GAS TURBINE AND JET ENGINE FUELS

PROGRESS REPORT NO. 7

NAVY BUWEP CONTRACT NO. (W) 61-0590-D

MARCH, 1962

38

PHILLIPS 66

PHILLIPS PETROLEUM COMPANY

Progress Report No. 7
Navy Contract NO(w)61-0590-d
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By

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38

SUMMARY

The final three months under Contract NO(w)61-0590-d have been spent continuing the study of effects of sulfur in jet fuels and ingested sea water on the durability of engine "hot section" components. Efforts during this period have included: (1) evaluation of the effect of sulfur and (in some cases) sulfur plus ingested sea water on durability of Udimet 500, Waspalloy, Stellite 25 and Inconel X simulated turbine inlet guide vanes in the two-inch high pressure combustor under conditions producing 2000F exhaust gas, and (2) further testing with the atmospheric pressure Phillips Microburner to develop a simpler, less time-consuming test method for evaluation of turbine blading metal durability.

The results obtained with the two-inch combustor during this reporting period indicate that: (1) none of the turbine blading alloys tested were detrimentally affected by as much as one per cent fuel sulfur at 2000F; (2) increases in metal loss attributable to ingested sea water were observed with Udimet 500 and Waspalloy vanes at 2000F, although the increase would appear significant only in the case of Waspalloy (data are not yet available on the effects of sea water on Stellite 25 or Inconel X); (3) the cobalt base alloy Stellite 25 showed the greatest resistance to oxidation followed in decreasing order by the nickel base alloys Inconel X, Udimet 500 and Waspalloy.

Additional developmental tests with the Microburner have shown that variations attributable to differences in de-scaling severity can be excessive and may account in large measure for the lack of repeatability in the tests conducted thus far. Further development is indicated in order to define a test method of adequate repeatability.

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PHILLIPS PETROLEUM COMPANY

BARTLESVILLE, OKLAHOMA

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I. INTRODUCTION

The last three months under Navy Contract NO(w)61-0590-d have been spent continuing the study of the effects of sulfur in jet fuels and ingested sea water on the durability of engine "hot section" components. Efforts during this period have included: (1) Evaluation of the effect of sulfur and (in some cases) sulfur plus ingested sea water on the durability of Waspalloy, Stellite 25 and Inconel X simulated turbine inlet guide vanes in the two-inch, high pressure combustor under conditions producing 2000F exhaust gas, and (2) further testing with the atmospheric pressure Phillips Microburner to develop a simpler, less time consuming test method for evaluation of turbine blading metal durability.

II. TEST METHODS AND APPARATUS

A. Phillips 2-Inch Research Combustor Tests

The Phillips 2-Inch Research Combustor, illustrated in Figure 1, has been described in previous reports (1). Briefly, this is a 2-inch diameter axial flow combustor embodying the principal features of modern jet engine combustion systems. Air is supplied to this combustor from a compression and heating plant described in (1), while fuel is supplied to the swirl type nozzle by nitrogen pressurization. The design of the combustor provides for ready removal of flame tubes and turbine blading test pieces for weighing and inspection.

The test conditions employed were the same as those used for previous investigations of the effect of sulfur and sea water on flame tubes and turbine inlet guide vanes which have been reported on in (2). Combustor pressure was held at 350 in. Hg abs., inlet air temperature at 700F and inlet reference velocity at 100 fps, providing a severity level which is realistic for high compression ratio turbojets operating at relatively low altitudes. The tests conducted during this reporting period have been carried out entirely at a fuel/air ratio of 0.020 (resulting in an exhaust gas temperature of approximately 2000F) in order to provide temperature conditions realistic in terms of the more advanced engine designs.

As mentioned in Progress Report 6, no change was made to the combustor for the investigations of turbine blading metal loss. The only change in apparatus was simply to add a six-inch spool piece downstream from the combustor and to cut a suitable holder cavity into its mating flange for the test pieces shown in Figure 2, placing these pieces in a position comparable to blading in an actual engine.

Weight losses from the blading test pieces were measured following each of three consecutive two-hour test periods. During this reporting period vane pieces fabricated from Waspalloy, Stellite 25 and Inconel X have been tested. The compositions of these alloys and Udimet 500 (tested earlier in this program) are shown in Table I. Waspalloy and Udimet 500 are alloys currently in use in operational turbojet engines. Stellite 25 was substituted for Stellite 31 since Stellite 31 is unavailable in the sheet form necessary for fabrication of test pieces. Stellite 25 is, however, comparable in composition to Stellite 31. Inconel X was included primarily as a high nickel alloy for reference testing purposes.

Since previous investigations (2) had shown sulfur compound type to be unimportant as compared to gross sulfur content, it was decided to continue using ditertiary butyl disulfide as the sulfur contaminant since it is inexpensive and available at adequate purity. As in previous tests this compound was employed at sufficient concentration to realize a fuel sulfur content of 1.0 per cent. This exaggerated sulfur severity was considered desirable for research purposes. In the tests involving sea salts synthetic sea water formulated according to ASTM D665-60 was used. As in previous tests the synthetic sea water was injected at the rate of 1.0 lb./hr. or 5000 times the rate indicated in (3) as representative of airborne sea water vapor concentration at an altitude of 50 feet above the ocean surface. Tests at realistic rates had shown no measurable effect of sea water.

The base fuel used in all the tests reported herein, as in previous tests, was a JP-5 type isoparaffinic alkylate containing 0.005 per cent or less sulfur.

B. Phillips Microburner Guide Vane Metal Loss Tests

Further developmental testing has been carried on during this reporting period using the Phillips Microburner which has been adapted for measuring metal losses from (simulated) turbine inlet guide vanes. This apparatus has been described in detail in (4). Briefly, this apparatus is a 1.25-inch diameter atmospheric pressure tangential flow bench scale combustor. It is illustrated schematically in Figure 3. The exhaust system has been modified to allow placement of test materials in the exhaust stream. Simplified test pieces consisting of four 1/16" x 1/4" x 1 1/2" metal strips have been used. The position of these strips in the exhaust stream is illustrated in Figure 4. The holder containing the strips is clamped between the flanges shown in

Figure 3. Exhaust gas temperature measurements are made by mean of four equal area center thermocouples placed just upstream from the strips. The conditions of operation chosen for the exploratory tests were 500F inlet air temperature, 25 f.p.s. inlet reference velocity and 0.055 fuel/air ratio. This lean fuel/air ratio was chosen so as to provide a moderate amount of excess air (this burner uses no secondary air).

It will be recalled from Progress Report No. 6 that difficulty was experienced with air and fuel flow metering during exploratory testing as a result of rotameter heating. This has been corrected during this reporting period by isolating the rotameters from the burner. This brought about no significant change in exhaust temperature, however, with temperatures of the order of 2000 $\pm$ 50F being obtained, simulating the most advanced engine designs.

Determination of weight losses from the test strips are made in the same way as in the 2-inch combustor tests. Weighings have been made at one-hour intervals for total test times as high as 15 hours, except in cases where severe corrosion prevented further testing. The data are reported herein as combined weight loss from all four test strips.

Some difficulty in repeatably de-scaling the test strips has been encountered during recent testing as a result of attempts to utilize two operators to conduct the tests. It was discovered that the severity of de-scaling (using a six-inch rotary wire brush) varied excessively from operator to operator. Upon further checking it was found that this variation was also undesirably high even with a single operator. It is believed that this effect may account in part for the poor repeatability observed in the tests reported in Progress Report No. 6. At any rate this prompted a trial revision of the descaling procedure in the direction of lowered severity by using a smaller (two-inch diameter) brush of reduced stiffness operating at lower r.p.m. It was hoped that this modified technique would permit removal of loose scale without cutting into the protective oxide layers or base metal. Data obtained thus far using this technique are reported herein.

In addition to the study of descaling techniques a brief investigation of sandblasting of the test pieces has been carried on to establish the feasibility of accelerating metal loss rates (for test purposes) by surface pre-treatment. This was prompted mainly by the marked decrease in metal loss observed when the de-scaling was made less severe.

The Microburner data are intended to eventually supplement the 2-inch combustor data and provide a means for more rapid evaluation of sulfur and sea salt effects on a wide variety of practical turbine blading alloys.

III. DISCUSSION OF EXPERIMENTAL RESULTS

A. Two-Inch Combustor Turbine Guide Vane Metal Loss Tests

The data obtained during this reporting period on metal loss from Waspalloy, Stellite 25 and Inconel X simulated turbine inlet guide vanes in the Phillips 2-Inch Research Combustor are shown in Table II and Figure 5. Also included are data on Udimet 500 vanes previously reported in Progress Report 6. These tests were run at an approximate exhaust gas temperature of 2000F, which is representative of maximum turbine inlet temperatures in advanced engine designs.

It will be observed from Figure 5 that 1.0 per cent sulfur had little or no detrimental effect on any of these four turbine blading alloys. The injection of synthetic sea water did appear to cause some increase in metal loss over and above the values observed for the runs with 1.0 per cent sulfur fuel with Udimet 500 and Waspalloy vanes. The increase attributable to sea water is considered insignificant in the case of Udimet 500 but does appear significant in the case of Waspalloy. Data on the effect of sea water are not as yet available for Stellite 25 and Inconel X vanes.

Considering the results shown in Figure 5 simply in terms of the relative oxidation resistances of the four alloys (tests with neat base fuel) it will be seen that Stellite 25 showed the greatest resistance followed by Inconel X, Udimet 500 and Waspalloy in that order. It is of interest that the single cobalt base alloy in the group, Stellite 25, showed marked superiority over the nickel base alloys in oxidation resistance. However, many other factors are of course to be considered in addition to oxidation resistance - for example, tensile strength at elevated temperatures. On this count Stellite 25 is inferior to either Udimet 500 or Waspalloy.

B. Phillips Microburner Turbine Guide Vane Metal Loss Tests

As mentioned previously, the work carried on with the modified Phillips Microburner during this period has been entirely developmental and centered around refinements in test technique to improve repeatability. Prior to further testing the problem of rotameter heating mentioned in Progress Report No. 6 was corrected by remounting both air and fuel rotameters in a remote panel. Upon completion of this modification the series of tests shown in Table III were run. These tests were completed using the original descaling method (six-inch rotary wire brush). As indicated in Table III an attempt was made to utilize two operators to run some of these tests, whereas previous tests had all been conducted with the same operator (indicated as CWB in Table III). Actually, these tests were intended to be part of the factorial experiment which is outlined in Appendix 1. However, as will be seen from Table III, repeatability was so poor that it was concluded that further test method development was necessary before the program shown in Appendix 1 could yield meaningful results. Since the switch to two operators had appeared to cause even poorer repeatability it was decided to investigate what intuitively seemed the most likely source of variance - variations in severity of de-scaling.

Test strips from Test 14 which had burned for 10 hours were buffed by the regular operator with what he considered normal severity and weighed, then they were lightly buffed and reweighed. Next they were heavily buffed and weighed again. The results are shown below:

	Total Weight Loss, mg
10th Hour Loss Based on 1st Buffing	38.0
10th Hour Loss Based on 2nd Buffing	61.2
10th Hour Loss Based on 3rd Buffing	92.9

It is apparent from the above that variations attributable to differences in de-scaling severity can be excessive and probably account in large measure for the lack of repeatibility in these tests.

With the above information at hand efforts were begun to revise the de-scaling procedure in such manner as to result in minimum variance from this source. Steps were taken in the direction of lowering buffing severity by using a smaller diameter wire brush of reduced stiffness operating at lower r.p.m. It was hoped that this decreased severity would permit the removal of loose scale without cutting into the protective oxides or base metal.

A pair of tests was run using the modified descaling method. These are shown in Table IV (Tests 15 and 16). This change brought about a marked reduction in total metal loss rate. Although test time was increased from 10 to 15 hours the terminal values were only about one-fourth of those observed with the original de-scaling method in ten hours. Deviations between runs were reduced somewhat although not greatly until near the end of the 15 hour test period. This change in de-scaling technique would not appear to be especially promising in light of the reduced loss rate, moderatly improved repeatability (for the same total loss) and necessary extension of test duration. It is of some interest that increases in weight of the strips were observed during the early part of these tests, indicating significant formation of surface oxides which were not removed by this brushing method.

Pre-treatment of the strips by sand blasting was also tried during this period in conjunction with the milder de-scaling method in an attempt to recover some of the metal loss rate lost by the change in descaling method. The reasoning here was that the increased surface area brought about by sandblasting would offer a more reactive surface for attack by oxygen/sulfur. These data are also shown in Table IV. Some increase in metal loss rate was observed but it became obvious after seven hours in the second test that repeatability had suffered and this approach was therefore abandoned. Intuitively it would seem difficult to sandblast the strips with equivalent severity test to test.

As of this writing it is apparent that further developmental work will be necessary to define a test method giving adequate repeatability for use of the Microburner in this application. Such further work is planned for the coming contract period.

IV. CONCLUSIONS

Two-inch combustor data obtained during the present reporting period on the effects of sulfur and sea water on simulated turbine inlet guide vanes suggest the following conclusions:

1. Udimet 500, Waspalloy, Stellite 25 and Inconel X were not detrimentally affected by 1.0 per cent fuel sulfur under conditions producing 2000F exhaust gases.
2. Increases in metal loss attributable to ingested synthetic sea water were observed with Udimet 500 and Waspalloy vanes at 2000F. The increase would appear significant only in the case of Waspalloy vanes. Data on the effect of sea water on Stellite 25 and Inconel X vanes are not yet available.
3. Under conditions producing 2000F exhaust gases Stellite 25 (cobalt base alloy) showed maximum resistance to oxidative metal loss followed in decreasing order by Inconel X, Udimet 500 and Waspalloy (nickel base alloys).

Further developmental turbine guide vane metal loss tests conducted with a modified version of the Phillips Microburner have shown that:

1. Variations attributable to differences in de-scaling severity can be excessive and may account in large measure for the lack of repeatability in the tests conducted thus far.
2. Revision of the de-scaling procedure in the direction of reduced severity failed to improve repeatability to a significant degree (for the same metal loss level) and markedly reduced loss rate, necessitating increased test duration. This revised procedure does not appear sufficiently promising for further pursuit at this time.

3. Further developmental work would appear necessary to define a test method of adequate repeatability for use of the Microburner in this application.

V. OUTLINE OF PROJECTED WORK

Evaluation of the effects of fuel sulfur and ingested sea water on simulated turbine inlet guide vanes will be continued in the Phillips 2-Inch Research Combustor during the one year period beginning April 1, 1962 under Contract N600(19)-58219. Alloys scheduled for evaluation during this period include René 41, Hastelloy R-235 and Udimet 700. It is planned to continue the development of a metal durability test method begun with the modified Phillips Microburner apparatus. The alloys cited above will also be included in this phase of the test program.

REFERENCES

1. Fromm, E. H.; "Design and Calibration of Phillips Jet Fuel Testing Facilities", Phillips Research Division Report 1252-55R, December, 1955.

2. Kittredge, G. D. and Streets, W. L.; "Gas Turbine and Jet Engine Fuels", Summary Report for Navy Contract NOas60-6009-c, Phillips Research Division Report 2760-61R, January, 1961.

3. Woodstock, Alfred H. and Gifford, Mary M.; "Sampling Atmospheric Sea Salt Nuclei Over the Ocean", Journal of Marine Research, Volume VIII, 1949.

4. Streets, W. L.; "Phillips Microburner - A Tool for Evaluating the Burning Quality of Jet Fuels", Phillips Research Division Report No. 1793-57R, May, 1957.

TABLE I

COMPOSITION OF ALLOYS USED IN TURBINE GUIDE VANE METAL DURABILITY TESTS

Alloy	Per Cent by Weight of Indicated Metal															
	Cr	W	Fe	C	Si	Co	Ni	Mn	Cb	Mo	P	S	Al	Ti	B	Zr	Cu
Udimet 500*	19.0	—	.36	.09	.15	18.7	51.04	<.10	-	4.35	-	.005	3.10	2.99	.003	<.01	<.10
Waspalloy*	19.5	—	.95	.053	.03	13.2	57.44	.01	-	4.41	.003	.003	1.23	3.10	.002	.06	.01
Stellite 25	20.0	15.0	3.00	.10	1.00	49.4	10.00	1.50	-	—	-	-	—	—	—	-	-
Inconel X	15.0	—	7.00	.05	.40	—	72.84	.50	.90	—	-	.007	.75	2.50	—	-	.05

* Actual analyses of metal samples tested. Values shown for other metals are typical compositions.

TABLE II

TURBINE GUIDE VANE DURABILITY TESTS IN PHILLIPS 2-INCH RESEARCH COMBUSTOR

Combustor Operating Conditions: P = 350 in. Hg abs.; V = 100 f.p.s.; IAT = 700F, F/A = 0.020; Exh. Temp. = 2000F Nominal

Guide Vane Metal Type	Test Fuel Description*	Sea Water Input, lb/hr.**	Test Time, Hr.	Accumulated Guide Vane Metal Loss, mg.
Udimet 500	Base Fuel	None	2	22.7
			4	87.6
			5.67	142.4
Udimet 500	Base Fuel + 1% Sulfur	None	2	0.0
			3.75	85.8
			5.75	154.6
Udimet 500	Base Fuel + 1% Sulfur	1.0	2	20.1
			4	124.0
			6	191.7
Waspalloy	Base Fuel	None	2	0.0
			4	73.8
			6	206.3
Waspalloy	Base Fuel + 1% Sulfur	None	2	39.3
			4	122.9
			6	206.3
Waspalloy	Base Fuel + 1% Sulfur	1.0	2	61.2
			4	115.2
			6	284.1
Stellite 25	Base Fuel	None	2	1.5
			4	18.5
			6	39.8
Stellite 25	Base Fuel + 1% Sulfur	None	2	7.6
			4	17.9
			6	46.2

(Continued)

TABLE II (Continued)

Guide Vane Metal Type	Test Fuel Description*	Sea Water Input, lb/hr.**	Test Time, Hr.	Accumulated Guide Vane Metal Loss, mg.
Inconel X	Base Fuel	None	2	0.0
			4	42.8
			6	117.4
Inconel X	Base Fuel + 1% Sulfur	None	2	13.2
			4	59.4
			6	124.2

* Base fuel was 350-550F isoparaffinic alkylate. Sulfur contaminant was ditertiary butyl disulfide.

** Synthetic sea water per ASTM D665-60.

TABLE III

PHILLIPS MICROBURNER DEVELOPMENTAL TURBINE GUIDE VANE METAL DURABILITY TESTS

Operating Conditions: P = 1 atmos.; V = 25 f.p.s.; IAT = 500F; F/A = 0.055, Nominal Exh. Gas Temp. = 2000 ± 50F
De-Scaling Method: 6 inch Rotary Wire Brush
Surface Preparation: None

Test No.	Metal Type	Test Fuel Description	Accumulated Guide Vane Metal Loss, mg. (4 Strips) 1 Hr.	2 Hr.	3 Hr.	4 Hr.	5 Hr.	6 Hr.	7 Hr.	8 Hr.	9 Hr.	10 Hr.
7	Udimet 500	Base Fuel (350-550F Alkylate)	22.8	66.3	109.0	179.3	251.1	306.5	364.2	423.2	511.4	605.3
			(←——— CWB ———→)									
9	Udimet 500	Base Fuel + 1.0% Sulfur	25.3	61.1	106.6	158.6	210.1	272.6	345.0	422.1	496.9	595.6
			(←——— CWB ———→)									
10	Udimet 500	Base Fuel	3.2	28.0	62.7	110.6	164.5	210.6	265.2	334.3	408.2	500.7
			(←——— CWB ———→)									
11	Udimet 500	Base Fuel + 1.0% Sulfur	19.9 (CWB)	81.3 (JJS)	161.5 (JJS)	222.6 (JJS)	279.9 (CWB)	340.2 (CWB)	410.8 (CWB)	470.3 (CWB)	540.3 (CWB)	668.2 (JJS)
12	Udimet 500	Base Fuel	48.0 (JJS)	90.8 (CWB)	150.4 (CWB)	213.2 (CWB)	274.9 (CWB)	337.6 (CWB)	413.2 (CWB)	509.5 (JJS)	631.8 (JJS)	744.2 (JJS)
13	Udimet 500	Base Fuel + 0.4% Sulfur	18.1 (CWB)	55.6 (CWB)	103.3 (CWB)	153.3 (CWB)	209.5 (CWB)	263.2 (JJS)	314.1 (JJS)	367.9 (JJS)	418.3 (JJS)	478.1 (CWB)
14	Udimet 500	Base Fuel + 0.4% Sulfur	32.3	63.2	107.5	160.8	222.3	292.6	347.1	412.9	503.1	541.1
			(←——— CWB ———→)									

Note: Letters in parenthesis below metal loss values indicate operator for that period.

TABLE IV

PHILLIPS MICROBURNER DEVELOPMENTAL TURBINE GUIDE VANE METAL DURABILITY TESTS

Operating Conditions: P = 1 atmos.; V = 25 f.p.s.; IAT = 500F; F/A = 0.055, Nominal Exh. Gas Temp. = 2000 ± 50F
De-Scaling Method: 2-Inch low speed rotary wire brush
Surface Preparation: See below; Operator: CWB all tests

Test No.	Metal Type	Surface Preparation	Test Fuel Description	Accumulated Guide Vane Metal Loss, mg (4 Strips) 1 Hr.	2 Hr.	3 Hr.	4 Hr.	5 Hr.	6 Hr.	7 Hr.	8 Hr.	9 Hr.	10 Hr.	11 Hr.	12 Hr.	13 Hr.	14 Hr.	15 Hr.
15	Udimet 500	None	Base Fuel + 0.4% Sulfur	+20.6	+30.8	+33.1	+23.2	+6.7	8.9	13.8	41.4	63.9	79.0	94.8	103.7	117.7	133.2	149.3
16	Udimet 50C	None	Base Fuel + 0.4% Sulfur	+25.9	+34.6	+36.3	+29.4	+22.0	+9.5	+1.6	11.6	26.0	37.9	64.8	85.0	101.3	116.8	140.8
18	Udimet 500	Sandblasted	Base Fuel + 0.4% Sulfur	+23.7	+17.6	+10.5	+10.8	7.2	29.1	52.0	66.8	87.0	106.6	131.5	153.3	—	—	—
19	Udimet 500	Sandblasted	Base Fuel + 0.4%	+3.6	9.5	25.8	47.0	66.5	89.3	103.9	Test Discontinued for Lack of Repeatability							

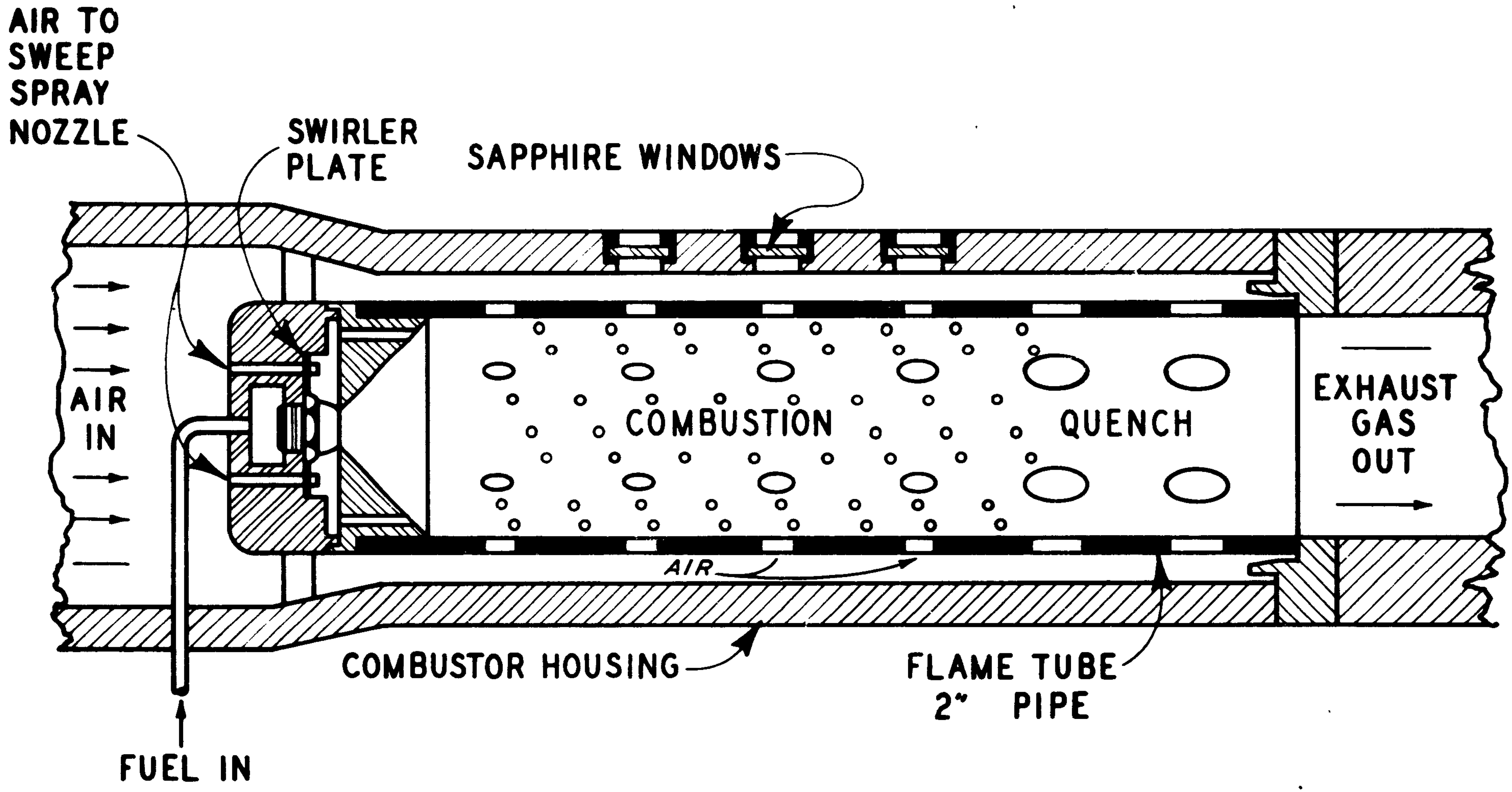
Note: Plus signs indicate weight <u>increases</u>.

APPENDIX I

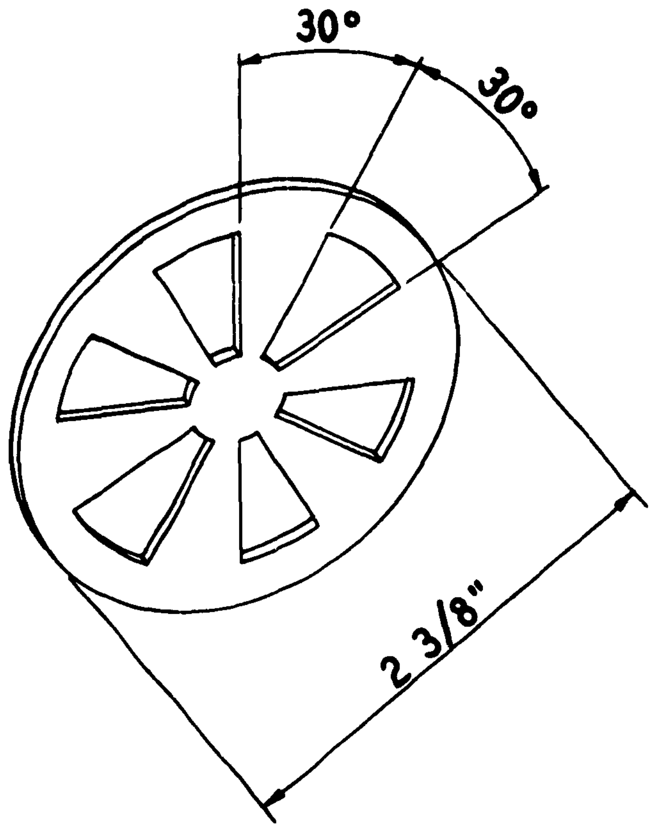
PROPOSED FACTORIAL EXPERIMENT FOR EVALUATION OF ALLOY EFFECTS, FUEL EFFECTS, INTERACTIONS AND REPEATABILITY OF TURBINE GUIDE VANE METAL DURABILITY TESTS USING THE MODIFIED PHILLIPS MICROBURNER APPARATUS

	Fuels		
Alloy	Base Fuel	Base Fuel + 0.4% Sulfur	Base Fuel + 1.0% Sulfur
Udimet 500	1	7	2
	5	8	4
	3	6	9
Waspalloy	5	6	9
	7	8	4
	3	2	1
Stellite 25	9	6	5
	7	8	3
	4	2	1
Inconel X	6	7	1
	5	2	9
	3	4	8
Hastelloy R-235	5	9	7
	3	6	4
	8	1	2
René 41	8	9	4
	1	6	5
	2	7	3
Udimet 700	9	4	8
	6	7	2
	1	3	5
Inconel 713	1	3	8
	9	4	6
	7	2	5

Note: Numbers indicate order of running of tests.



PHILLIPS LABORATORY SCALE TEST COMBUSTOR



MATERIAL: VARIOUS TYPES OF TURBINE BLADING ALLOYS (16 GA. SHEET)

FIGURE 2
SIMULATED TURBINE INLET GUIDE VANE INSERT FOR MEASUREMENT OF METAL LOSSES IN PHILLIPS 2-INCH RESEARCH COMBUSTOR

1. AIR PRESS. REGULATOR
2. AIR PRESS. GUAGE
3. AIR ROTOMETER
4. AIR FLOW CONTROL VALVE
5. ELECTRIC AIR PREHEATER
6. BURNER BASE PRESS. GAUGE
7. PHILLIPS MICROBURNER
8. FUEL DUMP VALVE
9. FUEL FLOW CONTROL VALVE
10. FUEL ROTOMETER
11. FUEL TANK
12. N_2 BLEED VALVE
13. N_2 PRESS. GUAGE
14. N_2 PRESS. REGULATOR
15. PROPANE PILOT VALVE

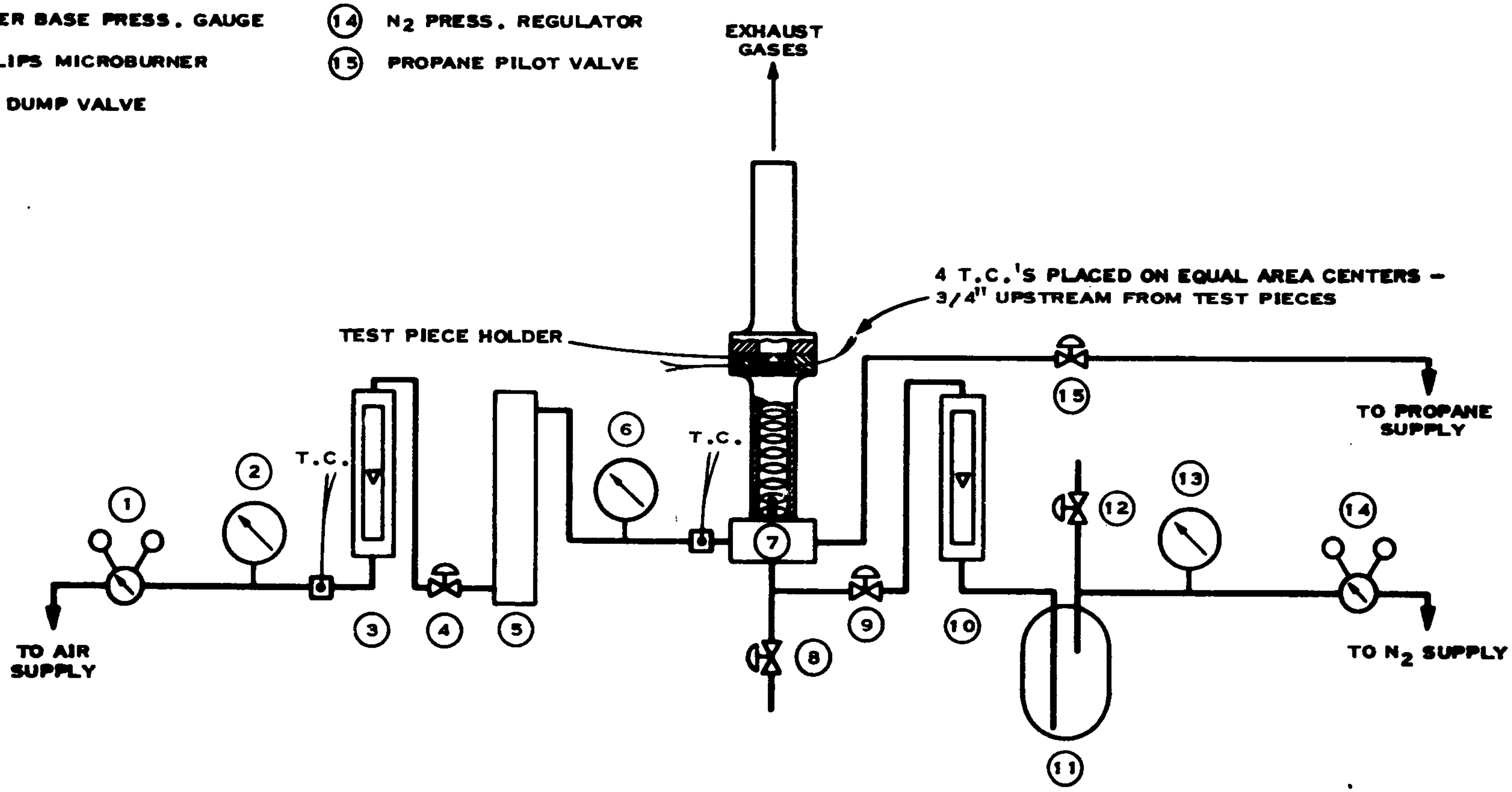
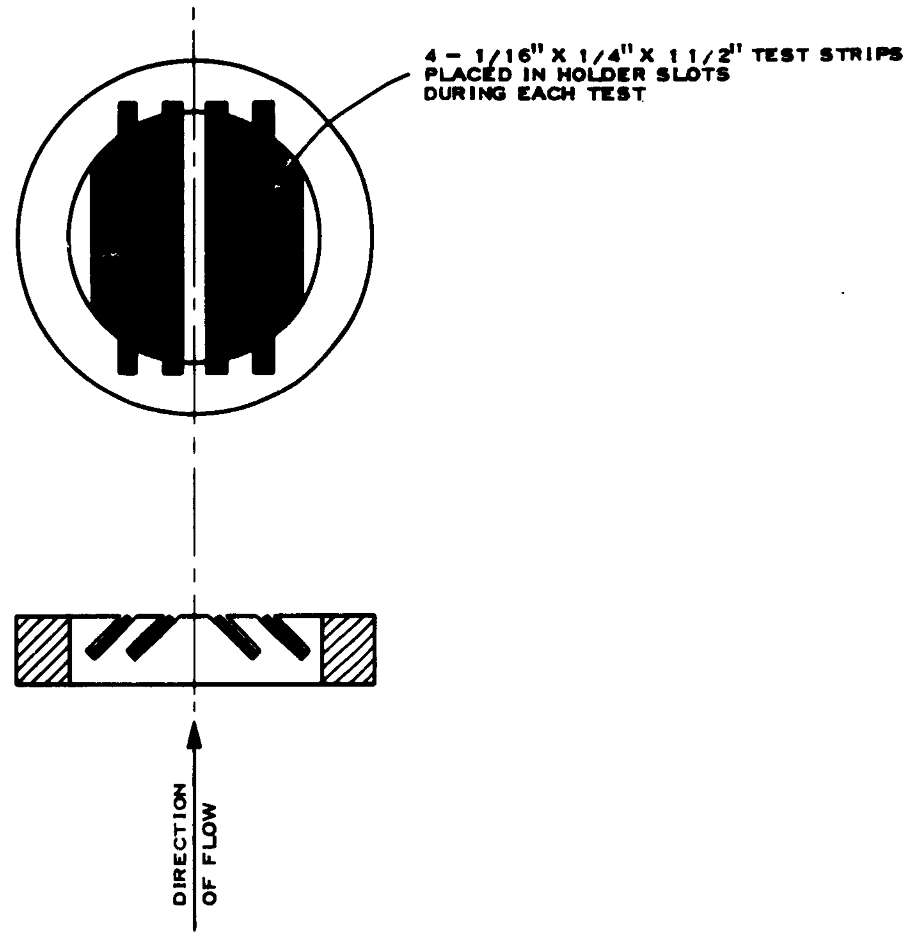


FIGURE 3
SCHEMATIC DIAGRAM OF PHILLIPS MICROBURNER ADAPTED FOR MEASUREMENT OF TURBINE GUIDE VANE METAL DURABILITY



HOLDER MAT'L: 310 SS; STRIP MAT'L: VARIOUS TURBINE BLADING ALLOYS

SCALE: FULL

FIGURE 4
METAL DURABILITY SPECIMEN HOLDER FOR MICROBURNER APPARATUS

PHILLIPS PETROLEUM COMPANY
RESEARCH DIVISION REPORT 3159-62R

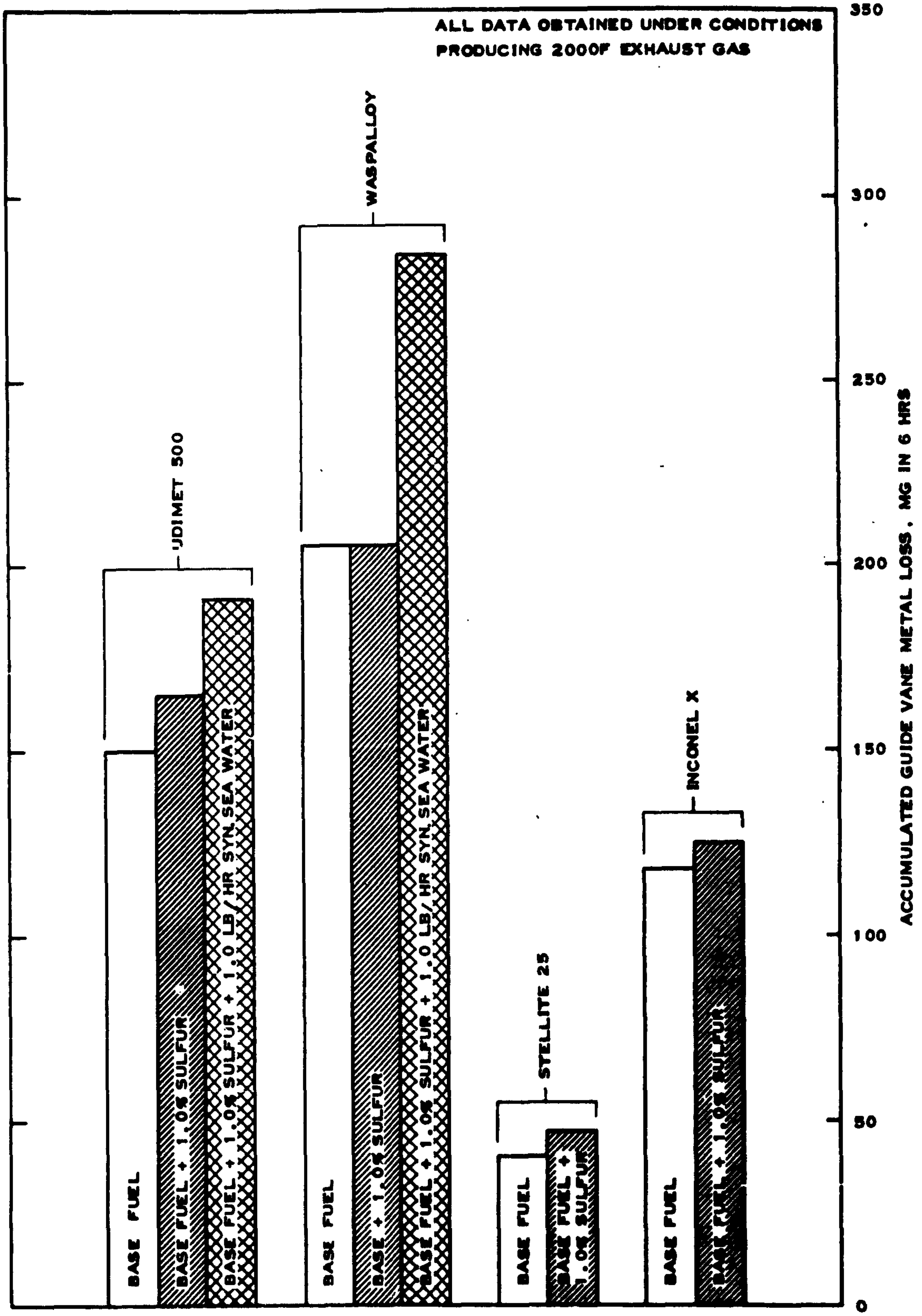


FIGURE 5
EFFECT OF SULFUR AND SEA WATER ON TURBINE INLET GUIDE VANE METAL LOSS FROM SEVERAL ALLOYS IN THE PHILLIPS 2-INCH RESEARCH COMBUSTOR