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# EFFECTS OF FUEL-VAPOR LOSS ON KNOCK-LIMITED PERFORMANCE AND INSPECTION PROPERTIES OF AVIATION FUELS

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# EFFECTS OF FUEL-VAPOR LOSS ON KNOCK-LIMITED PERFORMANCE AND INSPECTION PROPERTIES OF AVIATION FUELS

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## INTRODUCTION

Past experience has shown that, at certain temperature conditions, the fuel in the tank of an airplane loses a portion of the lower boiling-point components when the airplane rises to altitude. The investigation reported herein was conducted specifically to ascertain the effects of this fuel-vapor loss on the F-3 and F-4 knock-limited performance ratings and the inspection properties of two representative aviation fuels. Fuels meeting AN-F-28 and AN-F-33 aviation fuel specifications were used, 28-R and 33-R, respectively.

## APPARATUS AND TEST PROCEDURE

Samples of the 28-R and 33-R fuels were weathered in a simulated-altitude apparatus shown diagrammatically in figure 1 and photographically in figure 2. The apparatus consisted essentially of a small insulated plastic fuel tank 10 inches in diameter by 12 inches high mounted on a balance in an altitude chamber. The altitude chamber could be evacuated by means of a vacuum pump at a controlled rate of climb. Fuel losses were obtained directly from the balance readings and fuel and vapor temperatures were measured by thermocouples in the fuel tank.

A hot-water heat exchanger used as a fuel-temperature regulator heated the fuel sample to the desired initial temperature before it was run into the fuel tank. A flexible hose leading from the heat exchanger permitted the fuel to be transferred to the fuel tank at the end of the heating process. Because fuel-vapor loss is dependent on the temperature of the fuel in the airplane tank at the time of take-off, two initial fuel temperatures (90° F and 130° F) were assumed for the weathering tests on each fuel.

The fuels were weathered by a simulated flight consisting of a climb at a rate of 1000 feet per minute to an altitude of 30,000 feet. The altitude of 30,000 feet was maintained for approximately 10 minutes after the end of the climb.

Knock-limited performance ratings were obtained in F-3 and F-4 rating engines (CRC designations F-3-544 and F-4-443) for weathered and unweathered fuel samples. The F-3 engine was equipped with a barometrically controlled dry-air supply instead of a dehydrating ice tower. A 106360D piston was used in the F-4 engine instead of the specified 106360G.

Laboratory inspection data consisting of A.S.T.M. distillations, Reid vapor pressures, specific gravities, aromatic concentrations, and tetraethyl lead concentrations were obtained for each fuel sample (weathered and unweathered).

## DISCUSSION OF RESULTS

Weathering data. - Results of the simulated-flight weathering tests are shown in figures 3 and 4. The data in figure 3(a) indicate that with 28-R about 3.6 percent (by weight) of the fuel was lost during the test in which the initial fuel temperature was 90° F. For an initial temperature of 130° F (fig. 3(b)) the loss was about 12.8 percent. With 33-R (fig. 4) the losses were about 3.5 and 14.4 percent at temperatures of 90° F and 130° F, respectively.

The fuel-temperature drops during the tests were the same for both fuels, namely, a drop of 36° F from an initial fuel temperature of 130° F and a drop of 10° F from an initial temperature of 90° F.

Inspection data. - Inspection data for both weathered and unweathered fuel samples are shown in table I. In addition, the limits imposed by current Army-Navy specifications for AN-F-28, Amendment-3, and AN-F-33 fuels are included for comparison. The data in table I show that as a result of the weathering loss the distillation temperatures were increased and the Reid vapor pressures decreased. The greatest increase in distillation temperature occurred in the low-temperature range. Specific gravities, aromatic concentrations, and tetraethyl lead concentrations were increased.

If the data for the weathered samples are compared with the specification limits, it can be seen that the samples of 28-R and 33-R fuel weathered from an initial temperature of 90° F meet Army-Navy fuel requirements with the exception of lead concentrations. The 50-percent-evaporated temperature for 33-R is about 3° F higher than permitted, but this difference is within the precision of the A.S.T.M. distillation procedure.

For an initial temperature of 130° F the weathered sample of 28-R still meets the requirements with the exception of tetraethyl lead concentration, whereas that of 33-R is not acceptable because of the high 50-percent-evaporated temperature as well as the high tetraethyl lead concentration. Both weathered samples have Reid vapor pressures of 4.6 pounds per square inch, which is a lower value than that of most aviation fuels. Under current aviation-fuel specifications a low Reid vapor pressure is permissible as long as the low-end distillation (A.S.T.M.) temperatures are within the specified limits.

<u>F-3 and F-4 engine data.</u> - The F-3 (lean) and F-4 (rich) antiknock ratings for 28-R and 33-R are shown in the following table. For each fuel there are two rows of ratings. The first row is milliliters of tetraethyl lead per gallon in S reference fuel and the second row is the Army-Navy performance number.

| Fuel | Condition | F-3 rating | F-4 rating |
|---|---|---|---|
| 28-R | Nominal rating | 0 | 1.28 |
| | | 100 | 130 |
| 28-R | Unweathered | 0.08 | 1.31 |
| | | 103 | 130 |
| 28-R | Weathered ([a]90° F) | 0.10 | 1.31 |
| | | 104 | 130 |
| 28-R | Weathered ([a]130° F) | 0.07 | 1.52 |
| | | 103 | 133 |
| 33-R | Nominal rating | 0.47 | 2.78 |
| | | 115 | 145 |
| 33-R | Unweathered | 0.68 | 2.68 |
| | | 120 | 144 |
| 33-R | Weathered ([a]90° F) | 0.75 | 2.67 |
| | | 121 | 144 |
| 33-R | Weathered ([a]130° F) | 0.75 | 2.92 |
| | | 121 | 146 |

[a]Temperature of fuel at start of simulated flight.

The knock-limited performance curves from which the F-4 ratings were obtained are shown in figure 5. The F-3 ratings determined for unweathered 28-R and 33-R are higher than the nominal ratings for these fuels.

The data indicate that the loss of fuel vapor resulting from weathering has little or no effect on the ratings of the two fuels. If the changes in ratings can be assumed to be significant, the F-3 and F-4 performance numbers of both fuels increase slightly. Comparisons between weathered and unweathered samples of each fuel should be valid inasmuch as the data were obtained on the same operating day.

## SUMMARY OF RESULTS

Weathering tests made on samples of 28-R and 33-R aviation fuels under simulated-flight conditions consisting of a climb at a rate of 1000 feet per minute to an altitude of 30,000 feet with this altitude maintained for 10 minutes after the end of the climb showed that:

1. (a) For an initial fuel temperature of 90° F the loss (by weight) resulting from weathering 28-R fuel was 3.6 percent; for 33-R fuel the loss was 3.5 percent.

   (b) For an initial fuel temperature of 130° F the weathering loss for 28-R fuel was 12.8 percent; for 33-R fuel the loss was 14.4 percent.

2. (a) Inspection data for samples of 28-R and 33-R fuels showed that these fuels weathered from an initial temperature of 90° F meet current Army-Navy fuel specifications for fuels of these grades, except for high tetraethyl lead concentrations.

   (b) For an initial temperature of 130° F the weathered sample of 28-R fuel meets specification requirements with the exception of a high tetraethyl lead concentration, whereas the weathered sample of 33-R fuel is not acceptable because of the high 50-percent distillation point as well as a high tetraethyl lead concentration.

3. The F-3 and F-4 antiknock ratings for the weathered fuel samples showed little or no change resulting from loss of some of the lighter ends due to weathering. The small changes found indicate that the weathered samples have slightly higher ratings than the unweathered samples.

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TABLE I — INSPECTION DATA FOR WEATHERED AND UNWEATHERED SAMPLES

OF 28-R AND 33-R FUELS

| | 28-R | | | | 33-R | | | |
|---|---|---|---|---|---|---|---|---|
| | AN-F-28 specifications | Unweathered | Weathered | | AN-F-33 specifications | Unweathered | Weathered | |
| | | | [a]90° F | [a]130° F | | | [a]90° F | [a]130° F |
| Tetraethyl lead, ml/gal | 4.6 (max.) | 4.61 | 4.81 | 5.49 | 4.6 (max.) | 4.53 | 4.72 | 5.29 |
| Specific gravity 60°/60° F | ----------- | 0.725 | 0.729 | 0.739 | ---------- | 0.708 | 0.710 | 0.718 |
| Reid vapor pressure, lb/sq in. | 7.0 (max.) | 6.6 | 6.0 | 4.6 | 7.0 (max.) | 6.6 | 5.9 | 4.6 |
| Aromatics, percent by volume | ----------- | 15.1 | 15.3 | 17.7 | ---------- | 7.8 | 7.7 | 9.3 |
| A. S. T. M. distillation | | | | | | | | |
| Percentage evaporated | Temperature, °F | | | | | | | |
| 0 | ----------- | 109 | 108 | 117 | ---------- | 103 | 104 | 116 |
| 10 | 167 (max.) | 137 | 142 | 160 | 167 (max.) | 134 | 140 | 163 |
| 40 | 167 (min.) | 194 | 200 | 213 | 167 (min.) | 196 | 204 | 220 |
| 50 | 221 (max.) | 213 | 217 | 225 | 221 (max.) | 219 | 224 | 232 |
| 90 | 284 (max.) | 274 | 276 | 283 | 275 (max.) | 272 | 274 | 279 |
| End point | 356 (max.) | 322 | 326 | 330 | 356 (max.) | 344 | 349 | 357 |
| Sum of 10- and 50-percent points | 307 (min.) | 350 | 359 | 385 | 307 (min.) | 353 | 364 | 395 |
| Residue, percent | 1.5 (max.) | 0.6 | 0.6 | 0.4 | 1.5 (max.) | 0.9 | 0.9 | 0.8 |
| Loss, percent | 1.5 (max.) | 1.4 | 1.4 | 0.8 | 1.5 (max.) | 1.1 | 1.1 | 0.7 |

[a]Temperature of fuel at start of simulated flight.

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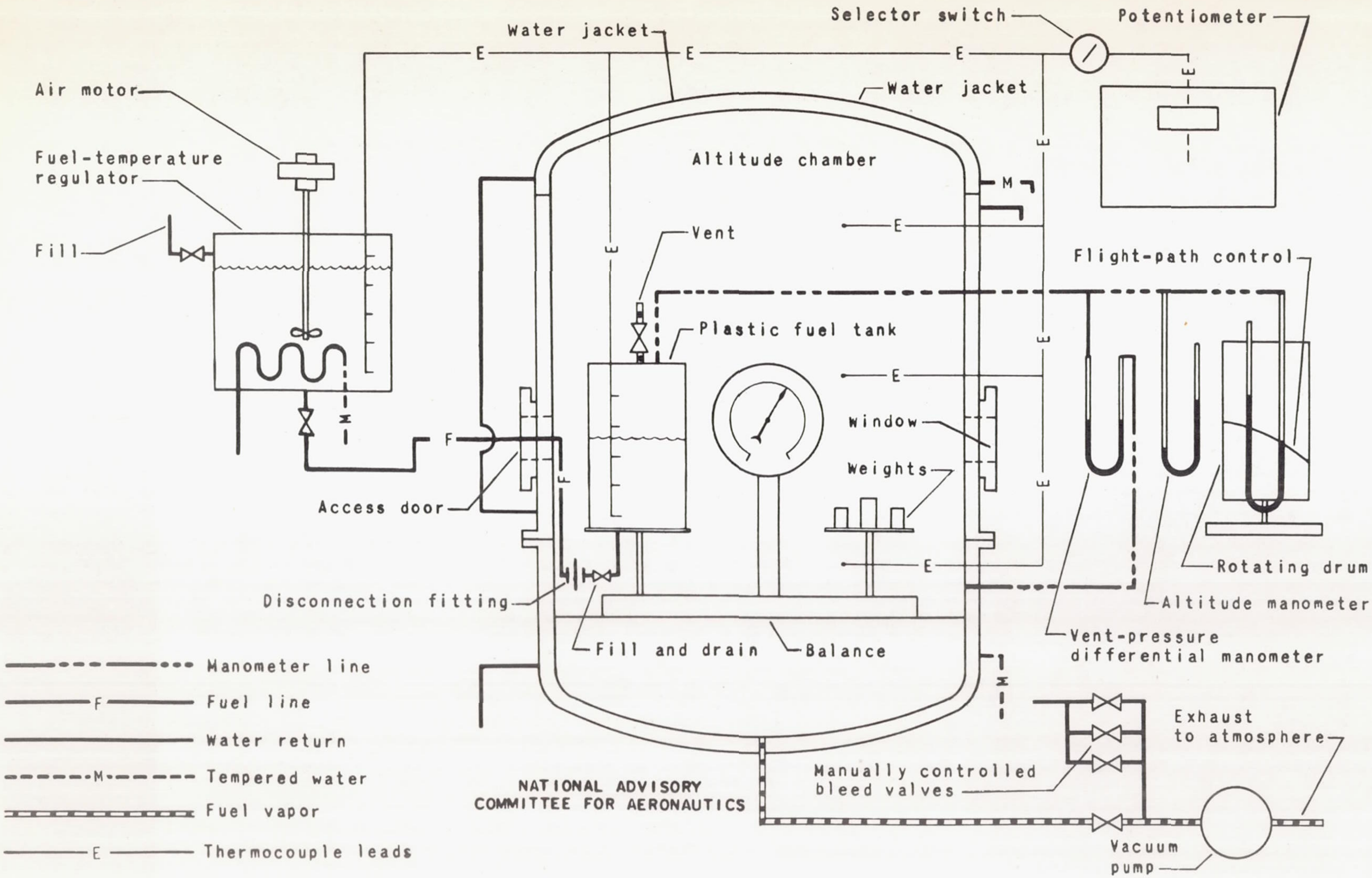
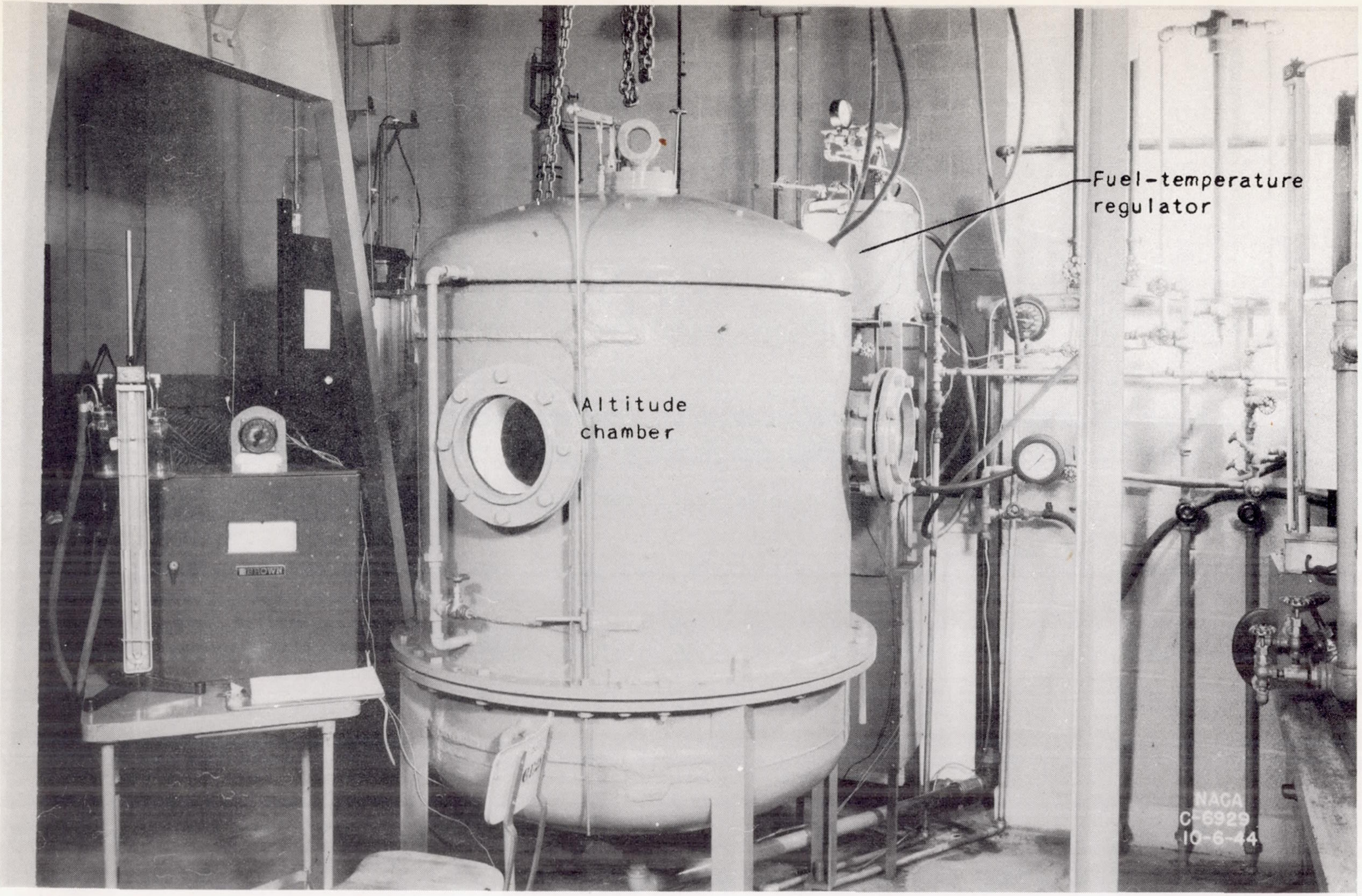
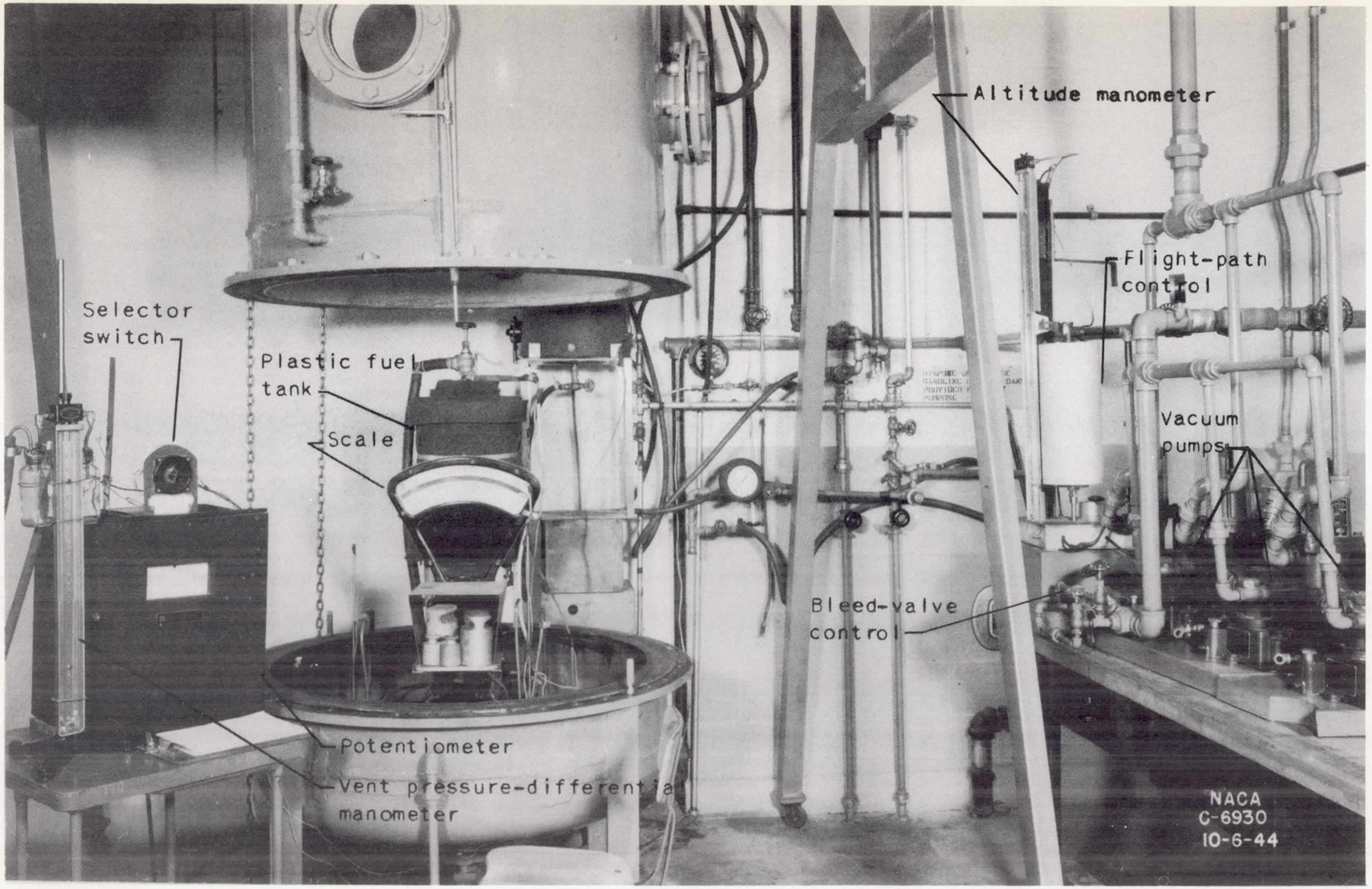



Figure 1. - Diagrammatic sketch of simulated-altitude bench-test installation.



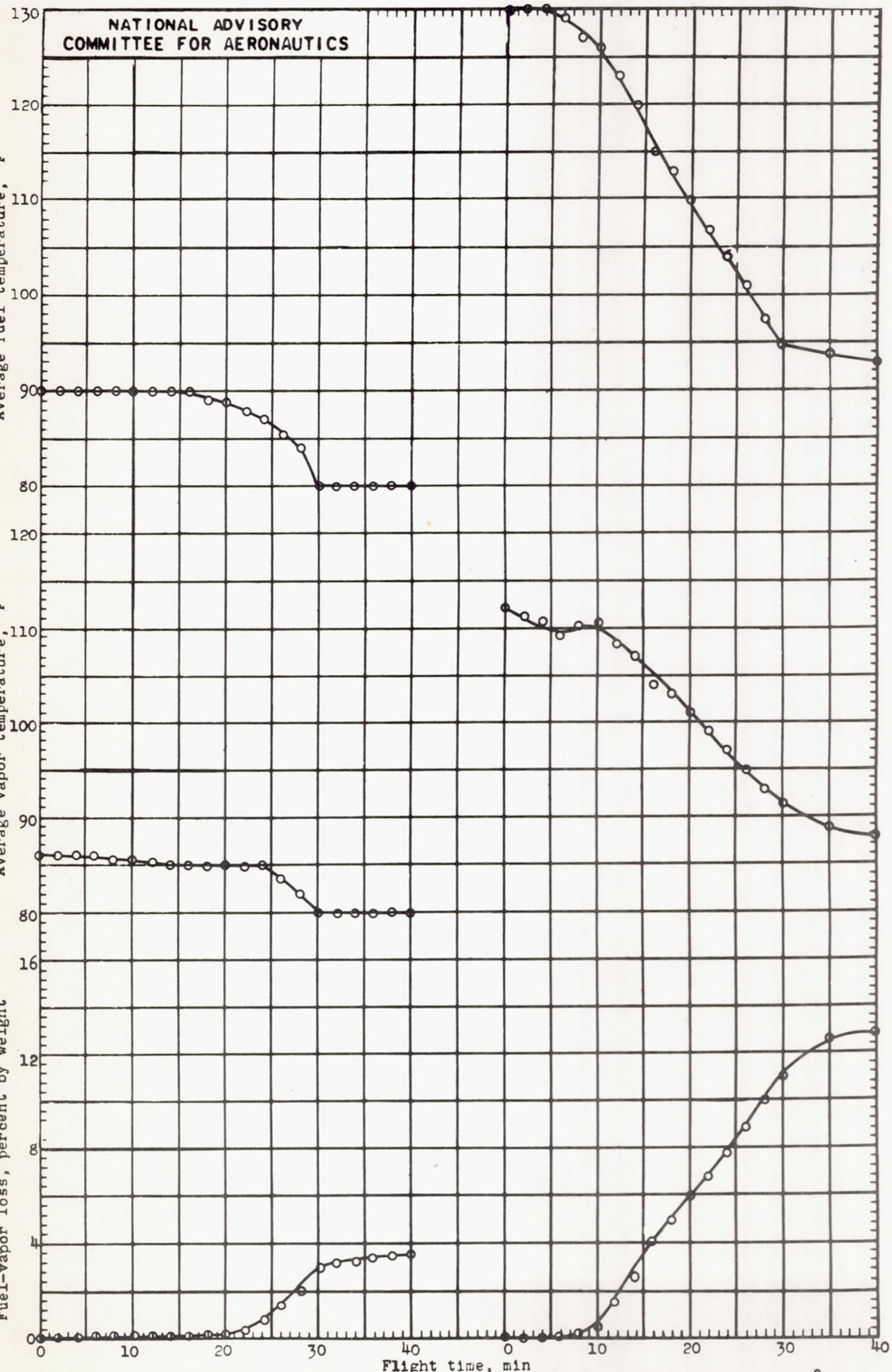

(a) Altitude chamber closed.

Figure 2. - Simulated-altitude bench-test installation.



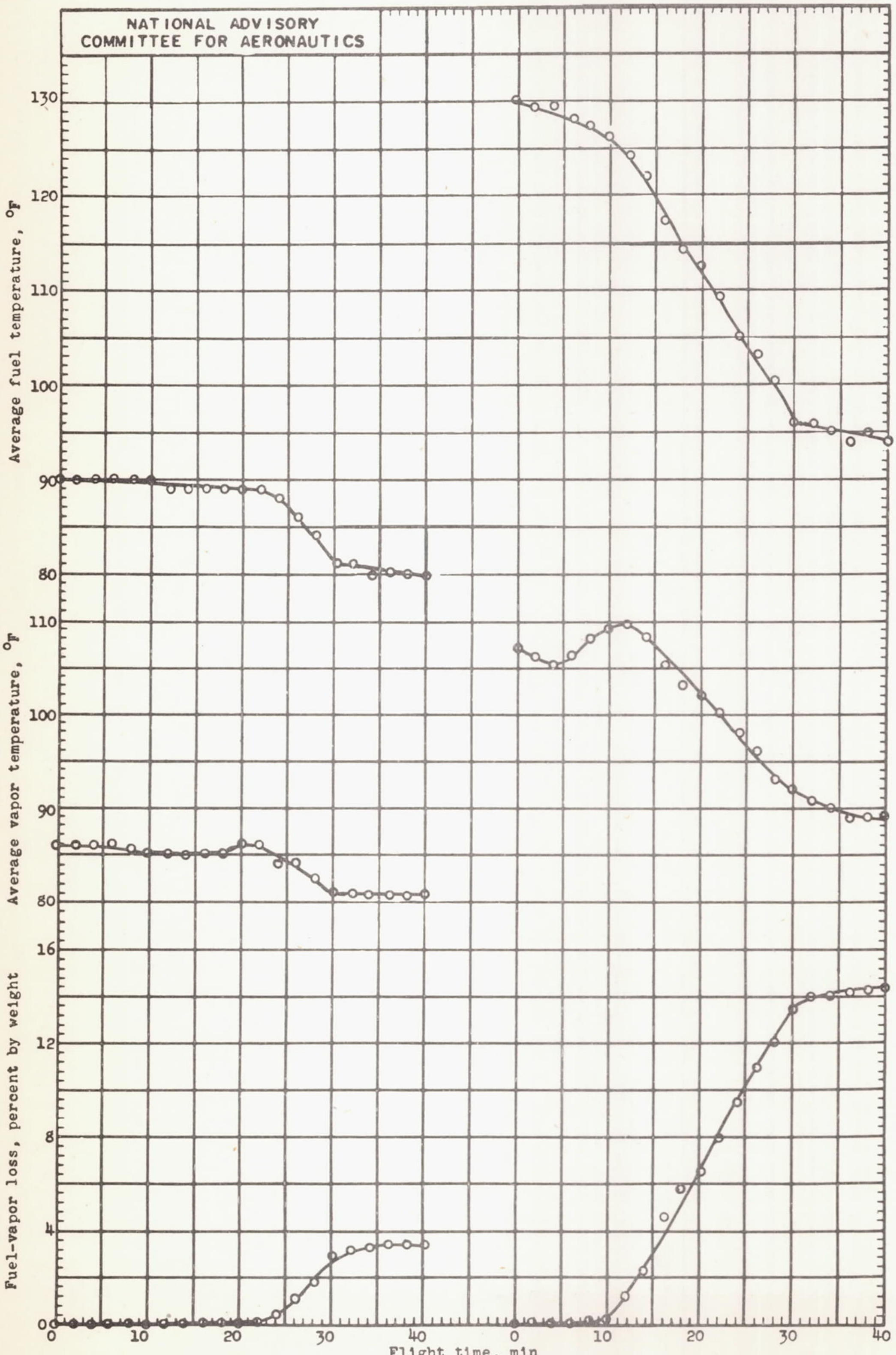

(b) Altitude chamber open.

Figure 2. - Concluded. Simulated-altitude bench-test installation.




(a) Initial fuel temperature, 90° F. (b) Initial fuel temperature, 130° F.

Figure 3. - Variation in fuel-vapor loss, vapor temperature, and fuel temperature while subjecting 28-R fuel to simulated-flight conditions. Rate of climb, 1000 feet per minute to an altitude of 30,000 feet with level flight at this altitude maintained to end of test.




(a) Initial fuel temperature, 90° F. (b) Initial fuel temperature, 130° F.

Figure 4. - Variation in fuel-vapor loss, vapor temperature, and fuel temperature while subjecting 33-R fuel to simulated-flight conditions. Rate of climb, 1000 feet per minute to an altitude of 30,000 feet with level flight at this altitude maintained to end of test.

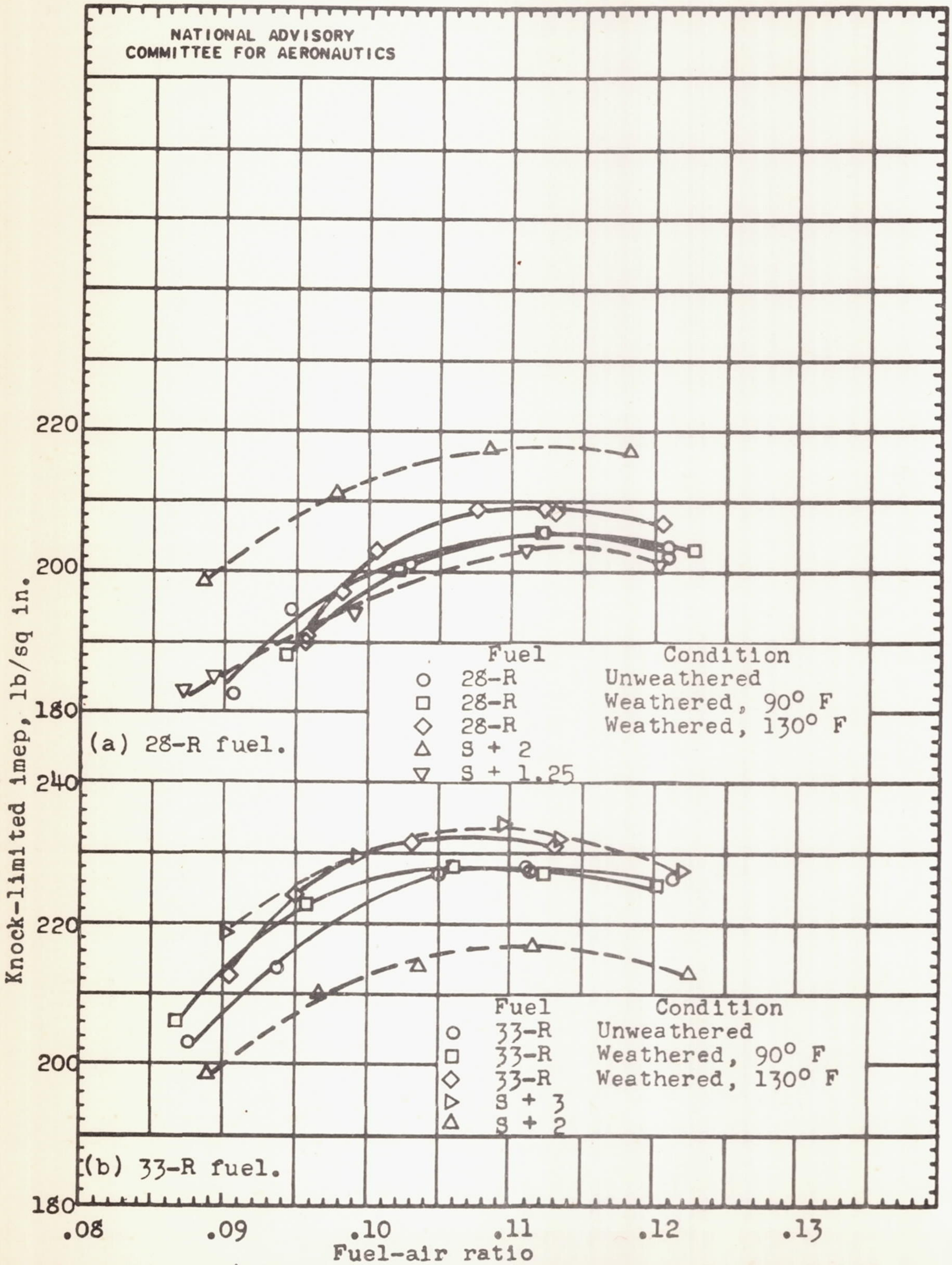



Figure 5. - F-4 knock-limited performance data of weathered and unweathered aviation-fuel samples.