small and structural failures may occur, while others are concerned over the possibility that they may be penalizing their design by the addition of useless weight.

PURPOSE OF REPORT

This situation led the Subcommittee on Recovery of Power from Exhaust Gas, which is concerned with high-speed exhaust turbine design, to request that available information on this subject be summarized and placed in convenient form. The object of this bulletin, then, is to present existing data on maximum rates of airplane angular motion, measured in both flight and model tests, to serve as a guide for the selection of appropriate design values. However, it is not the purpose of this paper to recommend any specific value.

SOURCES OF INFORMATION

The information contained herein was selected from data accumulated over a period of years in various flight and model tests reported by the NACA. An indication of foreign design values has been obtained from British and German sources. In order to obtain comments and information from persons familiar with various phases of the subject, the following members of the Committee's Langley Memorial Aeronautical Laboratory staff have been consulted: Messrs. M. N. Gough, H. A. Pearson, Philip Donley, and H. I. Johnson, of the Flight Research Section; and Mr. Oscar Seidman of the Free-Spinning Wind Tunnel Section.

DISCUSSION

Angular rates of rotation are experienced by aircraft in maneuvers involving pitching, rolling, or yawing, or combinations of these motions, such as spinning. In general, the greatest rates of angular motion are encountered in stalled rather than unstalled maneuvers. It may be expected, then, that greater gyroscopic forces will be imposed on rotating machinery during spins than during snap rolls, dive pull-outs, and similar unstalled maneuvers.

The angular rate of rotation of an airplane in roll is given by the commonly used design criterion $pb/2V$,
where

p rate of rolling, radians per second

b wing span, feet

V forward velocity of airplane, feet per second

(for axis nomenclature, see fig. 1)

The numerical value of pb/2v is usually known for a given airplane, and the rate of rolling may thus be obtained from this expression. For almost all combat aircraft the value p is less than 2 radians per second, and the highest rolling velocity obtainable with latest-type fighter airplanes is approximately 3 radians per second. The latter figure is based on extrapolation of low-altitude flight measurements on two aircraft having modified aileron control systems giving increased effectiveness.

It may be expected that maximum rates of roll can be attained at any altitude up to near the ceiling of a given airplane, since high forward velocity may be obtained at altitude by diving prior to entering a roll. This means that turbosupercharger installations on high-altitude aircraft may be subjected to a large angular velocities while operating at near or maximum turbine revolutions per minute.

Considerably greater rates of rotation are encountered in spins as compared with rolls, and for this reason, the bulk of the data included in this report deal with spin tests. Data accumulated during tests in the NACA Free-Spinning Wind Tunnel of 20 representative monoplanes were presented in reference 1. The Spin Tunnel Section at LMAL has investigated about 100 specific models and has obtained data on angular velocities in each case. These data have been examined to find cases where unusually high values of angular velocity were encountered. Table I lists values exceeding any reported in reference 1 for any type airplane, while table II lists high values for various type military aircraft. These data supplement the data presented in reference 1.

Table III contains data taken from various flight investigations conducted by the NACA and reported in references 2 to 8. While there is little full-scale information available for specific airplanes for comparison with model tests, on the basis of fairly complete data for two biplanes and limited data for three monoplanes, it appears that agreement between flight and model tests is reasonable. This point is discussed in some detail in reference 8.

The above data applies to upright spins. Angular velocities obtained for inverted spins in model tests are about the same as values obtained in upright spins. No flight measurement of velocities in inverted spins are available.

In general, the components of velocity about the longitudinal and normal body axes of airplanes in spins are about equal. For steep spins, however, rotation is chiefly about the longitudinal axis, and for flat spins the maximum rotation is about the normal axis. In all cases the rate of rotation about the lateral axis is small.

Although intentional spins are almost always performed with the engine idling, it is conceivable that spins could be entered accidentally at full engine power. At extreme altitudes during violent maneuvers such as might be employed in combat, it is possible if not probable that spins may occasionally accidentally occur. In this case some pilots may maintain full engine power to assist in regaining control of the airplane. The possibility of spinning under full power conditions at altitude, although rather remote, is, nevertheless, real.

The rates of rotation of single-engine airplanes in spins tend to be slightly higher than the rotating speeds of two-engine aircraft. This fact is indicated in reference 9 which gives rates of rotation in spins from 2.6 to 4.8 radians per second for a group of single-engine airplanes and from 1.9 to 3.8 for a group of multiengine airplanes.

Since angular velocities experienced in pitching maneuvers are not so great as those experienced in spinning and rolling, pitching maneuvers may be neglected in this study. Reference 12, which gives data obtained from tests of seven airplanes, does not list any angular pitching motion greater than 2 radians per second.

FOREIGN PRACTICE

Available published information indicates that both German and English design practice is based on an anticipation of maximum angular velocities of approximately 3 radians per second, which, with a safety factor of 2, gives a design value of 6 radians per second.

German airplane strength requirements described in detail in reference 10 state that angular velocities used in the design of engine mounts, wings, and tail surfaces, should be obtained from the following formulas:

$$\omega_x = \pm 0.35 \ \frac{V_h}{b} \qquad (1)$$

$$\omega_x = \pm 0.10 \ \frac{V}{b} \qquad (2)$$

$$\omega_Y = \frac{gn}{V_A} \tag{3}$$

where

ω_X, ω_Y angular velocities about the X and Y axes, radians per second

V_h maximum indicated airspeed in level flight, feet per second

V design diving indicated airspeed, feet per second

V_A indicated airspeed at which high angle of attack load factor is obtained, feet per second

b span of airplane, feet

g acceleration of gravity, feet per second per second

n high angle of attack load factor

Examples given in this reference indicate that the maximum angular velocity expected is about 3 radians per second. This value, with a safety factor of 2, gives a design value of 6, which is the figure used by certain American manufacturers.

English practice is described in reference 11 which states that in estimating the loads occurring on an airplane in a spin the yawing angular velocity should be chosen in accordance with the following:

(a) Single-engine training airplanes, 3.0 radians per second

(b) Twin-engine training airplanes, 2.5 radians per second

(c) Airplanes other than trainers, the service duties of which involve acrobatic manouvers:

Single-engine, 2.5 radians per second

Twin-engine, 2.0 radians per second

(d) Airplanes other than trainers, the service duties of

whic
which do <u>not</u> involve acrobatic maneuvers $0.5 \frac{g}{V_s} \sqrt{n}$

where

V_s stalling speed in level flight (flaps up)

This reference states that, for airplanes other than trainers the service duties of which involve acrobatic maneuvers (group (c) above), the spin may be regarded as occurring only accidentally. The designer is directed to eliminate the possibility of catastrophic failure in the spin; that is, failure of the engine mount, for example, must not occur, but compliance with proof-load conditions need not be considered.

An ultimate factor of 2.0 is required throughout the structure under the forces resulting from the above rates of rotation.

In discussing the gyroscopic forces on the engine-propeller installation, it is pointed out that the mean gyroscopic couple is $I\omega\Omega$ where

I polar moment of inertia of the propeller, slugs per square foot

ω angular velocity of the propeller, radians per second, appropriate to the specified revolutions per minute,

that is, $\frac{2}{60} \times$ (propeller) (rpm)

Ω angular velocity of the airplane as a whole

The actual value of the gyroscopic couple used for propeller-stress calculations depends on the number of propeller blades. For three or more blades the propeller behaves as a simple gyroscope, that is, a rotating uniform disk, and the resultant gyroscopic couple has a steady value $I\omega\Omega$.

For a propeller with only two blades the couple varies in magnitude and direction during a revolution. In the plane in which the steady gyroscopic couple would act for a simple gyroscope, the actual couple fluctuates between 0 and $2I\omega\Omega$, so that the latter value is used for stress determinations. There is also a couple in the plane at right angles to the above which fluctuates between $-I\omega\Omega$ and $I\omega\Omega$.

The actual couples to be taken are stated in the stressing cases. Each condition to be investigated, however, is frequently the worst of a number of possibilities and some selection has to be made. For convenience the gyroscopic couple is always assumed to be given by the formula $I\omega\Omega$, and the increase associated with a two-blade propeller is obtained by adjustment of the value assumed for the rate of rotation Ω of the airplane as a whole.

CONCLUDING REMARKS

A brief study of the British practice outlined above reveals little new information. Although no mention is made of difficulties arising from gyroscopic loads on superchargers, this factor has been given consideration in establishing specifications for engine mounts and propellers.

It is possible that the rotating rates of machinery carried by the airplane and the rotating rates of aircraft, which have been increased during recent years, are just approaching the point where difficulties may be experienced.

Although the gyroscopic couple is of primary concern to stress analysts studying rotating parts, designers should not overlook the fact that in a spin there is also an acceleration on various parts of the airplane because of their displacement from the axis of spin rotation. The staff of the Free-Spinning Wind Tunnel have observed accelerations in a steep spin as high as 3.5g along the airplane normal axis. Lower accelerations are encountered in flat spins.

Some of the angular velocities reported from model tests are extremely high. Rates of rotation thus measured are larger than the design values employed by any manufacturer, yet production parts such as exhaust gas turbines are generally giving satisfactory service. In such cases, the question arises as to why structural failures have not occurred in flight. Several answers to this question may be offered. In the first place, there is no assurance that some failures have not occurred. A few failures of exhaust gas turbine shafts have pointed toward gyroscopic forces as the possible cause. However, this point has not been proved, and there is certainly no indication of widespread trouble, as might be predicted in view of data presented from model tests.

Another answer to the question is that cases of full power spins during which the turbine was running at maximum revolutions per minute are extremely rare, if not nonexistent, and turbine wheels have thus not been subjected to the most severe possible gyroscopic forces.

CONCLUSIONS

It appears that in the great majority of cases, a maximum angular velocity design factor of 6 radians per second is adequate to provide for all intentional maneuvers and all except the most severe accidental maneuvers.

Despite the apparent absence of trouble from this factor at the present time, the trend toward ever-increasing rates of rotation of turbines and similar aircraft components may eventually lead to serious trouble in this respect. New airplanes with more effective control surfaces and capable of higher rates of rotation, which will soon be in production, may produce greater gyroscopic loads than have been experienced heretofore.

It may be possible that future evidence of the occurrence of structural failures, or the immediate possibility of such failures resulting from this cause may make it necessary to conduct a full-scale investigation of this factor, although such flight tests are not believed to be necessary at this time.

National Advisory Committee for Aeronautics,
Washington, D. C.

REFERENCES

1. Soulé, Hartley A.: Angular Velocities in Spins as Indicated by Model Tests in the NACA Free-Spinning Wind Tunnels. NACA C.B., Mar. 1942.

2. Rhode, Richard V.: The Pressure Distribution Over the Wings and Tail Surfaces of a PW-9 Pursuit Airplane in Flight. Rep. No. 364, NACA, 1930.

3. Dearborn, C. H., and Kirschbaum, H. W.: Maneuverability Investigation of the F6C-3 Airplane with Special Flight Instrument. Rep. No. 369, NACA, 1930.

4. Dearborn, C. H., and Kirschbaum, H. W.: Maneuverability Investigation of an F6C-4 Fighting Airplane. Rep. No. 386, NACA, 1931.

5. Scudder, Nathan F.: A Flight Investigation of the Spinning of the NY-1 Airplane with Varied Mass Distribution and Other Modifications, and an Analysis Based on Wind-Tunnel Tests. Rep. No. 441, NACA, 1932.

6. Scudder, N. F.: A Flight Investigation of the Effect of Mass Distribution and Control Setting on the Spinning of the XN2Y-1 Airplane. Rep. No. 484, NACA, 1934.

7. Scudder, N. F., and Seidman, Oscar: A Flight Investigation of the Spinning of the F4B-2 Biplane with Various Loads and Tail Surfaces. Rep. No. 529, NACA, 1935.

8. Seidman, Oscar, and McAvoy, William H.: Spin Tests of a Low-Wing Monoplane in Flight and in the Free-Spinning Wind Tunnel. T.N. No. 769, NACA, 1940.

9. Seidman, Oscar, and Kamm, Robert W.: Multiengine Airplane Spin Characteristics as Indicated by Model Tests in the Free-Spinning Wind Tunnel. NACA A.R.R., July 1942.

10. Siegel, von Gerhard: Angewandte Lastannahmen über Grösse and Angriff von Luftkräften an Flugzeugen. Berlin-Charlottenburg, C.J.E. Volckmann Nachfolger E. Wette, 1938.

11. Design Requirements for Aeroplanes for the Royal Air Force, Ministry of Aircraft Production Air Publication No. 970 with amendments to Amendment List 15.

12. Donley, Philip: The Forces and Moments on Airplane Engine Mounts. T.N. No. 487, NACA, 1936.

TABLE I

MAXIMUM ANGULAR VELOCITIES IN SPINS, OBTAINED FROM MODEL SPIN TEST DATA

[All data are for the rudder-with spins]

Airplane	Weight (lb)	Power (hp)	α[a] (deg)	ϕ[b] (deg)	Full-scale angular velocities[c] Ω (rad/sec)	r (rad/sec)	p (rad/sec)	q (rad/sec)	Control setting Ailerons	Elevator	Airplane condition	Airplane	Manufacturer
1	8984	1125 at 18,000 ft	13	-1	6.97	1.57	6.80	-0.122	With	Down	(d)	XP-39E	Bell
2	3387	-	82	2	6.65	6.59	.92	.232	Neutral	Neutral	(e)	XP-77	Bell
	3387	-	46 to 65	-49 to 15	2.95	[f]2.05 to 1.25	2.12 to 2.67	-2.230 to .761	Against	Up	(g)	XP-77	Bell

[a] Angle between the vertical and the thrust axis of the airplane.

[b] Angle of the right wing axis below the horizontal.

[c] p, q, and r are angular velocities about the body longitudinal, lateral, and normal axes, respectively.

[d] Normal loading, flaps and landing gear down.

[e] Normal loading.

[f] Accuracy of r, p, and q is questionable since the values were determined by using extreme values of α and ϕ together with average Ω.

[g] Center of gravity 5 percent M.A.C. forward of normal location.

TABLE II.- SUMMARY OF ANGULAR VELOCITIES IN SPINS

[Cases where component angular velocities are higher in a given airplane category than reported in reference; all data are for the rudder-with spins.]

Reference: "Angular Velocities in Spins as Indicated by Model Tests in the NACA Free-Spinning Wind Tunnels," by Hartley A. Soule, C.B., NACA, March 1942.

Air-plane	Weight (lb)	Power (hp)	α (deg)	ϕ (deg)	Full-scale angular velocities Ω (rad/sec)	r (rad/sec)	p (rad/sec)	q (rad/sec)	Control setting Ailerons	Ele-vator	Airplane condi-tion	Airplane	Manufacturer
Single-engine training monoplanes													
1	4,614	-	30	8	3.07	1.53	2.66	0.427	N	U	(a)	BT-9A	North American
2	3,290	320 at sea level	33	14	2.93	1.60	2.45	.710	N	U	(a)	XN5N-1	Naval Aircraft
2	3,290	320 at sea level	33	-17	3.60	1.96	3.02	-1.055	A	D	(a)	XN5N-1	Naval Aircraft
3	4,467	-	22	3	4.85	1.82	4.50	.254	W	D	(b)	BT-14	North American
Twin-engine training monoplanes													
1	12,197	-	26	-9	3.39	1.49	3.05	-0.530	A	D	(c)	XAT-15	Stearman
Single-engine fighting monoplanes													
1	13,633	-	-	-	5.59	-	-	-	N	U	(a)	XF14C-2	Curtiss
1	3,387	-	39 to 59	-20 to 30	3.70	[d]2.33 to 3.17	2.87 to 1.91	-1.265 to 1.850	N	U	(a)	XP-77	Bell
2	3,387	-	79	2	4.96	4.87	.95	.173	N	U	(a)	XP-77	Bell
2	3,387	-	46 to 65	-49 to 15	2.95	[d]2.12 to 2.67	2.05 to 1.25	-2.230 to .761	A	U	(a)	XP-77	Bell
	3,387	-	82	2	6.65	6.59	.92	.232	N	N	(a)	XP-77	Bell
3	8,984	1125 at 18,000 ft	13	-1	6.97	1.57	6.80	-.122	W	D	(f)	XP-39E	Bell
Twin-engine fighting monoplanes													
1	11,889	-	43	0	4.02	2.74	2.94	0	N	U	(a)	V-173	Vought-Sikorsky
1	11,889	-	65	1	5.27	4.78	2.23	.092	W	D	(g)	V-173	Vought-Sikorsky
1	6,283	-	43	1	5.52	3.76	4.04	.097	W	U	(h)	V-173	Vought-Sikorsky
1	6,283	-	38	7	5.03	3.10	3.96	.612	W	N	(i)	V-173	Vought-Sikorsky
2	20,260	1700 each at 25,000 ft	49	2	1.95	1.47	1.28	.068	N	U	(a)	XP-67	McDonnell
Single-engine scout and observation monoplanes													
1	5,097	-	28	-3	2.86	1.34	2.52	-0.149	N	U	(a)	O-52	Curtiss
1	5,097	-	34	-6	3.45	1.93	2.86	-.361	N	N	(a)	O-52	Curtiss
1	5,097	-	33	-17	3.39	1.85	2.85	-.993	A	D	(a)	O-52	Curtiss
2	6,320	-	64	-	3.00	2.69	1.32	-	A	D	(j)	XSE-1	Bellanca
3	4,675	-	22	1	3.27	1.22	3.03	.057	N	N	(a)	XOS2U-1	Chance-Vought

Single-engine bomber and torpedo monoplanes													
1	12,677	-	65	-1	2.64	2.40	1.12	-0.046	N	U	(a)	SB2C-1	Curtiss
2	7,615	950	18	-6	5.89	1.82	5.60	-.615	W	D	(k)	SBD-1	Douglas
2	7,615	950	21	-5	6.60	2.37	6.16	-.575	W	D	(l)	SBD-1	Douglas
2	7,615	950	72	-1	4.29	4.09	1.33	-.075	N	D	(m)	SBD-1	Douglas
Twin-engine bomber monoplanes													
1	25,730	-	27	-2	2.45	1.11	2.18	-0.085	N	U	(a)	A-26	Douglas
2	19,050	1275 each at 12,000 ft	43	8	3.10	2.12	2.27	.431	W	N	(f)	A-20	Douglas
2	19,050	1275 each at 12,000 ft	36	13	2.36	1.39	1.91	.530	W	U	(f)	A-20	Douglas
3	26,594	-	22	2	3.80	1.42	3.52	.132	1/2 W	D	(a)	B-26	Martin
Twin-engine transports and cargo airplanes													
1	41,945	1600 each at 13,500 ft	23	-2	2.07	.81	1.91	-0.072	N	U	(a)	XC-82	Fairchild
1	41,945	1600 each at 13,500 ft	22	-1	2.95	1.11	2.74	-.052	N	U	(f)	XC-82	Fairchild
1	41,945	1600 each at 13,500 ft	26	-9	2.26	.99	2.03	-.353	A	D	(n)	XC-82	Fairchild
2	25,554	-	35	-7	1.82	1.04	1.49	-.222	N	U	(a)	DC-3	Douglas
2	25,554	-	68	-6	2.20	2.04	.82	-.230	A	N	(o)	DC-3	Douglas
Four-engine transports and bombers													
1	120,000	-	15 to 75	-1 to 5	2.89	[d]0.75 to 2.80	2.80 to 0.75	-0.050 to 0.252	N	U	(a)	XB-29	Boeing
1	120,000	-	15 to 75	-6 to 13	2.07	[d]0.54 to 2.00	2.00 to 0.54	-.216 to 0.466	N	U	(p)	XB-29	Boeing

[a]Normal loading. [b]Normal loading, flaps 45° down. [c]Center of gravity 4 percent M.A.C. forward of normal location.

[d]Accuracy of r, p, and q is questionable since the values were determined by using extreme values of α and ϕ together with average Ω. [e]Center of gravity 5 percent M.A.C. forward of normal location.

[f]Normal loading, flaps and landing gear down. [g]Normal loading, leading edge stabilizers 30° down.

[h]Mass added along wings. [i]Intermediate loading.

[j]Moments of inertia A and C decreased 20 percent A and moments of inertia B and C increased 20 percent B.

N means Neutral, A Against, W With, U Up, D Down.

TABLE II (Concluded)

Air-plane	Weight (lb)	Power (hp)	α (deg)	Ø (deg)	Full-scale angular velocities Ω (rad/sec)	r (rad/sec)	p (rad/sec)	q (rad/sec)	Control setting Ailerons	Elevator	Airplane condition	Airplane	Manufacturer
Single-engine training biplanes													
1	1,762	-	60.5	-	3.46	3.01	1.71	-	N	U	(a)	XN2Y-1	Consolidated
2	2,704	-	40	-3	2.28	1.47	1.75	-0.119	N	U	(a)	XN3N-2	Naval Aircraft
3	2,847	200 at sea level	62	21	2.49	2.20	1.17	.892	N	U	(q)	NB-1	Boeing
3	2,544	200 at sea level	61	9	3.60	3.15	1.75	.564	W	N	(r)	NB-1	Boeing
3	2,544	200 at sea level	61	19	3.25	2.84	1.56	1.055	W	U	(a)	NB-1	Boeing
4	2,803	235 at sea level	20	10	3.28	1.12	3.08	.570	W	N	(s)	N3N-3	Naval Aircraft
Single-engine fighting biplanes													
1	3,334	-	39	-	3.87	2.45	2.77	-	N	U	(t)	F4B-2	Boeing
1	2,915	-	37	-	3.67	2.22	2.93	1.404	N	U	(a)	F4B-2	Boeing
2	3,334	-	49	2	3.39	2.56	2.23	.118	N	U	(a)	XBFB-1	Boeing
3	3,782	-	59	3	3.96	3.39	2.04	.208	N	D	(f)	F2F-1	Grumman
Single-engine scout and observation biplanes													
1	5,023	550 at 5000 ft	43	-3	2.82	1.92	2.07	-0.147	N	U	(a)	XOSN-1	Naval Aircraft
1	5,299	550 at 5000 ft	53	-1	3.34	2.67	2.02	.058	A	N	(q)	XOSN-1	Naval Aircraft
1	5,299	550 at 5000 ft	25	7	4.08	1.73	3.70	.497	W	N	(q)	XOSN-1	Naval Aircraft
2	5,356		21	2	5.21	1.87	4.86	.182	W	N	(q)	XOSS-1	Stearman

[k]Moments of inertia A and C increased 15 percent A.
[l]Normal loading, canopy open, landing gear down.
[m]Center of gravity 6 percent M.A.C. forward of normal location.
[n]Center of gravity 10 percent M.A.C. rearward of normal location. Moments of inertia B and C increased 52 percent B.
[o]Moments of inertia B and C increased 25 percent B.
[p]Moments of inertia A and C decreased 53 percent A.
[q]Normal seaplane loading.
[r]Moments of inertia A and C increased 30 percent A, center of gravity 5 percent M.A.C. forward of normal location.
[s]Moments of inertia B and C increased 30 percent B. [t]Normal carrier loading.

TABLE III

HIGH ANGULAR VELOCITIES MEASURED IN FLIGHT

Airplane	Ω (rad/sec)	Maneuver	Source of data
Boeing PW-9	2.7 2.7	Roll Spin	Reference 2 (1930)
Curtiss F6C-3	4.8 3.95	Roll Spin	Reference 3 (1930)
Curtiss F6C-4	2.72 3.78	Roll Spin	Reference 4 (1931)
Consolidated NY-1	3.47	Spin	Reference 5 (1932)
XN2Y-1	4.62	Spin	Reference 6 (1934)
Boeing F4B-2	4.3	Spin	Reference 7 (1935)
North American BT9-A	3.28	Spin	Reference 8 (1940)

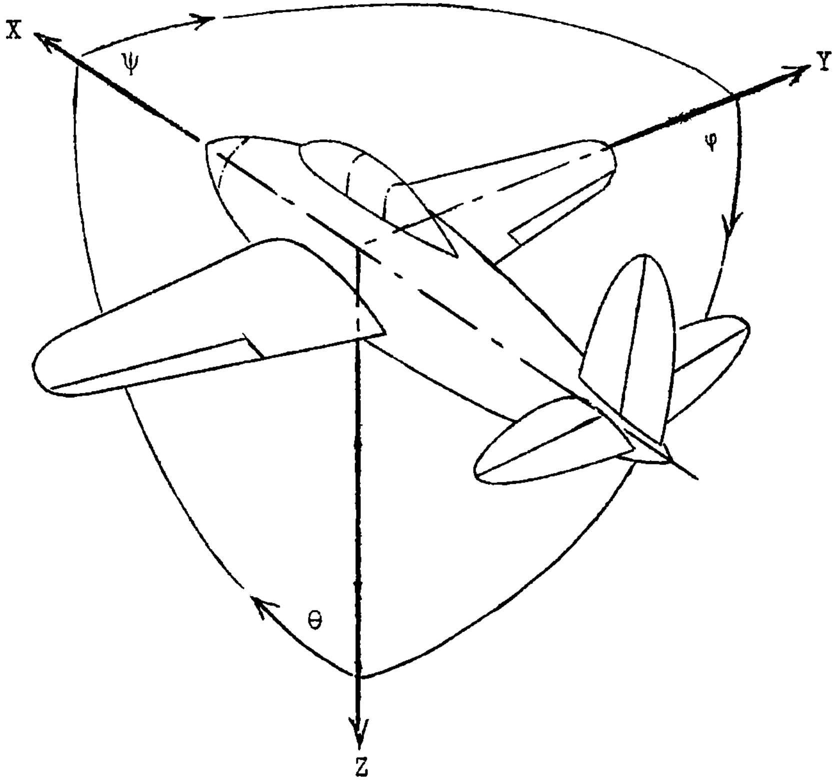

Figure 1.- Explanation of axes used in describing angular motion of aircraft.

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 ⟶ Z	Roll ---	φ	u	p
Lateral--------	Y	Y	Pitching----	M	Z ⟶ X	Pitch---	θ	v	q
Normal---------	Z	Z	Yawing------	N	X ⟶ Y	Yaw------	ψ	w	r