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RESEARCH MEMORANDUM

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Naval Medical Research Institute

AERODYNAMIC MEASUREMENTS MADE DURING NAVY INVESTIGATION OF HUMAN TOLERANCE TO WIND BLASTS

By Donald L. Loving

Langley Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

This report presents the aerodynamic measurements made during a Navy investigation conducted in the Langley 8-foot high-speed tunnel to determine the actual human tolerance to wind blasts. Those tests were made at the request of the Naval Medical Research Institute, Bethesda, Md., to obtain direct evidence of the forces involved when the human head is suddenly thrust into a rapidly moving air stream, as is the case in bail-outs from aircraft at high speeds, and also to determine the maximum speed considered safe for the unprotected face to be exposed to wind blasts.

INTRODUCTION

At the request of the Naval Medical Research Institute, Bethesda, Md., tests were made on two volunteer enlisted men (Navy) in the Langley 8-foot high-speed tunnel to determine the human tolerance to wind blasts. Since these tests were primarily medical in nature, this report contains only the results of aerodynamic measurements obtained during the test. All medical analysis has been prepared by Dr. R. M. Wilder of the Naval Medical Research Institute.

Previous tests have been made by the Germans to determine effects of air blasts on the human head (references 1 and 2). However, most of these tests were made using some kind of wide head board as a protective device, especially at the highest speeds. These head boards minimized the effect of the air blasts to a large degree.

The purpose of the investigation for which results are presented herein was to determine the effect of air blasts on the unprotected human face. Included in this report are the aerodynamic results of the

pressure measurements over a dummy forehead and the air-blast forces on the unprotected heads tested as obtained through the use of a strain gage attached to the head rest of the test apparatus.

APPARATUS

The human tolerance to wind blasts investigation was conducted in the Langley 8-foot high-speed tunnel which is a single-return closed-throat type. The tunnel speed is continuously controllable. A speed range, by small increments, from a Mach number of 0.04 to 0.65 was used for this test.

The tests were made at a tunnel section approximately 10 feet downstream from the regular Langley 8-foot high-speed-tunnel test section. The tunnel entrance door was removed and replaced with a curved steel plate having a 22- by 40-inch opening cut in its longitudinal center. The vertical plane above this hole was considered the test section for this investigation. Test results were obtained by elevating vertically the test configurations through the hole into the tunnel air stream (wind blast).

The elevating procedure was accomplished through the use of a test seat and carriage supplied by the Navy, and carriage tracks and supports made by the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics. The carriage and seat were elevated into the tunnel by from six to eight men lifting on a 3-inch outside-diameter pipe extending from side to side under the carriage frame. The complete moving assembly was counterweighted to facilitate ease of operation (fig. 1).

A velocity survey rake having 25 impact tubes and 10 static tubes was mounted vertically on the carriage plate in place of the test seat (fig. 2). The rake was secured in position so that the front of the impact tubes was in the same approximate vertical plane as would be occupied later by the human subjects. For the velocity calibration run, the carriage with the rake in place was elevated until the top impact tube was 29.5 inches from the floor of the tunnel. The top static tube was then 25.8 inches from the floor of the tunnel. The static tubes were in alternate positions among the impact tubes on the rake. Flexible tube connections were made between the rake tubes and a 10-foot tetrabromoethane manometer board. During the velocity survey run the manometer board tubes were read visually and also photographed for more accurate calculation of the velocities in the plane of the survey rake.

Woolen tufts were attached to the side of the velocity survey strut in order to determine the direction of air flow in the region of the area to be occupied by the human subjects and also to determine any disturbance to the air flow that might be caused by the hole in the tunnel floor (fig. 3).

Preliminary tests were made using a wooden dummy secured in the test seat. A soft balsa block was inlaid in the face of the dummy head to determine the kind, size, and amount of dirt expected to flow through the tunnel (fig. 4). The dummy head was not attached to the body of the dummy, but was mounted on a head rest behind which a strain gage was attached (fig. 5). The strain gage was of the beam type with four wire elements connected in the form of a Wheatstone bridge. When the bridge circuit was unbalanced a standard National Advisory Committee for Aeronautics recording galvanometer made a permanent force-time history on a light-sensitive film. In order to simulate the bending of the head backward at the neck, the dummy head was pivoted about a point 6.56 inches below the point of strain-gage attachment. Permanent strain-gage records were made each time the dummy was elevated into the air stream. The maximum upward travel of the dummy into the tunnel was limited by stops securely attached to the carriage tracks. In its maximum up position the top of the dummy head was 24 inches from the floor of the tunnel. Seven static tubes (orifices) were also mounted on the forehead of the dummy head in order to obtain local velocities over this portion of the head and thereby get some idea of the local velocities encountered by the guinea pigs strapped to the dummy forehead (fig. 5).

Preliminary tests were made on live guinea pigs with shaved backs put in place of the soft balsa block in the dummy face (fig. 6), and later secured to the dummy forehead with the shaved back of the guinea pig toward the air blast, (fig. 7). The guinea pigs were also strapped to the head of the dummy with the face of the guinea pig toward the air blast (fig. 8).

The human subjects were secured in the test seat through the use of a regulation shoulder harness and seat belt. A standard summer flight jacket, cloth helmet with a chin strap, and Navy issue dungarees were the only protective coverings used (fig. 9). No other special equipment was employed. A round flat head rest $5\frac{1}{2}$ inches in diameter was used behind the human subjects heads up to a Mach number of 0.25. Thereafter, a curved head rest was used (fig. 10). Both head rests used the same strain-gage attachment, and air-blast forces were recorded as well as length of time the human subjects were subjected to the air blast. When the test seat was elevated to its maximum position, the heads of the human subjects were approximately 24 inches from the tunnel floor. A visual check of the time of

exposure for the various configurations was made with the aid of a stop watch. It was decided that the limiting times of exposure would be 3 seconds for the dummy and guinea pigs and 2 seconds for the humans.

In order to obtain the maximum air-blast force at any given Mach number, it was decided to first bring the tunnel-empty velocity up to the desired Mach number and then quickly inject the subjects into the air stream. Since the tunnel velocity was not appreciably changed in the short length of time it took to elevate the subjects to the farthest up position, it was possible to obtain the maximum air-blast force on the heads before the stream velocity slowed down.

This method was used because, (1) greater length of exposure, in order to allow the tunnel velocity to reach some constant value, would have unduly endangered the lives of the volunteer subjects, and (2) the highest test Mach number obtainable would have been considerably lower than desired.

RESULTS

The tabulated pressure-distribution data obtained for the dummy forehead are presented in pressure-coefficient form in table I,

where

$$\text{Pressure coefficient} = \frac{\text{Local static pressure} - \text{free-stream static pressure}}{\frac{1}{2}\rho V^2}$$

The pressure-coefficient data are presented for a Mach number range from 0.237 to 0.618.

The force-time curves obtained from the wire strain gage attached to the head rest behind the dummy head are shown in figure 11. All the available force-time results for both volunteer subjects are presented in figures 12 and 13.

Figure 14 presents the maximum force variation with Mach number for the various heads tested. The dummy head strain-gage forces were

taken about the point of strain-gage attachment, 6.56 inches from the pivot point. However, it is believed that the forces would be more accurate if they were assumed to be acting through a point nearer the center of the dummy face. Therefore, the maximum forces have been corrected to indicate the results which would be obtained if the point of strain-gage attachment had been 4.5 inches from the pivot.

The variation of maximum force coefficient (based on head frontal area) with Mach number for the three heads tested is shown in figure 15.

A chart has been prepared (table II) from the faired maximum force coefficient values to show the approximate impact forces which can be expected to occur on the various heads tested at altitudes from sea level to 30,000 feet. These forces were obtained from:

$$F = C_{F_{max}} qS$$

where

$C_{F_{max}}$ maximum force coefficient (fig. 15)

q dynamic pressure at altitude for a constant speed $\left(\frac{1}{2} \rho V^2\right)$

S frontal area of each head
The dummy head frontal area - 0.53 square foot
The volunteer subject 1 - 0.272 square foot
The volunteer subject 2 - 0.246 square foot

Faired values of maximum force coefficient were used in order to minimize the error introduced through the human reactions.

DISCUSSION

Dummy pressures.- The tabulated pressure data (table I) show that the dummy forehead has a high sharp negative pressure peak just back of orifice 3 (fig. 5). This peak is followed by a large positive pressure gradient conducive to separation of the flow which in turn

caused the shaking and buffeting of the head witnessed during the test. This condition is aided by a like pressure distribution existing over the side of the dummy face because of the similarity between the shape of the dummy face-side and the forehead. A similar high suction pressure will occur over the forehead and face-side of the human beings. The buffeting of the human heads and irregular flapping of the facial skin can be attributed to the flow separation resulting from these high negative pressures.

Guinea pigs.- The first series of tests on the guinea pigs were made with them mounted upright in the middle of the dummy face. The pressure measurements of the dummy forehead indicated a positive pressure for this region. Because of the manner in which the guinea pigs were mounted, their backs were subjected to a dynamic pressure approximately 50 percent of the free-stream value. The flat dummy face gave the same type of protection to the guinea pigs as the wide head boards gave in the German tests in which reductions in dynamic pressure on the human face from 50 to 95 percent were obtained.

Guinea pigs were also tested on the forehead of the dummy. High induced flows approximately 35 percent higher than free-stream velocities were indicated for this region by the pressure measurements obtained.

Air-blast forces on dummy and human heads.- The primary purpose of the investigation was to determine the effect of air blasts on the unprotected head suddenly exposed to a rapidly moving air stream. Therefore, no protective devices were used to minimize any of the effects of exposure to high-velocity wind blasts. In order to determine the degree of air-blast force normal to the unprotected head, a strain gage was attached to the head rest bracket. Normally, the strain-gage records were read for every one-twentieth of a second and it is safe to assume that all the force values are correct within ± 2 pounds. In some cases, the records could not be read because of the lack of a visible trace on the film. In such cases the missing part of the record is indicated by a dashed line in the force-time curves. No attempt was made to determine any oscillations or fluctuations from the strain-gage records.

The data presented are from the actual values on the strain-gage film records even though scatter and other irregularities may be noted. The decrease in force with time shown in figures 11, 12, and 13 is the result of the slowing down of the tunnel speed after the subjects were injected into the air blast. The interval of time exposure was too short to enable the tunnel operator to adjust the speed to a constant value, but it was long enough for the energy loss in the air stream due to the wake behind the heads to cause a gradual decrease in the tunnel speed. The scatter in the human subjects data

should be expected rather than thought of as an exception, compared to the dummy results, because of the human reactions involved. In general, at all speeds the subjects either could have been pulling their heads away from the head rest or pushing against it. The effect of this fore and aft motion would be expected to show up in the results to a larger degree at the lower speeds before the force of the air blasts at the higher speeds exceeded the strength of the neck muscles. This assumption is borne out in the results of figure 14 where a large amount of scatter in the maximum forces may be noted for speeds up to a Mach number of 0.44. The data from a Mach number of 0.46 to 0.58 indicate that the strength of the neck muscles is being exceeded gradually since no scatter is apparent.

In figure 15 the maximum strain-gage forces have been reduced to coefficient form. The coefficients are based on head frontal areas (dummy = 0.530 square foot, subject 1 = 0.272 square foot, and subject 2 = 0.246 square foot) and can be compared to the drag coefficients of similarly shaped bodies. A sphere with a diameter of 7 inches would have a drag coefficient of approximately 0.20 at a Mach number of 0.58. A cylindrical turret, designated TB-R in reference 3, had a drag coefficient of 0.68 at a Mach number of 0.58. A maximum force coefficient of 0.86 at a Mach number of 0.58 was obtained for subject 1. The higher coefficient values for the human subjects are due to the helmet on the head, the flapping of the facial skin, and other irregularities of the human face. The large size and shape of the dummy head will account for its maximum force coefficient of 1.23 at a Mach number of 0.58.

The tests on the humans were concluded at a Mach number of 0.58 because it was considered unsafe to go to higher speeds. It was feared that some damage might be done to the human faces if larger forces were encountered at higher speeds. The maximum force recorded at the highest speed tested was about 95 pounds and the effective altitude in the tunnel at which this force was obtained was approximately 6350 feet.

It may be seen from table II that this force of 95 pounds will diminish to about 35 pounds for the same Mach number at 30,000 feet.

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National Advisory Committee for Aeronautics
Langley Field, Va.

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Approved: for John V Becker
John Stack
Chief of Compressibility Research Division

RCA

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2. Knackstedt: Investigation of the Effects of High Slipstream Pressures on the Human Body. Quoted from Wright Field Aero-Medical Report of Aug. 31, 1945.

3. Stack, John, and Moberg, Richard J.: Drag of Several Gunner's Enclosures at High Speeds. NACA ACR, July 1941.

TABLE I

DUMMY FOREHEAD PRESSURE COEFFICIENTS

Tube	Orifice location (in. from dummy face)	Pressure coefficient, P					
		M = 0.237	M = 0.301	M = 0.333	M = 0.365	M = 0.395	M = 0.421
1	0.03	0.11	0.07	0.08	0.09	0.04	0.09
2	.21	-.82	-.89	-.90	-.89	-.94	-.92
3	.65	-1.61	-1.77	-1.79	-1.82	-1.88	-1.85
4	1.33	-1.01	-1.11	-1.13	-1.15	-1.23	-1.20
5	2.11	-.41	-.50	-.51	-.53	-.61	-.59
6	3.45	-.14	-.21	-.21	-.22	-.28	-.24
7	4.86	-.09	-.13	-.13	-.14	-.19	-.14
		M = 0.444	M = 0.470	M = 0.495	M = 0.520	M = 0.541	M = 0.618
1	0.03	0.09	0.10	0.12	0.12	0.14	0.24
2	.21	-.91	-.89	-.87	-.85	-.85	-.73
3	.65	-1.86	-1.86	-1.86	-1.87	-1.89	-1.79
4	1.33	-1.21	-1.20	-1.20	-1.17	-1.17	-1.15
5	2.11	-.62	-.63	-.66	-.69	-.72	-.74
6	3.45	-.26	-.27	-.27	-.31	-.33	-.38
7	4.86	-.15	-.15	-.15	-.15	-.15	-.18

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TABLE II

AIR-BLAST FORCES ON HEADS AT ALTITUDE

M	Maximum force, F, lb						
	Sea level	5,000 ft	10,000 ft	15,000 ft	20,000 ft	25,000 ft	30,000 ft
Dummy forces taken about point 4.5 in. from pivot point							
0.40	123	101	83	70	57	46	36
.425	145	119	97	81	65	54	42
.45	166	138	112	94	76	63	49
.475	191	159	130	109	89	72	57
.50	219	181	150	124	101	82	64
.525	247	207	171	140	115	93	73
.55	283	233	192	158	129	104	84
.575	314	262	217	178	146	116	94
.60	355	294	244	200	164	131	104
.625	395	328	271	223	182	146	117
.65	441	365	302	247	202	162	130
Subject 1							
0.45	77	64	52	43	35	29	22
.475	81	68	55	46	37	31	24
.50	86	72	59	49	40	33	26
.525	94	79	65	53	44	35	28
.55	104	86	71	58	48	38	31
.575	114	95	78	64	53	42	34
.58	116	96	80	66	54	43	35
Subject 2							
0.475	101	84	69	57	47	38	30
.50	103	86	71	59	48	39	31
.525	109	91	75	62	51	41	32

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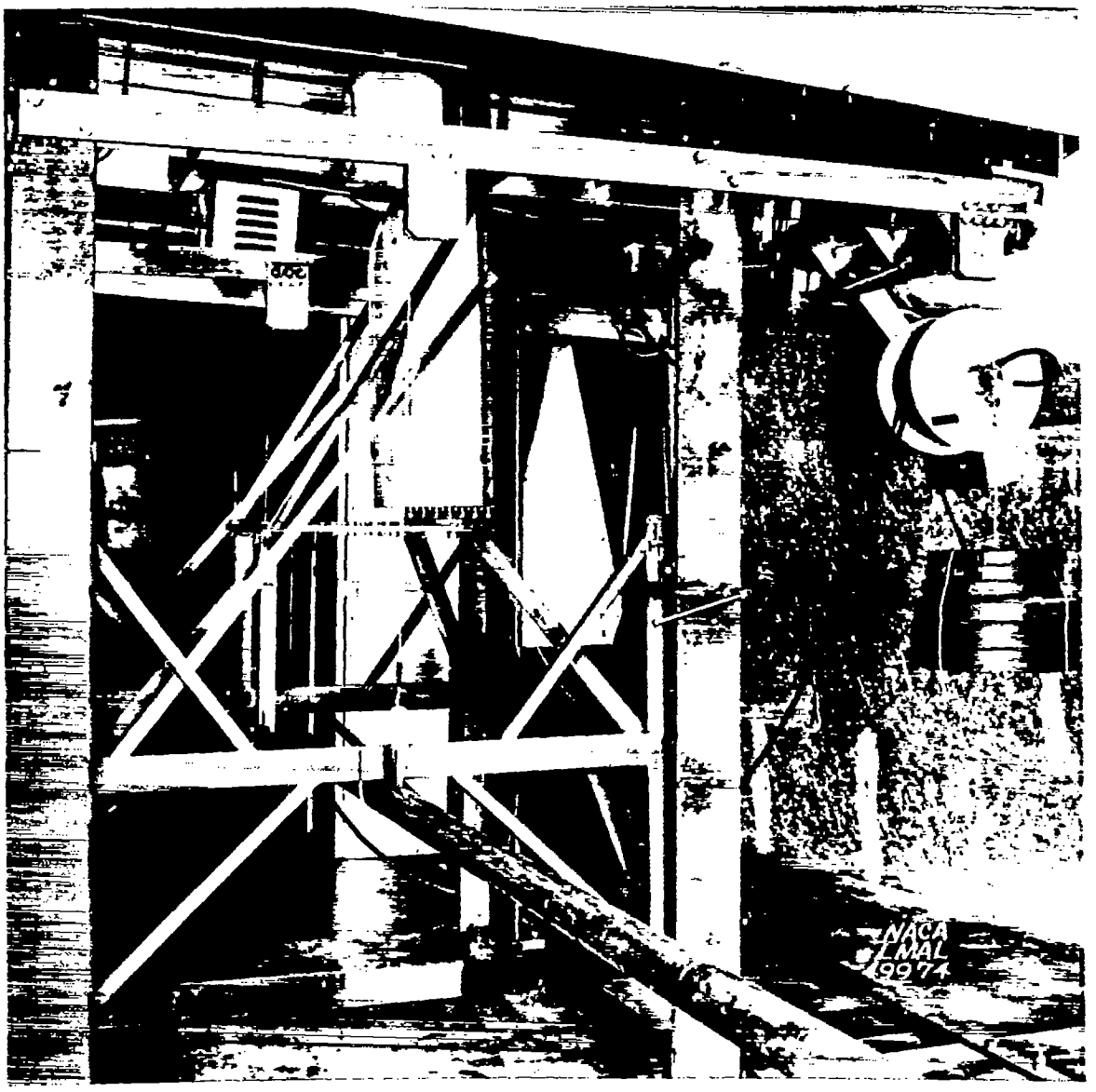

Figure 1.- Assembly of test apparatus for Navy investigation of human tolerance to wind blasts in the Langley 8-foot high-speed tunnel showing dummy mounted in test seat.

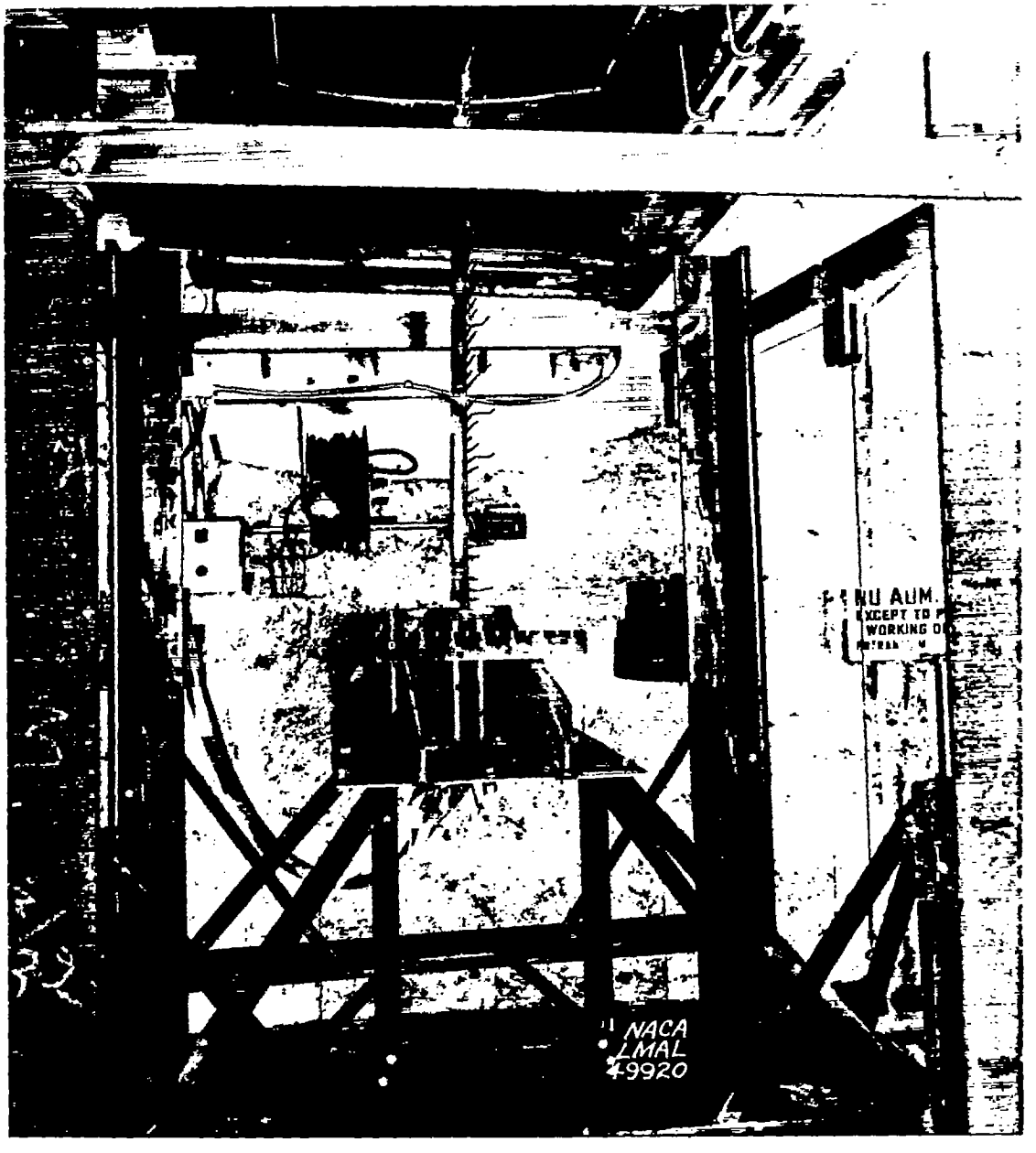

Figure 2.- Velocity survey rake mounted on carriage plate in place of test seat.

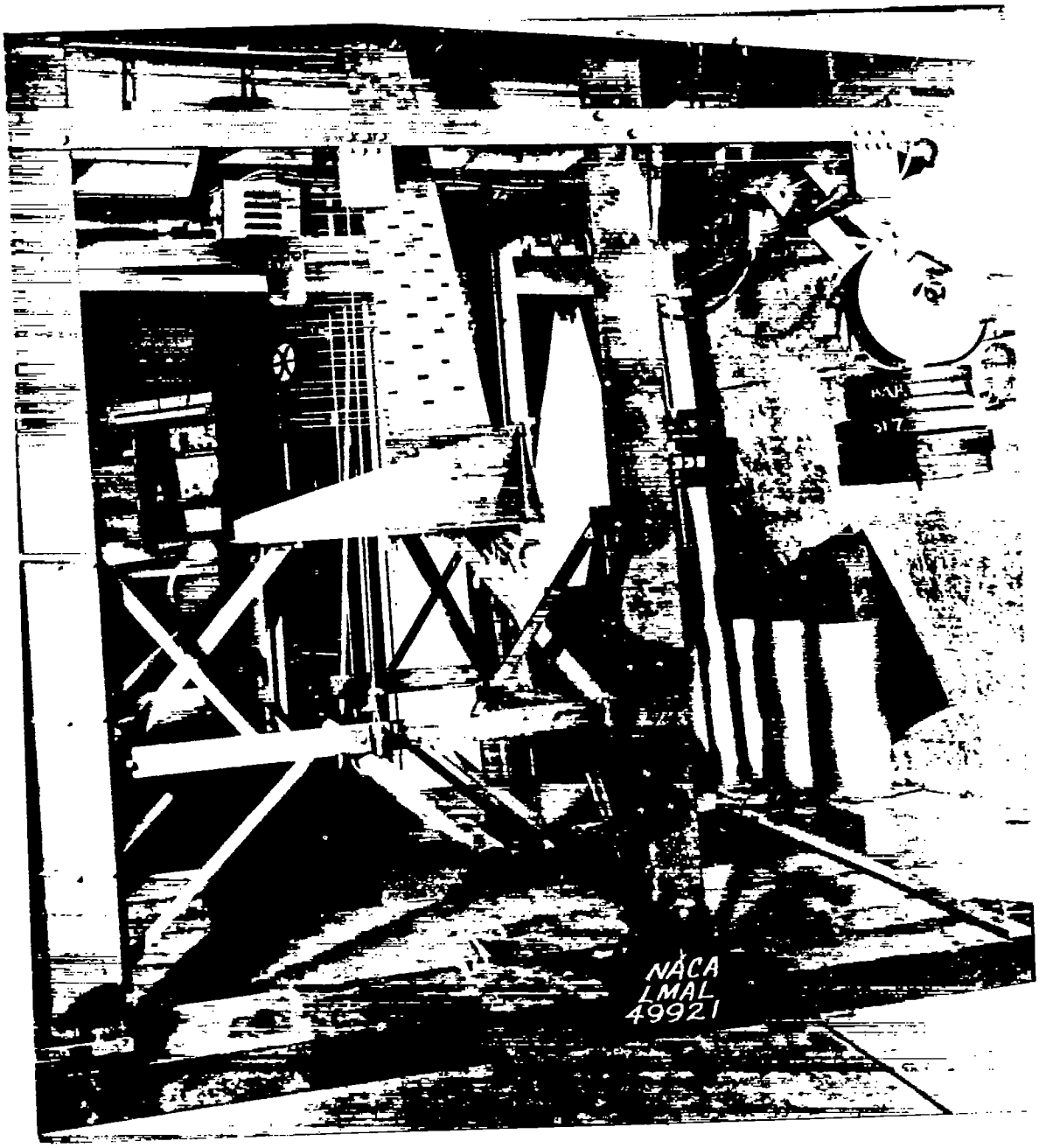

Figure 3.- Woolen tufts attached to the side of the velocity survey strut.

Figure 4.- Soft balsa block in wooden dummy face. Dummy in up position in tunnel.

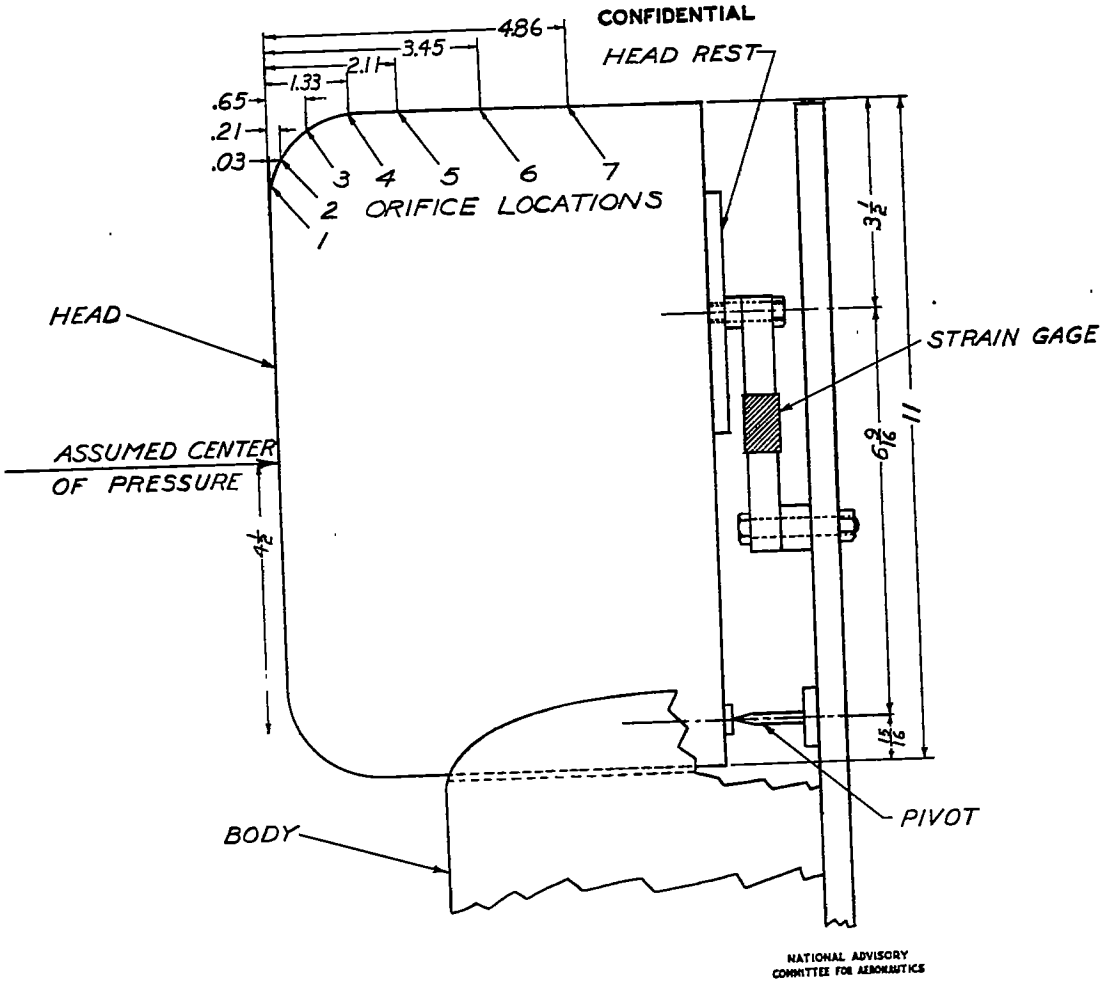

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FIGURE 5 - DIAGRAM OF DUMMY HEAD SHOWING ARRANGEMENT OF STRAIN GAGE AND ORIFICE LOCATIONS. ALL DIMENSIONS IN INCHES.

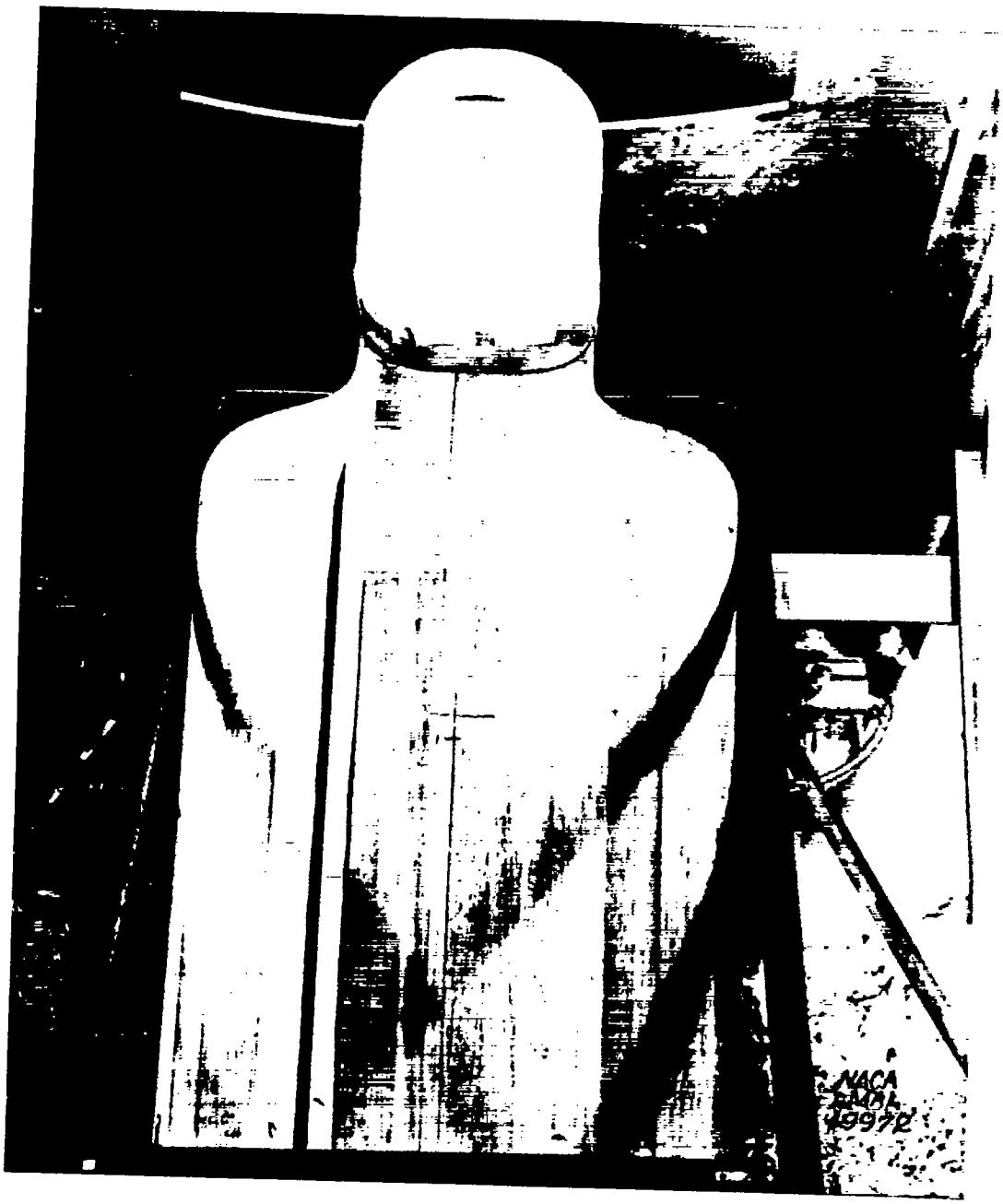


Figure 6.- Guinea pig with shaved back in place of soft balsa block in dummy face.

Figure 7.- Guinea pig with shaved back toward air blast secured to dummy forehead.

Figure 8.- Guinea pig with face toward air blast secured to dummy forehead.

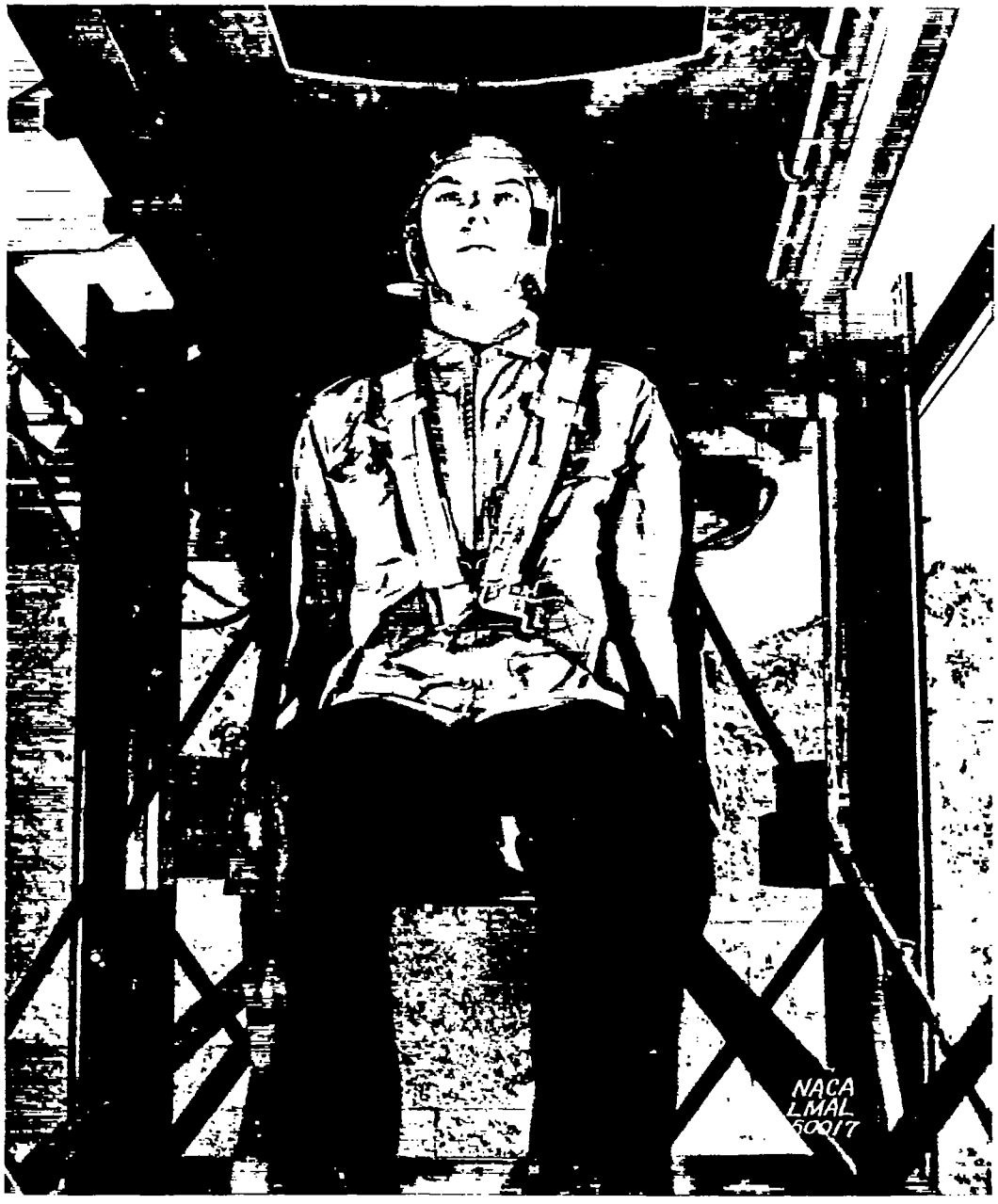


Figure 9.- Human subject secured in test seat.

Figure 10.- Curved head rest attached to test seat.

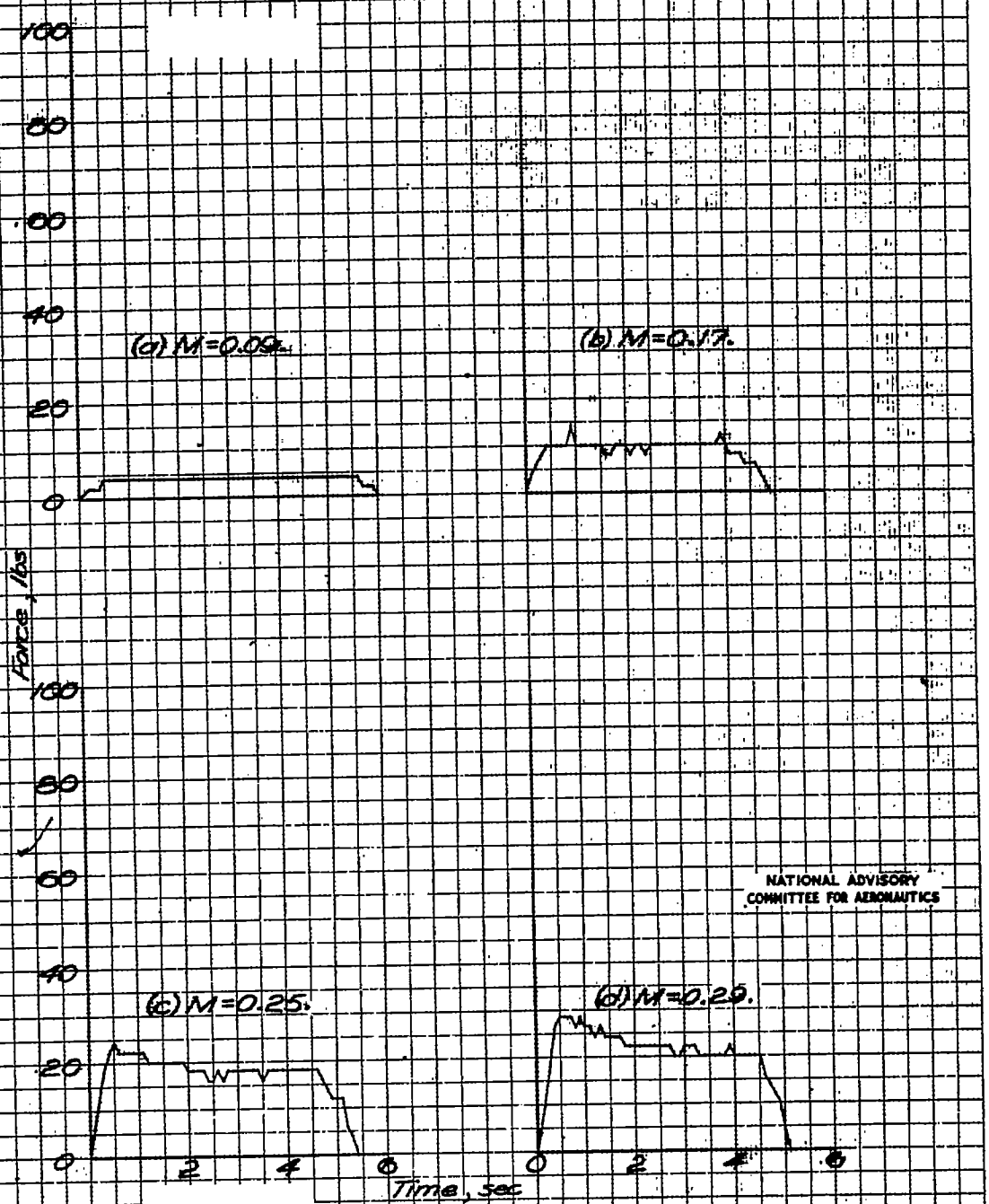
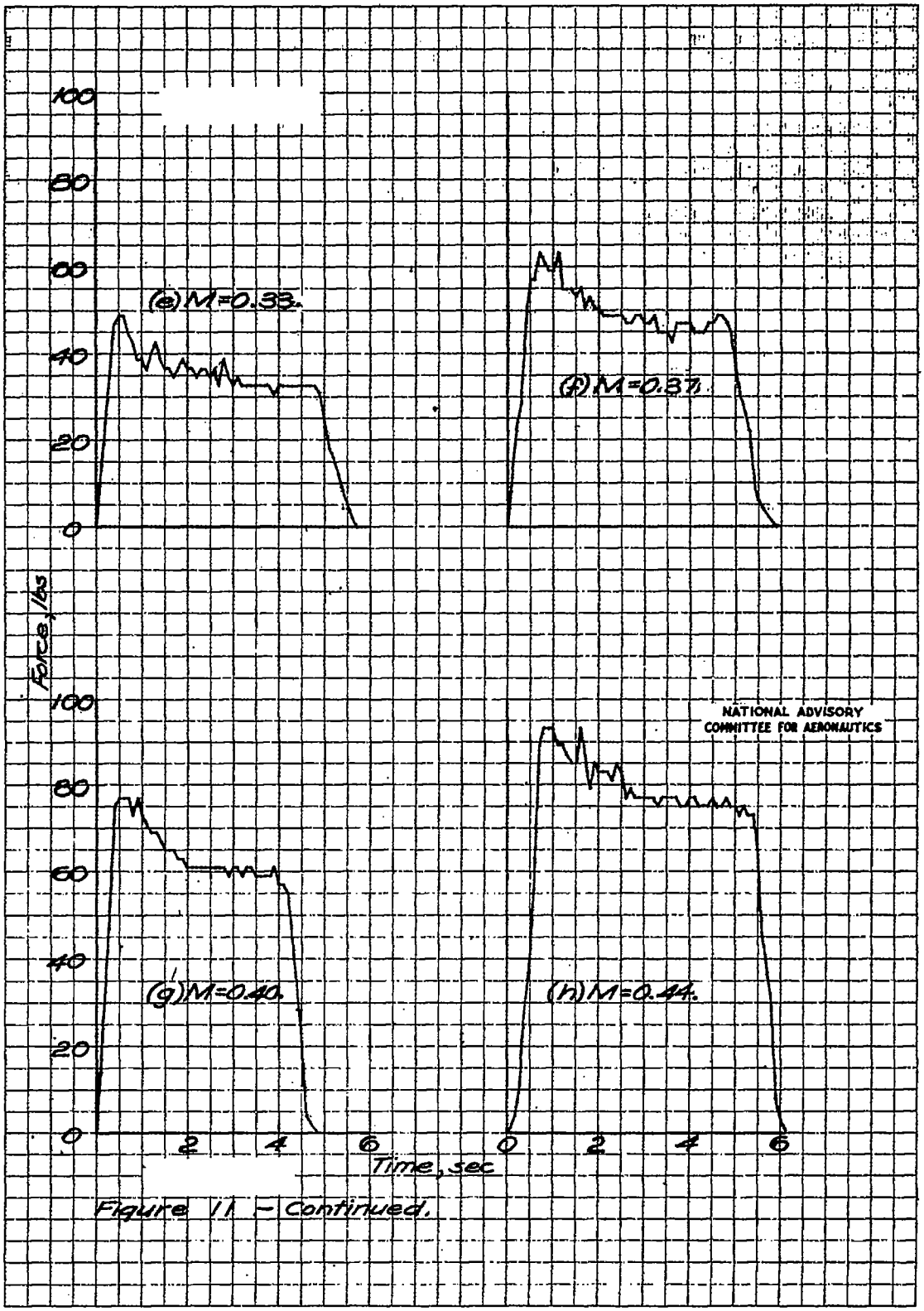


Figure 11.- Variation of force on dummy head with time of exposure. Forces measured at a point 6.56 inches from the pivot.



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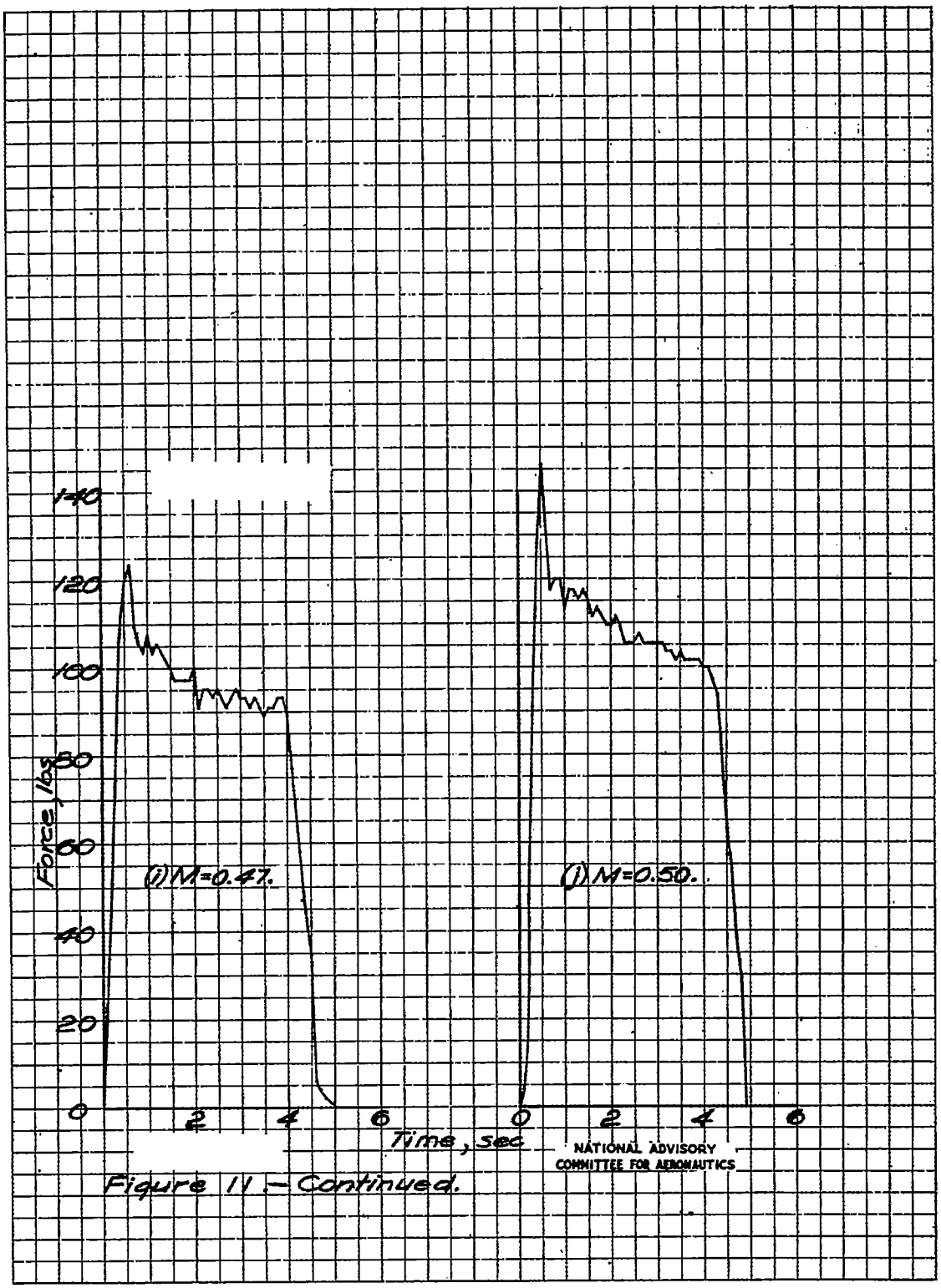

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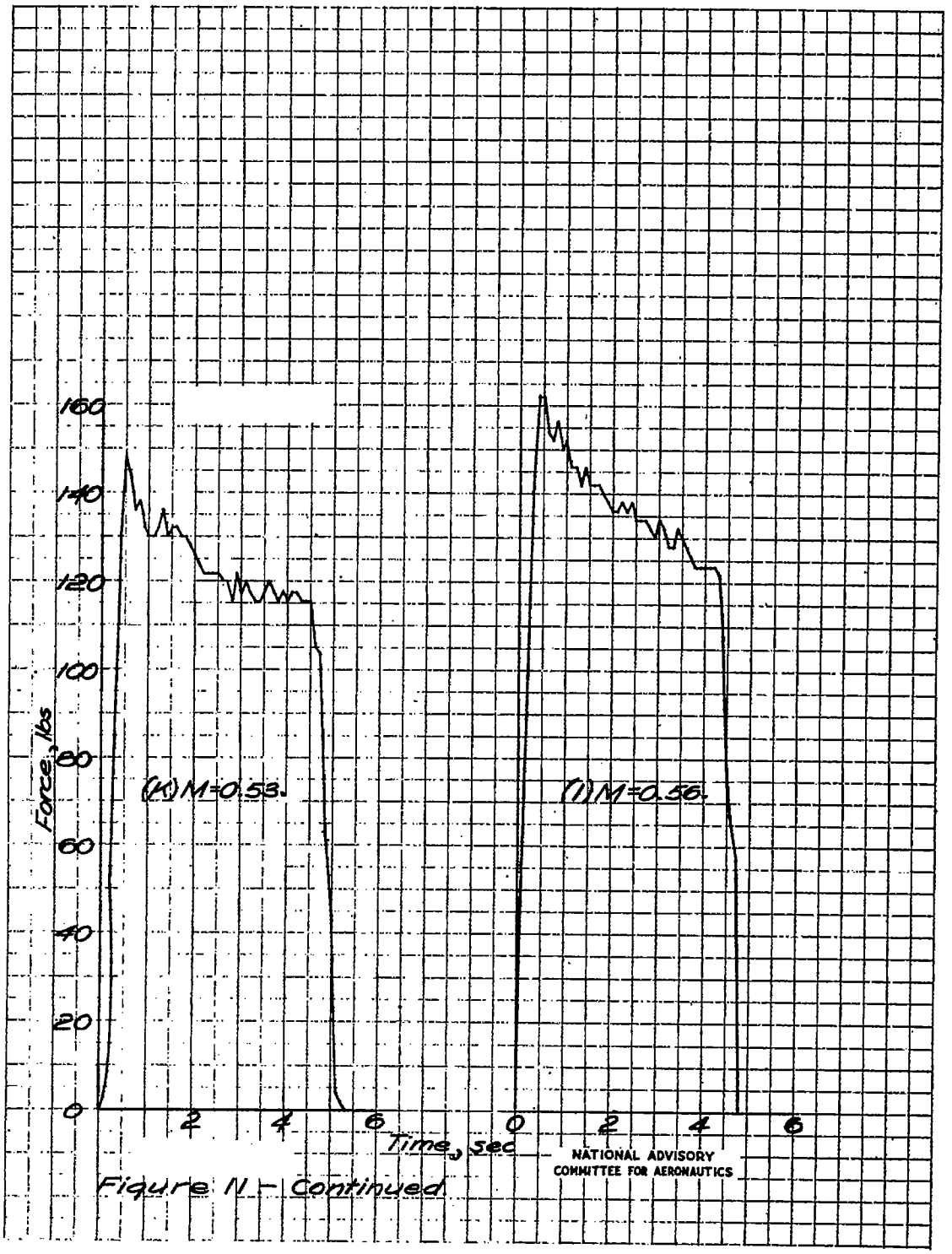

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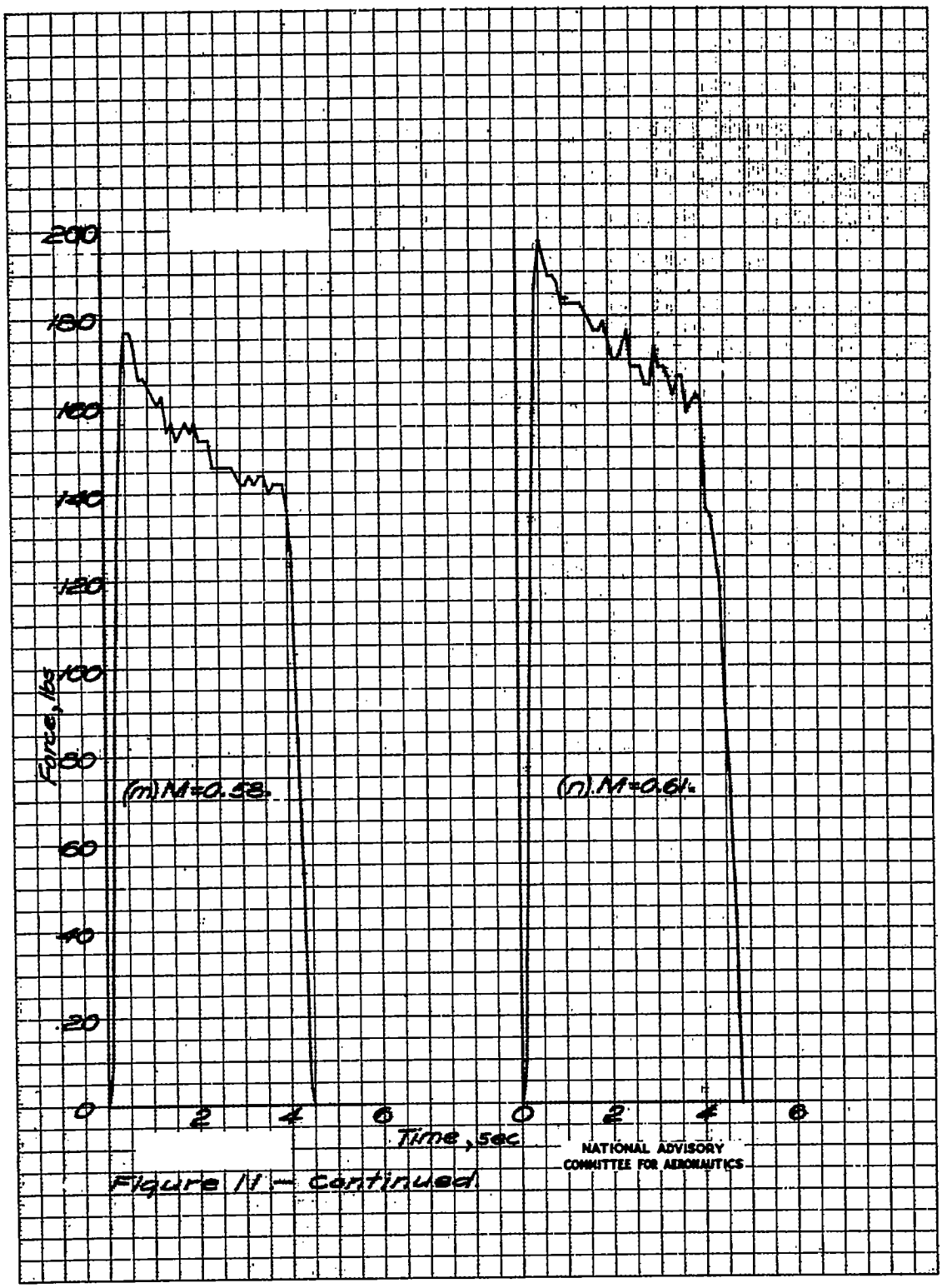

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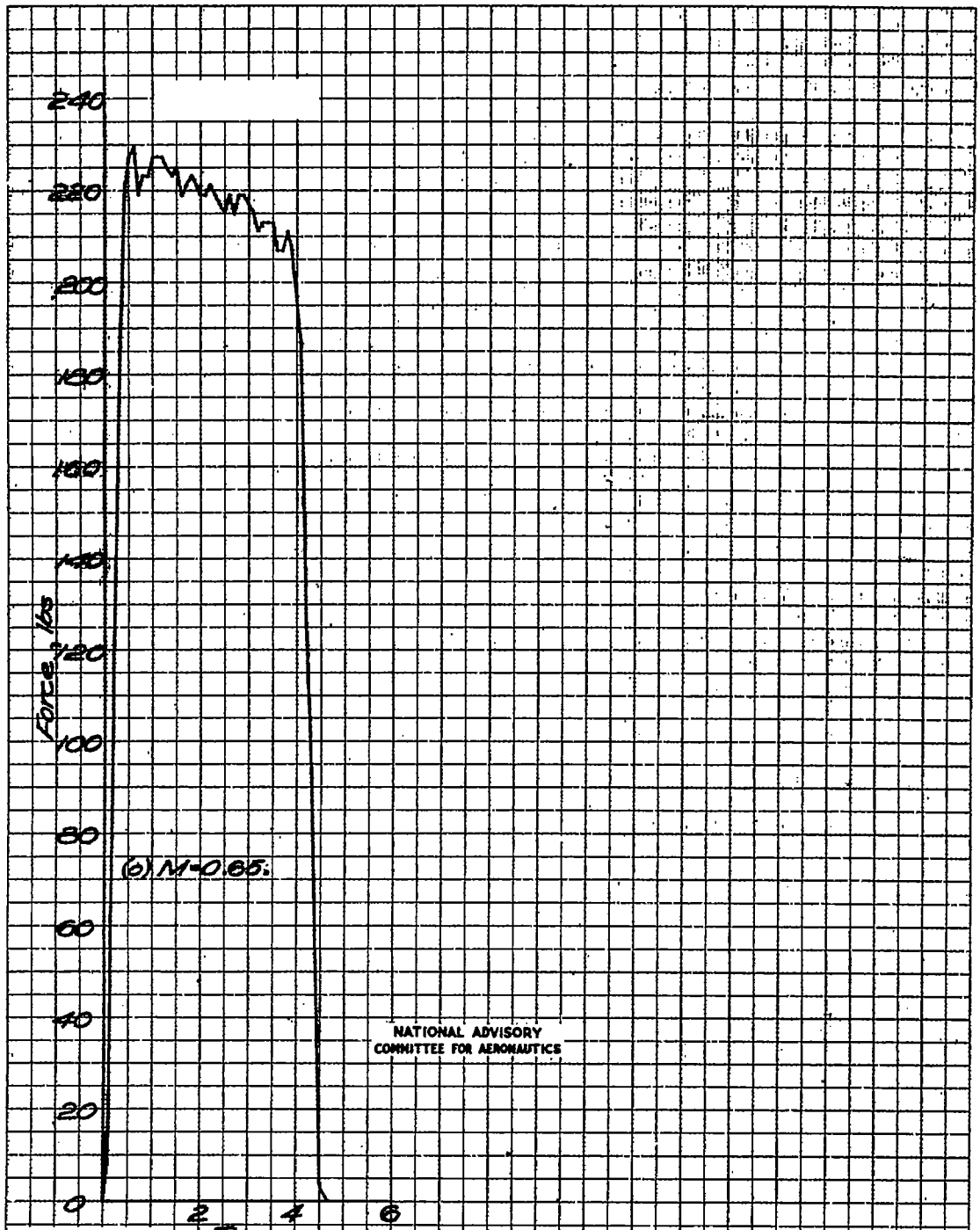

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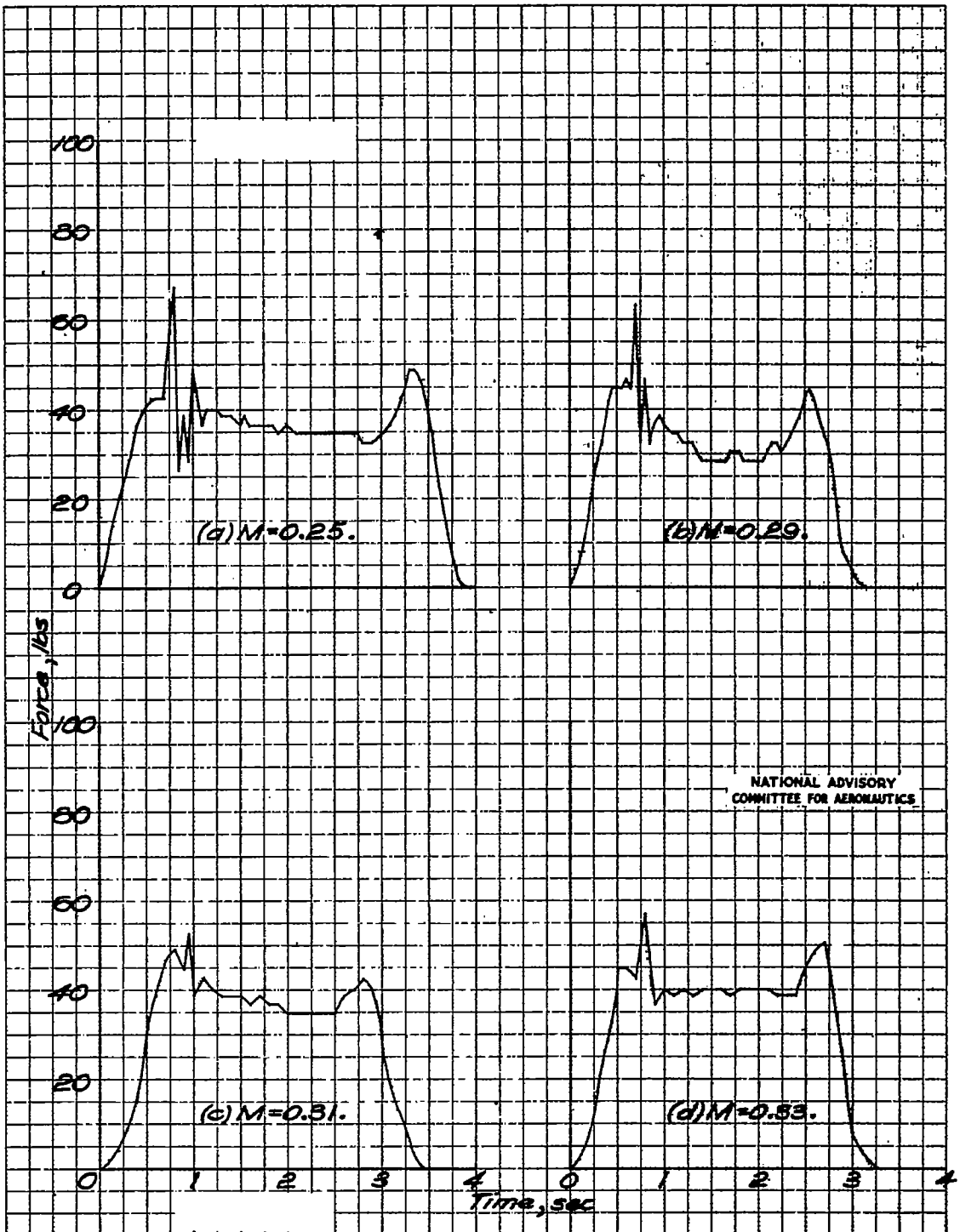
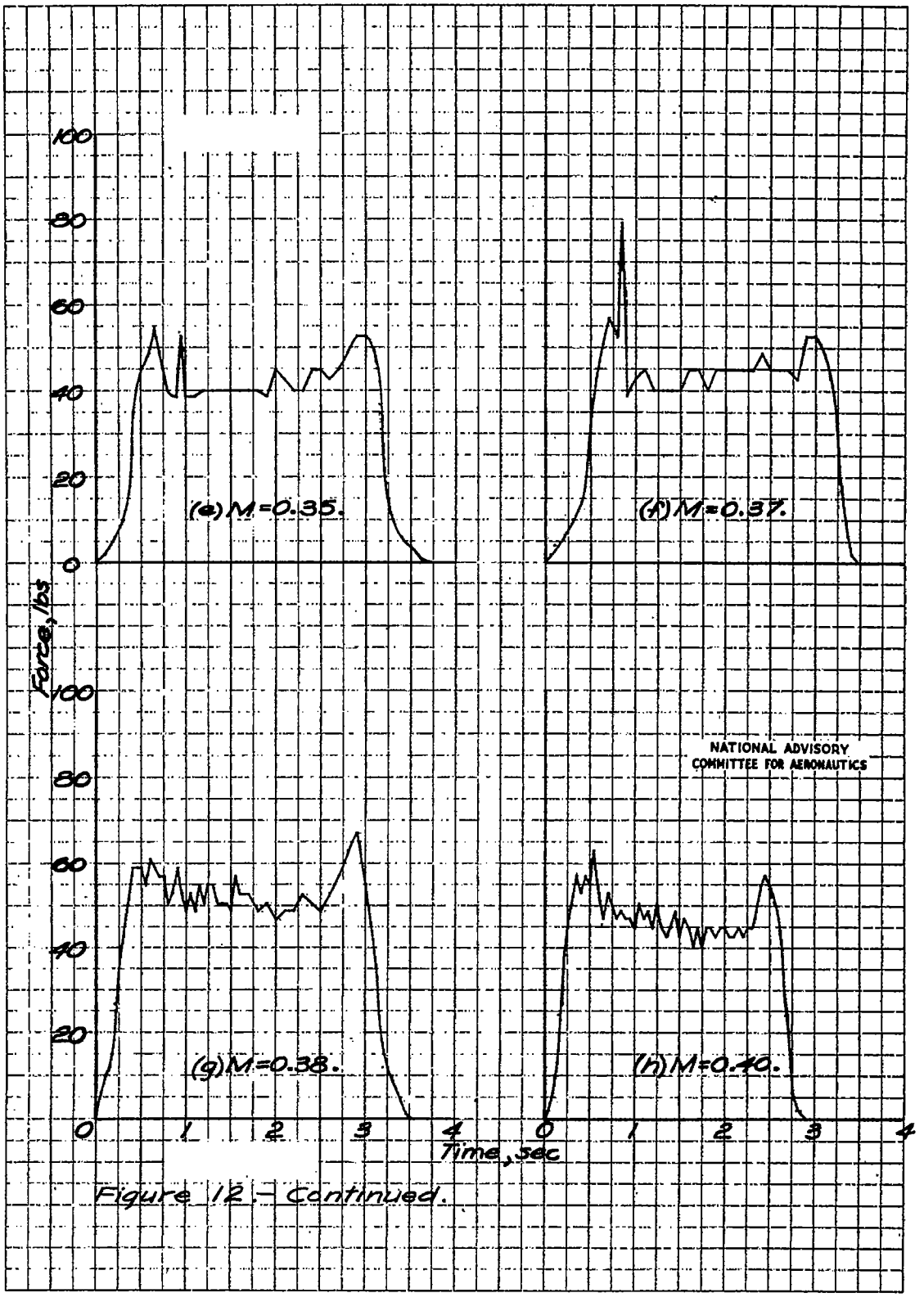


Figure 12.- Variation of force on head of subject 1 with time of exposure.



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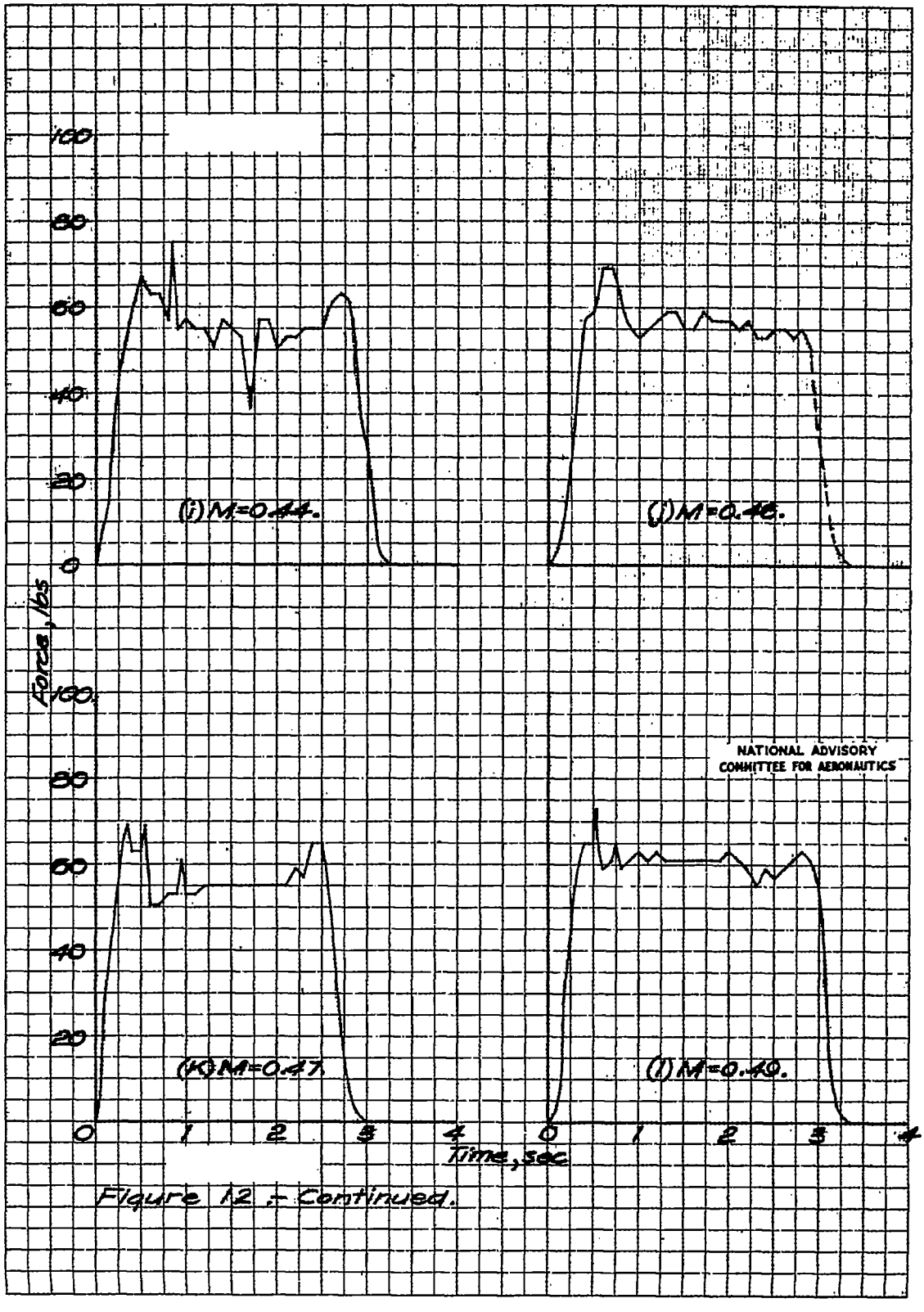

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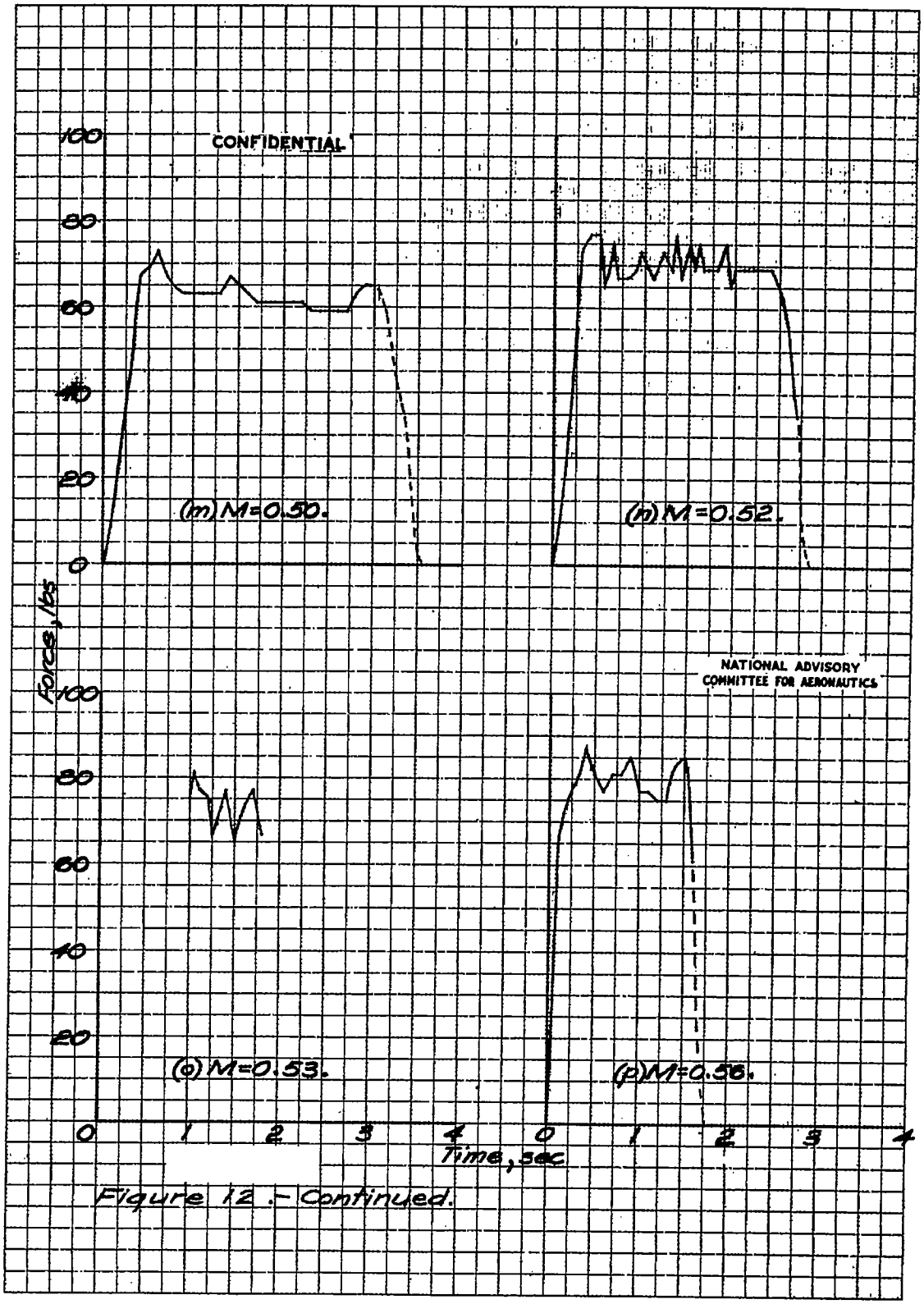

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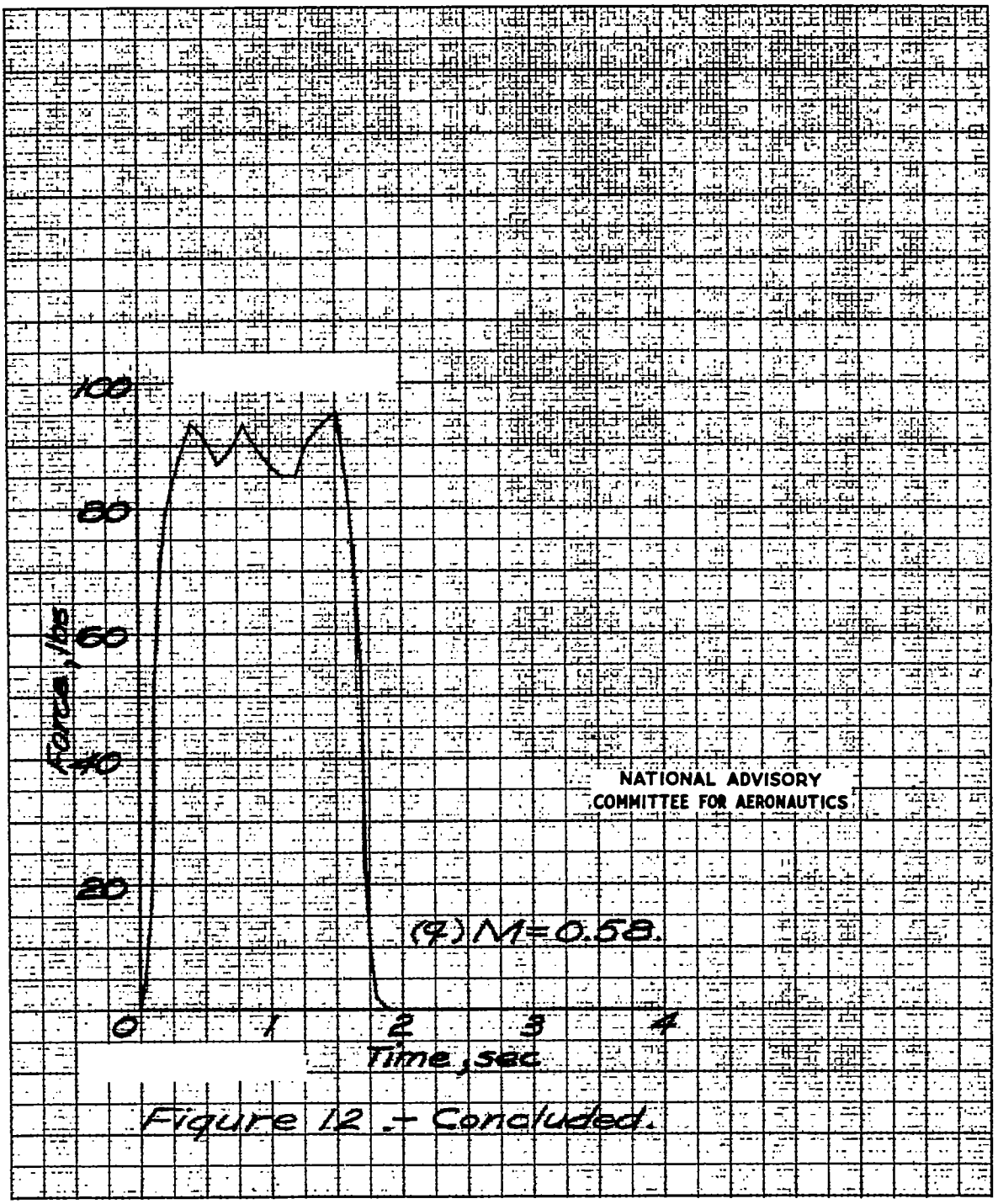

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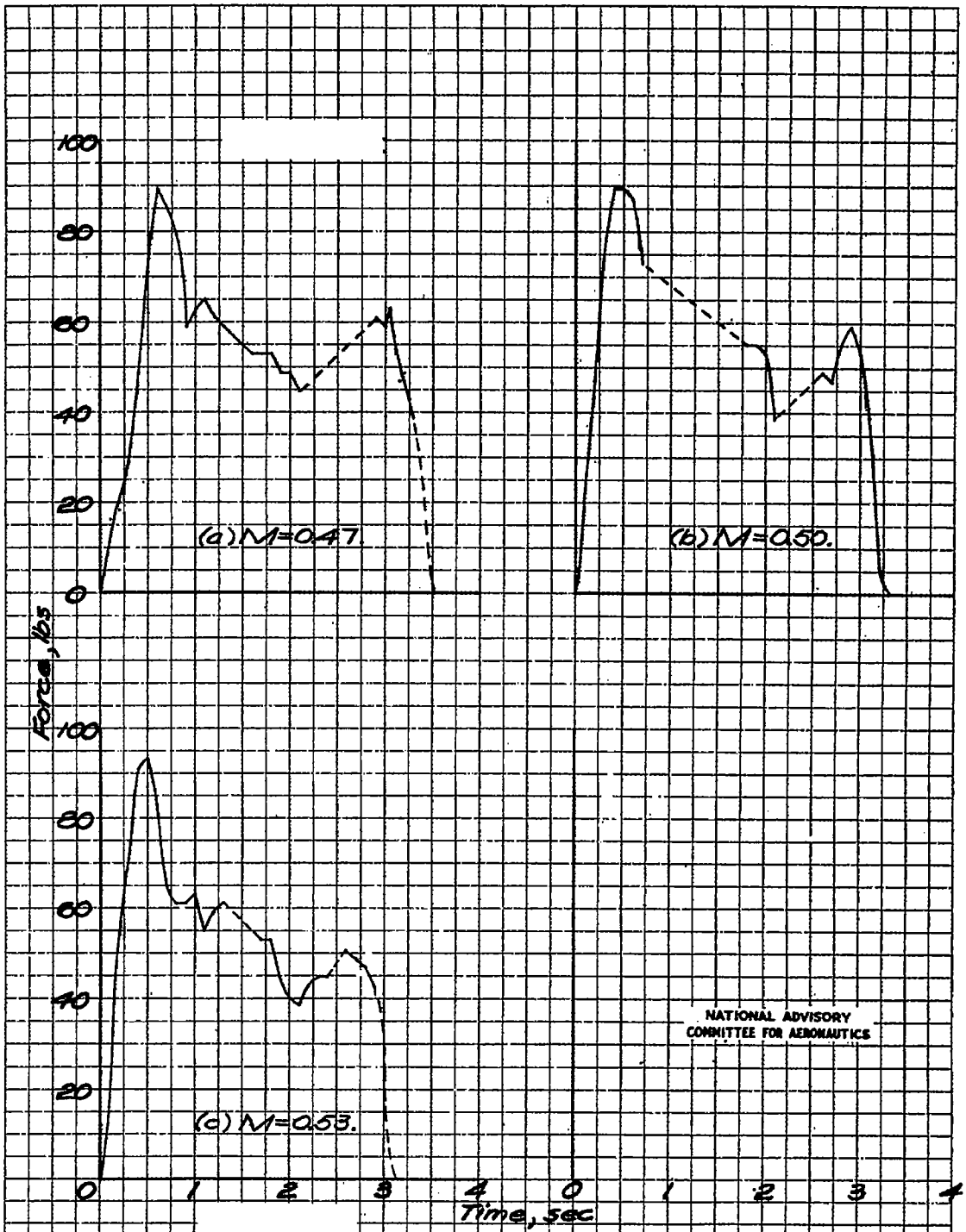

Figure 13.- Variation of force on head of subject 2 with time of exposure.

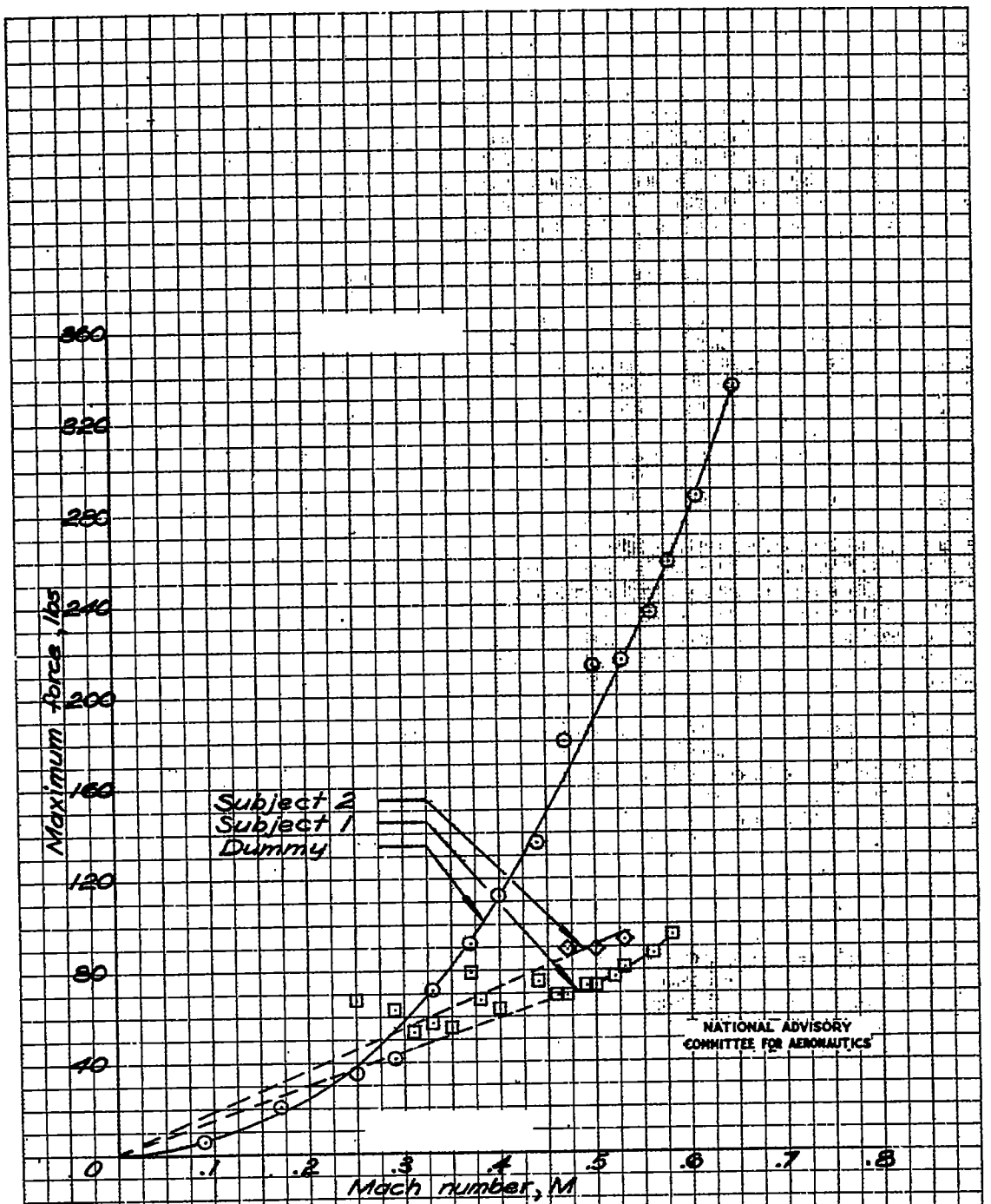

Figure 14.- Variation of maximum force with Mach number for the various heads tested. Dummy head maximum force for a point 4.5 inches from the pivot.

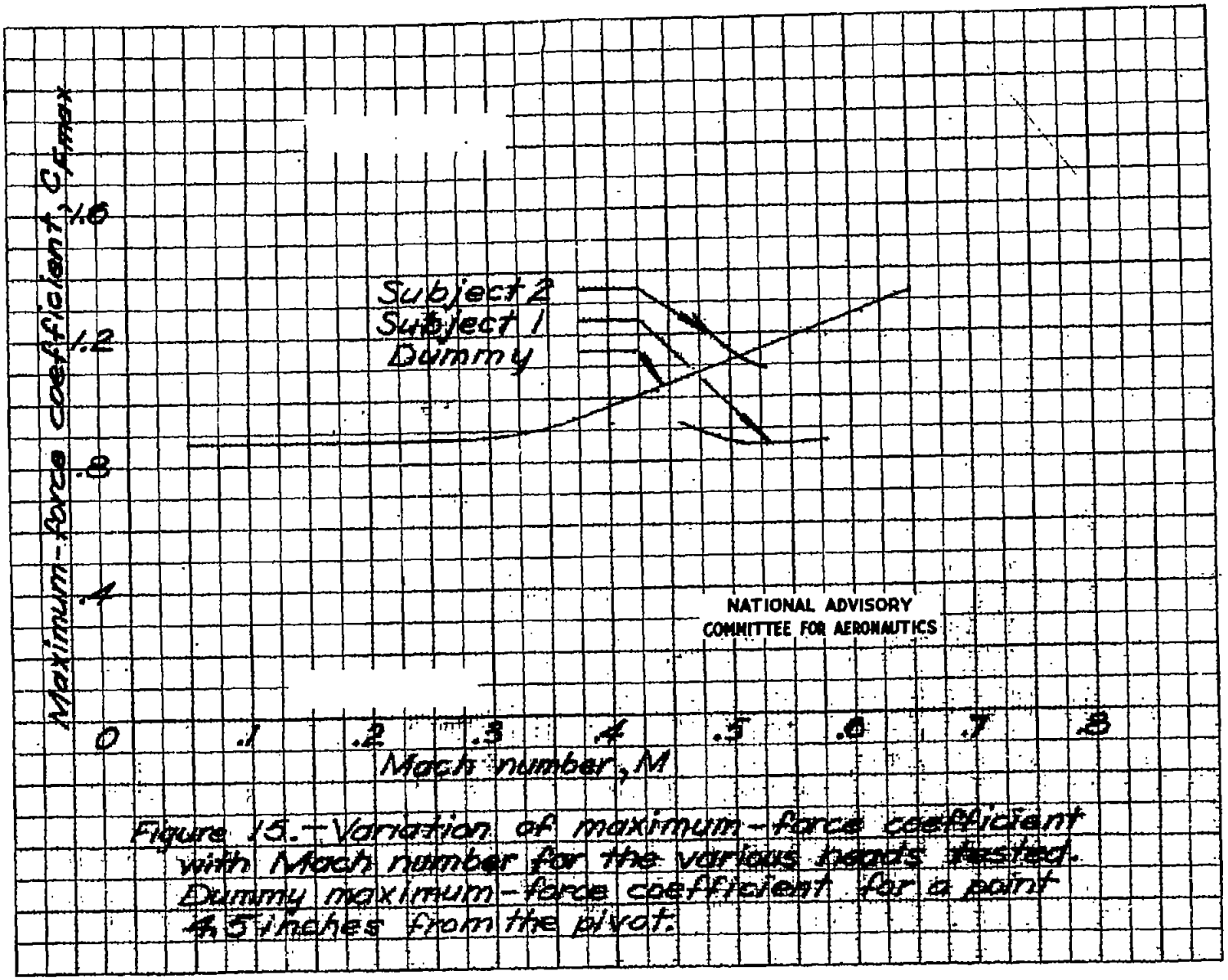

Figure 15.- Variation of maximum-force coefficient with Mach number for the various heads tested. Dummy maximum-force coefficient for a point 4.5 inches from the pivot.

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