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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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ANALYSIS AND CORRELATION OF DATA OBTAINED BY SIX LABORATORIES
ON FUEL-VAPOR LOSS FROM FUEL TANKS DURING SIMULATED FLIGHT

By Charles S. Stone, Sol Baker, and
Gerald W. Englert

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NACA

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

ANALYSIS AND CORRELATION OF DATA OBTAINED BY SIX LABORATORIES ON

FUEL-VAPOR LOSS FROM FUEL TANKS DURING SIMULATED FLIGHT

By Charles S. Stone, Sol Baker, and
Gerald W. Englert

SUMMARY

Data on fuel-vapor loss from fuel tanks during simulated flight obtained by six laboratories were analyzed to show the effects of individual variables such as altitude, initial fuel temperature, rate of climb, booster-pump agitation, fuel depth, fuel-surface area, types of fuel, and vent-line pressure drop on fuel-vapor loss. From this analysis, the following conclusions were reached:

1. Fuel-vapor losses during flight were appreciable (3 percent) for flights to altitudes as low as 20,000 feet with an initial fuel temperature of 120° F. For a flight consisting of a climb to a 35,000-foot altitude with this altitude maintained for 8 hours and with the booster pump in operation, losses of 20 percent could be obtained with AN-F-25 fuel at an initial temperature of 120° F.
2. Most of the fuel-vapor loss occurred during the climb portion of the flight with relatively little loss during the remainder of the flight at constant altitude when no booster pump was used.
3. The fuel-vapor loss increased linearly with altitude beyond a critical altitude (the theoretical altitude at which fuel-vapor loss begins).
4. The critical altitude increased with decreased initial fuel temperature.
5. The fuel-vapor loss increased linearly with an increase in fuel temperature above approximately 80° F.
6. Booster-pump agitation markedly increased the fuel-vapor loss only during the constant-altitude portion of the flight.

7. Rate of climb to a given altitude had little or no effect on the fuel-vapor loss for rates of climb from 500 to 4000 feet per minute.

8. Fuel depth had no effect on fuel-vapor loss for depths varying from 1/3 foot to 2 feet. The loss due to foaming, surging, or boiling-over were not investigated.

9. Variations in fuel-surface area had little or no effect on fuel-vapor loss for surface areas varying from 0.034 square foot to 2.7 square feet.

10. Vent-line pressure differential increased with increased rate of climb and, at a constant rate of climb, built up rapidly soon after the critical altitude had been reached. When a constant rate of climb was maintained, the vent-line pressure differential tended to level off.

INTRODUCTION

The fuel-vapor loss from an aircraft fuel tank during flight is controlled by flight variables and by fuel characteristics. Some of the basic concepts relating fuel characteristics to the problem of fuel-vapor loss have been investigated in connection with studies made on vapor-locking of fuel systems. The changes in fuel characteristics during flight, the effect of weathering, and the effect of air dissolved in the fuel on the vapor-locking tendencies of the fuel, as well as a method of reducing fuel-vapor loss by cooling the fuel before flight, have been discussed in several progress reports of the Coordinating Research Council. The factors affecting fuel-vapor loss discussed herein include altitude, initial fuel temperature, rate of climb, booster-pump agitation, fuel depth, fuel-surface area, types of fuel, and vent-line pressure drop.

Data covering the effect of these variables on fuel-vapor loss were obtained in 1943 and 1944 by six laboratories - Boeing Aircraft Company, Bush Engineering Company, Ohio State University Research Foundation, Pesco Products Company, Pratt & Whitney Aircraft, and Thompson Products, Inc. - for the Army Air Forces, Air Technical Service Command, and the Navy Department, Bureau of Aeronautics. At the request of the Army Air Forces, these data were analyzed at the NACA Cleveland laboratory during August and September of 1944.

APPARATUS AND TEST PROCEDURE

The apparatus used by each of the six laboratories is listed in table I for comparison. In general, the apparatus consisted of a fuel tank subjected to altitude pressures by a vacuum pump, a means of measuring fuel loss during the test, and a means of controlling and measuring the fuel temperatures. The simulated-flight control usually consisted of a manually or automatically operated bleed valve in the line between the vacuum pump and the fuel tank for regulating the rate of climb and the altitude. The altitude pressure was measured by a manometer connected to the outer end of the vent line, by a manometer connected to the inside of the fuel tank, or both. The amount of fuel-vapor loss was found by measuring the change in fuel weight of a fuel tank mounted on a balance, by measuring the change in fuel volume with a calibrated glass window in the tank, or by condensing the escaping fuel vapor and taking volume measurements of the condensate.

A similar test procedure was followed by each of the six laboratories. The fuel was first heated to the desired initial fuel temperature and the fuel tank was then evacuated according to the desired flight path. Altitude-pressure and fuel-temperature readings were recorded at definite time intervals. A sample of the fuel was taken at the beginning and at the end of each test in order to measure Reid vapor pressures and to obtain A.S.T.M. distillation curves. The procedure followed and the simulated flights conducted by each of the laboratories are presented in table II.

EVALUATION OF TEST PROCEDURE

General Sources of Error

In order to evaluate properly the data presented, the several possible sources of error in the test procedure and the differences between the conditions that may occur during actual flight and those that may occur during simulated flight should be considered. These sources of error common to most of the test installations used to obtain the data in the six laboratories are discussed in the following paragraphs, not necessarily in the order of their relative importance because that order is not known.

1. Air leaks through the seams, the welds, and the fittings of the fuel tank are the most serious possible sources of error. A relatively small air leak near the bottom of the fuel tank would produce appreciable losses at the higher simulated altitudes and the losses would increase as the duration of the flight increased. In all tests, except those conducted by Nash, atmospheric pressure

was on the outside of the fuel tank and altitude pressure was on the inside. In most cases it was rather difficult, if not impossible, to be certain that no leaks were present.

2. In none of the tests, except those conducted by Nash and by Boeing (test setup No. 2), was any attempt made to control the temperature of the air surrounding the fuel tank. Although in all cases the fuel tank was insulated to some extent, any heat transfer from the fuel to the outside air would affect the test results. In the tests conducted by Nash, the surrounding-air temperature was maintained at 70° F; whereas, during the tests conducted by Boeing, the surrounding-air temperature was maintained equal to the fuel temperature.

3. In all of the tests except those conducted by Ohio State, the fuel temperature was measured at a single point in the fuel tank. In tests conducted with small quantities of fuel, such as those performed by Boeing on the preliminary test setup and on test setup No. 2 where 2 liters of fuel were used, it is entirely possible that the average fuel temperature was measured. With the larger quantities of fuel (5 to 50 gal) used by the other laboratories, it is highly improbable that the average temperature of the fuel throughout the tank at the start of the test could be measured at a single point unless the fuel was agitated for a long period of time. In the tests conducted by Ohio State, the thermocouples were located 6, 12, 18, 24, and 30 inches from the bottom of the tank. Thus an accurate check on the fuel temperature throughout the full depth of the tank was possible.

4. The effect on fuel-vapor loss of the amount of air dissolved in the gasoline was not investigated by any of the laboratories. This variable may have introduced some error in the reported test results but its magnitude cannot be estimated because the effect of dissolved air on fuel-vapor loss is not known.

5. Airplane altitude is usually considered to be the pressure altitude outside the airplane, which is the same as the pressure altitude outside the fuel-tank vent line. In the simulated flights conducted by most of the laboratories, the pressure altitude at the end of the vent line was controlled. In the tests conducted by Boeing and by Pratt & Whitney, however, the measured altitude was the pressure altitude existing within the fuel tank and therefore should differ from that measured by the other laboratories by the difference between the pressure within the fuel tank and the pressure at the end of the vent line.

Individual Sources of Error

The individual sources of error and the differences between actual-flight conditions and simulated-flight conditions for the test procedures of each of the six laboratories are as follows:

Boeing Aircraft Company. - Three test installations, referred to as "preliminary setup," "test setup No. 1," and "test setup No. 2," were used in the test conducted by Boeing. The test results obtained with test setup No. 2 were considered by Boeing to be the most reliable and the greatest emphasis was placed on these results.

In the fuel-tempering process in the preliminary setup and setup No. 2, the fuel was electrically heated. During this heating process, localized boiling might possibly have taken place and caused some fuel loss or weathering prior to the simulated flight. The Boeing report does not state whether the system was closed to the atmosphere during the tempering process nor whether attempts were made to measure any fuel loss occurring during this process.

The Boeing report does not state whether the weighing scale used in the preliminary setup and setup No. 2 was calibrated. With the vent and the manometer line connected directly to the flask, an incorrect weight measurement could possibly have been obtained.

Wash Engineering Company. - In the tests conducted by Wash, the fuel was brought to the desired temperature by circulating it through an external heat exchanger by a booster pump. The Wash report does not state whether the vent to the atmosphere was closed during this tempering process or whether an attempt was made to measure the loss, if any, during this period.

All fuel measurements were made on a volume basis and had to be corrected to present the data in terms of weight loss of fuel. Involved in the conversion are compensations for the temperature and for the specific gravity of the remaining fuel. The method used of determining the variation of specific gravity with percentage loss is not stated.

No fuel-loss measurements were made during the climb period. The fuel loss was calculated only at 10 minutes after the end of the climb and at the end of the test, although data were taken at definite time intervals throughout the constant-altitude portion of the simulated flight.

Ohio State University Research Foundation. - The data presented by Ohio State show that the Reid vapor pressure of the gasoline

measured before the start of the tests varied from 5.32 to 6.42 pounds per square inch. Figure 1, obtained from test data, shows that a variation of initial Reid vapor pressure between these limits may cause a variation of as much as 8 percent in the fuel-vapor loss. (The initial Reid vapor pressure of test No. 2-120-B1 was 2.03 pounds per square inch. Inasmuch as this initial Reid vapor pressure was lower than the final Reid vapor pressure of this particular test, it was considered to be a typographical error.)

The Reid vapor pressure of the fuel at the start of the tests decreased with an increase in the initial fuel temperature. This decrease indicates that the fuel may have been weathered during the heating process. In some cases the gasoline was stirred in the fuel tank to equalize the fuel temperature within the tank but the method of stirring the gasoline is not stated. Stirring of the gasoline may weather the fuel and affect the fuel-vapor loss, especially if the tank is vented to the outside atmosphere during this process.

Pasco Products Company. - Very little information is presented in the Pasco report about the test procedure used. From the information obtained during a telephone conversation with Mr. R. B. Wallace, project engineer for these tests, it was concluded that some of the possible sources of error are as follows:

1. The scale used during the tests was not calibrated. With the vent, the manometer, the thermocouple, and the booster-pump lines connected directly to the fuel tank, it is possible that an incorrect weight measurement could have been obtained.

2. The fuel was heated by circulating it through the coils of an oil bath maintained at a temperature of approximately 150° F. Some localized boiling of the fuel may have occurred in the oil bath because the initial boiling point of the fuel is below 150° F (normally between 100° F and 120° F).

3. Some of the vapor formed during the tempering process by localized fuel boiling and agitation may have escaped through the vent line inasmuch as it was open during this period. The Pasco report does not state whether any measurements of possible fuel loss during this period were made. No check on this possible loss can be made because the initial fuel sample was removed before the fuel-tempering process.

4. The fuel temperature was measured by a single thermocouple located approximately 1 1/2 inches from the bottom center of the tank, which may not have measured the true average fuel temperature within the tank.

Altitude

The effect of altitude on fuel-vapor loss is shown in figure 3, in which the fuel loss during the climb period has been plotted as a function of altitude with initial fuel temperatures of 60°, 80°, 90°, 100°, 110°, and 120° F. A representative average has been drawn for each temperature and these curves are presented in figure 4. In these curves the data obtained by Pascoe varied so greatly from the average of the data obtained by the other laboratories that they were disregarded when the average curve was drawn. In figure 4 the curves for the various initial fuel temperatures follow the same general trend. Each curve shows a negligible loss up to an approximate critical altitude (the theoretical altitude at which fuel-vapor loss begins) from which point the fuel-vapor loss increases linearly with increased altitude. The small transition section preceding the linear portion of the curve may be caused by the presence of air either in solution within the fuel or above the fuel, which, upon being removed, carries with it some fuel vapor. The fact that the variation of fuel-vapor loss with altitude is a linear function is amply brought out in figure 5, in which data are plotted from a test conducted by Boeing to an altitude of 55,000 feet.

Inasmuch as the slopes of the linear portions of the curves of figures 4 and 5 are very nearly equal, the following equation based on the average slopes of these curves, neglecting the transition section where the loss is small, can be derived to approximate the variation of fuel-vapor loss with altitude during a climb:

$$L = \frac{Z - Z_c}{1.65} \quad (1)$$

where

- L fuel-vapor loss, percent
- Z altitude, in 1000 feet
- Z_c critical altitude, in 1000 feet

Initial Fuel Temperature

The marked effect that initial fuel temperature has on fuel-vapor loss is shown in figure 4. Because the vapor pressure of the fuel increases with temperature, the critical altitude decreases with increased fuel temperature. The critical altitude can be obtained by extending the linear portion of the curve of fuel-vapor loss plotted against altitude to the point of zero loss. The

critical altitudes thus obtained from figures 4 and 5 are plotted as a function of temperature in figure 6. This figure indicates that a linear relation exists between the initial fuel temperature and the critical altitude. This relation for the fuels used in these tests may be expressed by the equation

$$Z_0 = 59.4 - 0.37 T \quad (2)$$

where T is the initial fuel temperature in $^{\circ}\text{F}$.

Equation (2) may be combined with equation (1) to give a possible general equation for the fuels used in these tests relating the fuel-vapor loss during a climb to altitude with initial fuel temperatures between 60°F and 120°F :

$$L = \frac{Z + 0.37 T - 59.4}{1.65} \quad (3)$$

It may be necessary to obtain additional data to establish completely equation (3) for future use.

The fuel-vapor loss at several periods during the test (10 min, 1 hr, and 8 hr after the end of the climb period) is plotted in figure 7, which shows that fuel-vapor loss tends to vary linearly with initial fuel temperatures above approximately 80°F after the end of the climb period as well as during the climb period.

Rate of Climb

The effect of rate of climb to a given altitude on fuel-vapor loss is shown in figure 8. Although all the data presented were obtained by Boeing, the results indicate that the rate of climb to a given altitude had little or no effect on fuel-vapor loss with rates of climb varying from 500 to 2000 feet per minute. The Nash tests also indicated that no appreciable change in fuel-vapor loss occurred with a change in the rate of climb from 2000 to 4000 feet per minute. The data obtained by Boeing cannot be directly compared with those obtained by the other laboratories because the Boeing tests were conducted with an initial fuel temperature of 110°F , whereas the tests of the other laboratories were conducted with initial fuel temperatures of 120°F and 100°F . The two average fuel-vapor curves from figure 4 at initial fuel temperatures of 120°F and 100°F with rates of climb of 4000 feet per minute are also shown in figure 8. The curves obtained by Boeing fall very nearly midway between the other two curves with almost the same characteristics and slope, which seems to indicate that rate of climb has little or no effect on fuel-vapor loss, even up to a rate

of climb of 4,000 feet per minute. Increased rates of climb above 4,000 feet per minute may cause increased fuel loss if surging and foaming are encountered.

Booster-Pump Agitation

A series of curves showing fuel-vapor loss as a function of initial fuel temperature (fig. 9) similar to the series showing the effect of initial fuel temperature on fuel-vapor loss was obtained with the fuel agitated and circulated by a booster pump. This series of curves and the series obtained with the fuel unagitated are replotted in figure 10 for comparison. This figure indicates that the fuel-vapor loss both with and without agitation tends to be nearly equal at the end of the climb period. Figure 10 also indicates that, as the flight progresses at constant altitude, the loss with agitated fuel becomes increasingly greater than that with the unagitated fuel. During the climb period, the high rate of fuel loss resulting from the boiling of the fuel is accompanied by considerable agitation of the fuel. The action of the booster pump adds little to the agitation already present or to the fuel loss during the relatively short climb period. During the relatively long quiescent constant-altitude portion of the simulated flight, however, the additional loss due to booster-pump agitation is readily evident.

Fuel Depth

Data obtained by three laboratories (Ohio State, Thompson, and Nash) on the effect of fuel depth on fuel-vapor loss at 10 minutes after the end of the climb to 55,000 feet with an initial fuel temperature of 120° F are presented in figure 11. This figure indicates that fuel depth has no effect on the fuel-vapor loss for fuel depths varying from 1 1/2 feet to 2 feet. The losses due to surging, foaming, or boiling-over when the fuel tank is filled close to capacity were not investigated.

Fuel-Surface Area

Nash, the only laboratory reporting tests on the effect of fuel-surface area on fuel-vapor loss, conducted similar tests with two fuel tanks, one having a fuel-surface area of 1 square foot and the other a fuel-surface area of 2.7 square feet. Nash reports an average fuel-vapor loss of 16.7 percent (average of four tests) during a simulated flight with the smaller tank and 16.37 percent (average of three tests) with the larger tank for the same simulated

flight. These results seem to indicate that the variation of surface area has a negligible effect on fuel-vapor loss.

Table I indicates that four of the other laboratories conducted tests in which the fuel-surface areas were nearly equal (approximately 2.7 sq ft); whereas Boeing (with test setup No. 2) conducted tests in which the fuel-surface area was extremely small (approximately 0.034 sq ft). The fuel-vapor-loss correlation obtained among the six laboratories in figures 3, 7, and 10 indicates that the surface area of the fuel has little, if any, effect on fuel-vapor loss. Insufficient data are presented for a more comprehensive analysis.

Types of Fuel

Several fuels were used by the various laboratories in the tests conducted to determine the fuel-vapor loss during simulated flight. Boeing and Pratt & Whitney (and, although not stated, probably Thompson and Ohio State) used AI-F-23 fuel; Pesco used 87-octane and 65-octane fuel; and Nash used AI-VV-F-775, Amendment-3 fuel and AI-VV-F-781, Amendment-5 fuel. (See table I.)

As indicated in figure 2, the fuels used by Nash resulted in a slightly lower fuel-vapor loss than those used by Ohio State and Thompson. The loss under the same conditions for Pesco is not plotted in this curve because it was so large as to preclude the possibility of any cause except air leakage. (Loss at the end of the Pesco test for the same conditions as those shown in fig. 2 was 38.4 percent.) In figure 7 the fuel-vapor losses at several initial fuel temperatures for each of the laboratories, except Boeing, are compared and show no general trend. Insufficient evidence is presented for a comprehensive analysis.

Pressure Drop in the Vent Line

The pressure drop in the fuel-tank vent lines is important because a pressure differential less than a specified maximum must be maintained across the wall of the fuel tank during flight to assure the self-sealing properties of the fuel tank when it is penetrated by gun fire.

Data obtained by three laboratories (Nash, Thompson, and Boeing) on the pressure drop in vent lines during simulated-flight tests under several flight conditions are presented in figures 12 and 13. Because of the variations in size and configuration of the vent lines

used in the various tests, the results obtained from these laboratories cannot be compared; the results obtained by each laboratory, however, will be discussed individually.

Mash Engineering Company. - The vent line consisted of 10 feet of 1-inch-outside-diameter vent pipe and was wound in a large loop around the fuel tank within the altitude chamber. The pressure drop in the vent line was measured by a differential manometer connected between the inside of the fuel tank and a point near the end of the vent line.

The variation in vent-line pressure differentials during simulated flight for several initial fuel temperatures (shown in fig. 12(a)) is similar, with the initial pressure differential occurring at the initial point of appreciable fuel-vapor loss (probably close to the critical altitude). The pressure differential tends to reach a maximum within a relatively short time and then levels off for the remainder of the climb period. The leveling-off can be expected because the rate of fuel-vapor loss with altitude is constant during this period of the simulated flight and the pressure differential through the vent line is a function of the weight rate of flow through it.

Thompson Products, Inc. - The vent line used in the tests conducted by Thompson consisted of 10 feet of 1-inch-outside-diameter tubing containing three 90° bends and made up of seven sections in all, each connected by flexible couplings. The pressure drop in the vent line was recorded as the difference between the pressure in the fuel tank and that in the "altitude tank." The curves of pressure drop as a function of altitude (fig. 12(b)) are of the same general shape and start at approximately the same altitude as those shown in the Mash report (fig. 12(a)). The rapid increase in pressure drop over the pressure drop reported by Mash is possibly due to the increased resistance offered by the bends and couplings in the vent line.

Boeing Aircraft Company. - The curves presented in figure 13 were plotted from data obtained on test setup No. 1, in which the vent-pressure drop during simulated flight at several rates of climb was plotted as a function of altitude. The company report does not state how the pressure drop in the vent line was measured. It is therefore assumed that the pressure drop was measured as the difference between the pressure in the vacuum tank and that in the Erlensmeyer flask. From an inspection of the photograph of the test installation, the vent line appears to be about 3 feet long and to contain a 3/8-inch orifice connected by sections of 1-inch self-sealing hose to a gate valve mounted on the altitude tank. The curves show that the pressure drop in the vent tube at a given

altitude increases with an increase in rate of climb. This condition is to be expected because the rate of fuel-vapor loss increases with increased rate of climb and the pressure differential across the vent line is a function of the weight rate of flow through the vent line. The drop in pressure differential with increase in altitude before the end of the climb period, however, was probably due to the fact that a constant rate of climb of 2000 and 4000 feet per minute could not be maintained.

General trends. - On the basis of the data presented from the Nash, Boeing, and Thompson laboratories, several general trends can be noted. The vent-line pressure differential: (1) increases with increased rate of climb; and (2) increases rapidly with increased altitude at the point at which appreciable fuel-vapor loss occurs and has a tendency to level off if a constant rate of climb is maintained.

CONCLUSIONS

On the basis of a comparison of the data presented by six laboratories on the fuel-vapor loss from fuel tanks during simulated flight, the following conclusions have been reached:

1. Fuel-vapor losses during flight were appreciable (3 percent) for flights to altitudes as low as 20,000 feet with an initial fuel temperature of 180° F. For a flight consisting of a climb to a 35,000-foot altitude with this altitude maintained for 8 hours and with the booster pump in operation, losses of 20 percent could be obtained with AN-F-25 fuel at an initial temperature of 120° F.
2. Most of the fuel-vapor loss occurred during the climb portion of the flight with relatively little loss during the remainder of the flight at constant altitude when no booster pump was used.
3. The fuel-vapor loss increased linearly with altitude beyond a critical altitude.
4. The critical altitude increased with decreased initial fuel temperature.
5. The fuel-vapor loss increased linearly with an increase in fuel temperature above approximately 80° F.
6. Booster-pump agitation markedly increased the fuel-vapor loss during the constant-altitude portion of the flight only.

7. Rate of climb to a given altitude had little or no effect on the fuel-vapor loss for rates of climb from 500 to 4000 feet per minute.

8. Fuel depth had no effect on fuel-vapor loss for depths varying from $1/3$ foot to 2 feet. The losses due to foaming, surging, or boiling-over were not investigated.

9. Variations in fuel-surface area had little or no effect on fuel-vapor loss for surface areas varying from 0.034 square foot to 2.7 square feet.

10. Vent-line pressure differential increased with increased rate of climb and, at a constant rate of climb, built up rapidly soon after the critical altitude had been reached. When a constant rate of climb was maintained, the vent-line pressure differential tended to level off.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, December 12, 1944.

TABLE I - APPARATUS USED IN PULSED-FLAME-LESS TESTS

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TABLE II - PROCEDURES AND VARIABLES IN SIMULATED-FLIGHT FUEL-VAPOR-LOSS TESTS

Variable	Boeing Aircraft Company		East Engineering Company	Ohio State University	Pezco Products Company	Pitt & Whitely Aircrafts	Thompson Products, Inc.
	Preliminary test setup Approx. 2 liters	Test setup No. 1 Approx. 8 gal					
Fuel quantity			1 1/2-; 2 1/2-; 1- and 2-ft depths, 1- and 2.7-sq ft surface Approx. 2.5 to 20.5 gal	1- and 8-ft depths, approx. 134 and 848 lb	1- and 8-ft depths, approx. 135 and 270 lb	9/10 to 30 gal	1- and 8-ft depths, approx. 95 and 190 lb
Initial fuel temperature, °F	110 111	107 110	60, 80, 100, 120 130	60, 80, 100, and 120	60, 80, 100, and 120	80, 100 and 120	60, 80, 100, and 120
Simulated flight rate of climb, ft/min	1000	500, 1000, 2000, and 4000	2000 and 4000	4000	4000	1000	4000
Altitude, ft	40,000	40,000	15,000 25,000 35,000 50,000 65,000	35,000	35,000	25,000 50,000 35,000 60,000	35,000
Duration of flight, hr	Climb only	Climb only	Climb only	5	5	2	5
Agitation	None	None	1. None 2. With booster pump	1. None 2. With booster pump	1. None 2. With booster pump	1. None 2. With booster pump	1. None 2. With booster pump

*Depending upon amount of loss anticipated.

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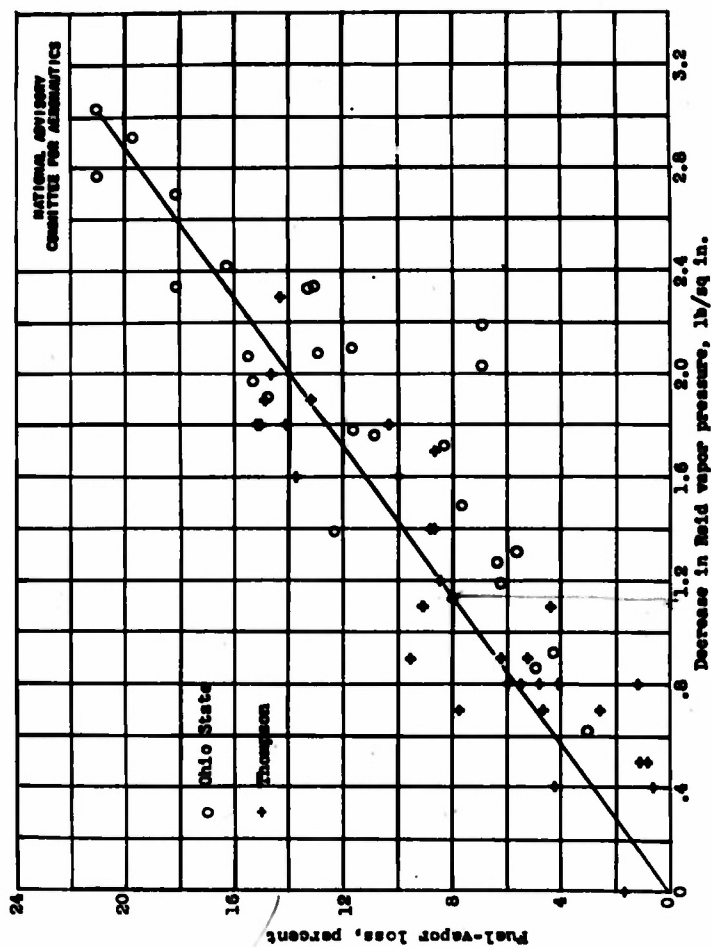


Figure 1.- The variation of fuel-vapor loss with decrease in the Reid vapor pressure of the fuel.

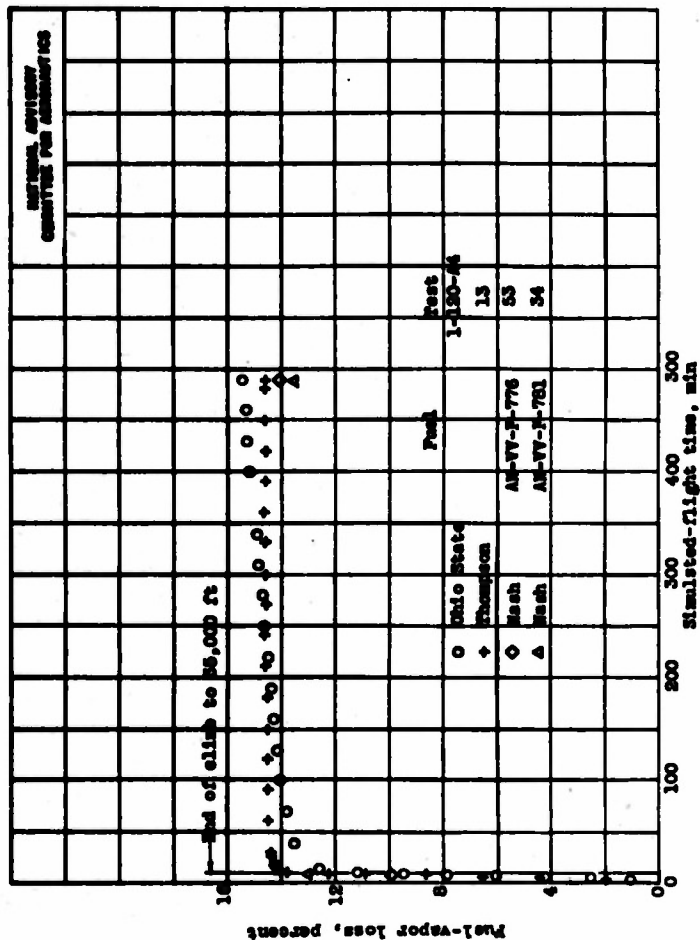
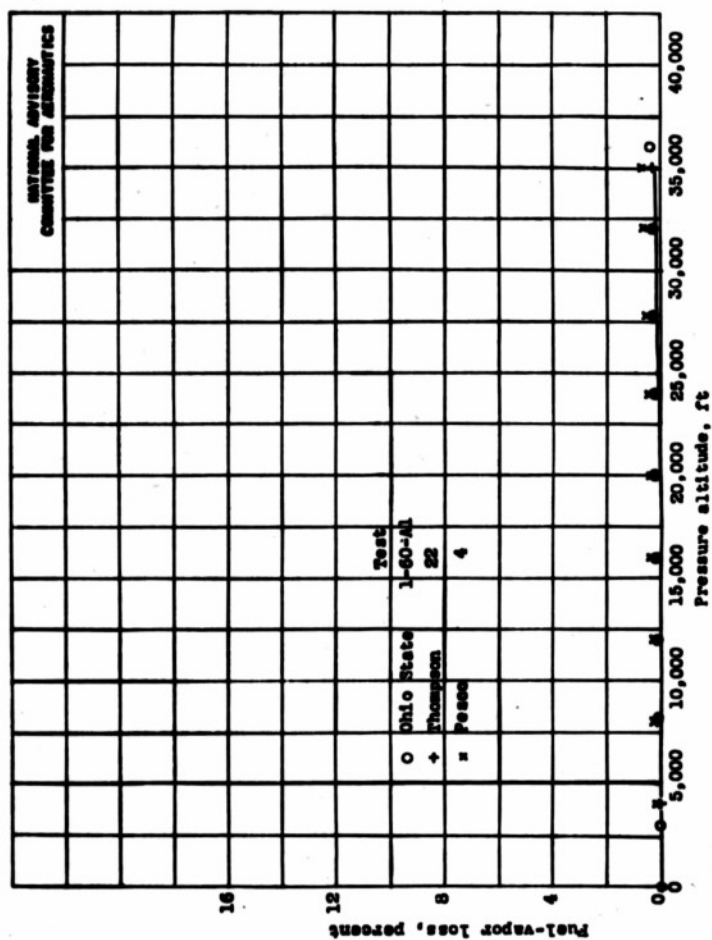
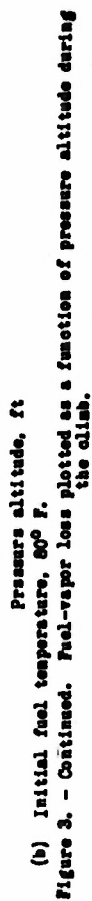


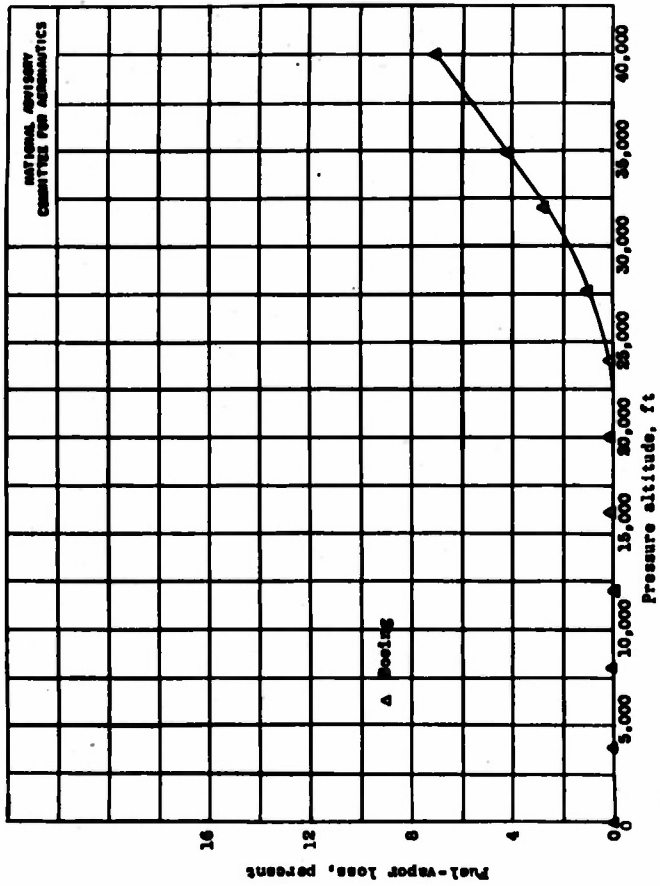
Figure 2. - Fuel-vapor loss plotted as a function of simulated-flight time. Rate of climb, 4000 feet per minute to 35,000-foot altitude, with this altitude maintained to end of test; initial fuel temperature, 120° F.



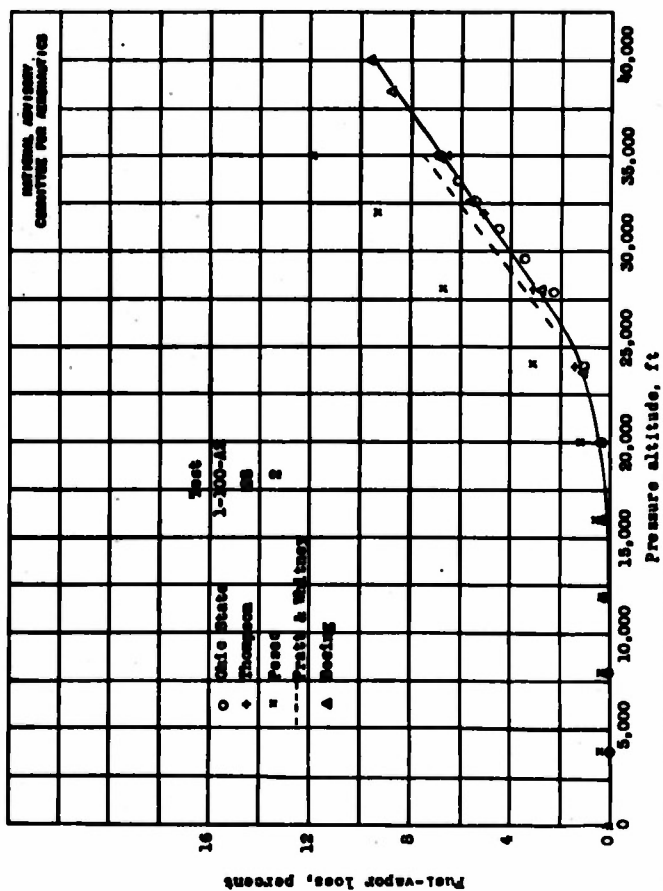
(a) Initial fuel temperature, 60° F.
Figure 3. - Fuel-vapor loss plotted as a function of pressure altitude during the climb.



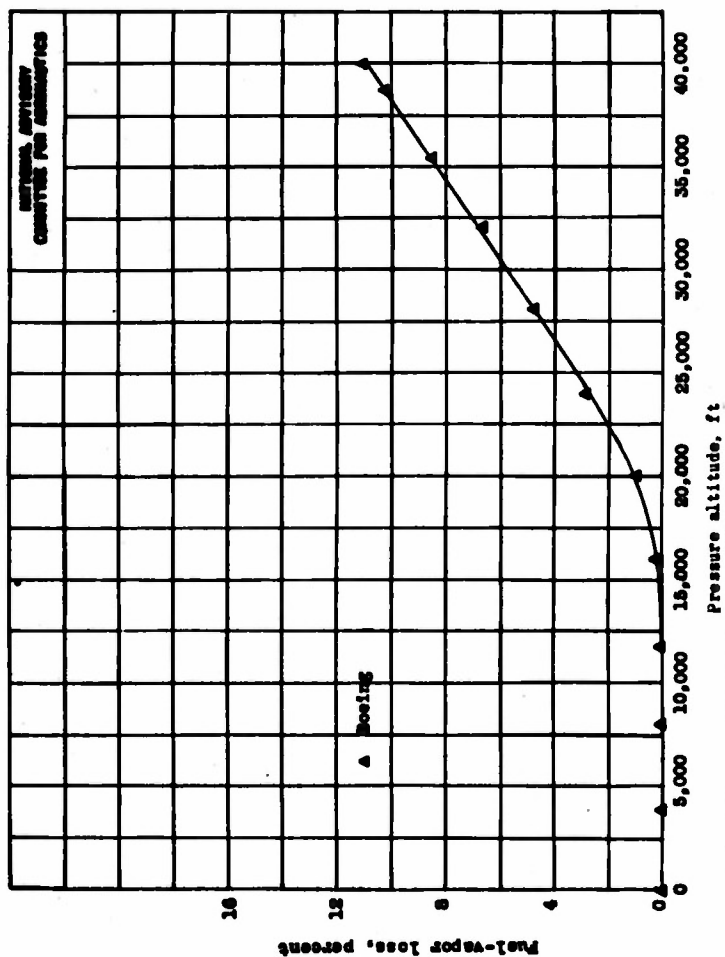
(b) Initial fuel temperature, 80° F.



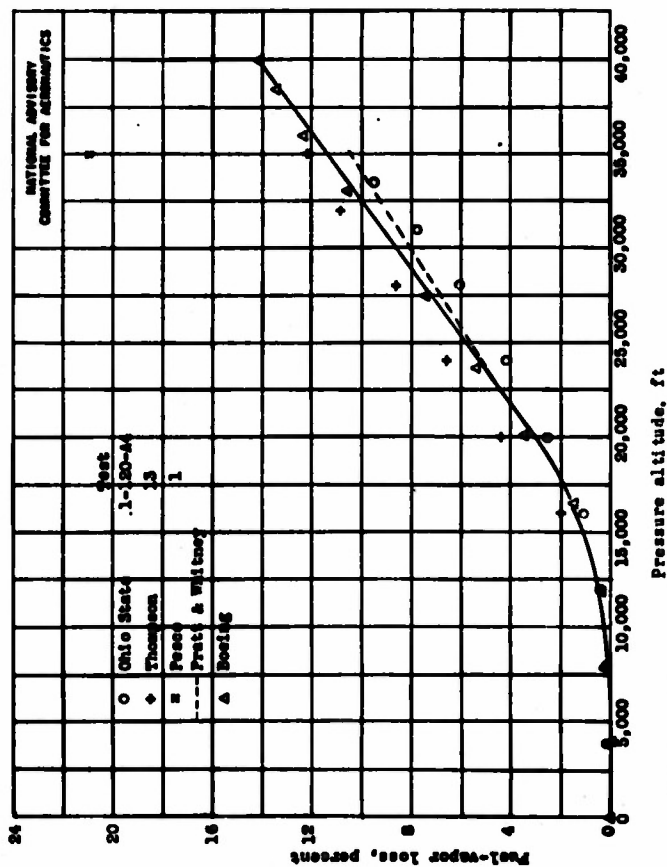
(c) Initial fuel temperature, 90° F.
Figure 3. - Continued. Fuel-vapor loss plotted as a function of pressure altitude during the climb.



(d) Initial fuel temperature, 100° F.
Figure 3. - Continued. Fuel-vapor loss plotted as a function of pressure altitude during the climb.



(e) Initial fuel temperature, 110° F.
Figure 3. - Continued. Fuel-vapor loss plotted as a function of pressure altitude during the climb.



(2) Initial fuel temperature, 120° F.
Figure 3. - Concluded. Fuel-vapor loss plotted as a function of pressure altitude during the climb.

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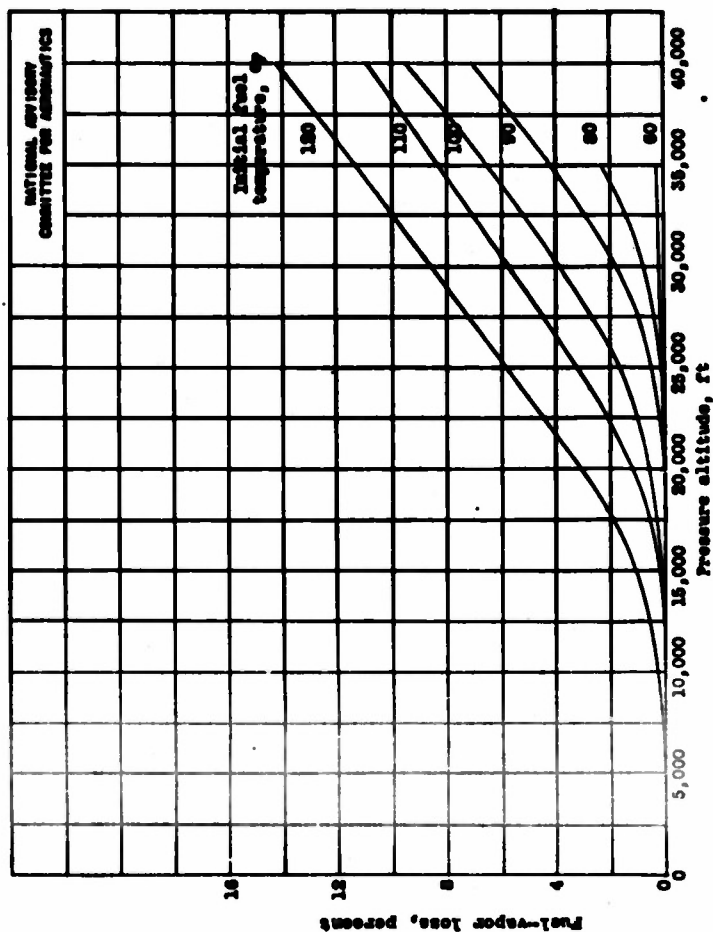


Figure 4. - Fuel-vapor loss plotted as a function of pressure altitude during the climb for several initial fuel temperatures. (Replot of average curves from fig. 3.)

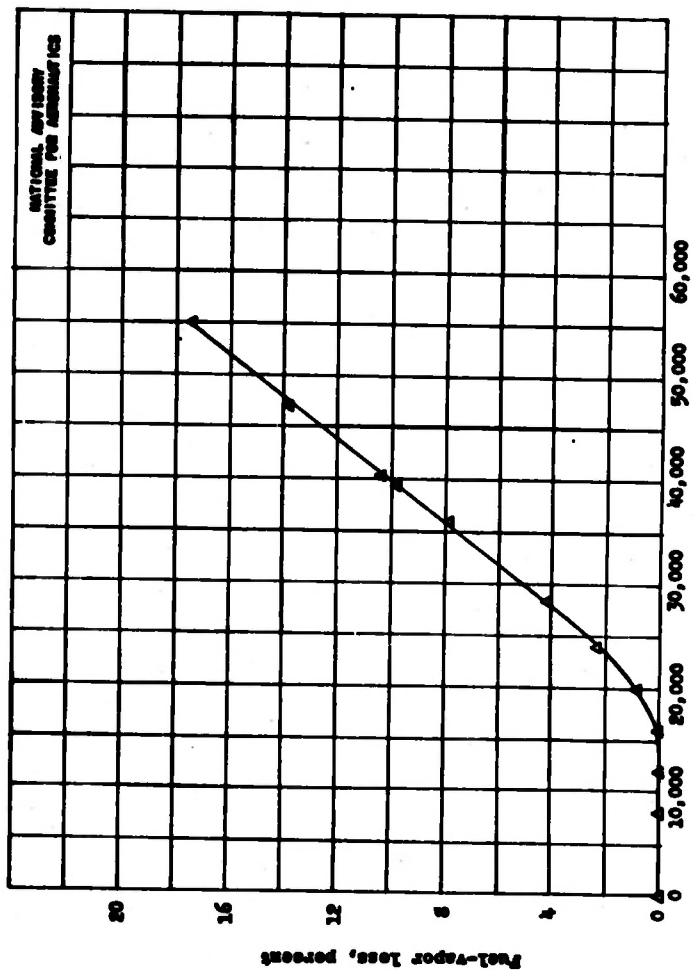


Figure 5. - Fuel-vapor loss plotted as a function of pressure altitude during the climb. Initial fuel temperature, 110° F.

E-185

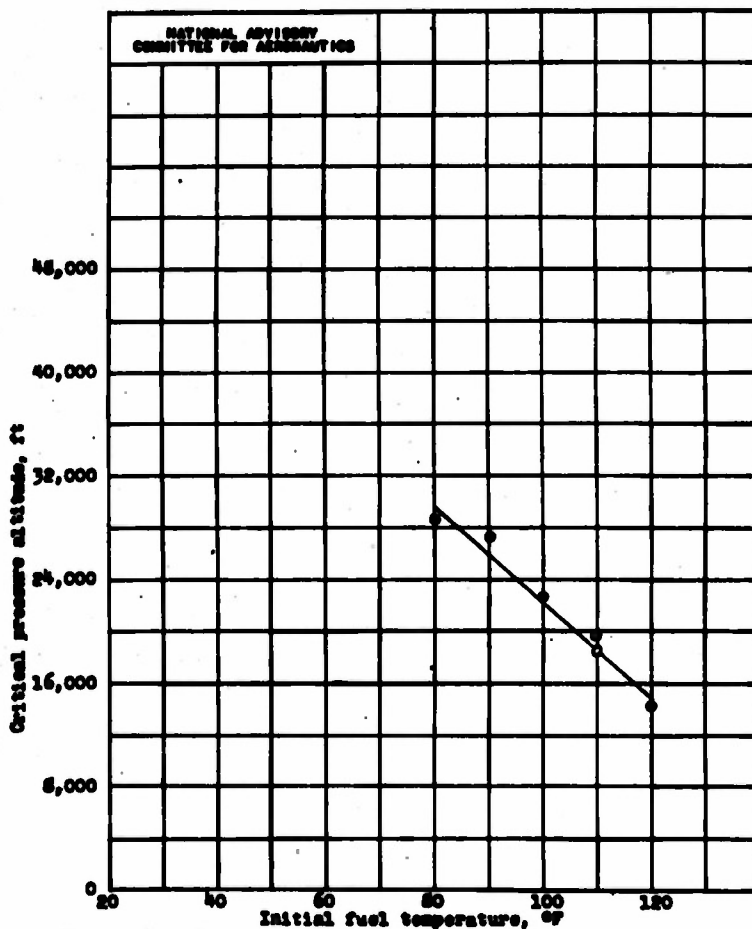
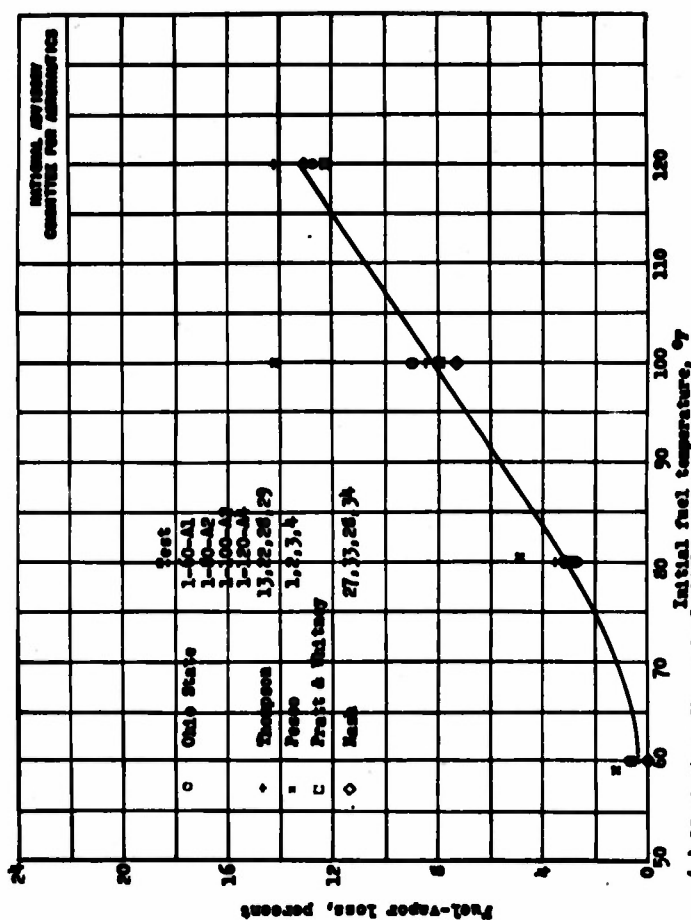
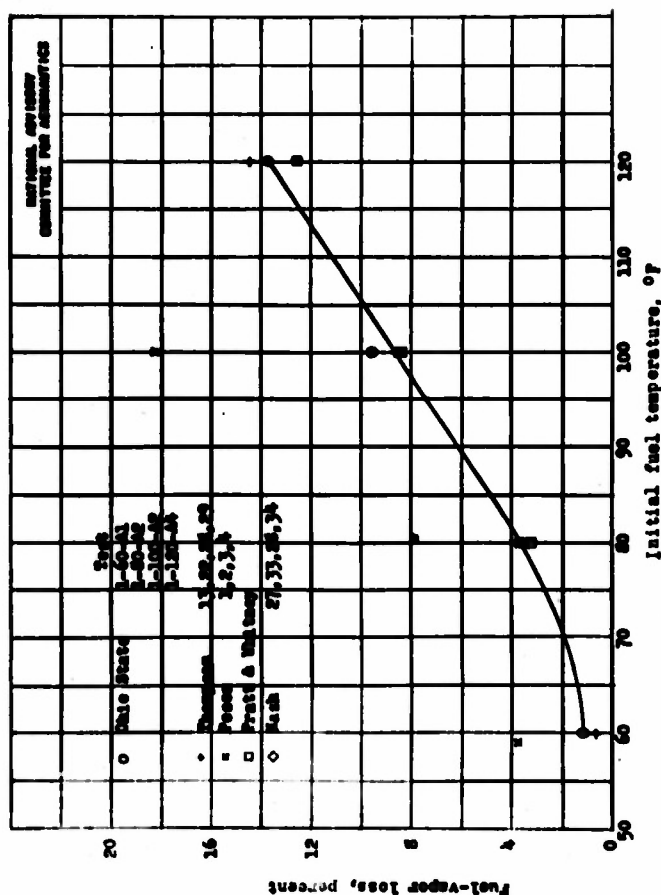


Figure 6. - Critical pressure altitude plotted as a function of initial fuel temperature. (Data derived from figs. 4 and 5.)

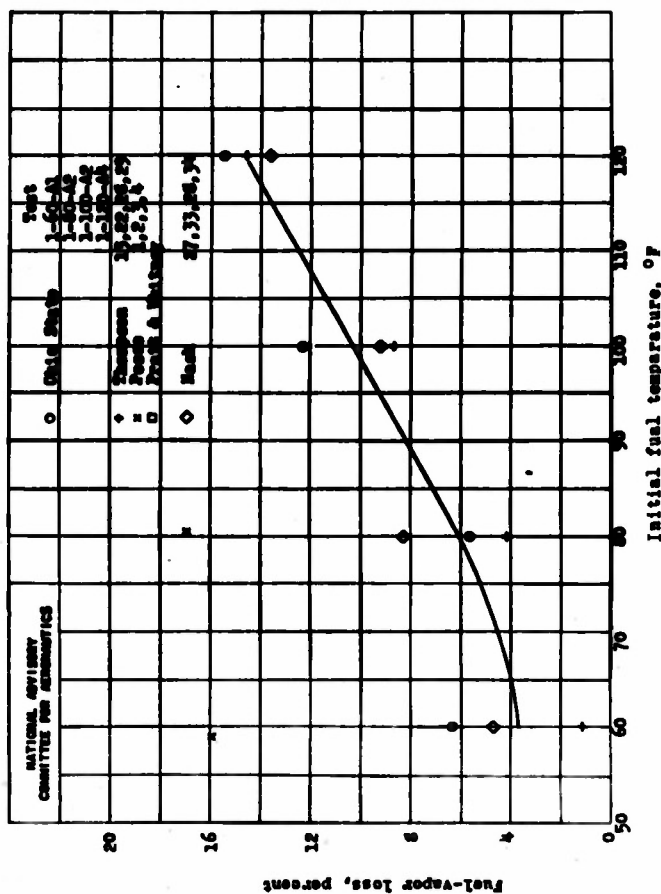


(a) 10 minutes after end of climb.



(b) 1 hour after end of climb.

E-185



(c) 8 hours after end of oilab.
Figure 7. - Concluded. Fuel-vapor loss plotted as a function of initial fuel temperature with fuel unagitated. Clial to 35,000 feet with this altitude maintained to the end of the flight. (Data points obtained by interpolating tabular data where necessary.)

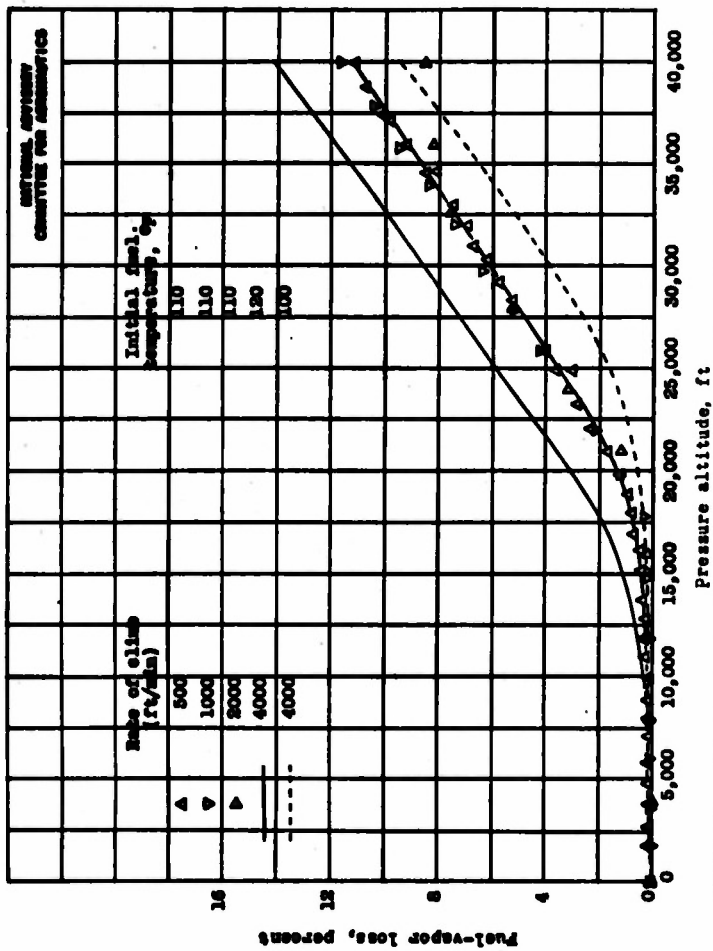
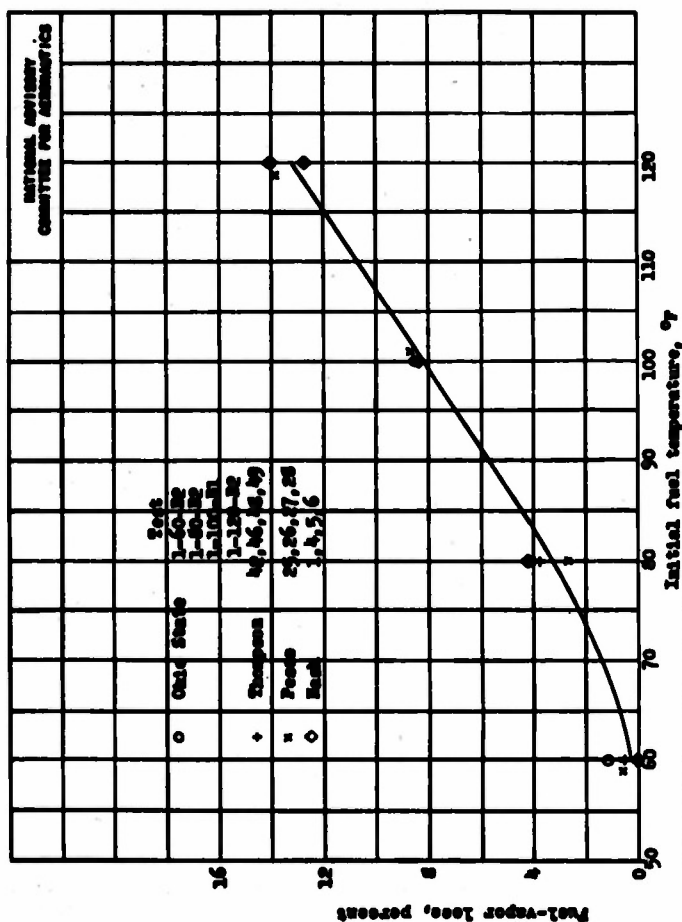
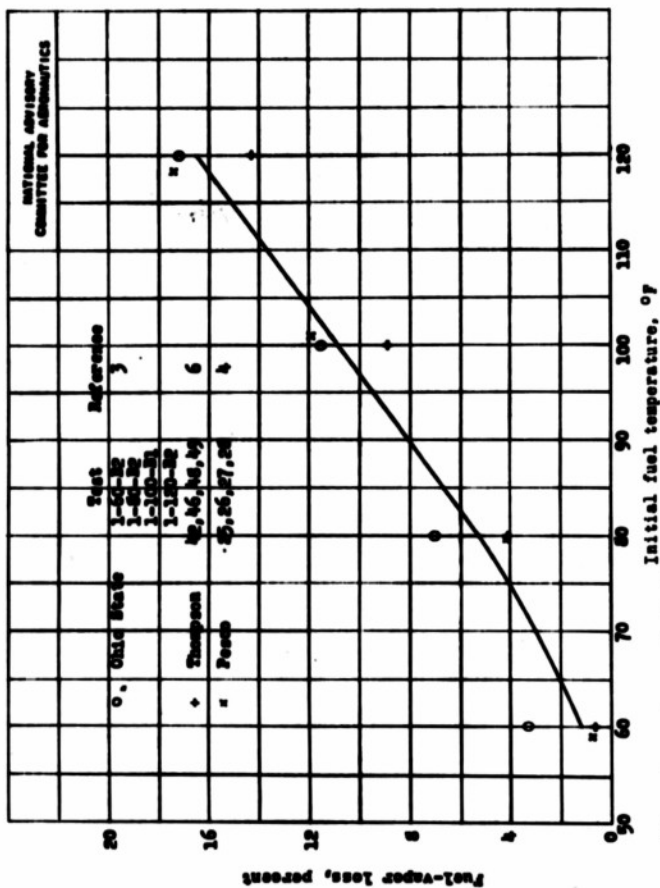


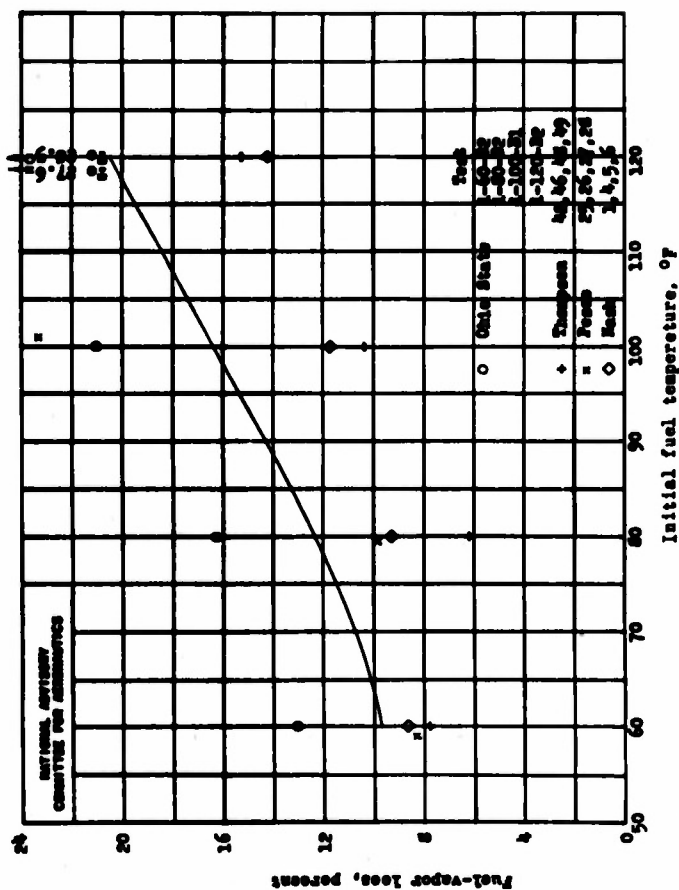
Figure 8. - Effect of rate of climb on fuel-vapor loss during the climb period of a simulated flight. (Data from Boeing tests.)



(a) 10 minutes after end of climb.
 Figure 9. - Fuel-vapor loss as a function of initial fuel temperature with fuel agitated by booster pump. Climb to 75,000 feet with this altitude maintained to end of test. (Data points obtained by interpolating tabular data where necessary.)



(b) 1 hour after end of climb.



(c) 8 hours after end of climb.

Figure 9. - Concluded. Fuel-vapor loss as a function of initial fuel temperature with fuel agitated by booster pump. Climb to 35,000 feet with this altitude maintained to end of test. (Data points obtained by interpolating tabular data where necessary.)

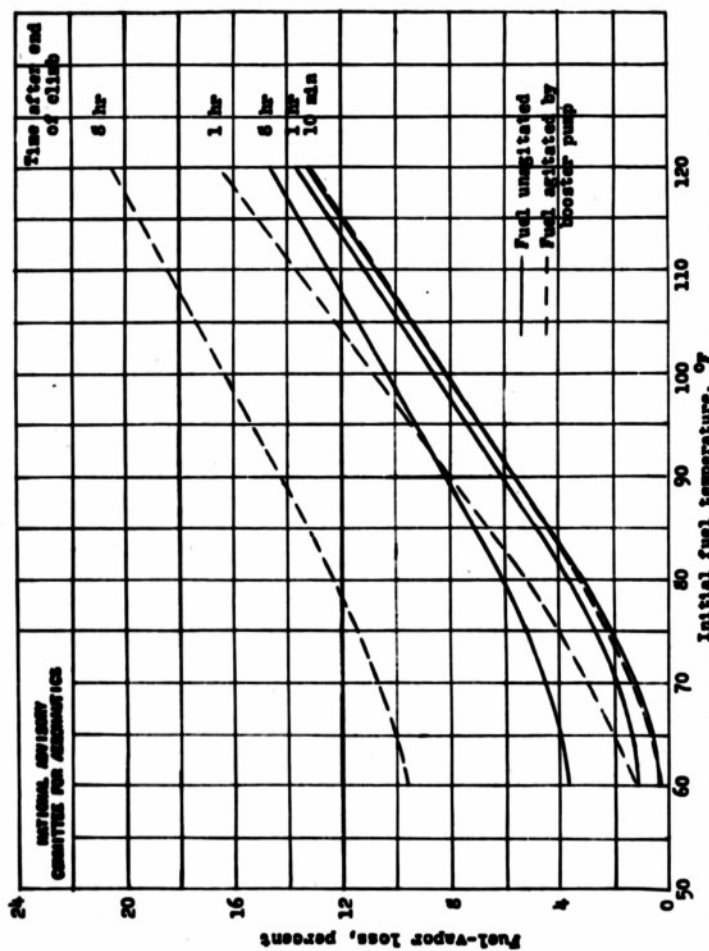


Figure 10. - The effect of agitation on fuel-vapor loss during simulated flight. Climb to 35,000 feet with this altitude maintained to end of test. (Replot of average curves from figs. 7 and 9.)

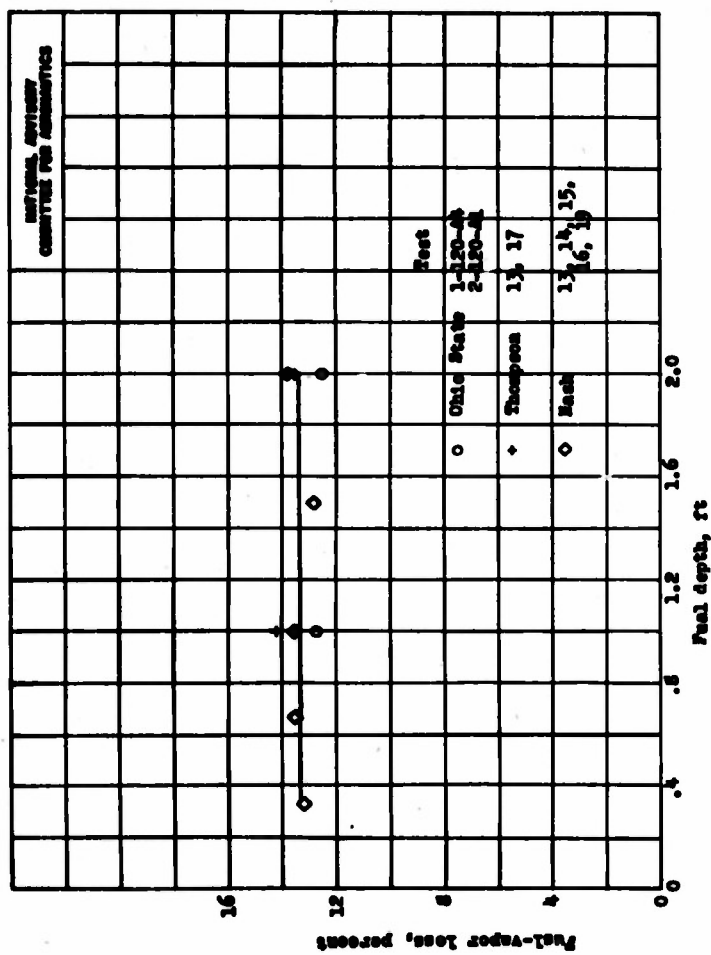
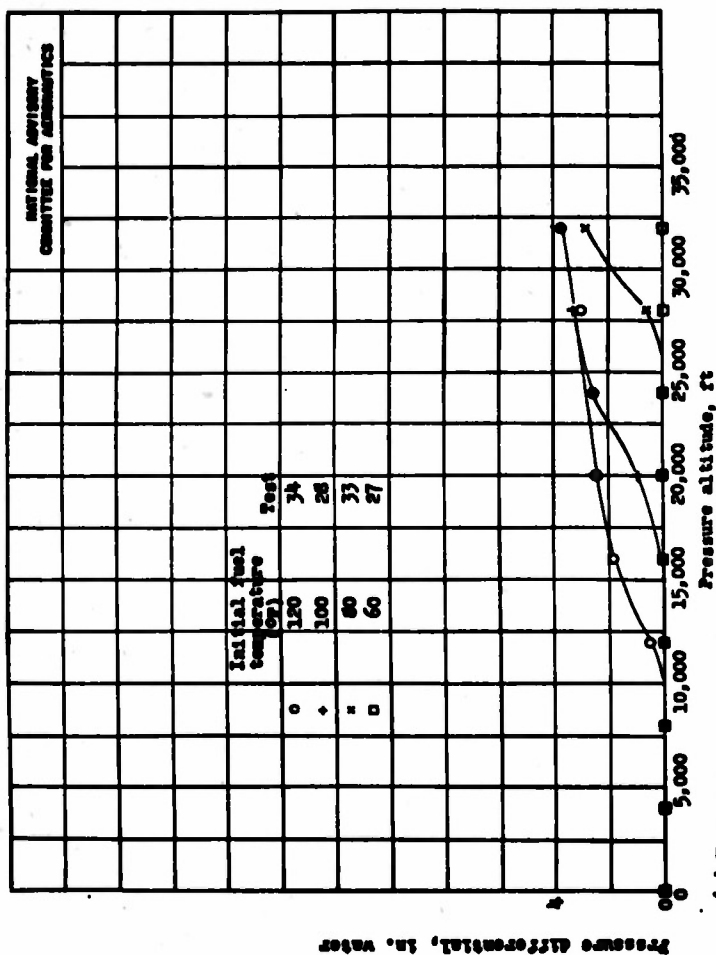
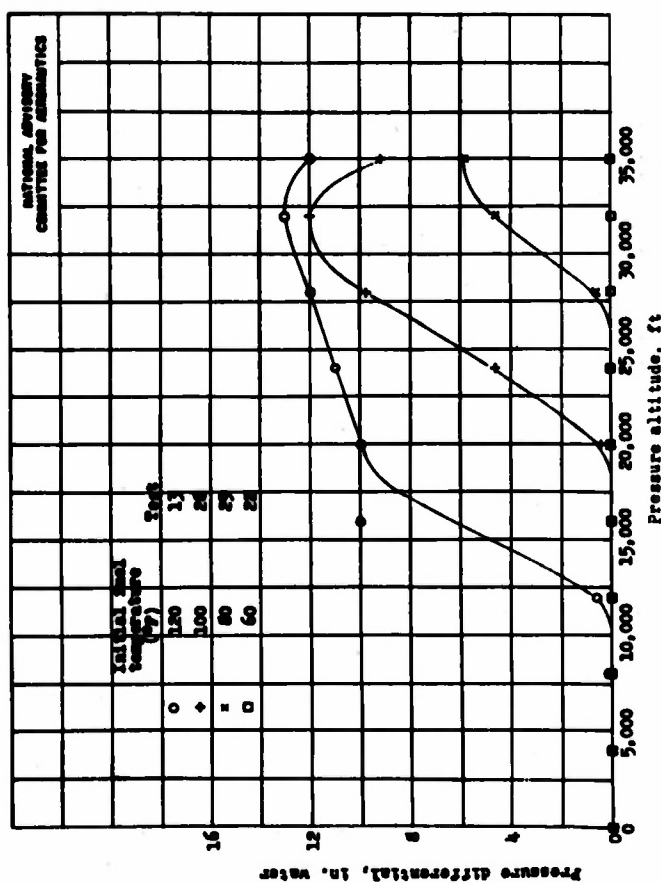


Figure 11. - Variation of fuel-vapor loss with fuel depth during simulated flight. Climb to 35,000 feet with this altitude maintained for 10 minutes; initial fuel temperature, 120° F.



(a) Mach data.

Figure 12. - Vent-line pressure differential plotted as a function of pressure altitude for several initial fuel temperatures. Rate of climb, 4000 feet per minute.



(b) Thompson data.
Figure 12. - Concluded. Vent-line pressure differential plotted as a function of pressure altitude for several initial fuel temperatures. Rate of climb, 4000 feet per minute.

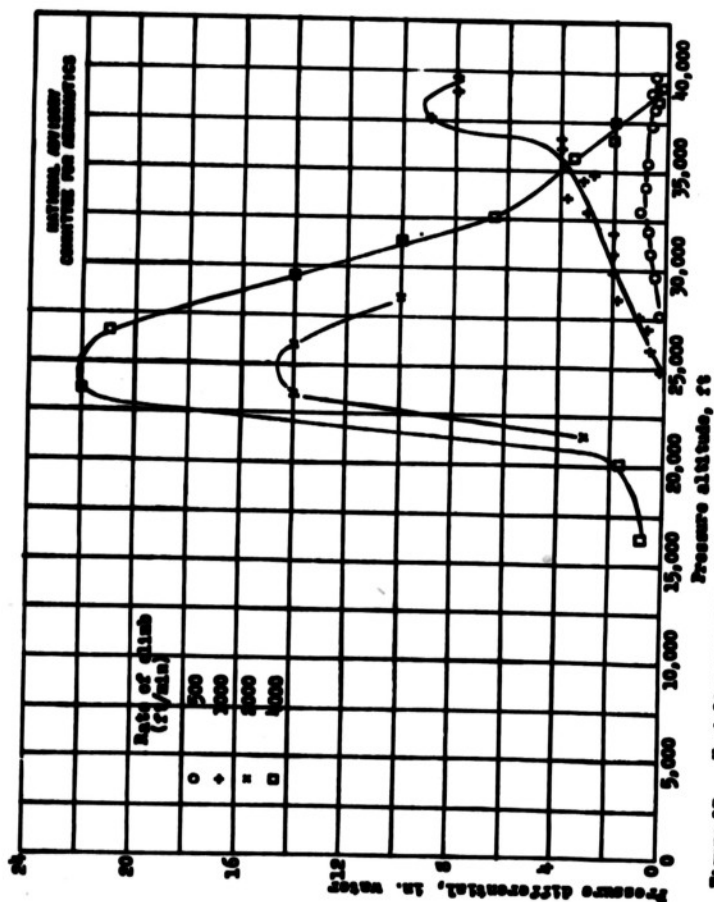


Figure 13. - Vent-line pressure differential plotted as a function of pressure altitude during simulated flights at several rates of climb obtained by Boeing. Initial fuel temperature, 110° F.

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EDITION (B K 47)

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Baker, Sol
Englert, G. W.

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NOTE: Requests for copies of this report must be addressed to: N.A.C.A., Washington, D. C.

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