ARR No. L5C09b

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
April 1945 as
Advance Restricted Report L5C09b

TANK TESTS OF A FLYING-BOAT MODEL EQUIPPED WITH SEVERAL TYPES OF FAIRING DESIGNED TO REDUCE THE AIR DRAG OF THE MAIN STEP

By James M. Benson and Robert F. Havens

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NACA ARR No. L5C09b

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

TANK TESTS OF A FLYING-BOAT MODEL EQUIPPED WITH SEVERAL TYPES OF FAIRING DESIGNED TO REDUCE THE AIR DRAG OF THE MAIN STEP

By James M. Benson and Robert F. Havens

SUMMARY

Tank tests were made of a flying-boat model having various types of fairing with and without ventilation ducts behind the main step to investigate the hydrodynamic characteristics of the model. All the types were designed to reduce significantly the air drag chargeable to the main step. The fairings that were made merely by adding a filler block behind the main step had an adverse effect on the take-off and landing stability. Those fairings that offered the greater restriction to the flow of air into the region under the afterbody had the greater adverse effect.

The configuration that combined the best stability with a good aerodynamic form consisted of a shallow step (depth, about 1 percent of the beam) and an adjoining ventilation aperture having an area about 7 percent of the square of the beam. With this form of step, the landing stability of the model compared favorably with that of the conventional model.

INTRODUCTION

Air Drag of Step

In large long-range flying boats of current design having a depth of step 5 or 6 percent of the beam (reference 1), the air drag of the step is significant, being of the order of 2 percent of the total air drag (parasite drag plus induced drag at maximum lift-drag ratio). Numerous configurations whereby the air drag of the conventional step could be reduced or eliminated have been suggested (references 1 to 4) but, for various reasons, have not been widely used. Some discrepancies exist in published results of wind-tunnel tests, but it is generally indicated that increasing the depth of step increases the air drag by an amount roughly proportional to the depth (references 2, 5, and 6). With the present tendency toward the use of steps having a depth as large as 10 percent of the beam to avoid instability while planing and while landing, the air drag chargeable to the step may be as large as 4 percent of the total drag. It therefore becomes increasingly important to devise practical methods of reducing the air drag of the step.

Function of Main Step

At low speeds the step serves no useful purpose. The conventional step is of value mainly at planing speeds, where it is desirable to confine the wetted area of the planing bottom of the hull to a relatively small portion of the forebody. By restricting the wetted area to the minimum necessary to develop hydrodynamic lift, the frictional resistance is minimized and at the same time the travel of the center of pressure accompanying a change in trim is limited, so that the available aerodynamic control is sufficient for the pilot to control the trim during take-off and landing.

Relation between Depth of Step and Ventilation

Tank tests and flight tests have shown that the allowable water resistance is exceeded and that hazardous forms of instability occur during landing and take-off if the main step is not sufficiently ventilated by providing either a deep step or a shallow step with ventilation ducts of adequate size. The results cited in reference 7 indicate that, as the amount of ventilation is increased, the depth of step may be decreased. One purpose of the present investigation is to determine to what extent this principle may be followed in reducing the depth of step.

Effects of Fairing behind Step

Aerodynamic and hydrodynamic tests at the Royal Aircraft Establishment (reference 2) showed that a straight wedge-type fairing behind the main step is very effective in reducing the air drag, in spite of the angular breaks introduced, provided the length of fairing is at least four times the depth of step. Figure 1, which is taken from reference 2, summarizes the results of the R.A.E. wind-tunnel tests and shows the effect of varying the length of the fairing. A disadvantage in the use of fairings has been that the take-off and landing characteristics are adversely affected, as mentioned in reference 3. In reference 4 a concave fairing is described that leaves a very shallow step across the hull and that has been used on a large flying boat (presumably the Sunderland III).

The present report includes the results of tank tests to determine the stability characteristics of several fairings of the type used on the Sunderland III and the results obtained by adding ventilation ducts to reduce the instabilities caused by fairings. Inasmuch as the landing characteristics of a flying boat provide a reliable basis for judging the adequacy of the ventilation of the main step, a large part of the present tests consisted in a study of landings made with the different modifications. The trim limits of stability and the free-to-trim resistance of promising modifications were then obtained at speeds near the hump and near get-away.

MODEL AND METHOD OF TESTING

The general arrangement and the dimensions of the powered model used in the tests are shown in figure 2. The model was dynamically similar to a twin-engine flying boat having a normal gross weight of 65,000 pounds. A description of a powered model of the type used in the Langley tanks is given in reference 8.

Tests were made with 15 types of step fairing. Fairings 1 to 9 were formed by the addition of a fillet (filler block) behind the main step, as shown in figure 3. Fairing 4 was somewhat similar to the fairing used on the Sunderland III. Fairings 10 to 15 incorporated ventilation through an aperture behind the main step. In order to provide ventilation through this aperture, the afterbody was moved aft 1 inch, the sides of the model were sealed, and a watertight duct was extended well above the water line. As shown in figure 4, fairings 10 to 13 supplied different amounts of ventilation through apertures between the step and the filler block. Both configurations shown in figure 5, fairings 14 and 15, consisted merely of a very shallow step (depth, about 1 percent beam) with large ventilation apertures in the afterbody (area, 6.8 percent beam squared for fairing 14 and 4.1 percent beam squared for fairing 15). In order to form the shallow step, the forward end of the afterbody was lowered to the desired position. In this manner the sternpost angle (angle between the forebody keel extended and a line joining the step and the sternpost at the keel) was not altered.

The method of testing dynamic models in Langley tank no. 1 is described in reference 9. In the present tests of the landing stability, the model was flown off the water and was then landed at various angles of trim. For most of the tests the flaps of the model were deflected 45°, the center of gravity was at 28 percent mean aerodynamic chord, and the propellers developed one-fourth full thrust. Landings were made with the conventional model and with the model equipped with step fairings at gross load coefficients C_{Δ_o} of 0.91 and 1.14. In most cases the motions of the model in trim and in rise were recorded by means of scribers that registered on a uniformly moving tape of waxed paper. The trim of the model was measured between the base line (in the case of this model, the forebody keel) and the surface of the water. Rise was defined as the height of the center of gravity of the model above or below its position when the forebody keel of the model just touched the surface of the water at 0° trim.

RESULTS AND DISCUSSION

Results of the landing tests at two gross load coefficients are summarized in tables I and II, which give the trim at contact and the number and type of vertical oscillations that developed during the landing runs. Typical time histories of the trim and rise of the conventional model are given in figure 6. This figure, together with tables I and II, shows that the landing stability of the conventional model was satisfactory for all test conditions. Time histories of landings made at a trim of 6.0° when the model was equipped with each of several representative fairings are shown in figures 7 and 8. The results showed that each of the fairings, including those with ventilation, produced increased porpoising and skipping. As a rule, the fairings that permitted the larger amount of ventilation had the lesser adverse effects on the landings. Although complete trim limits of stability were not obtained, it appeared from a spot check that the principal effect of the fairings on the trim limits was to lower the lower branch of the upper limit by an amount roughly corresponding to the increase in the landing instability.

The stability characteristics of the model with a shallow step and with the larger ventilation aperture (fairing 14, fig. 5(a)) appeared to be almost as satisfactory as those of the basic model of conventional form. The behavior during landing is noted in table II and time histories of the trim and rise during several landings are shown in figure 9. Measurements of the free-to-trim resistance of the model with fairing 14 indicated that the resistance at the hump speed and at a speed about nine-tenths of get-away was nearly 10 percent greater than that of the conventional model. A combination of this type of step and ventilation aperture may be found which would have a resistance during take-off about equal to that of the conventional step of normal depth and which would have a greatly reduced increment in air drag chargeable to the step. It is anticipated from observations made during the tests that the afteredge of the aperture must be about 0.313 inch above the forebody keel (fig. 5(a)) in order to remain clear of the wake from the forebody at high planing speeds. It is also possible that some improvement in the characteristics of the shallow ventilated step may be gained by departures from the straight transverse arrangement.

SUGGESTIONS FOR FURTHER DEVELOPMENT

At the present time, data are not available for estimating the aerodynamic effect of the ventilation aperture during flight. Wind-tunnel tests are required to determine whether the ducts should receive air from the interior or the exterior of the hull and also to determine whether the ducts should remain open in flight. The structural weight of the ventilation ducts with possible closures has not been estimated, but it may be pointed out that no part of the duct system is subjected to heavy loads. The stringers in the bottom of the hull could presumably be made continuous across the shallow step without appreciably restricting the ventilation; the weight of the ducts would be offset by some saving in the weight associated with the abrupt discontinuity introduced in the structure by the conventional step.

A further possibility that should be investigated in the development of the ventilated step is that of landing with ducts closed. Tests have been made (reference 10) with a model having zero depth of step and one angular discontinuity between the forebody and afterbody planing surfaces ahead of the center of gravity (fig. 10). Landings entirely free of porpoising and skipping could be made with this model at trims from about 6° (afterbody horizontal) to about 12° (full stall). Further testing is required to determine whether equally stable landings can be made with an arrangement somewhat like that shown in figure 11. In this arrangement the step is farther aft than is shown in figure 10 and two angular breaks are produced in the bottom of the hull when the ventilation orifices are closed by retractable flaps.

CONCLUDING REMARKS

Take-off and landing tests of a powered dynamic model of a flying boat typical of current design showed that:

1. The addition of a filler block to form an aerodynamic fairing behind the main step produced hazardous forms of porpoising and skipping.

2. Those fairings that offered the greater restriction to the flow of air into the region under the afterbody had the greater adverse effect upon the stability.

3. Satisfactory stability in landing and take-off was obtained with a very shallow step (depth of the order of 1 percent beam) in combination with ventilation ducts having an area of apertures equal to nearly 7 percent of the square of the beam. Such an arrangement offers

considerable promise as a practical method of reducing the increment in air drag chargeable to the step to a small fraction of the increment chargeable to a conventional step.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

REFERENCES

1. Benson, James M., and Lina, Lindsay J.: The Use of a Retractable Planing Flap Instead of a Fixed Step on a Seaplane. NACA ARR No. 3E31, 1943.

2. Coombes, L. P., and Clark, K. W.: The Air Drag of Hulls. Aircraft Engineering, vol. IX, no. 106, Dec. 1937, pp. 315-321, 328.

3. Fletcher, G. L., and Llewelyn-Davies, D. I. T. P.: Note on Some Tank Tests on the Sunderland III for Take-Off at Extreme Overload. Rep. No. Aero 1887, British R.A.E., Nov. 1943.

4. Smith, Leonard: Work in an Experimental Seaplane Tank. Jour. R.A.S., vol. XLVII, no. 393, Sept. 1943, pp. 290-314.

5. Hartman, Edwin P.: The Aerodynamic Drag of Flying-Boat Hull Models as Measured in the N.A.C.A. 20-Foot Wind Tunnel - I. NACA TN No. 525, 1935.

6. Parkinson, John B., Olson, Roland E., Draley, Eugene C., and Luoma, Arvo A.: Aerodynamic and Hydrodynamic Tests of a Family of Models of Flying-Boat Hulls Derived from a Streamline Body - NACA Model 84 Series. NACA ARR No. 3I15, 1943.

7. Parkinson, John B.: Notes on the Skipping of Seaplanes. NACA RB No. 3I27, 1943.

8. Parkinson, John B., and Olson, Roland E.: Tank Tests of a 1/5 Full-Size Dynamically Similar Model of the Army OA-9 Amphibian with Motor-Driven Propellers - NACA Model 117. NACA ARR, Dec. 1941.

9. Olson, Roland E., and Land, Norman S.: The Longitudinal Stability of Flying Boats as Determined by Tests of Models in the NACA Tank. I - Methods Used for the Investigation of Longitudinal-Stability Characteristics. NACA ARR, Nov. 1942.

10. Benson, James M., and Freihofner, Anton: Landing Characteristics of a Model of a Flying Boat with the Depth of Step Reduced to Zero by Means of a Retractable Planing Flap. NACA RB No. 4B08, 1944.

TABLE I

LANDINGS WITH GROSS LOAD COEFFICIENT $C_{\Delta_0} = 0.91$ AND CENTER OF GRAVITY

AT 28 PERCENT MEAN AERODYNAMIC CHORD

[S, skip; H, heave; UL, upper-limit porpoising. Skipping involves a large change in trim, with step clearing water. A heave is a rapid decrease in draft with little change in trim and with step always in water. Double line indicates separation between stable and unstable landings.]

Fairing	None (basic model)	1	2	3	4	5	6	7	8	9	10	11	12	13
Form of fairing														
Flap deflection (deg)	45	45	20	45	45	45	45	45	45	45	20	20	45	45
Thrust / Trim (deg)	1/4	1/4	Full	1/4	1/4	1/4	1/4	1/4	1/4	1/4	Full	Full	1/4	1/4
3.0		Stable						1H						
3.5	1H			Stable									Stable	2H
4.0		1H	Stable		Stable	1H			1H					1H
4.5	1H	1H								1H			Stable	
5.0	1H	3S, 1H	Stable	1S	Stable	2S, UL	1H	2H	1H, 1S, UL		1H	Stable	1S, 3H	
5.5				3S	1S	1H, 1S, UL	1H	3H					2S, UL	2S, 2H
6.0	1H	4S	1S	1S, 3H	1S	1H, 1S, UL	2H, 1S, UL	3H	2S, 4H		2S	1S, 2H		
6.5	1H		2S				1H, 1S, UL		1S, UL	1H			2S, UL	1S, UL
7.0	2H	1S, UL						1S, 3H	1S, UL	2H	3S			1S, UL
7.5	1H		2S					1S, 1H		2H, 1S				
8.0		1S, UL			1S, 5H	1S, UL	1S, UL	1S, 1H	1S, 2H		2S	2S, 2H		1S, UL
8.5			1S			1S, UL		1S					1S, UL	
9.0										3S, UL	1S			
9.5		1S, UL			2H					3S, 2H				
10.0					Stable	4H	1S, UL						1S, UL	
10.5	2H					5H							1S, UL	2H
11.0			1S					UL				3S, 2H		
11.5										1S, 2H				
12.0														

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

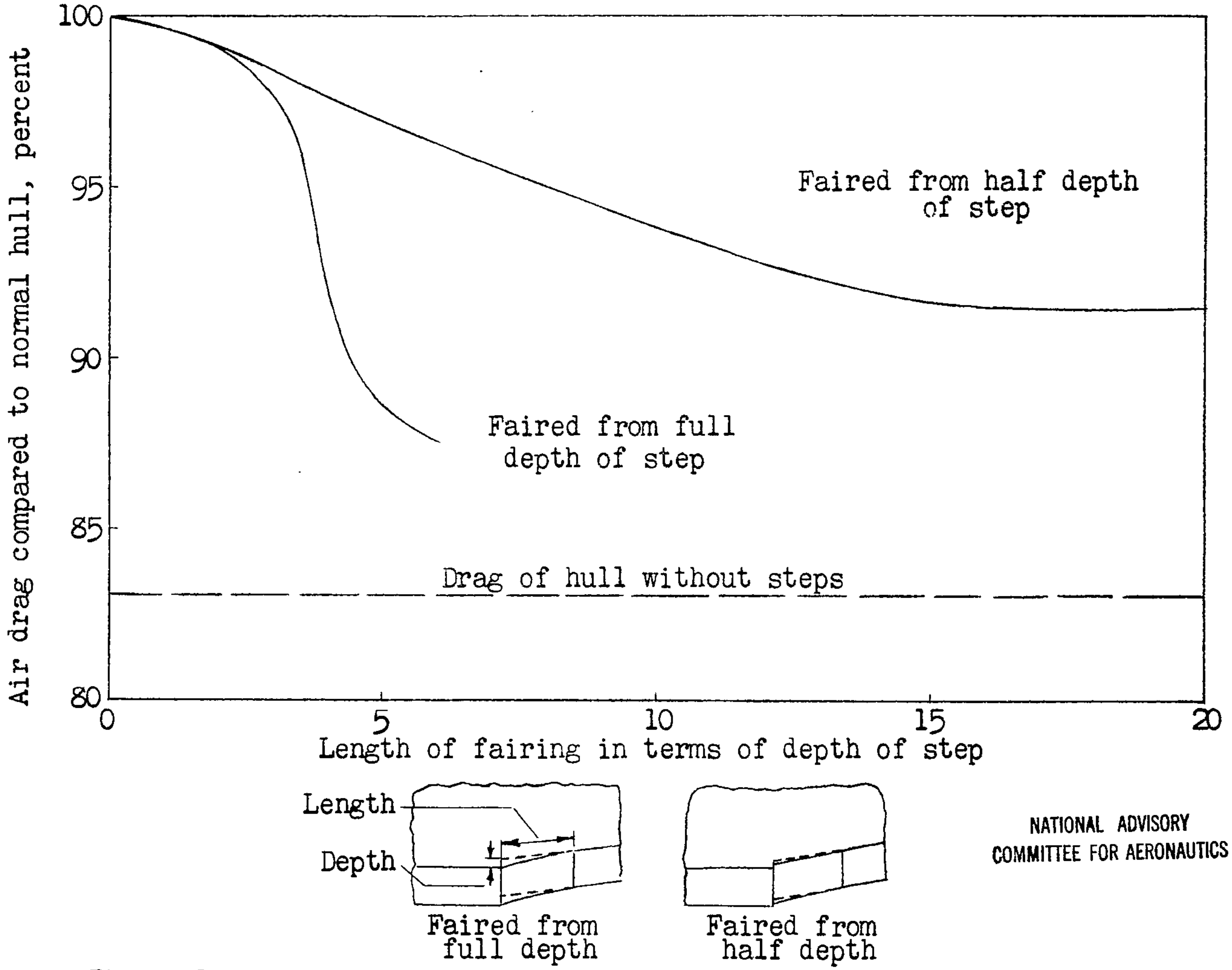
TABLE II

LANDINGS WITH GROSS LOAD COEFFICIENT $C_{\Delta_0} = 1.14$ AND WITH ONE-FOURTH FULL THRUST AND FLAPS AT 45°

[s, skip; H, heave; UL, upper-limit porpoising. Skipping involves a large change in trim, with step clearing water. A heave is a rapid decrease in draft with little change in trim and with step always in water. Double line indicates separation between stable and unstable landings.]

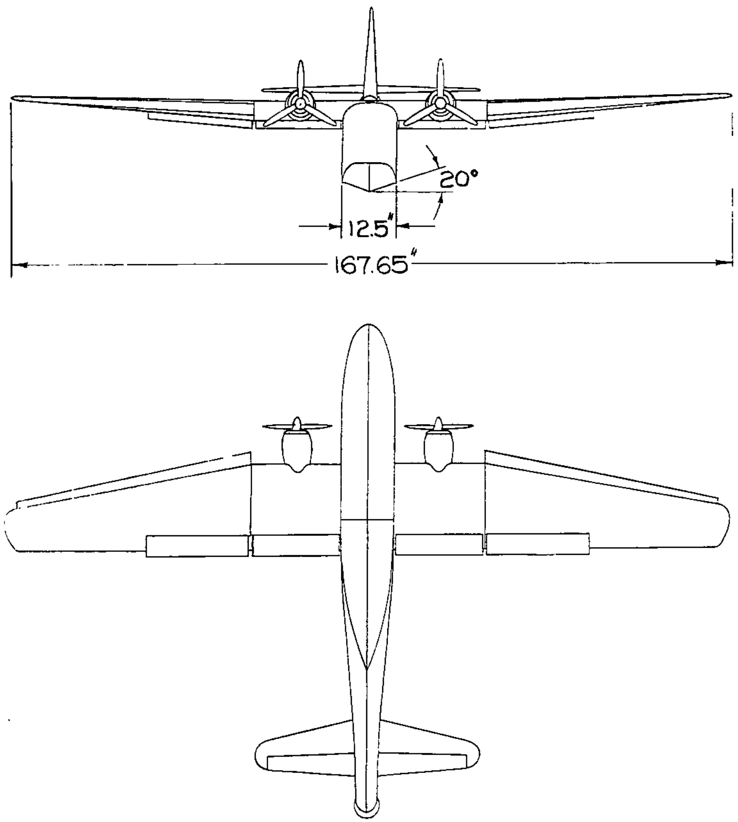
Fairing	None (basic model)			1	5	6	7	8	9	12	13	14	15
Form of fairing													
Trim (deg) \ c.g. (percent M.A.C.)	22	28	35	28	28	28	28	28	28	28	28	28	28
3.0				1H			1H	1H					
3.5		Stable	Stable			Stable							1H
4.0	Stable	Stable							1H		1H	Stable	
4.5		Stable	Stable	1H									3H
5.0	1H	1H			2H		1H	2H, 1s, UL	1H		2s	1s, UL	1s, UL
5.5		1H		1H, 2s		3H			1H	2H		1s, UL	UL
6.0	1H	1H	1H	2s, 3H	2s	1s, UL		1s, UL		2H	2s, UL		2s, UL
6.5				2s, 2H		2s, UL	2s, UL		1H	1H	2s, UL	1s, UL	2s, UL
7.0	2H	1H		2s, 4H				1s, UL	4s, UL	2s, UL		UL	
7.5	2H		2H			2s, UL			4s, UL		1s, UL		1s, UL
8.0		1H		1s, 4H				1s, 3H	4s, UL	2s, UL		UL	
8.5									3s, UL		1s, UL		
9.0	1H				1s, UL	1s, UL							
9.5				1s, 5H						1s, UL		UL	
10.0	2H	1s. 1H	2s, 3H			1s, UL	UL		3s, UL		1s, UL		
10.5										1s, UL			

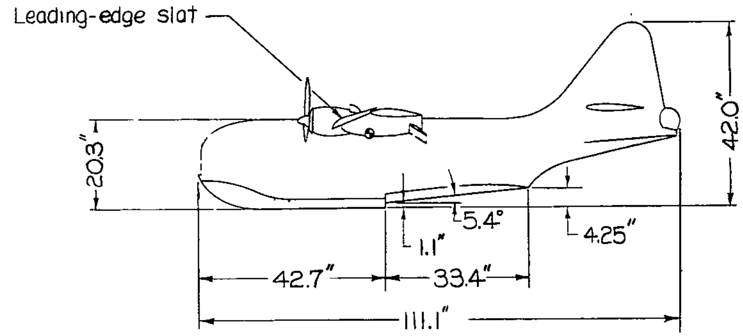
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Figure 1.- Drag saved by fairing the main step; air drag of hull with unfaired steps taken at 100 percent. (Fig. 17 of reference 2.)

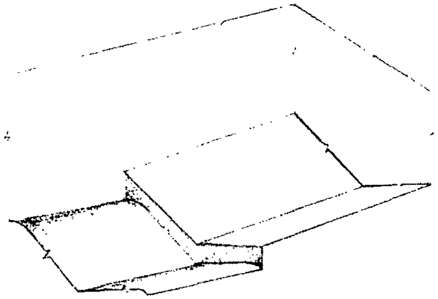




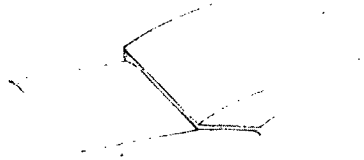
Wing area, sq ft	18.264
Airfoil section	Boeing 117
Root chord, in.	19.20
M.A.C., in.	16.52
Area of flaps, sq ft	3.12
Moment of inertia of model, slug-ft^2	4.54

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

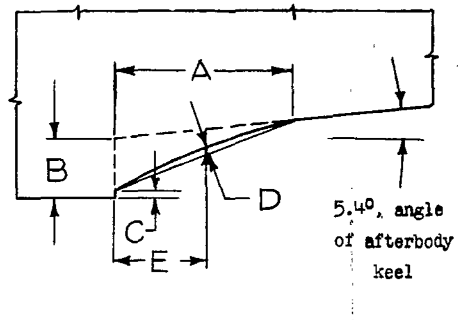
Figure 2.- Model used in tests of step fairings and ventilation.



Normal step



Typical step fairing without ventilation



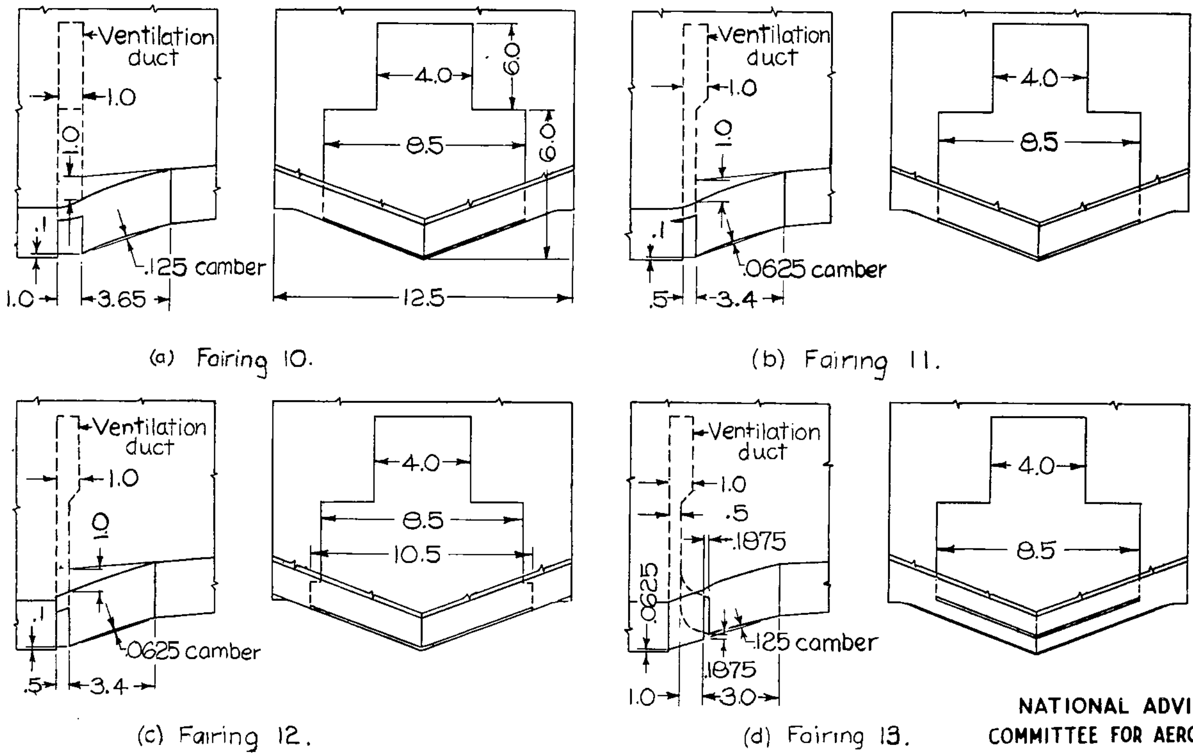
Section through keel of model with typical step fairing

Fairing designation	Dimensions, in.					Description[1]
	A	B	C	D	E	
1	4.0	1.1	0	0	----	Straight, 4:1 fillet without break at forebody
2	3.85	1.1	.15	0	----	Straight, 4:1 fillet with break at forebody
3	4.0	1.1	0	.12	2.0	Curved, 4:1 fillet without break at forebody
4	3.65	1.1	.1	.12	1.82	Curved, 4:1 fillet with break at forebody; maximum camber at midpoint
5	4.0	1.1	.1	.12	1.0	Curved, 4:1 fillet with break at forebody; maximum camber forward
6	4.0	1.1	.1	.25	2.0	Curved, 4:1 fillet with break at forebody; maximum camber increased
7	1.4	1.1	.15	0	----	Straight, 3:2 fillet with break at forebody
8	6.6	1.1	.1	.25	3.3	Curved, 6:1 fillet with break at forebody
9	6.0	1.5	.1	.25	3.0	Curved, 4:1 fillet with break at forebody; afterbody raised

[1]Fairing ratio $\approx \frac{A}{B - C}$

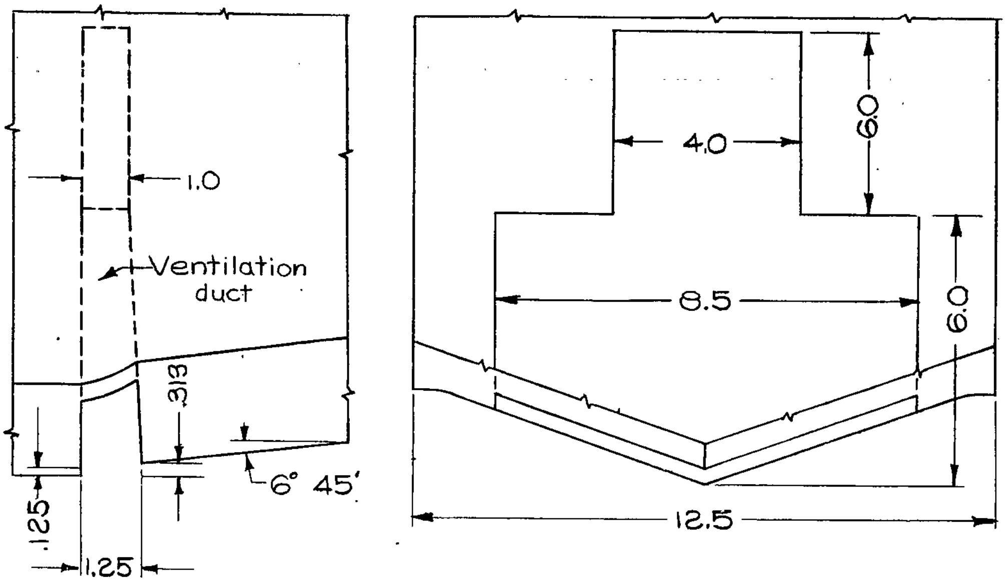
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Figure 3.- Dimensions and descriptions of step fairings 1 to 9.

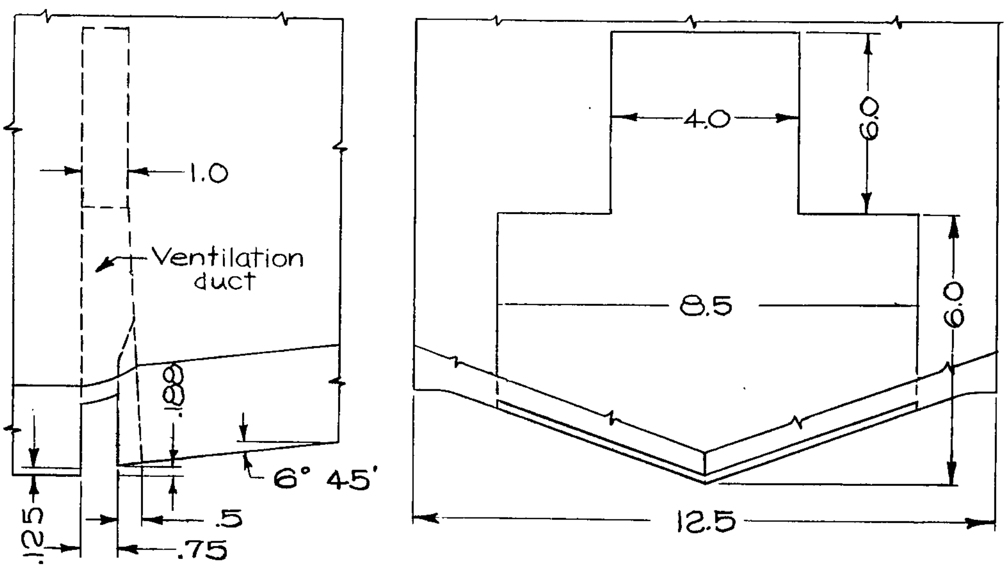


NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 4. – Step fairings with ventilation. Dimensions in inches.

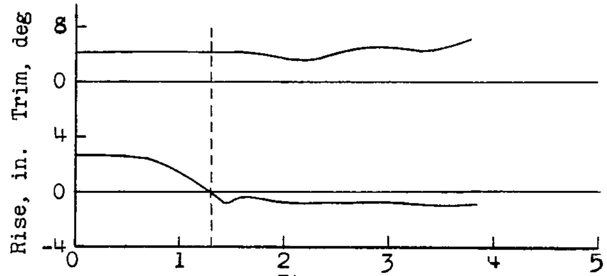


(a) Fairing 14.

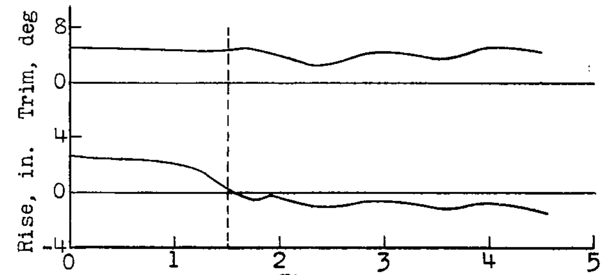


(b) Fairing 15.

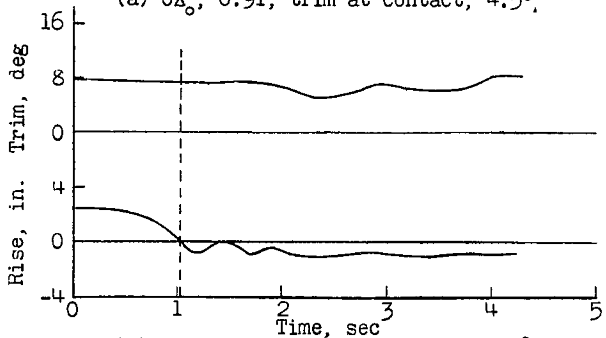
Figure 5.- Shallow step with ventilation ducts.
Dimensions in inches.



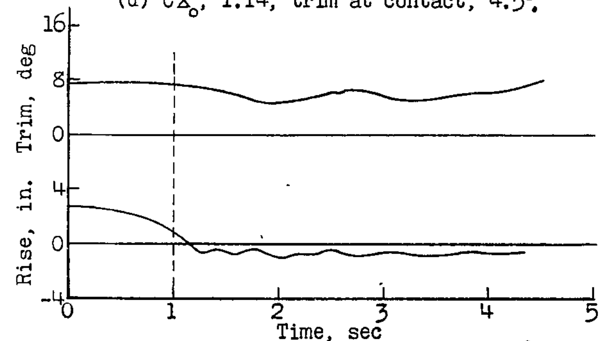
(a) C_{Δ_o}, 0.91; trim at contact, 4.5°.



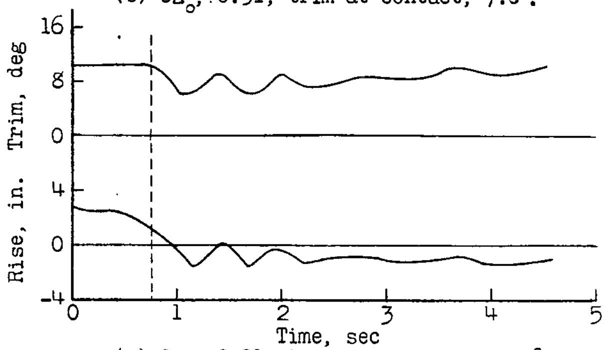
(d) C_{Δ_o}, 1.14; trim at contact, 4.5°.



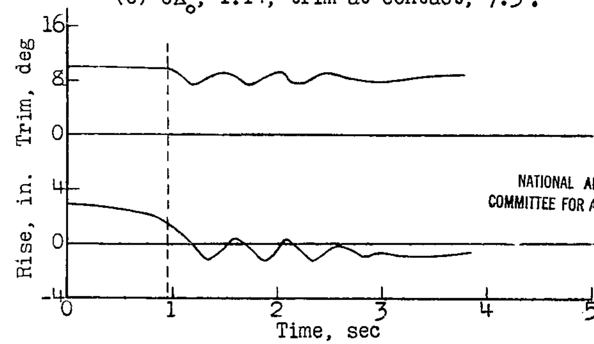
(b) C_{Δ_o}, 0.91; trim at contact, 7.0°.



(e) C_{Δ_o}, 1.14; trim at contact, 7.5°.

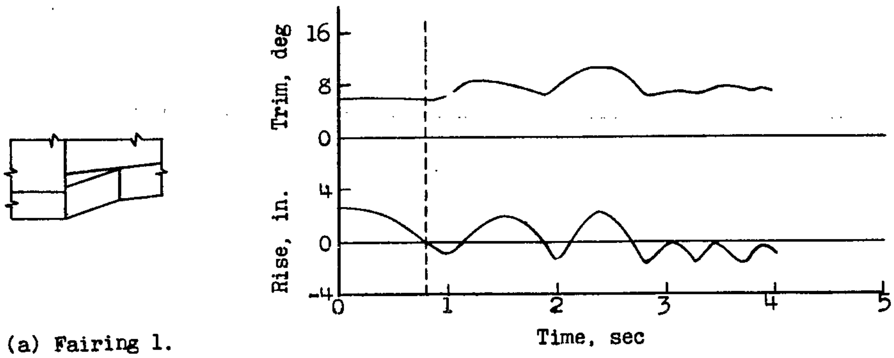


(c) C_{Δ_o}, 0.91; trim at contact, 10.5°.

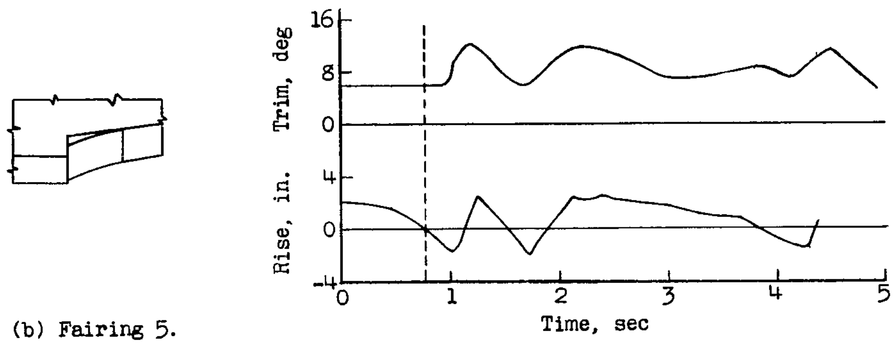


(f) C_{Δ_o}, 1.14; trim at contact, 10.0°.

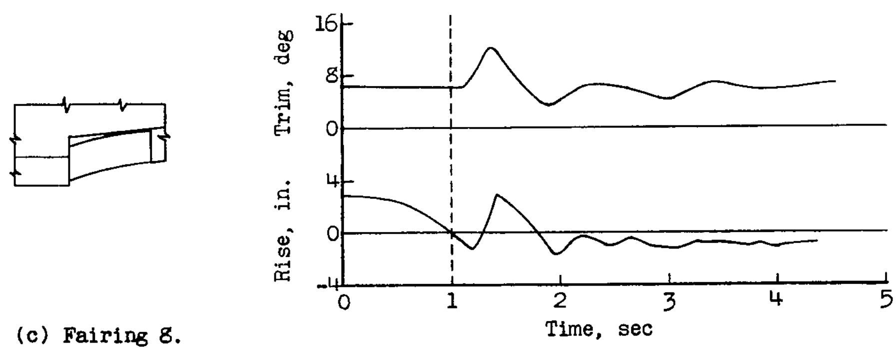
Figure 6.- Time histories of landings of conventional model. Center of gravity, 28 percent mean aerodynamic chord. Dashed line indicates time of contact.



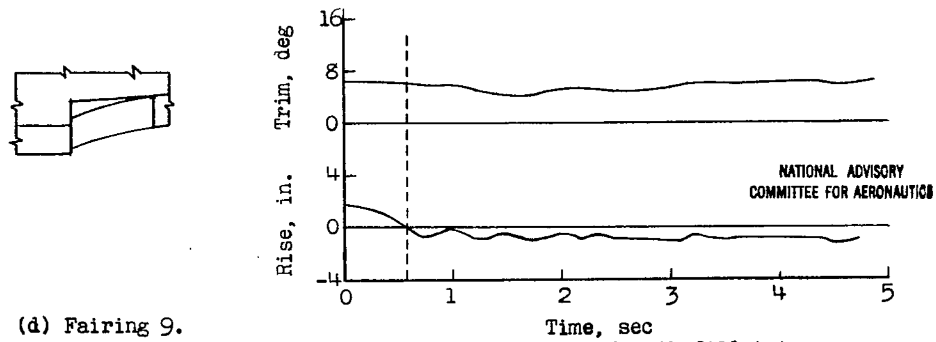
(a) Fairing 1.



(b) Fairing 5.

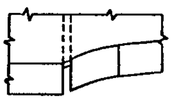
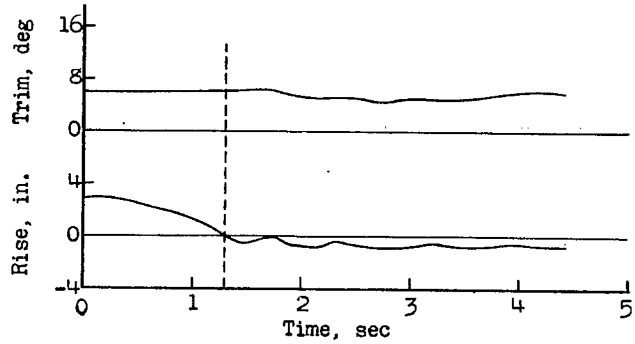


(c) Fairing 8.

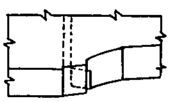
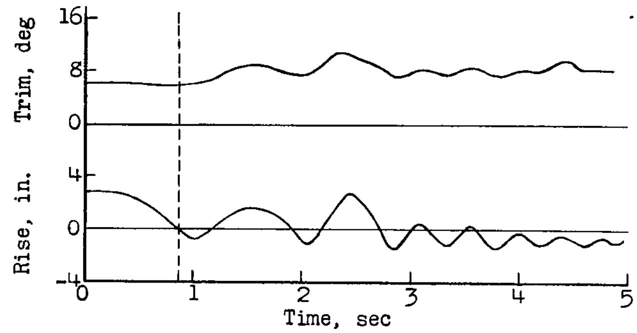


(d) Fairing 9.

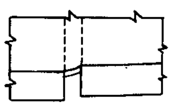
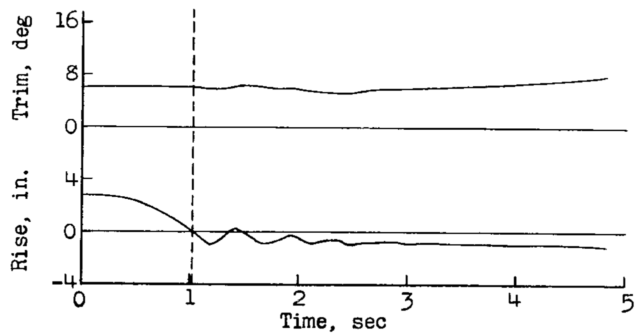
Figure 7.- Time histories of landings of model equipped with fillet-type step fairings. Trim at contact, approximately 6.0° for all landings; C_{Δ_0}, 1.14; center of gravity, 28 percent mean aerodynamic chord. Dashed line indicates time of contact.

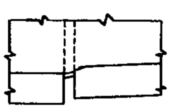
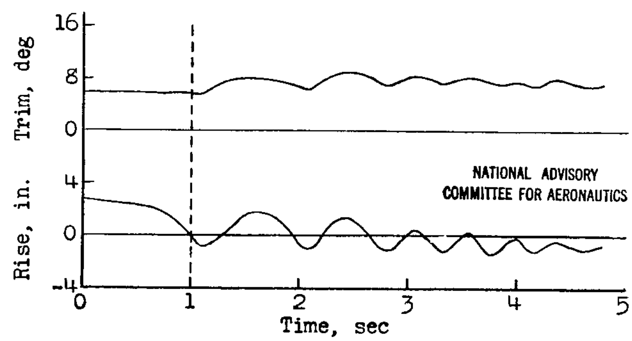
(a) Fairing 12.

(b) Fairing 13.

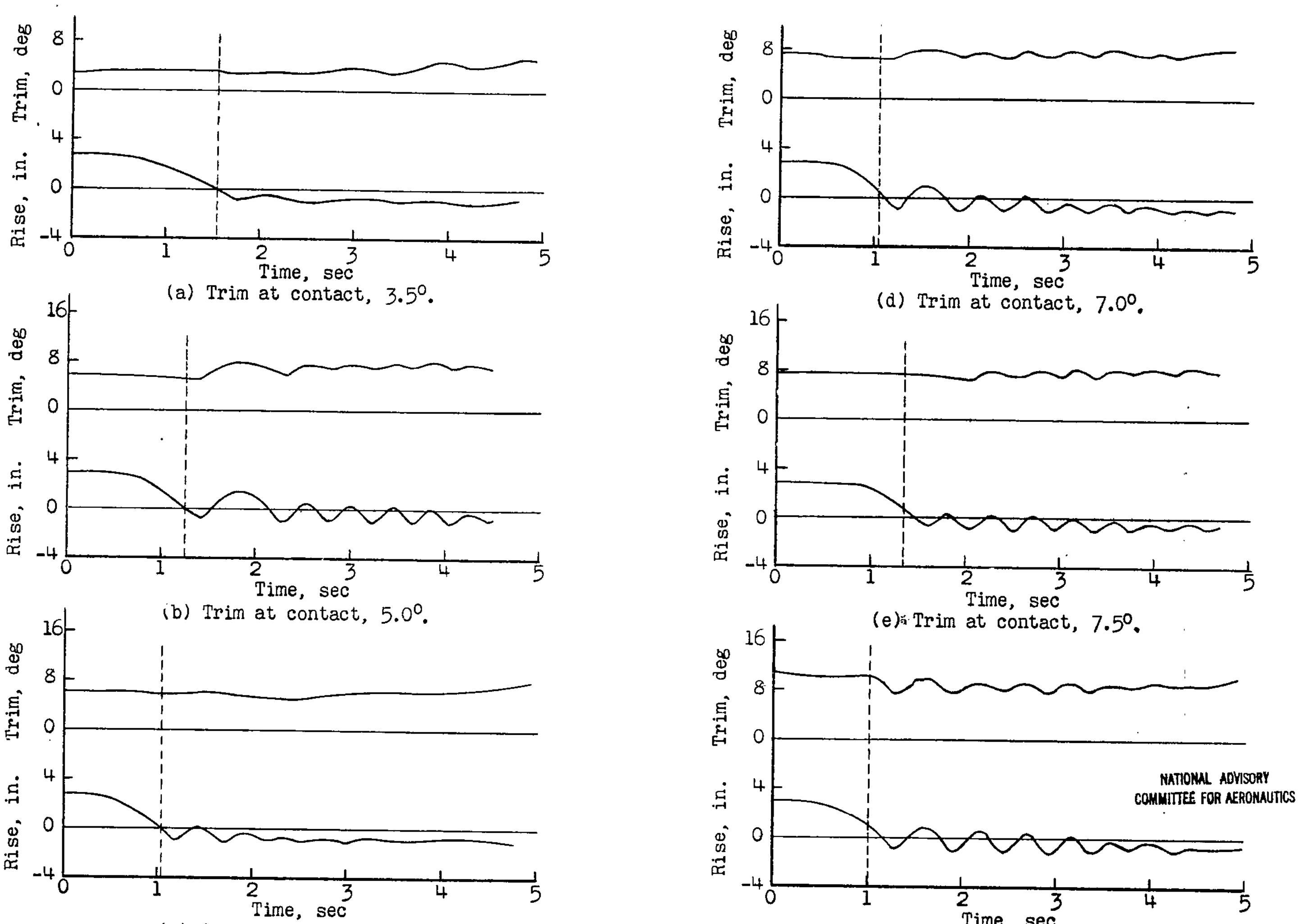



(c) Fairing 14.

(d) Fairing 15.

Figure 8.- Time histories of landings of model equipped with ventilated step fairings. Trim at contact, approximately 6.0° for all landings; C_{Δ_0}, 1.14; center of gravity, 28 percent mean aerodynamic chord. Dashed line indicates time of contact.



(a) Trim at contact, 3.5°.

(b) Trim at contact, 5.0°.

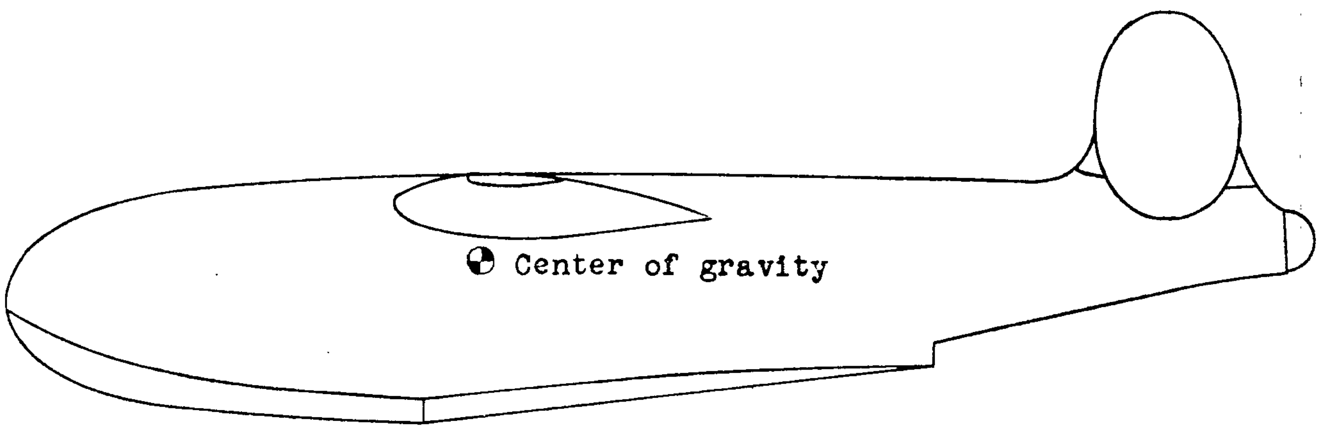
(c) Trim at contact, 6.0°.

(d) Trim at contact, 7.0°.

(e) Trim at contact, 7.5°.

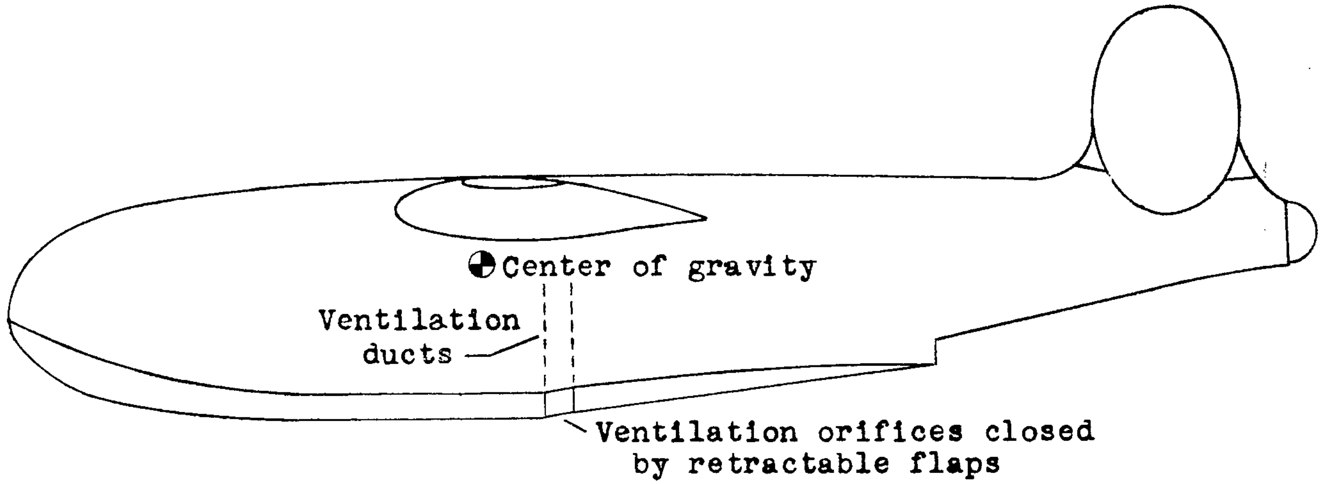
(f) Trim at contact, 10.0°.

Figure 9.- Time histories of landings of model with ventilated step fairing 14 (shallow step with large vents). C_{Δ_0}, 1.14; center of gravity, 28 percent mean aerodynamic chord. Dashed line indicates time of contact.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 10.- Model used for tests of reference 10.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

Figure 11.- Model equipped with shallow, ventilated step.