

PISTON TEMPERATURE
MEASUREMENT AND PISTON
DESIGN INVESTIGATION
ON A C. F. R. ENGINE

BY

N. O. WITTMANN

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PISTON TEMPERATURE MEASUREMENT

AND

PISTON DESIGN INVESTIGATION

ON A C.F.R. ENGINE

By

By
Lieutenant N. O. Wittmann
Secretary of Lt. Com. N.O. Wittmann (USN)
Massachusetts Institute of Technology,
Cambridge, Massachusetts, and

Dear Professor Lt. Com. J.H. Smith, Jr. (USN)

Submitted in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

from the
Massachusetts Institute of Technology

June 1946

Thesis
W68

PISTON TECHNOLOGY MANAGEMENT

by

PISTON TECHNOLOGY MANAGEMENT

AS A U.S. MAJOR

of

Dr. Don R. Williams (1968)

and

Dr. Don R. Williams, Jr. (1968)

Submitted in partial fulfillment of the
requirements for the degree of

MAJOR OF SCIENCE

from the

Massachusetts Institute of Technology

June 1968

Cambridge, Massachusetts

June 1, 1946

Professor G. W. Swett, Executive Laboratory, Massachusetts
Secretary of the Faculty,
Massachusetts Institute of Technology, March 1, 1946
Cambridge, Massachusetts.

Dear Professor Swett:

We submit herewith, a thesis entitled "Piston
Temperature Measurement and Piston Design Investigation
on a C.F.R. Engine".

This thesis is submitted in partial fulfillment of
the requirements for the degree of Master of Science in
Aeronautical Engineering.

Respectfully submitted,

1948

OFFICE OF THE SECRETARY

Massachusetts Institute of Technology

June 1, 1948

Professor C. W. Smith
Secretary of the Society
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Professor Smith:

We would be pleased to have a thesis entitled "The
Temperature Dependence of the Rate of Reaction
on a C.A.S. System".

This thesis is considered in partial fulfillment of
the requirements for the degree of Master of Science in
Chemical Engineering.

ACKNOWLEDGMENT

The investigation reported in this thesis was conducted in the Sloan Automotive Laboratory, Massachusetts Institute of Technology, over the period March 1, 1946 to June 1, 1946.

Acknowledgment of, and appreciation for, assistance in this thesis is given to the following sources:

Professor J. A. Leary (M.I.T. Staff)

Pratt and Whitney Aircraft, East Hartford, Conn.

Mr. J. C. Livengood (M.I.T. Staff)

Mr. E. Gagger "

The mechanics and assistants of the Sloan Laboratory.

Any opinions or statements contained herein represent the private views of the authors, and are not to be construed as official or in any sense reflecting those of the Navy and the naval service.

PREFACE

occasional difficulties. They were an attempt to investi-

The purposes of this investigation were twofold:

1. To construct a satisfactory arrangement for the measurement of piston crown temperature in a C. F. R. Engine.
2. To determine the effect of piston crown design on piston temperature, with and without a forced system of cooling on the inside of the piston.

The subject was chosen for its particular interest to the authors in view of the considerable amount of piston "scouring" in present day engines of high speed and power. So much time has been spent on cylinder head design and so relatively little on interior piston design that it was thought advisable to attempt to find some of the trends occurring with changes in the design of the piston crown interior, and to note the effect of changes in some engine operating variables on piston crown temperatures.

T. Yamamoto and H. Nakamura ("Effect of Changes in Design and Operating Conditions on Cooling" M.I.T., 1935) attempted to measure piston temperatures on a C.F.R. engine and note the change of piston temperature with changes in crown thickness but were not highly successful due to

The purpose of this investigation was to determine the effect of the amount of piston crown temperature in a combustion chamber on the rate of piston cooling.

1. To determine the effect of piston crown temperature on the rate of piston cooling, with and without a forced system of cooling in the form of the piston.

The subject was chosen for the purpose of determining the effect in view of the essential nature of this factor in the design of piston crowns and the fact that the rate of cooling has been shown to be directly related to the rate of wear of the piston crown. It was thought desirable to attempt to determine the effect of the piston crown temperature on the rate of cooling of the piston crown, and to determine the effect of the amount of cooling on the rate of wear of the piston crown.

2. To determine the effect of the amount of cooling on the rate of wear of the piston crown, with and without a forced system of cooling in the form of the piston.

The subject was chosen for the purpose of determining the effect in view of the essential nature of this factor in the design of piston crowns and the fact that the rate of cooling has been shown to be directly related to the rate of wear of the piston crown. It was thought desirable to attempt to determine the effect of the piston crown temperature on the rate of cooling of the piston crown, and to determine the effect of the amount of cooling on the rate of wear of the piston crown.

mechanical difficulties. They made no attempt to investigate the effect on piston temperature of changes in interior piston crown design.

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Notes on the use of the tables

Index

**PISTON TEMPERATURE MEASUREMENT
AND
PISTON DESIGN INVESTIGATION
ON A C.F.R. ENGINE**

By

Lt. Com. W. O. Wittmann (USN)

and

Lt. Com. J. H. Smith, Jr. (USN)

April - May 1946

PLIQUOR INVESTIGATION

AND

PLIQUOR INVESTIGATION

ON A C.F.A. BASIS

BY

Mr. G. W. C. ... (1951)

and

Mr. G. W. C. ... (1951)

SUMMARY

A method of measuring piston temperature on a C.F.R. engine under operating conditions was carried through with the following results noted:

1. The method of piston temperature measurements proved very satisfactory.
2. Finning on the inside of the piston crown causes the piston to run hotter than with no finning.
3. A stream of oil under pressure applied to the under side of the piston crown lowers the piston temperature considerably, and is much more effective on a piston with deep fins on the inside of the crown than on one with no fins.
4. Piston temperatures tend to increase with an increase of engine speed.
5. Piston temperatures tend to increase with an increase of water jacket temperature.
6. Piston temperatures are highest as the fuel air ratio approaches that of best power, and drop off rapidly as the mixture is made leaner or richer than this value.
7. Inlet temperature has little effect on piston temperature.
8. Indications on one run tended to show that "blow by", caused by damaged piston rings, caused piston temperatures to be higher until rings were "worn in", indicating that a portion of the heat transfer from the piston goes to the cylinder walls via the rings.

RESULTS

A method of measuring piston temperature on a 0.5-2.0 engine under

operating conditions was evolved through the following results

noted:

1. The method of piston temperature measurement proved very satisfactory.
2. Flaring on the inside of the piston crown causes the piston to run hotter than on a flat.
3. A stream of oil under pressure applied to the water side of the piston crown lowers the piston temperature considerably and is much more effective on a piston with deep flares on the inside of the crown than on one with no flares.
4. Piston temperatures tend to increase with an increase of engine speed.
5. Piston temperatures tend to increase with an increase of water jacket temperature.
6. Piston temperatures are highest on the first six rings especially that of bore power, and drop off rapidly as the distance is made toward or ahead from this ring.
7. Inlet temperature has little effect on piston temperatures.
8. Indications on one run tended to show that "blue" flames caused by damaged piston rings, caused piston temperatures to be higher until rings were worn in, following which a portion of the heat transfer from the piston crown to the cylinder walls was the rings.

There is a considerable amount of investigation to be done in this field and it provides an excellent opportunity for future students to study other phases of this subject. The working system has already been constructed, they need only investigate.

All tests were made in the Sloan Automotive Laboratory of the Massachusetts Institute of Technology by Lt. Com. N. O. Wittmann, USN, and Lt. Com. J. H. Smith, Jr., USN, under the direction of Prof. W. A. Leary of the school staff.

There is a considerable amount of investigation to be done in this

field and it presents an excellent opportunity for future students to
study other phases of this subject. The writer wishes that already had
concluded, they need only investigate.

All tests were made in the Glass Laboratory of the
Bureau of Entomology and Plant Quarantine, U. S. Department of
Agriculture, Washington, D. C., under the direction of Prof. E. A.
Lary of the school staff.

1. The first test was made on the 1st of August, 1914, and was a
test of the ability of the fly to fly through a fine mesh screen.
The fly was placed in a glass jar and the jar was held over a
candle flame. The fly was seen to fly through the screen and
was caught in a glass jar.
2. The second test was made on the 2nd of August, 1914, and was a
test of the ability of the fly to fly through a fine mesh screen.
The fly was placed in a glass jar and the jar was held over a
candle flame. The fly was seen to fly through the screen and
was caught in a glass jar.
3. The third test was made on the 3rd of August, 1914, and was a
test of the ability of the fly to fly through a fine mesh screen.
The fly was placed in a glass jar and the jar was held over a
candle flame. The fly was seen to fly through the screen and
was caught in a glass jar.
4. The fourth test was made on the 4th of August, 1914, and was a
test of the ability of the fly to fly through a fine mesh screen.
The fly was placed in a glass jar and the jar was held over a
candle flame. The fly was seen to fly through the screen and
was caught in a glass jar.
5. The fifth test was made on the 5th of August, 1914, and was a
test of the ability of the fly to fly through a fine mesh screen.
The fly was placed in a glass jar and the jar was held over a
candle flame. The fly was seen to fly through the screen and
was caught in a glass jar.

PISTON TEMPERATURE MEASUREMENT AND PISTON DESIGN INVESTIGATION
ON A C.F.R. ENGINE.

INTRODUCTION

Although there have been investigations made on piston temperatures, there has been little successful work along these lines attempted in this laboratory. This project has been a necessarily hastened attempt to get some satisfactory results from the measurement of piston temperature in a standard C.F.R. engine under operating conditions.

Briefly, the objects of this project were:

1. To set up a satisfactory system of measuring piston temperatures in a C.F.R. engine under operating conditions.
2. To measure the piston head temperature of three different types of pistons and note how their designs affected cooling.
3. To determine the cooling effect of a stream of oil on the lower side of the crown of each piston.
4. To determine the effect on piston temperature of changes in some of the engine operating variables.

All tests were made in the Sloan Automotive Laboratory of the Massachusetts Institute of Technology by Lt. Com. H. O. Wittmann, USN, and Lt. Com. J. H. Smith, Jr., USN, under the direction of Prof. W. A. Leary of the school staff.

PISTON TEMPERATURE MEASUREMENT AND PISTON RING INVESTIGATION
ON A C.F.R. ENGINE

INTRODUCTION

Although there have been investigations made on piston temperatures, there has been little successful work along these lines attempted in this laboratory. This project has been a necessarily hasty attempt to get some satisfactory results from the measurement of piston temperatures in a standard C.F.R. engine under operating conditions.

Basically, the object of this project was:

1. To set up a satisfactory system of measuring piston temperatures in a C.F.R. engine under operating conditions.
2. To measure the piston head temperature of some different types of pistons and note their behavior relative to cooling.
3. To determine the cooling effect of a stream of oil on the lower side of the crown of each piston.
4. To determine the effect of piston temperature of change in heat of the engine operating variables.

All tests were made in the Diesel Research Laboratory of the

Massachusetts Institute of Technology at Cambridge, Mass., and

by Gen. J. W. Baker, Jr., D.E.S., under the direction of Prof. W. A. Lang

of the school staff.

EQUIPMENT

A standard C.F.R. single cylinder, water cooled, variable compression ratio engine of 3.25 inch bore and 4.5 inch stroke was used. (Figures 1 and 2.)

The fuel air inlet system consisted of a puff tank and a vaporizing tank, the temperature of which was controlled by any desired combination of steam or cold water. The air supply came directly from the atmosphere through a measuring orifice. The pressure differential across the orifice was measured with a standard manometer, enabling the air flow to be computed exactly at all engine speeds and conditions. The fuel was metered through a calibrated rotometer which allowed any desired fuel air ratio to be set and held constant.

The exhaust system led through a puff tank around which cold water circulated. The exhaust pressure remained essentially constant at atmospheric pressure.

The spark was controlled by a breaker mechanism coupled directly to the crankshaft in order to hold a constant spark advance.

The cylinder jacket was water cooled and the temperature of the jacket could be maintained as desired by proper admittance of cold water or steam.

The power generated by the engine was absorbed by a dynamometer of the conventional cradle type. The speed could be accurately controlled by means of a variable field coil, tachometer, and strobetac operating on a 60 cycle frequency.

The engine oil temperature could be varied by the proper regulation of steam and cold water to the oil heat exchanger.

The three pistons used were essentially standard C.F.R. pistons with variations in design of the inside of the crown. All the pistons had the

APPENDIX

A standard 0.75 H.P. single cylinder, water cooled, vertical compression engine of 3.5 inch bore and 4.5 inch stroke was used. (Figure 1 and 2.)

The fuel air ratio system consisted of a fuel tank and a regulating valve, the pressure of which was controlled by an external condenser of steam or cold water. The air supply came directly from the atmosphere through a breathing orifice. The pressure differential across the valve was measured with a standard manometer, reading the air line as the control valve at all engine speeds and conditions. The fuel was metered through a calibrated rotameter which allowed any desired fuel air ratio to be set and held constant.

The exhaust system led through a hot lead exhaust which could either be closed. The exhaust pressure remained essentially constant at atmospheric pressure.

The engine was controlled by a pressure mechanism which directly to the mechanism in order to hold a constant speed during the test.

The cylinder jacket was water cooled and the temperature of the jacket could be regulated as desired by varying the amount of cold water of flow.

The power furnished by the engine was measured by a dynamometer of the conventional crank type. The speed could be recorded by means of a variable field coil, tachometer, and indicator operating on a 50 cycle frequency.

The engine oil temperature could be varied by the proper regulation of steam hot cold water to the oil heat exchanger.

The three pistons and rods were essentially standard 0.75 H.P. pistons with variations in design of the heads of the pistons. All the pistons had the

same crown thickness and the same ring arrangement.

The first piston (termed the "plain piston") was a standard cast C.F.R. piston with no machining on the inside (Figures 3 and 4).

The second piston (termed the "ribbed piston") was a special casting with a grilled ribbing on the inside of the crown (Figure 5).

The third piston (termed the "finned piston") was another special casting with the deepest possible fins cast on the inside of the crown (Figures 6 and 7).

The iron constantan thermocouples were installed at a distance of $1/32$ inch from the top of the piston and in the same relative position from the center of the piston, $3/8$ inch from the center, laterally. The iron and constantan leads were brought down inside the piston to iron and constantan buttons on the lower edge of the piston skirt. These leads were held in place by small wire loops through drilled "V" holes in the piston wall. The thermocouples were installed in drilled holes approximately $1/32$ inch in diameter, and were held in place with dental cement. The iron and constantan buttons in the edge of the piston skirt were installed in micarta blocks which were shrunk fit into drilled holes in the piston skirt. The entire system, except the actual faces of the contact points, was given several coatings of glyptol (Figures 3, 5 and 6).

The take off switch was mounted on a bracket and plate which was attached to the side of the crankcase after removal of one of the crankcase side plates. Elongated holes in the plate allowed for up and down adjustment to get proper contact of switch points with the contact points on the piston skirt.

The switches were constructed from magneto breaker points that were modified to give desired results. One switch required the addition of a

same crown fit class and the same ring arrangement.

The first piston (called the "plain piston") was a standard cast

C.V.R. piston with no machining on the inside (Figures 3 and 4).

The second piston (called the "ribbed piston") was a special cast-

ing with a drilled ribbing on the inside of the crown (Figure 5).

The third piston (called the "ribbed piston") was another special

casting with the deepest possible fine cast on the inside of the crown

(Figures 6 and 7).

The iron constant thermocouples were installed at a distance of

1/32 inch from the top of the piston and in the same relative position

from the center of the piston, 3/8 inch from the center, laterally. The

iron and constant leads were brought down inside the piston to iron

and constant buttons on the lower edge of the piston skirt. These

leads were held in place by small wire loops through drilled "V" holes

in the piston wall. The thermocouples were installed in drilled holes

approximately 1/32 inch in diameter, and were held in place with dental

cement. The iron and constant buttons in the edge of the piston skirt

were installed in master blocks which were struck fit into drilled holes

in the piston skirt. The entire system, except the actual leads of the

contact points, was given several coatings of epoxy (Figures 8, 9 and 10).

The talc off switch was mounted on a bracket and plate which was at-

tached to the side of the crankcase after removal of one of the crossbars

side plates. Electrical holes in the plate allowed for up and down adjust-

ment to get proper contact of switch points with the contact points on the

piston skirt.

The end holes were counterbored from opposite bearing points that were

modified to give tapered threads. One bearing required the addition of a

constantan button to which a constantan lead wire was directly soldered. The other switch had an iron button attached to the spring, from which an iron wire was led. Both switches were insulated from each other and the bracket by bakelite. The whole assembly was covered with several coatings of glyptol (Figure 8). The switches could be adjusted laterally and vertically by set screws to match the piston skirt contacts and to contact simultaneously.

The iron and constantan leads were covered with plastic tubing and glyptol, to prevent entrance of moisture. They were led out through the switch plate to a direct reading Leeds and Northrup type potentiometer. The potentiometer was equipped with a special sensitive type of galvanometer with the following characteristics:

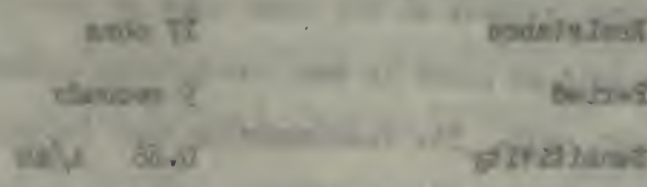
Resistance	17 ohms
Period	5 seconds
Sensitivity	0.66 μ /MM

The potentiometer was located far enough from the engine to be free of all vibrations.

The oil stream for use on the under side of the piston was taken directly from the electrically driven engine oil pump, through the contact bracket plate, and into a nozzle formed from a piece of copper tubing. The oil was supplied at a rate of 17 lbs. per minute.

The other side of the iron plate is also covered with a thin layer of
 lead. The lead is not only used to protect the iron plate from
 oxidation, but also to provide a smooth surface for the
 deposition of the metal. The lead is also used to provide a
 smooth surface for the deposition of the metal. The lead is also
 used to provide a smooth surface for the deposition of the metal.

The iron and concrete plates were covered with lead which was
 placed in between the plates. They were laid out through the
 water tank to a vessel containing lead and mercury. The
 potential was applied to a point of contact with the
 water in the following manner:



The potential was applied to the water in the tank as follows:

The iron plate was connected to the positive terminal of the power
 source and the concrete plate was connected to the negative terminal.
 The potential was applied to the water in the tank as follows:

The iron plate was connected to the positive terminal of the power
 source and the concrete plate was connected to the negative terminal.
 The potential was applied to the water in the tank as follows:

PROCEDURE

All runs were made by setting the engine up at the desired running condition, loosening the take off switch bracket cap screws, raising the contact points until contact was evidenced on the potentiometer and then setting the contacts up approximately .02 inches further. It was found that this setting gave the most consistent results.

For each of the three pistons, the following runs were made:

1. Variation of water jacket temperature (90°F , 150°F , 210°F) for each of three different engine speeds (800, 1000 and 1200 rpms).

2. Same runs as above, but with a continuous stream of oil on the under side of the piston crown.

3. For the grilled piston, the following additional runs were made:

(a) Variation of fuel air ratio.

(b) Variation of fuel air inlet temperature.

Unless otherwise noted, the engine operating variables were kept at the following values:

Inlet temperature	T_1	150°F
Water jacket temperature	T_w	150°F
Crankcase oil temperature	T_o	90°F
Engine oil pressure	P_o	50 #/in.^2
Engine fuel pressure	P_f	10.7 #/in.^2
Fuel air ratio	F	.08

EXHIBIT

All tests were made by running the engine up at the desired loading condition, maintaining the lube oil sump level and pressure, reading the contact points until contact was obtained on the potentiometer and then setting the contacts up approximately 10 inches further. It was found that this method gave the most consistent results.

For each of the three phases, the following tests were made:
1. Variation of water jacket temperature (100°, 120°, 140°, 160°) for each of three different contact points (100, 1000 and 10000 rpm).
2. Same test as above, but with a continuous stream of oil on the water side of the piston crown.

3. For the fuelled phase, the following additional tests were made:
(a) Variation of fuel air ratio.
(b) Variation of fuel air ratio temperature.

When operating under the engine operating conditions were kept at the following values:

1	120°	Water jacket temperature
2	120°	Water jacket temperature
3	120°	Water jacket temperature
4	120°	Water jacket temperature
5	120°	Water jacket temperature
6	120°	Water jacket temperature
7	120°	Water jacket temperature
8	120°	Water jacket temperature

RESULTS AND DISCUSSION

A tabulation of the results obtained for this project is given in Tables I, II and III.

This arrangement for the measurement of piston temperatures seemed to be entirely satisfactory. No part of the system gave mechanical trouble and once the arrangement was set up, no particular difficulty in measuring the temperature was encountered. All runs were checked as many times as possible and in all cases the results were in excellent agreement.

Contrary to what had been anticipated, the plain piston ran cooler than the ribbed piston, and the latter cooler than the finned piston. In Fig. 9 the effect of changes in engine speed on piston temperature can be seen. There is a general rise in piston temperature when engine speed is increased, with all other engine operating conditions held constant. It can be seen that the finned piston ran the hottest. Just why this is so is not definitely known, although it is suspected that the deep fins retard air circulation and oil splashing on the under side of the piston crown and thus more heat is retained by the crown, causing higher temperatures. Some of the difference in temperature may be due to the additional amount of piston material above the piston pin bosses in the plain piston, causing more heat to be carried away through this path, and consequently giving better cooling of the piston. However, the fact that the finned piston runs hotter than the ribbed piston of similar design and weight tends to discount this theory.

The forced system of carrying heat away proves very effective in all cases, and particularly so in the case of the finned piston. The final

RESEARCH AND DEVELOPMENT

a detailed study of the results covered for this project is given in

Tables I, II and III.

This arrangement for the measurement of latent heat transfer seemed

to be entirely satisfactory. In fact, the results have been

found to be in good agreement with those obtained by other

methods of the literature and experiment. All runs were checked in

many cases as possible and in all cases the results were in excellent

agreement.

Consequently, it was felt that the data obtained from this system

from the latent heat, and the latent heat from the latent system.

In fact, the effect of change in engine speed on latent heat transfer

can be seen. There is a marked drop in latent heat transfer when engine

speed is increased, and in all other cases, the latent heat transfer

remains constant. It can be seen that the latent heat from the latent

heat is so low that it is not definitely shown, although it is suggested that

the data from the latent heat and all other data on the latent heat

of the latent heat and that data is related to the other, constant

latent heat transfer. Some of the differences in comparison are due to the

in the different amount of latent heat transfer from the latent heat

in the latent heat transfer, which may be due to the fact that the

data, and consequently, the latent heat transfer from the latent heat

can be seen that the latent heat transfer from the latent heat

latent heat transfer and engine speed is discussed in the report.

The latent heat transfer from the latent heat transfer is all

latent heat transfer, and particularly so in the case of the latent heat transfer. The latent

result is not as encouraging as was to be expected since the finned piston ran much hotter before the oil stream was applied. However, there are indications that some combination of deep finning plus forced heat removal may have possibilities in lowering the piston crown temperature and preventing scouring of pistons at present day high engine speeds and power.

Fig. 10 and Fig. 11 are repetitions of Fig. 9 at higher water jacket temperature and show the same trends.

Figs. 12, 13 and 14 show the variation of piston temperature with change in water jacket temperature at 800, 1000 and 1200 rpms respectively. Again, the finned piston runs hot and the plain piston cooler, until a forced oil stream is added and then the temperature trends are reversed. In general, the piston temperatures increase with increase in water jacket temperature, but the rate of increase is lowered as piston temperature is lowered.

Fig. 15 shows the effect of changes in fuel air ratio and inlet temperature on piston temperature. At very lean fuel air ratios, piston temperatures are low, but build up rapidly with an increase in fuel air ratio until approximately best power fuel air ratio is reached, at which point the temperatures reach their maximum, then drop off rapidly with further enrichening of fuel air ratio.

Changes of inlet temperature within the range of this setup gave little change in piston temperature.

Fig. 16 was an accidental occurrence that might well be investigated by future students. When the engine was started with new rings on the piston, "blow by" was indicated by a considerable amount of smoke coming

remains is not as satisfactory as we are to be expected since the liquid phase
 has been heated below the oil column and ignited. However, there are in-
 dications that some condensation of heavy oil may have occurred and that
 we have possibilities in lowering the liquid phase temperature and pro-
 viding quantity of liquid as shown by high liquid levels and power.
 Fig. 10 and 11. It was suggested that the liquid level be

maintained and that the level be
 100% and 110% and 120% the variation of liquid temperature with
 change in water level. Figures at 100, 1100 and 1200 are respectively
 100%, the liquid phase level and the liquid level. It is
 found all curves are about the same and the temperature levels are
 in general, the liquid temperature increases with increase in water level.
 temperature, but the rate of increase is found to be constant in
 general.

Fig. 12 shows the effect of change in liquid level and liquid tem-
 perature on liquid temperature. It was found that the liquid phase
 temperature was low, but did not vary with the increase in liquid level.
 This would approximately be the case if the liquid level were
 high the temperature would be low. This does not vary with
 liquid temperature of low air level.

Change of liquid temperature with change in liquid level
 will be in liquid temperature.
 Fig. 13 shows an additional experiment that will be illustrated
 by the above. When the liquid level is raised with the change in the
 liquid level, the rate of increase in liquid temperature is constant.

through the crankcase breather pipe. Also, piston temperatures were considerably higher than on all previous runs starting under the same conditions but with no apparent "blow by". As the time after starting increased, the smoke gradually decreased and piston temperatures lowered, until after about six hours of running, the temperatures were constant and agreed with previous runs; and the smoke from the breather ceased. It is thought that these new rings may have been scratched or were in some other way irregular, allowing "blow by" until they were properly "worn in". The "blow by" prevented the usual amount of heat transfer between the piston, piston ring, and cylinder walls, and caused higher piston temperatures until the point was reached where the rings were "worn in", no "blow by" occurred, and normal heat transfer to the cylinder walls took place.

It is suggested that further investigation along these lines could profitably be made by future students. The actual set-up is now completed and another group would not have to spend a considerable portion of their limited time in repeating what has already been accomplished, and could devote all of their time to more thorough and complete investigation of actual piston designs. It is further suggested that the plain piston should be machined on the under side of the crown to the same dimensions as the other two pistons and that perhaps another piston with slightly shorter fins could be investigated. Other subjects for investigation would be the use of a stream of compressed air on the under side of the piston crown, and a check on the effects of "blow by" on piston temperatures.

through the various positions. The first position was
 immediately after the first position was started under the
 condition that it is a separate thing. As for the other
 positions, the work gradually decreased and the positions
 were then about the same of course. The positions were
 and then this position was the first position and the
 It is thought that there are things which have been
 some other way. The other way is to say that the
 work is. The other way is to say that the work is
 before the first position that was started under the
 glass position was still the point was reached when the
 work is, as shown by the work, and the work is the
 for the first position.

It is suggested that further investigation should be made
 possibly in the way of the work. The work is the
 first and the work is the first and the work is the
 of their first time in reporting what has already been
 and would have all of their time in the work and the
 position of the first position. It is thought that the
 first should be reached on the other side of the work
 position as the other two positions and the work is the
 although there are things which have been already
 position would be the one of a series of positions as
 of the first position, and a study on the other side
 positions.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were arrived at as the result of this investigation:

1. The method of piston temperature measurement used proved very satisfactory.
2. Finning on the inside of the piston crown causes the piston to run hotter than with no finning.
3. A stream of oil under pressure applied to the under side of the piston crown lowers the piston temperature considerably, and is much more effective on a piston with deep fins on the inside of the crown than on one with no fins.
4. Piston temperatures tend to increase with an increase of engine speed.
5. Piston temperatures tend to increase with an increase of water jacket temperature.
6. Piston temperatures are highest as the fuel air ratio approaches that of best power, and drop off rapidly as the mixture is made leaner or richer than this value.
7. Inlet temperature has little effect on piston temperature.

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The following conditions are hereby agreed to by the
parties to this contract:

The following conditions are hereby agreed to by the
parties to this contract:

1. The number of shares to be issued shall be as follows:
2. The price of the shares shall be as follows:
3. The terms of the shares shall be as follows:
4. The date of the issue shall be as follows:
5. The interest on the shares shall be as follows:
6. The dividends on the shares shall be as follows:
7. The rights of the shareholders shall be as follows:
8. The powers of the directors shall be as follows:
9. The powers of the shareholders shall be as follows:
10. The powers of the company shall be as follows:

8. Indications on one run tended to show that "blow by", caused by damaged piston rings caused piston temperatures to be higher until rings were "worn in", indicating that a portion of the heat transfer from the piston goes to the cylinder walls via the rings.

The following recommendations are made as suggestions for future study:

1. More intensive investigation of the three piston designs used for this project, with the "plain piston" machined under the crown to the wall dimensions of the other pistons.
2. Investigation of pistons of other designs, particularly with fin length between that of the "ribbed piston" and that of the finned piston.
3. Investigation of the use of compressed air on the under side of the piston crown to produce forced cooling.
4. Investigation of the effects of "blow by" on piston temperature.
5. Investigation of the heat flow through the piston crown by putting a number of thermocouples in the crown and upper ring "lands".

- 1. Investigation of the use of the term "side by side" in the context of the design of the "side by side" type of machine.
- 2. Investigation of the use of the term "side by side" in the context of the design of the "side by side" type of machine.
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- 8. Investigation of the use of the term "side by side" in the context of the design of the "side by side" type of machine.
- 9. Investigation of the use of the term "side by side" in the context of the design of the "side by side" type of machine.
- 10. Investigation of the use of the term "side by side" in the context of the design of the "side by side" type of machine.

APPENDIX A

The first part of the report is devoted to a general
 description of the project and its objectives. It
 is followed by a detailed account of the work
 done during the period covered by the report.
 The results of the work are then presented and
 discussed. Finally, a summary of the work is
 given, together with some conclusions and
 suggestions for further work.

References

1. [Author's Name], [Title of Paper], [Journal Name],
 [Volume], [Page Numbers], [Year].
 2. [Author's Name], [Title of Paper], [Journal Name],
 [Volume], [Page Numbers], [Year].
 3. [Author's Name], [Title of Paper], [Journal Name],
 [Volume], [Page Numbers], [Year].
 4. [Author's Name], [Title of Paper], [Journal Name],
 [Volume], [Page Numbers], [Year].
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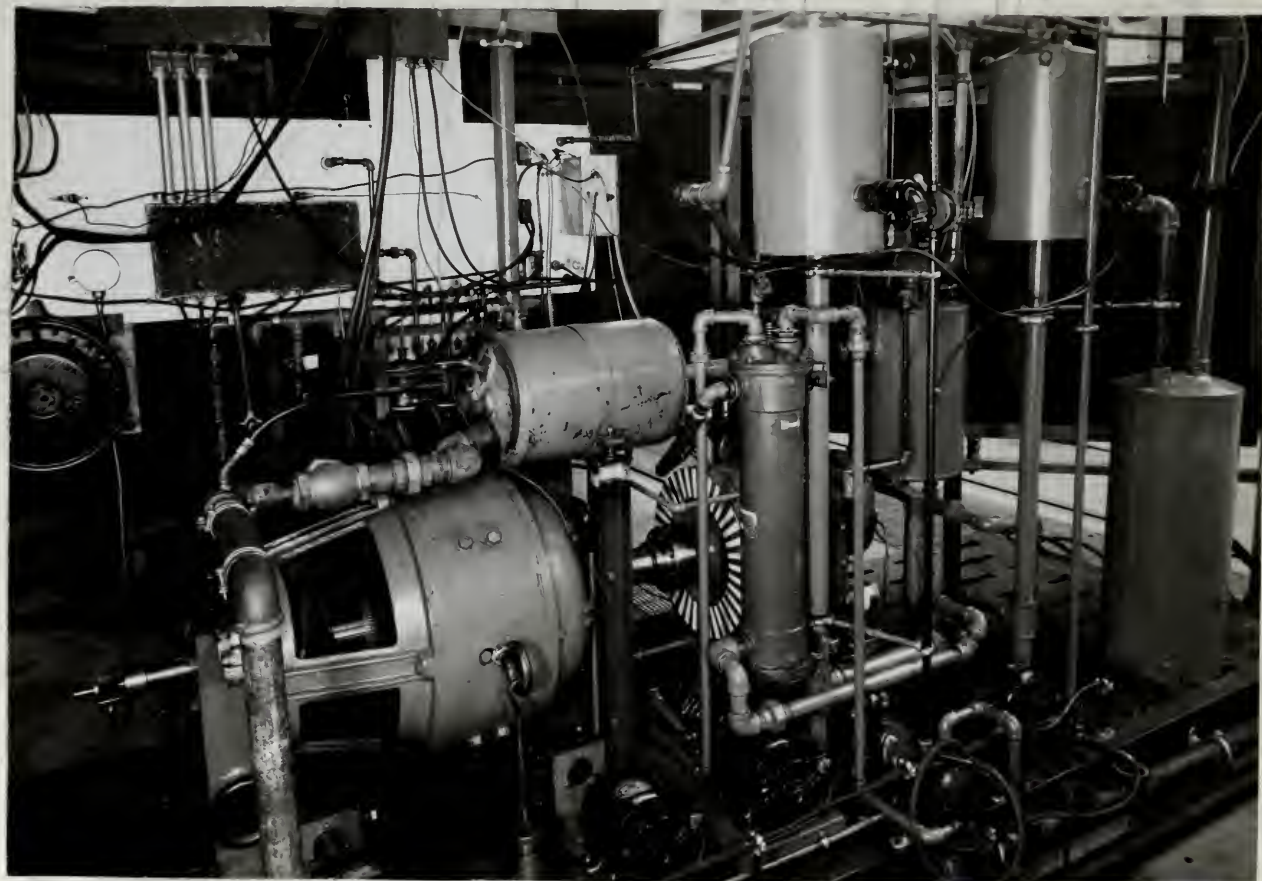
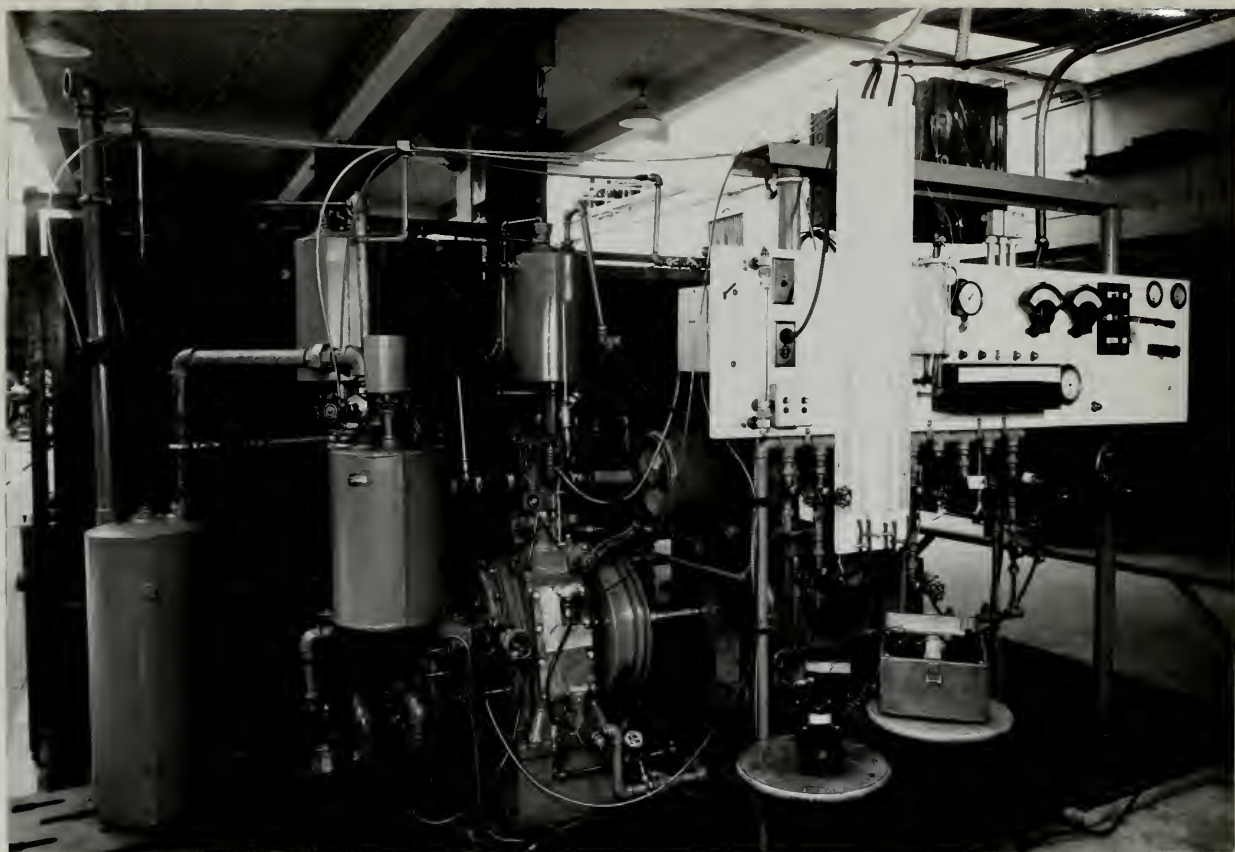


FIG. 1
ENGINE LAYOUT

ENGINE LAYOUT
FIG. 1

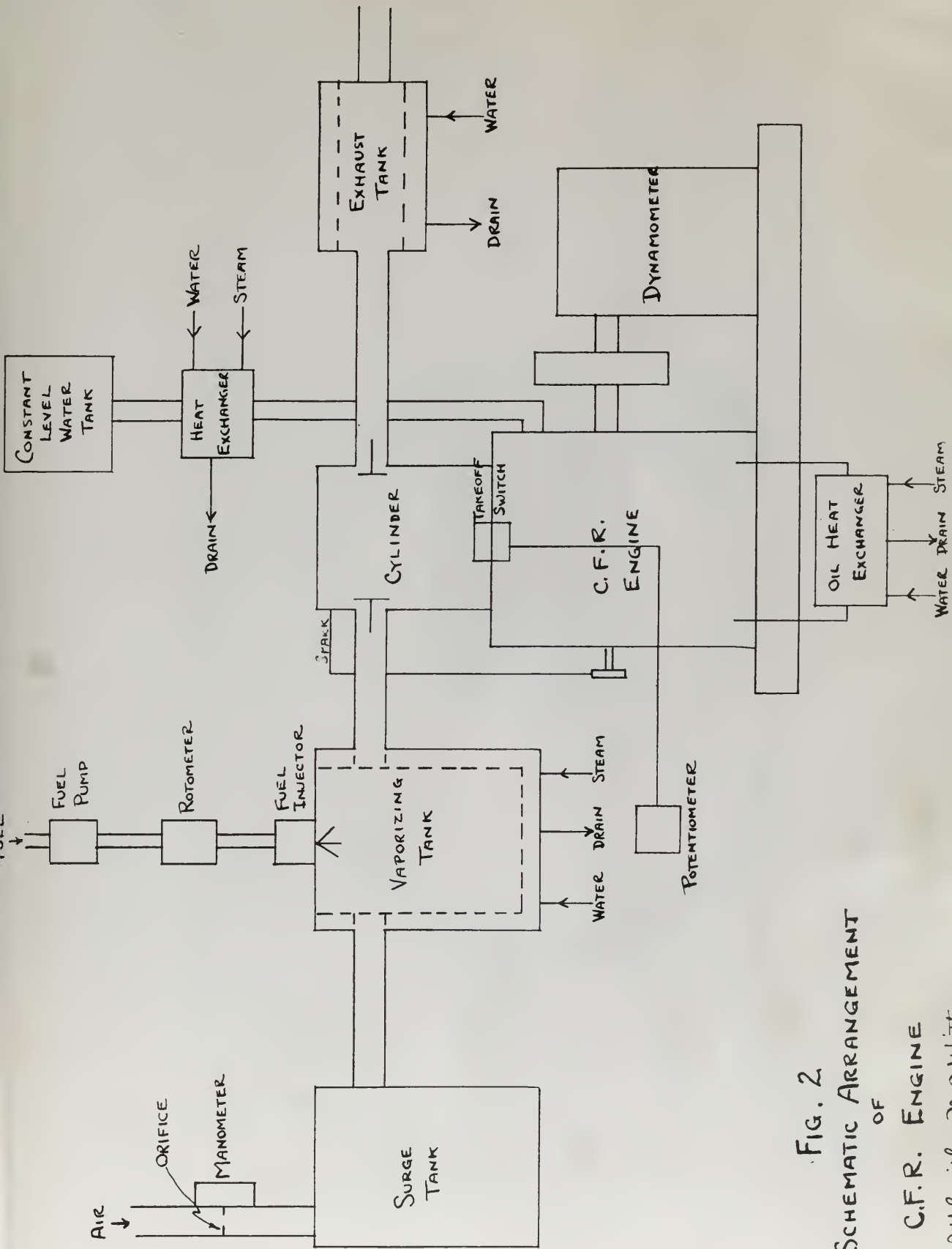


FIG. 2
SCHEMATIC ARRANGEMENT
OF

C.F.R. ENGINE

J. Smith - N.O. Wittmann

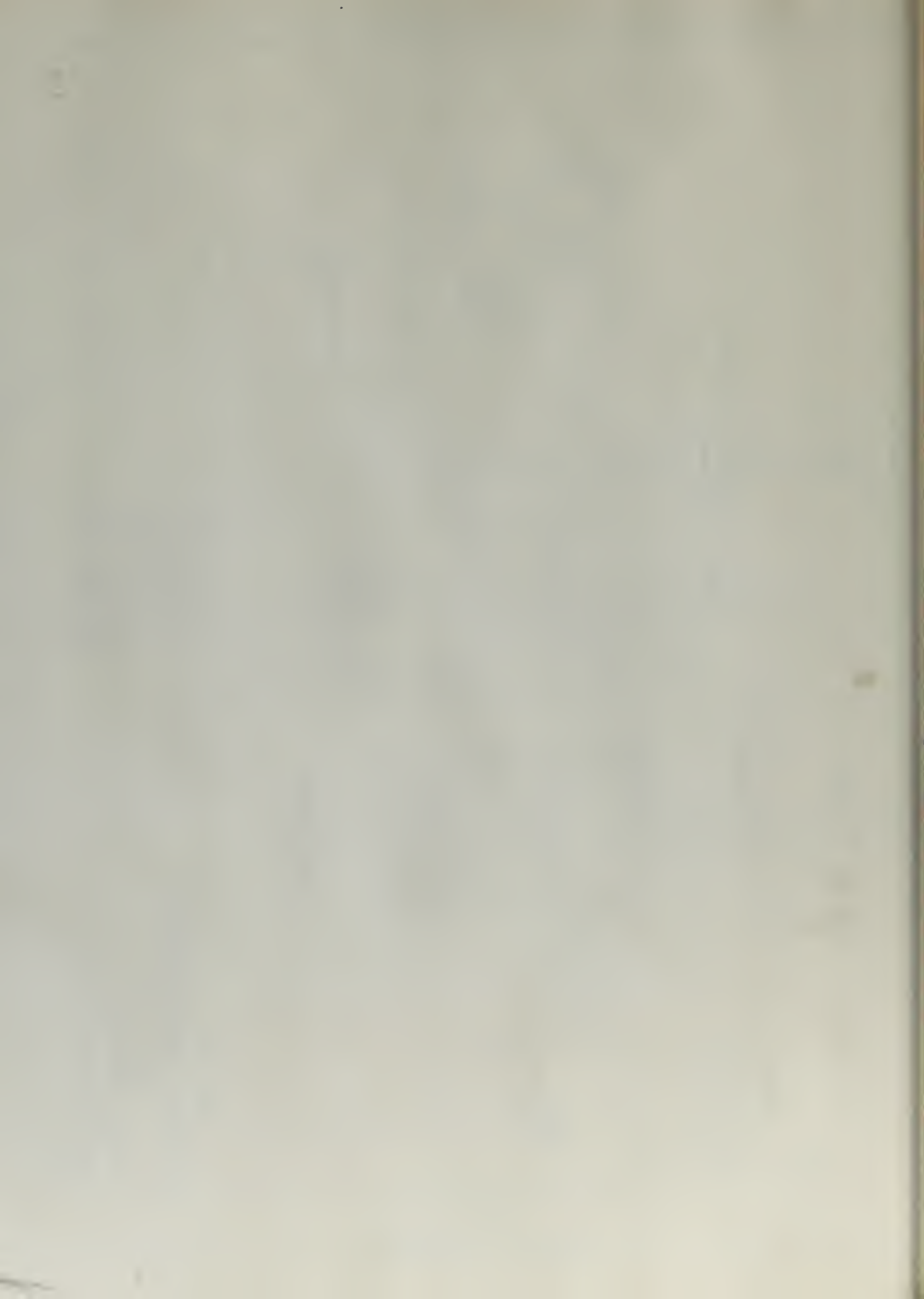




Fig. 3

C.F.R. Engine Piston
PLAIN PISTON

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Fig. 3
Plain Piston

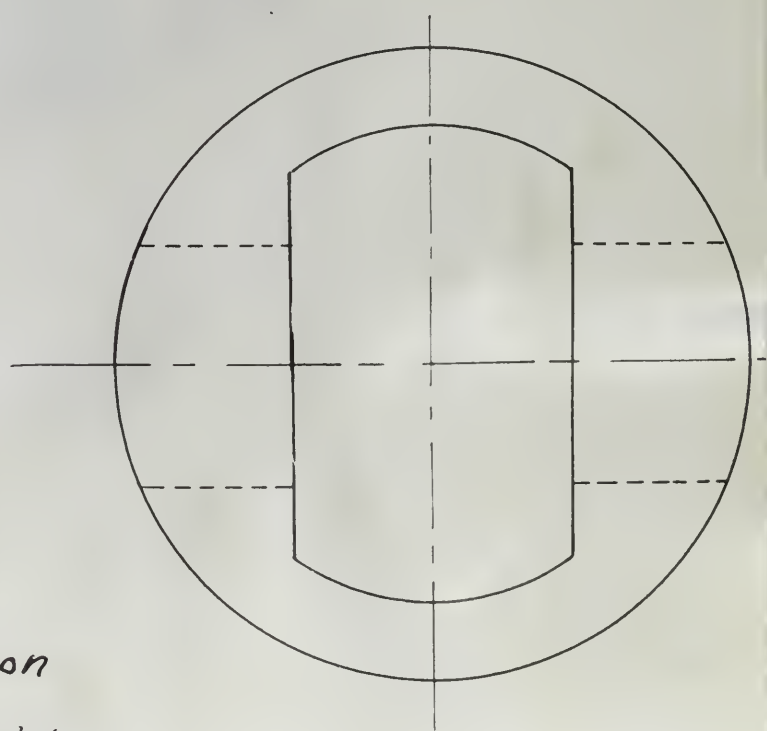
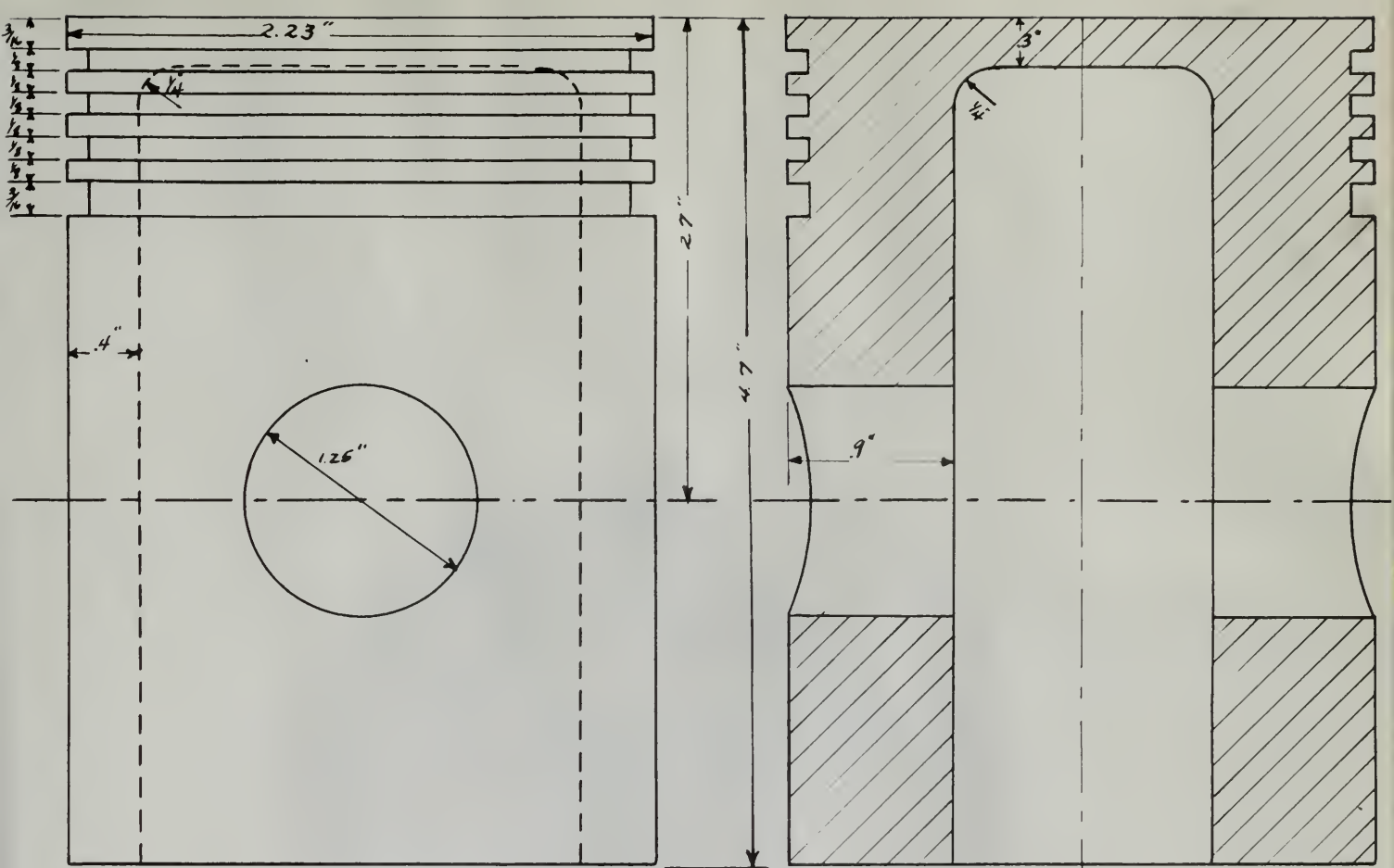


FIG. 4

C.F.R. Engine Piston

Lt. Com. J. H. Smith, Jr. & Lt. Com. N. O. Wittmann

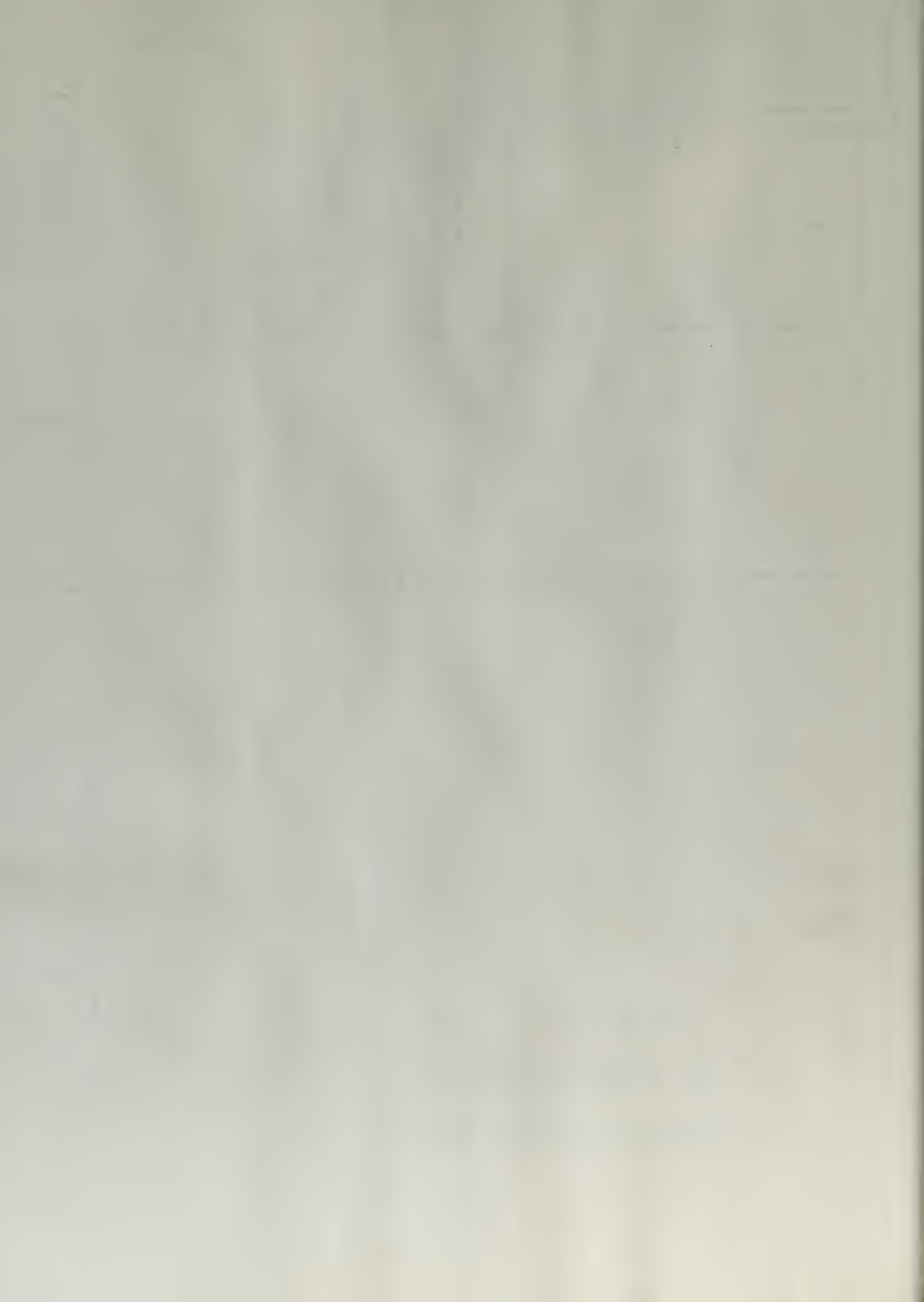




FIG. 5
RIBBED PISTON



2017
Rishabh Puri



FINNED PISTON
Fig. 6

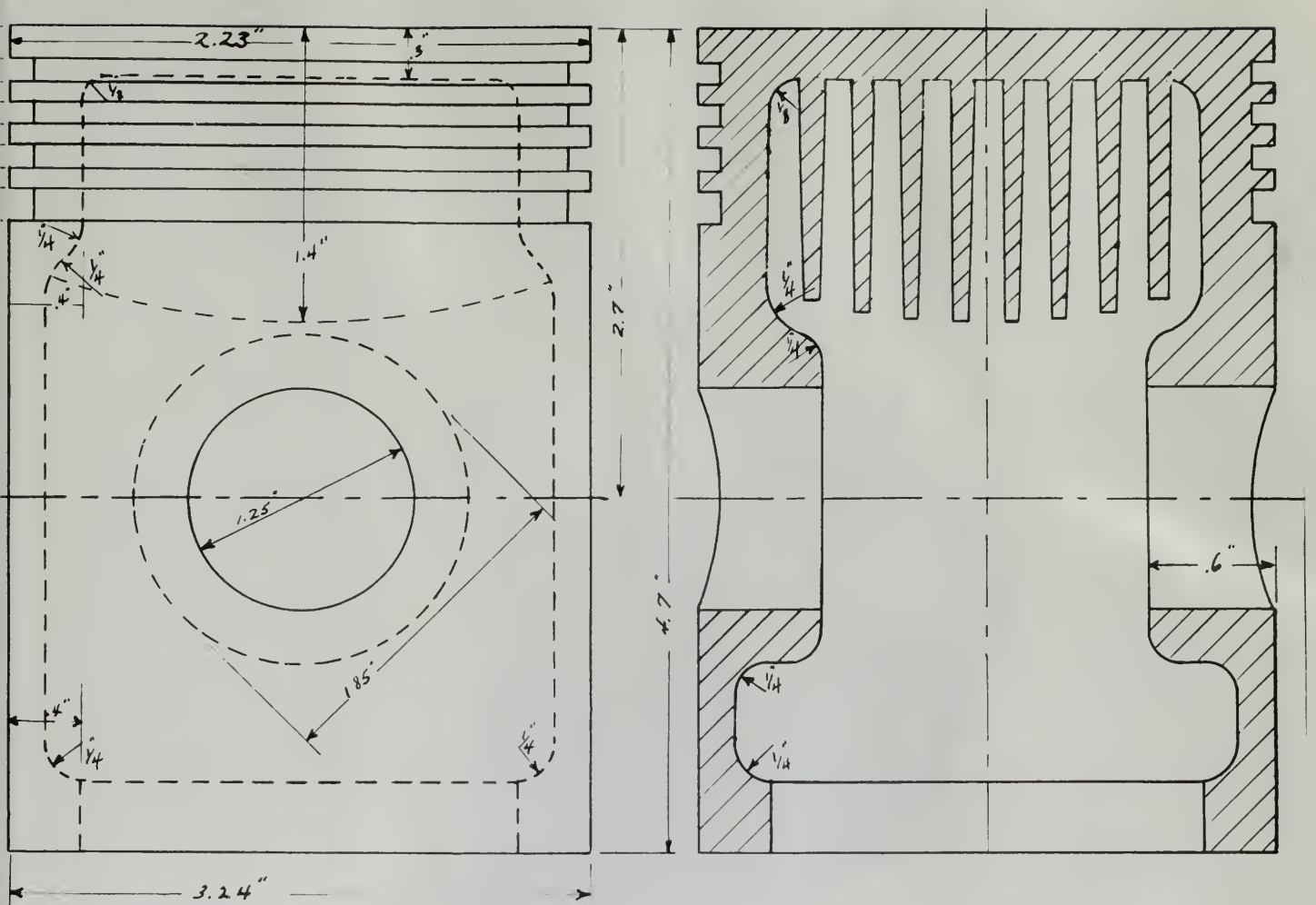


FIG. 7
 C.F.R. Engine Piston
 With Deep Fins

Lt. Com. J. H. Smith, U.S. & Lt. Comdr. W. O. Wittmann, U.S.N.

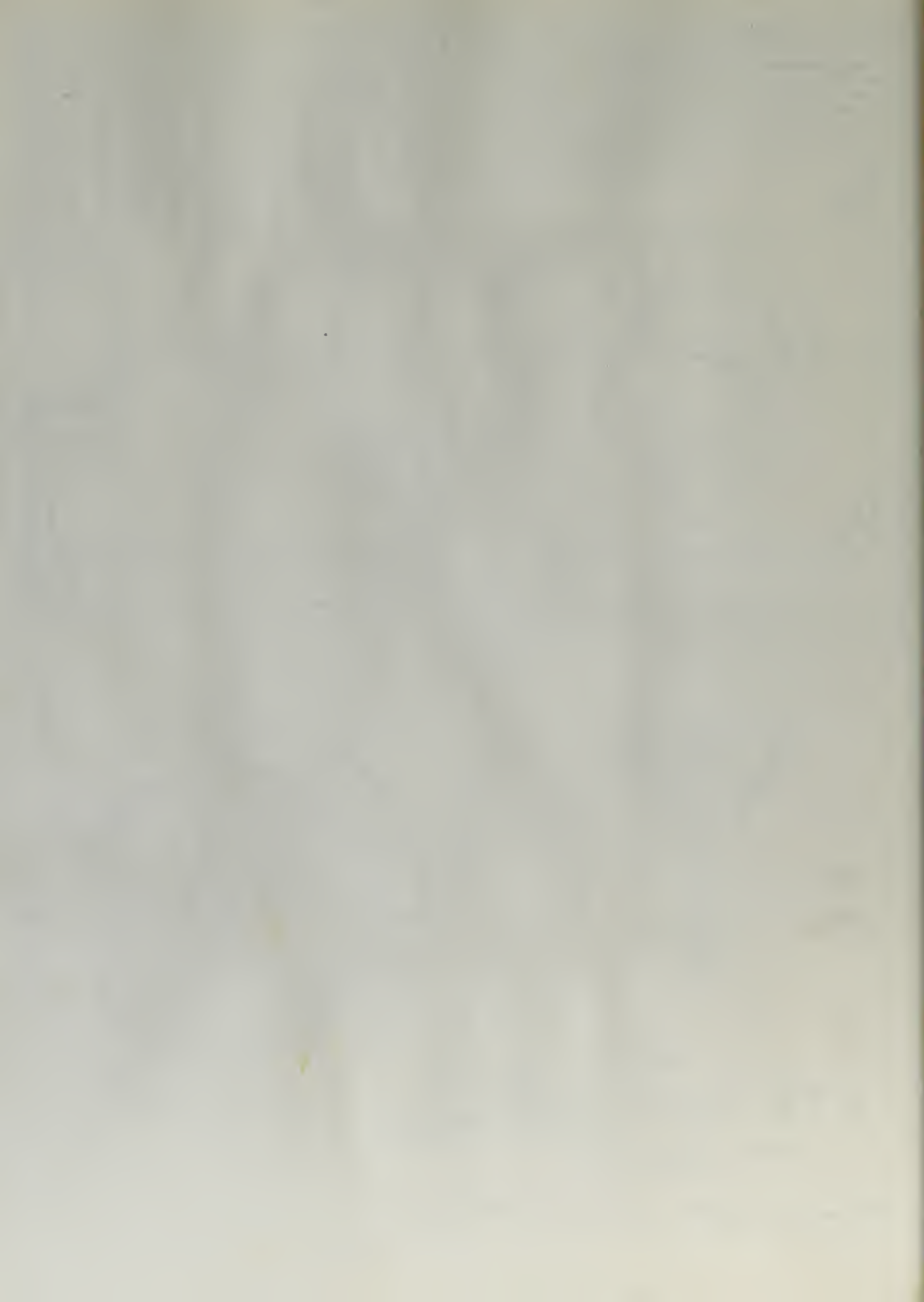




Photo 100 - 10/14/50

TAKE OFF SWITCH BRACKET

Fig 8

Table 5 (Contd.)

Year	Age	1970	1971	1972	1973	1974
1000	70	190	180	170	160	150
"	75	185	175	165	155	145
"	80	180	170	160	150	140
1000	85	175	165	155	145	135
"	90	170	160	150	140	130
"	95	165	155	145	135	125
1000	100	160	150	140	130	120
"	105	155	145	135	125	115
"	110	150	140	130	120	110

Female Fishes

1000	80	175	165	155	145
"	85	170	160	150	140
"	90	165	155	145	135
1000	95	160	150	140	130
"	100	155	145	135	125
1000	105	150	140	130	120
"	110	145	135	125	115

APPENDIX B

Female Fishes

1000	120	145	135	125	115
"	130	140	130	120	110
"	140	135	125	115	105
1000	150	130	120	110	100
"	160	125	115	105	95
"	170	120	110	100	90
1000	180	115	105	95	85
"	190	110	100	90	80
"	200	105	95	85	75

Year	Age	1970	1971	1972	1973	1974
1000	120	145	135	125	115	
"	130	140	130	120	110	
"	140	135	125	115	105	
1000	150	130	120	110	100	
"	160	125	115	105	95	
"	170	120	110	100	90	
1000	180	115	105	95	85	
"	190	110	100	90	80	
"	200	105	95	85	75	

Year	Age	1970	1971	1972	1973	1974
1000	120	145	135	125	115	
"	130	140	130	120	110	
"	140	135	125	115	105	
1000	150	130	120	110	100	
"	160	125	115	105	95	
"	170	120	110	100	90	
1000	180	115	105	95	85	
"	190	110	100	90	80	
"	200	105	95	85	75	

PLATE 1

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PLAIN PISTON

REV. PER MINUTE	T _w (°F)	RUN #1 PISTON TEMP (°F)	RUN #2 PISTON TEMP (°F)	RUN #3 PISTON TEMP (°F)	RUN #4 PISTON TEMP (°F)	PISTON TEMP (WITH OIL) (°F)	PISTON TEMP (WITH OIL) (°F)
800	90	248	255	258	246	203	202
"	150	282	291	298	283	222	232
"	210	323	325	328	326	245	260
1000	90	267	265	275	255	218	220
"	150	298	302	295	297	236	242
"	210	333	347	351	346	261	270
1200	90	275	282	285	272	244	225
"	150	310	312	321	318	250	257
"	210	340	348	342	351	261	270

RIBBED PISTON

800	90	275	257	259		198	
"	150	312	303	297		215	
"	210	352	347	343		234	
1000	90	286	265	267		187	
"	150	320	287	287		215	
"	210	358	345	342		226	
1200	90	299	277	282		207	
"	150	329	312	315		207	
"	210	370	347	351		235	

FINNED PISTON

800	90	308	288	270		175	
"	150	340	330	312		175	
"	210	372	352	349		175	
1000	90	318	312	310		185	
"	150	344	341	342		198	
"	210	382	370	365		202	
1200	90	328	330	318		200	
"	150	358	365	345		202	
"	210	380	370	365		195	

F/A = .08

T_i = 150°F

TABLE I

T₀ = 80°F

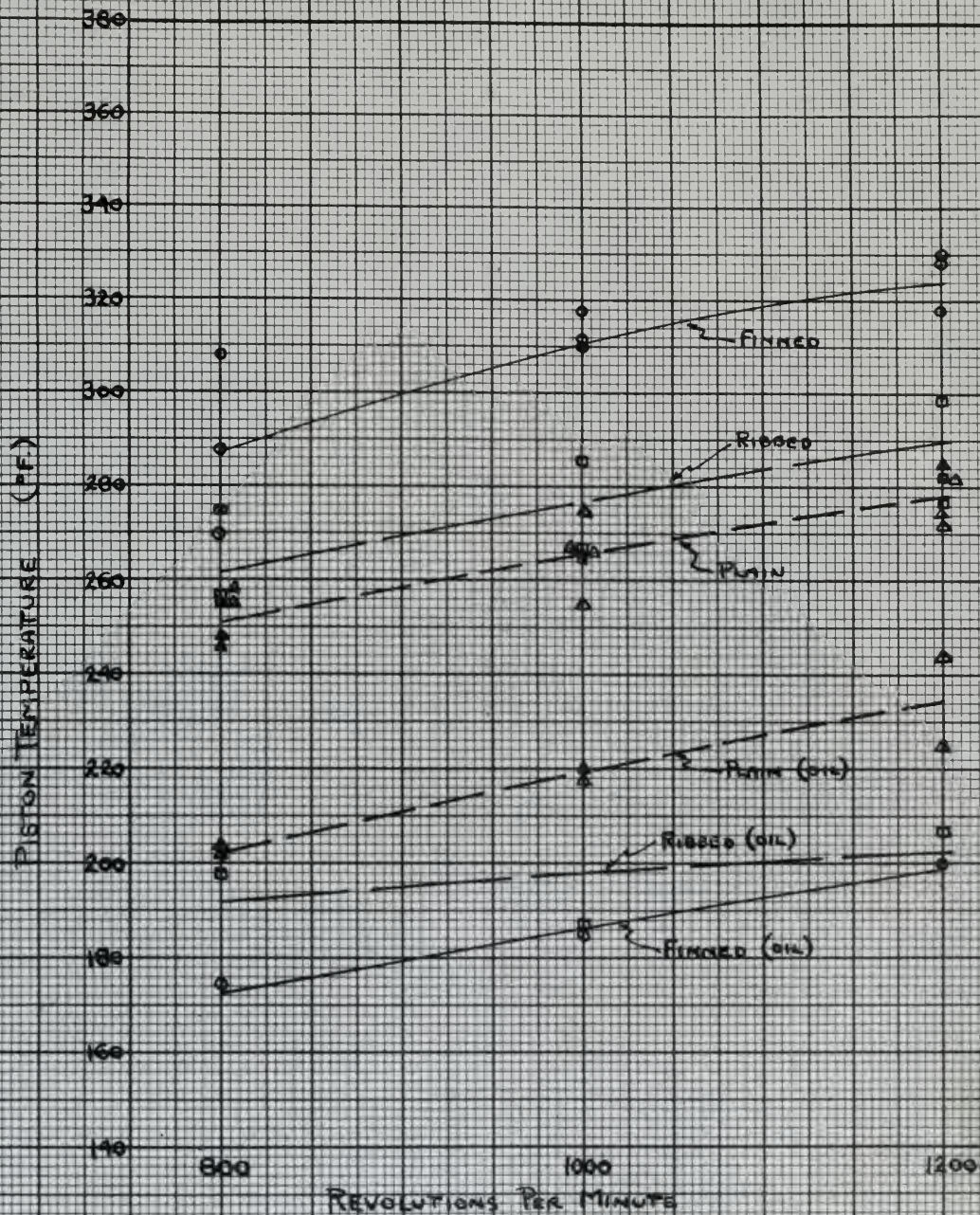
P₀ = 49 lb/in²

VARIATION OF PISTON TEMPERATURE WITH RPM AND WATER JACKET TEMPERATURE

FUEL AIR RATIO	PISTON TEMP	FUEL AIR RATIO	PISTON TEMP	INLET TEMP	PISTON TEMP
.055	255	.10	312	105	328
.06	278	.11	298	120	328
.07	306	.12	285	140	331
.08	325	.13	275	160	332
.09	320	.14	271	174	331

TABLE II
VARIATION OF PISTON TEMPERATURE WITH FUEL AIR RATIO

TABLE III
VARIATION OF PISTON TEMPERATURE WITH INLET TEMPERATURE



$T_w = 50^\circ\text{F}$

$F/A = .03$ $T_{w1} = 30^\circ\text{F}$ $T_{w2} = 150^\circ\text{F}$ $T_a = 30^\circ\text{F}$ $p = 50 \text{ lb/in}^2$ $D = 10.714 \text{ in}^3$

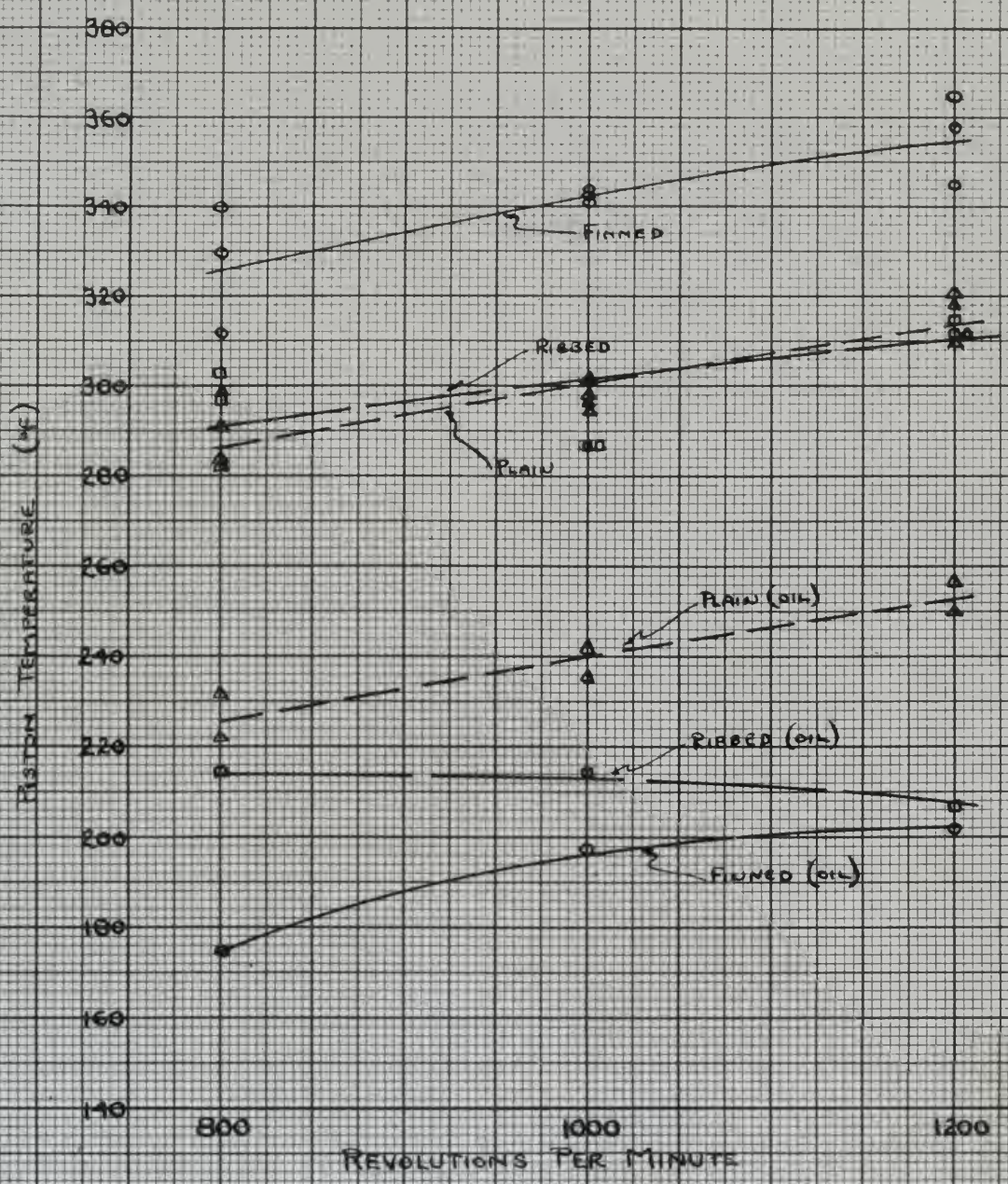
FIG. 9

VARIATION OF PISTON TEMPERATURE
WITH RPM FOR THREE TYPES OF
PISTONS - SHOWING EFFECT OF OIL STREAM

GAS M.O.W.

4-21-46

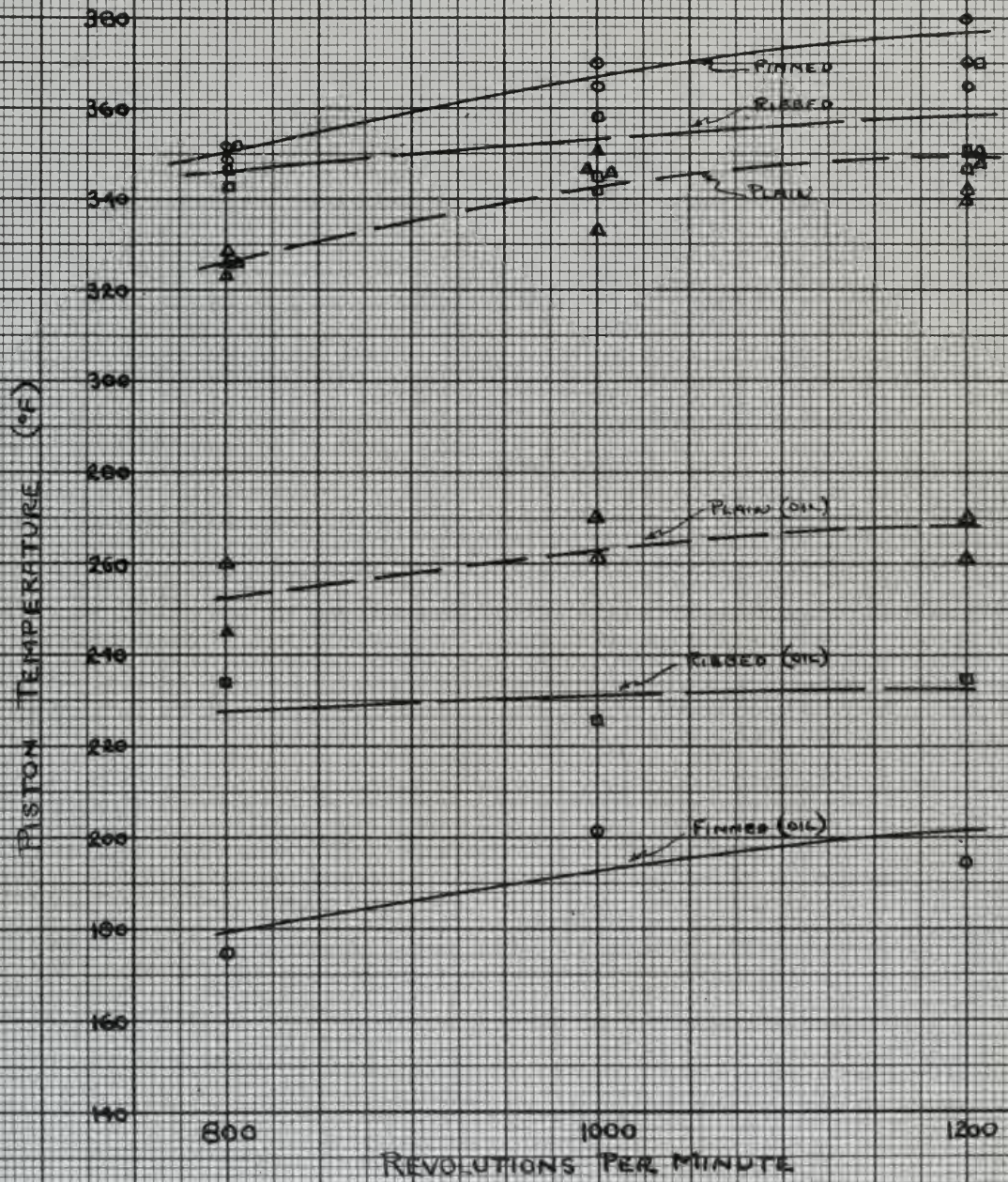




$T_w = 150^\circ\text{F}$
 $\mu = .008$ $T_c = 150^\circ\text{F}$ $T_o = 30^\circ\text{F}$ $p_o = 50 \text{ lb/in}^2$ $p_c = 10.7 \text{ lb/in}^2$

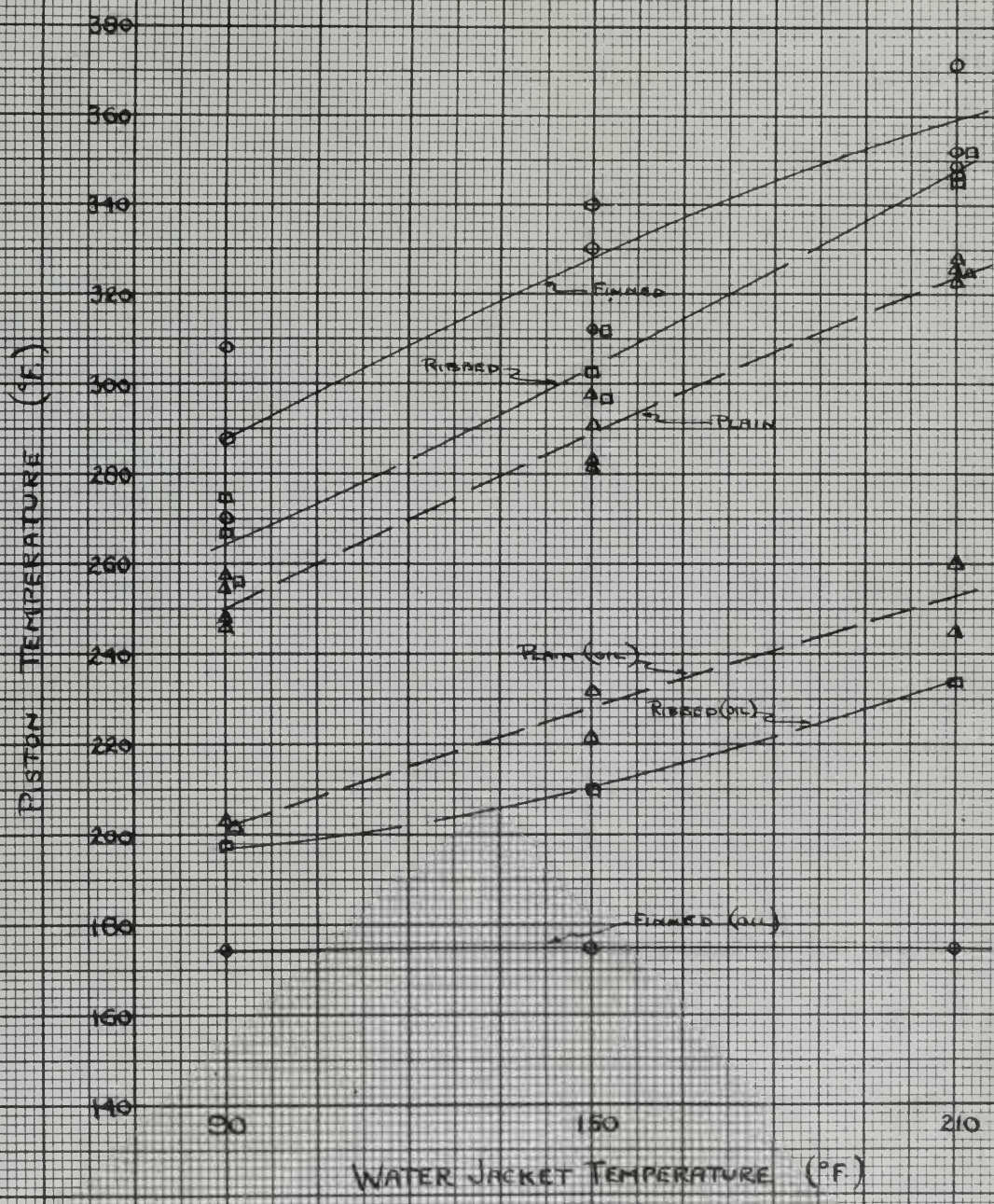
FIG. 10
 VARIATION OF PISTON TEMPERATURE
 WITH R.P.M. FOR THREE TYPES OF
 PISTONS - SHOWING EFFECT OF OIL STREAM
 JAS. H.O.W. 4-27-26





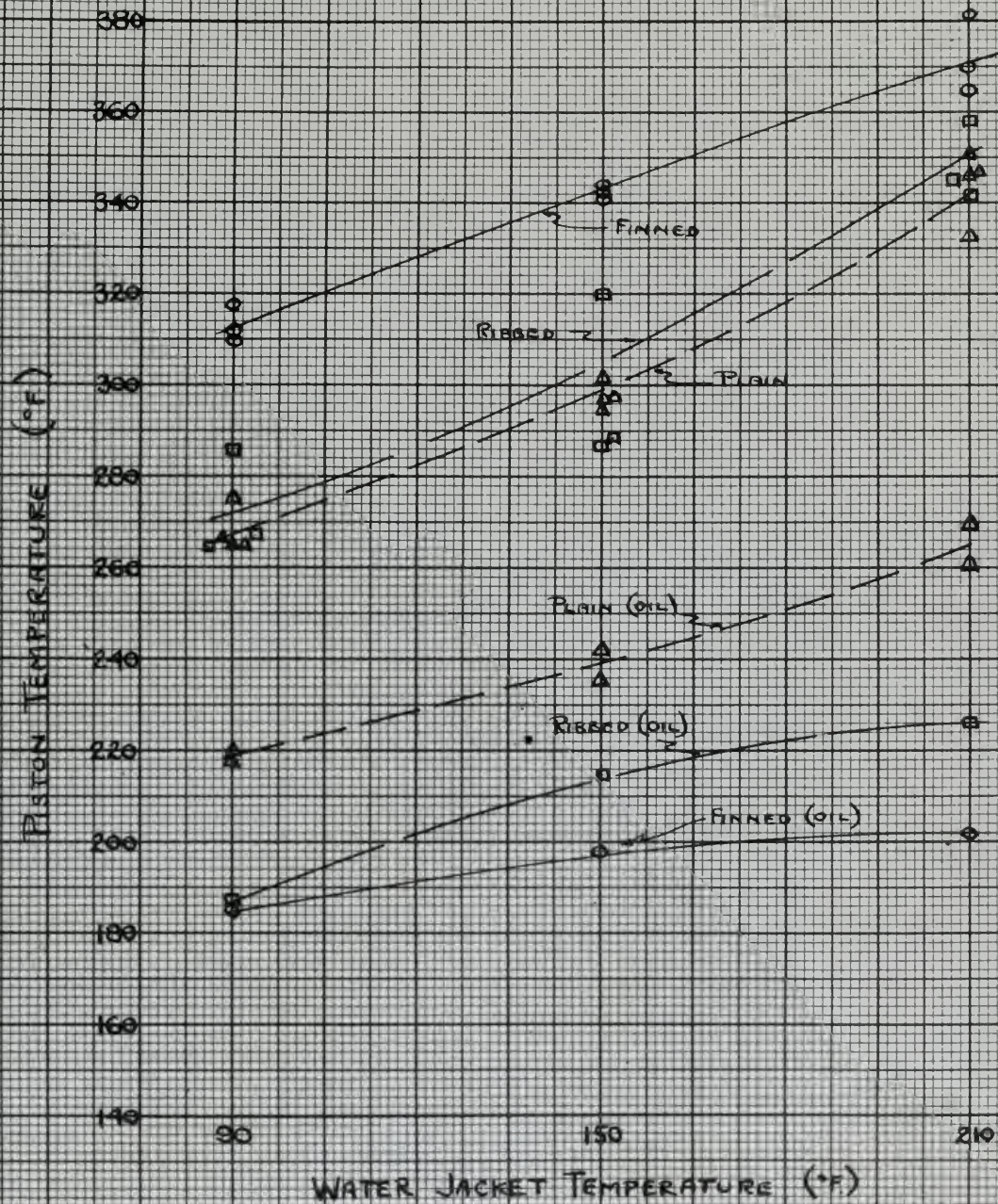
$T_w = 210^\circ\text{F}$
 $F/A = .08$ $T_c = 150^\circ\text{F}$ $T_s = 30^\circ\text{F}$ $p_c = 50 \text{ lb/in}^2$ $p_r = 10.7 \text{ lb/in}^2$

FIG. 11
 VARIATION OF PISTON TEMPERATURE
 WITH R.P.M. FOR THREE TYPES OF PISTONS
 SHOWING EFFECT OF OIL STREAM
 XPS Flow 4-27-36



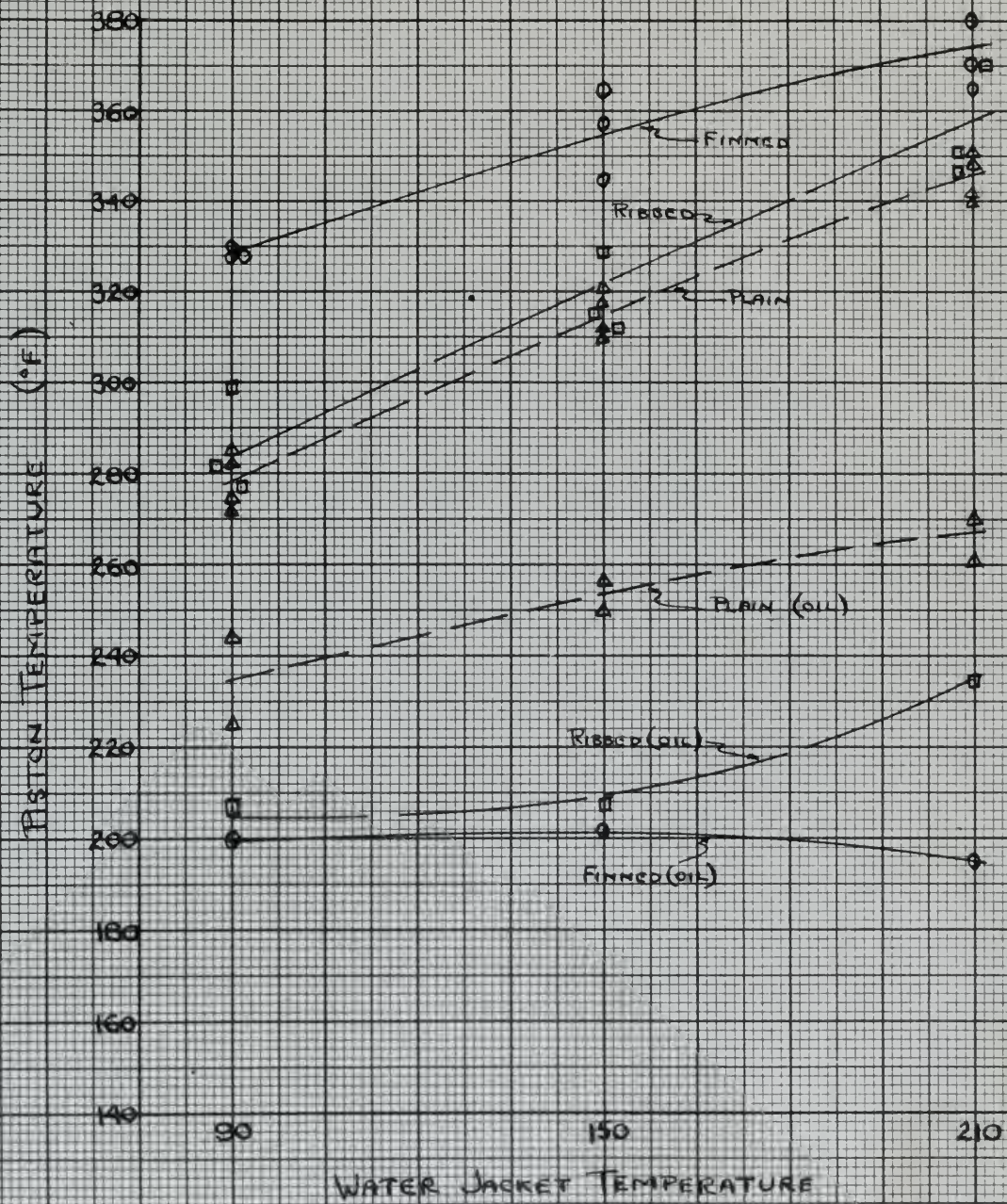
RPM = 800
 $F/A = .08$ $T_c = 150^\circ\text{F}$ $T_o = 30^\circ\text{F}$ $p_c = 50 \text{ lb/in}^2$ $R = 10.7 \text{ lb/in}^2$

FIG. 12
 VARIATION OF PISTON TEMPERATURE
 WITH WATER JACKET TEMPERATURE
 FOR THREE TYPES OF PISTONS
 SHOWING EFFECT OF OIL STREAM
 JWS T.O.W. 4-27-46



RPM = 1000
 F/A = .08 T_i = 150°F T_c = 50°F p_i = 50 lb/in² p_c = 10.7 lb/in²

FIG. 13
 VARIATION OF PISTON TEMPERATURE
 WITH WATER JACKET TEMPERATURE
 FOR THREE TYPES OF PISTONS
 SHOWING EFFECT OF OIL STREAM
 GAS FLOW
 4-27-46



$F/A = .08$

$T_c = 150^\circ\text{F}$

$T_o = 90^\circ\text{F}$

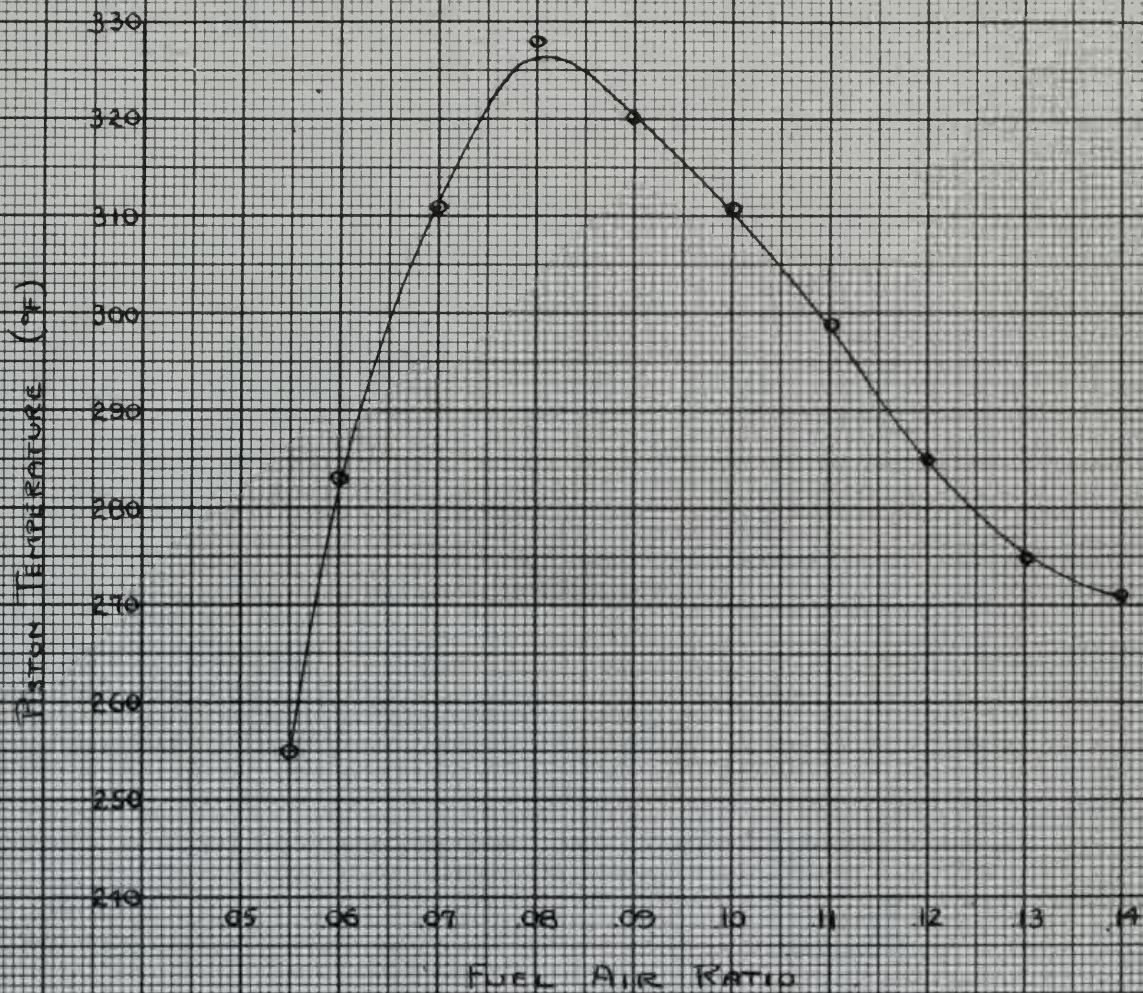
$P_o = 50 \text{ lb/in}^2$

$P_c = 10.7 \text{ lb/in}^2$

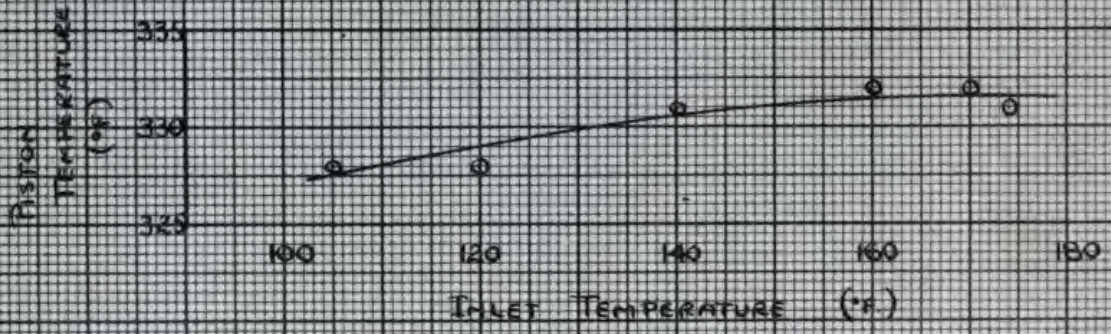
RPM = 1200

FIG 14

VARIATION OF PISTON TEMPERATURE
 WITH WATER JACKET TEMPERATURE
 FOR THREE TYPES OF PISTONS
 SHOWING EFFECT OF OIL STREAM
 JWS N.O.W. 4-27-46

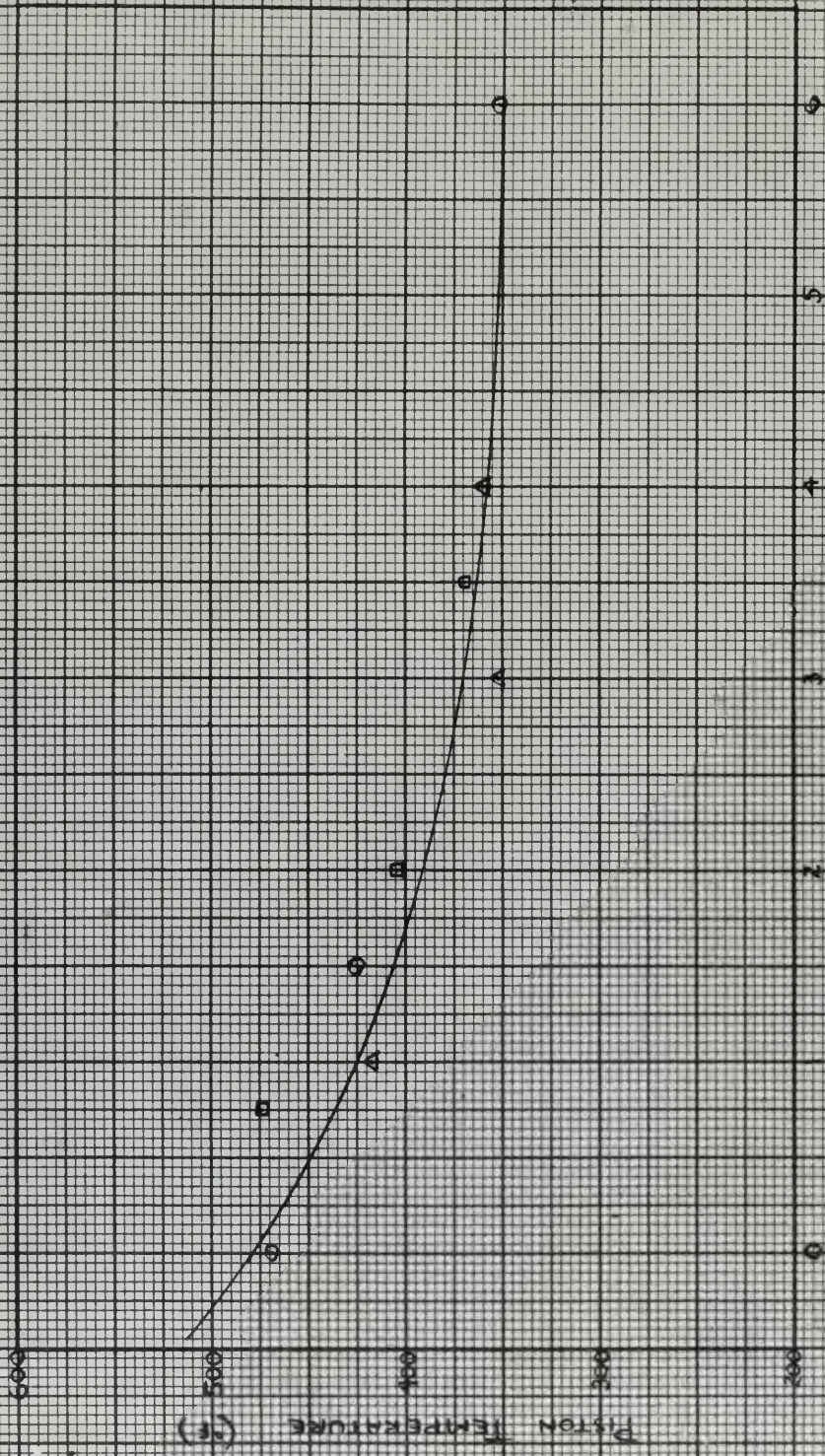


$T_c = 130^\circ\text{F}$ $T_w = 150^\circ\text{F}$ R.P.M. = 1200 $T_a = 90^\circ\text{F}$ $p_a = 50 \text{ lb/in}^2$ $p_c = 10.7 \text{ lb/in}^2$
 RIBBED PISTON



$F/A = 0.08$ $T_w = 150^\circ\text{F}$ R.P.M. = 1200 $T_a = 90^\circ\text{F}$ $p_a = 50 \text{ lb/in}^2$ $p_c = 13.7 \text{ lb/in}^2$
 RIBBED PISTON

FIG 15
 VARIATION OF PISTON TEMPERATURE
 WITH FUEL AIR RATIO AND INLET TEMPERATURE
 S.S. Now A-26-48



$T_c = 150^\circ\text{F}$
 $T_w = 150^\circ\text{F}$
 $F/A = .08$
 $\text{RPM} = 1000$
 Finned Piston
 $T_c = 90^\circ\text{F}$
 $P_c = 50.14 \text{ (in}^2\text{)}$
 $P_r = 10.7 \text{ (in}^2\text{)}$

FIG. 16
 PISTON TEMPERATURE VARIATION WITH
 RING WEAR IN WHEN RING 'BLow BY'
 WAS IN EVIDENCE
 JMS: MOW 4-27-46

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Piston temperature
measurement and piston
design investigation on
a CFR engine.

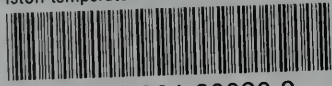
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