N74 10730
NASA CR-121271

MICROFOG LUBRICANT APPLICATION SYSTEM FOR ADVANCED TURBINE ENGINE COMPONENTS - PHASE III

by

R. J. Petrucco and S. J. Leonardi

MOBIL RESEARCH AND DEVELOPMENT CORPORATION

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
CONTRACT NO. NAS 3-16729
William R. Loomis, Project Manager

1. Report No. NASA CR-121271	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle MICROFOG LUBRICANT APPLICATION SYSTEM FOR ADVANCED TURBINE ENGINE COMPONENTS - PHASE III		5. Report Date July 30, 1973
		6. Performing Organization Code
7. Author(s) R. J. Petrucco and S. J. Leonardi		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Mobil Research and Development Corporation Research Department Paulsboro, New Jersey 08066		11. Contract or Grant No. NAS 3-16729
		13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

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NASA Lewis Research Center
Cleveland, Ohio

16. Abstract

The wetting characteristics and deposit forming tendencies of a series of lubricants were evaluated using a microfog jet delivery system to a flat heated rotating disc. The performances of the nine lubricants are discussed in terms of the various testing parameters which include temperature, disc speed and lubricant gas flow rates. Also discussed are the heat transfer characteristics of two of the lubricants on that same plane disc specimen. A brief evaluation of the wetting characteristics and heat transfer characteristics of one of the lubricants on a complex disc simulating bearing geometry is also discussed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Microfog Lubrication; advanced turbine lubrication; high-temperature lubricants; wettabilities of microfogs; heat transfer by microfogs.	Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	128	$3.00

* For sale by the National Technical Information Service, Springfield, Virginia 22151

NASA-C-168 (Rev. 6-71)

MICROFOG LUBRICANT APPLICATION SYSTEM FOR ADVANCED TURBINE ENGINE COMPONENTS - PHASE III

FINAL REPORT

by

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Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

July 31, 1973

CONTRACT NAS 3-16729

NASA Lewis Research Center
Cleveland, Ohio
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I. INTRODUCTION

Initial studies (1, 2) under NASA Contract NAS3-9400 developed techniques, including equipment design, for the evaluation of the wetting characteristics of five high temperature lubricants. For these studies, the wetting characteristics of these lubricants were measured using a static heated metal surface at temperatures ranging from 588°K to 700°K in an inert nitrogen atmosphere.

Later work (3, 4) developed additional information on the wettability and heat transfer capabilities of a series of high temperature lubricants using the heated surface of a plane metal disk under a variety of testing conditions, including different disc temperatures, disc angular velocities, and air flow rates through the mist system.

The present study had a two-fold purpose: first, to aid in the optimization of a mist system by providing additional basic information on the effects of key parameters, and second, to narrow the choice of a lubricant for an optimized mist system by screening promising fluids of different types. Primary emphasis was on the ability of a fluid pneumatically atomized by air to wet and cool a hot metallic surface, and resist the formation of deposits on the heated surface.

The program was comprised of three tasks:

Task I - An evaluation of the wetting characteristics and deposit forming tendencies of nine lubricants on a heated rotating disc in an air atmosphere. Testing parameters included the angular velocity of the disc (104 and 262 rad/s), chamber and disc temperature (533.3°K and 588.8°K) and air flow rate (1.17 x 10^{-3} m^3/s and 1.98 x 10^{-3} m^3/s).

Task II - Further testing of four lubricants, selected on the basis of results obtained in Task I, on the plane disc specimen. The testing conditions selected for this task included three disc temperatures (477.7°K, 533.3°K, and 588.8°K), three air flow rates (.769 x 10^{-3} m^3/s, 1.17 x 10^{-3} m^3/s, and 1.98 x 10^{-3} m^3/s) and two disc rotational velocities (104 and 262 rad/s). Also included in this task was an evaluation of the wetting characteristics of one of the above lubricants using a complex disc specimen, which simulated the geometry of a bearing.

Task III - An evaluation of the surface cooling capabilities of two of the fluids included in Task II, using the plane disc specimen under the same test conditions as Task II, and surface cooling studies using the complex disc specimen described under Task II.

The complete work statement of the present contract is attached as Appendix A.

II. SUMMARY AND CONCLUSIONS

Nine lubricants as microfogs, with air as the gas phase, were evaluated for their abilities to wet a heated rotating plane disc, and for their tendencies to form deposits on the heated disc, under a variety of conditions. Two of the nine fluids were subsequently evaluated for their surface cooling capabilities with the plane disc, and one fluid for its wetting and surface cooling of a complex disc which simulated bearing geometry. The nine fluids in the test program were:

1. XRM 205 F, a synthetic paraffinic hydrocarbon having a kinematic viscosity of 39×10^{-6} m^2/s at 372°K (39 cs at 210°F).

2. XRL 850 A, a paraffinic synthetic hydrocarbon having a kinematic viscosity of 6×10^{-6} m^2/s at 372°K (6 cs at 210°F).

3. XRL 850 A containing five wt % Kendall 0839 Heavy Paraffinic Resin.

4. XRM 232 A, an advanced type II ester fluid.

5. XRM 232 A containing 10 wt % Freon BF.

6. DN-600, a synthetic polyalkyl aromatic hydrocarbon fluid having a kinematic viscosity of 10×10^{-6} m^2/s at 372°K (10 cs at 210°F).

7. DN-600 containing five wt % Kendall 0839 Heavy Paraffinic Resin.

8. MCS-1370, a modified C-ether fluid having a kinematic viscosity of 3×10^{-6} m^2/s at 372°K (3 cs at 210°F).

9. A blend of polyglycol ethers containing 10 wt % distilled water and having a kinematic viscosity of approximately 43×10^{-6} m^2/s at 372°K (43 cs at 210°F).

A. Wettabilities of Test Fluids on Plane WB-49 Disc

Each of the nine fluids was evaluated for wettability at disc temperatures in the range of 477.7 to 588°K, disc angular velocity of 142 rad/s and/or 262 rad/s, and air flow rates in the range from 0.769×10^{-3} to 1.98×10^{-3} m^3/s through a pneumatically generated mist system. The wetting process was followed by means of high speed motion pictures. General trends noted were:

- Improved wettability (wetting rate and area wetted) as the air flow rate was increased.

- Decreased wettability with rising disc temperature.

The effect of increasing disc angular velocity was inconsistent, increasing the wettabilities of certain fluids at some conditions, but having negligible influence on other fluids.

Other conclusions were as follows:

- XRL 850 A, XRM 205 F, XRL 850 A + 5% Kendall 0839 resin, and XRM 232 A, in roughly that order, gave, overall, the highest wetting rates and largest fractions of disc area wetted.

- XRM 205 F had very outstanding wetting efficiency - i.e., a high ratio of wetting rate to rate of mist formation.

- The mist output of XRM 205 F was adversely affected by its high viscosity, but the negative effect of low mist output on wetting appeared to be offset by enhanced wetting brought about by high viscosity, or some property associated with high viscosity - e.g., low volatility.

- Wettabilities of MCS-1370 and the Ucon Fluid blend appeared to be adversely affected by erratic misting which, in turn, appeared to be caused by the high surface tensions of these fluids.

B. Deposit-Forming Tendencies of Test Fluids

The deposit-forming tendencies of the nine test fluids were evaluated on the plane WB-49 disc at disc temperatures of 533 and 588°K, a disc angular velocity of 262 rad/s, and air flow rates of 1.17×10^{-3} and 1.98×10^{-3} m^3/s.

Test results led to the following observations and conclusions:

- Deposit formation in thirty minutes by six of the nine test fluids fell within the range of very light to moderate. Overall, XRM 232 A was the cleanest fluid, with five others grouped closely behind. The most severe deposits were formed by XRM 205 F, and by DN-600 with and without Kendall 0839 resin.

- The severity of deposits increased, as expected, with rising temperature.
- Deposit severity decreased with increasing air flow rate, a phenomenon attributed to the increased film thickness and shortened residence time of the test fluid on the disc at the higher oil flows produced by the higher air flows.

C. Surface Cooling Effects on Plane Disc

Surface cooling studies on the plane disc were conducted using XRM 232A and XRL 850A lubricants. These two fluids had given the best overall performance in the wettability and deposit-forming studies. Test run conditions included initial disc temperatures of 477.7 to 588.8°K, disc angular velocities of 104 and 262 rad/s, and air flow rates from 0.769×10^{-3} to 1.98×10^{-3} m^3/s, with a constant input of thermal energy to the disc. Results and conclusions were as follows:

- Air in the microfog streams has the major cooling effect, while that of the oil is minor.
- Air alone under the above test conditions produced disc temperature declines ranging from 32 to 92°K.
- Net disc temperature declines due to the presence of KRL 850 A or XRM 232 A in the microfog streams ranged from 0 to 11.2°K.
- No significant differences in the cooling effects of the two lubricants were evident.
- Larger disc temperature drops were measured with increasing air flow rate.
- Larger drops in disc temperature were measured as the initial disc temperature was elevated.
- The angular velocity of the disc had little effect on the size of the disc temperature decline.

D. Wettability Studies on Complex Disc Simulating Bearing Geometry

A complex disc having features which simulated the inner race, cage and outer race of a bearing, was employed to determine whether lubricant impinging as a microfog against the "inner race" could be effectively distributed via the perforated "cage" to "outer race". The test oil in this study series was XRM 232A, the advanced type II ester.

The absence of stray mist usually seen in the test chamber indicated that the efficiency of oil particle collection on the complex disc was higher than on the plane disc. This is attributable in part to closer proximity of the reclassifying nozzle to the complex disc but may also be due to other geometrical factors.

Inspection of high speed films appeared to reveal oil droplets being ejected from the "cage" to the "outer race", and inspection after the test run revealed an oil film on the "outer race".

E. Surface Cooling Studies with Complex Disc

Surface cooling studies of the complex disc, with XRM 232 A as microfog lubricant, revealed the same general trends observed with the plane disc.

The cooling effect of the oil was minor relative to that of the air.

Microfog streams produced significantly larger disc temperature drops with the complex disc than with the plane, suggesting improved contact between the complex surface and the air/oil stream.

III. DETAILED REPORT

A. Materials

The nine lubricants tested in the present contract are:

1. XRM 205 F - Experimental viscous synthetic paraffinic hydrocarbon formulated against oxidation and wear.

2. XRL 850 A - Experimental synthetic paraffinic hydrocarbon formulated against oxidation and wear.

3. XRL 850 A containing five weight percent Kendall 0839 Paraffinic Heavy Resin.

4. Conoco DN-600 - Formulated type II polyalkyl aromatic hydrocarbon.

5. Conoco DN-600 containing five weight percent Kendall 0839 Paraffinic Heavy Resin.

6. Monsanto MCS-1370 - Experimental modified C-ether fluid.

7. XRM 232 A - Experimental advanced type II ester fluid.

8. XRM 232 A containing ten weight percent Freon BF (CCl_2F-CCl_2F).

9. Blend of Union Carbide Ucon 50 HB polyglycol ether fluids containing ten weight percent water, blended to attain a final viscosity of 43.5×10^{-6} m^2/s at 372°K. The blend used had the following composition:

Blend G-10

Component	Wt %
Ucon 50 HB 5100	39.0
Ucon 50 HB 400	51.0
Distilled Water	10.0

Physical properties and additional identifying information for the above nine fluids are listed in Appendix B-1.

For test runs requiring the plane disc specimen, the wetted surface was provided by a circular plate 10.1 cm in diameter and 0.63 cm thick (Figure 1). The disc was manufactured from WB-49 case hardened CVM material and finished to a smooth surface by circumferentially grinding it to 4 to 8 microinches (1×10^{-7} to 2×10^{-7} m) RMS. A freshly ground disc was used for each run.

The complex ("stepped") disc (Figure 2) was fabricated of types 416 and 302 stainless steel, and was solvent cleaned using naphtha and acetone after each run.

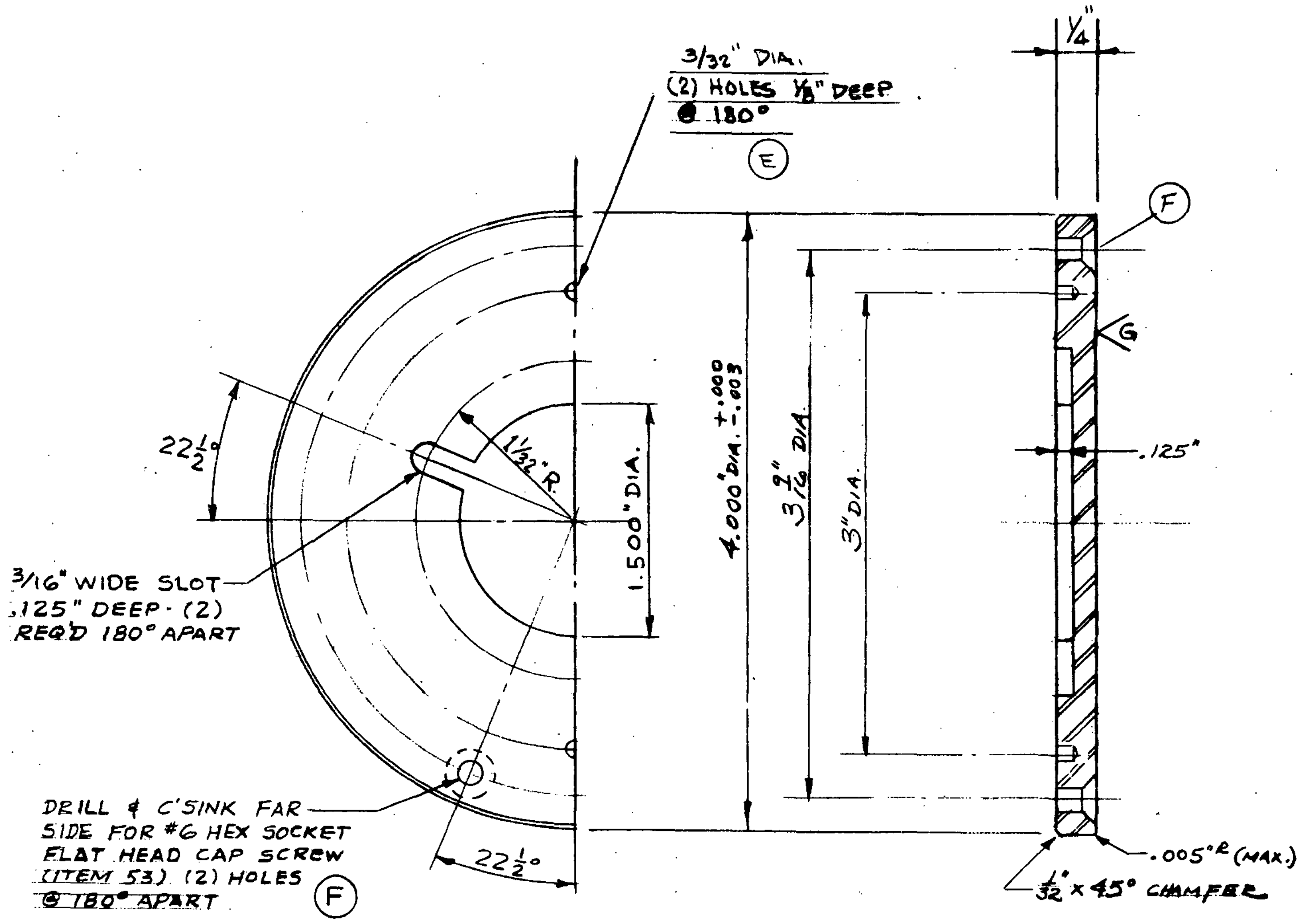
The reclassifying nozzle (Figure 3) and the oil delivery system used with the plane disc were described previously (4). An engineering drawing of the modified reclassifying nozzle and delivery system used for the studies involving the complex disc is shown in Figure 4. The nozzle for the complex disc was modified only in its external geometry to allow closer proximity to the disc.

In all studies, the misting gas was dried and purified high pressure house air.

B. Apparatus and Procedure

The basic apparatus used for the wetting rate determinations has been described previously (3, 4). Several modifications of the unit described were required by the terms of the present contract. Piping changes were made to allow for use of purified, dried, high pressure house air in place of nitrogen previously employed as the misting and aerosol carrier gas. Also, because of the large volume of air required for the 30-minute deposit runs, additional heating capacity was required to maintain the air at 366°K for the duration of the tests. This was accomplished by installation of a Chromalox series 2100 circulation air heater. Control valves were also installed to equalize the pressure of air exhausted from the test chamber and from the generator. This was required for the heat transfer studies in order to insure that the mass flow of air directed to the disc during line-out was identical to that in the microfog stream directed to the disc when the solenoid was actuated, switching the air from disc to exhaust, and air/oil mist from exhaust to disc. Thus any temperature change measured was due to the cooling effect of the oil alone.

FIGURE 1



ITEM (7) SPECIMEN PLATE

TOOL STEEL #W849 VACUUM MELT

FURNISHED BY VENDOR

FIGURE 2

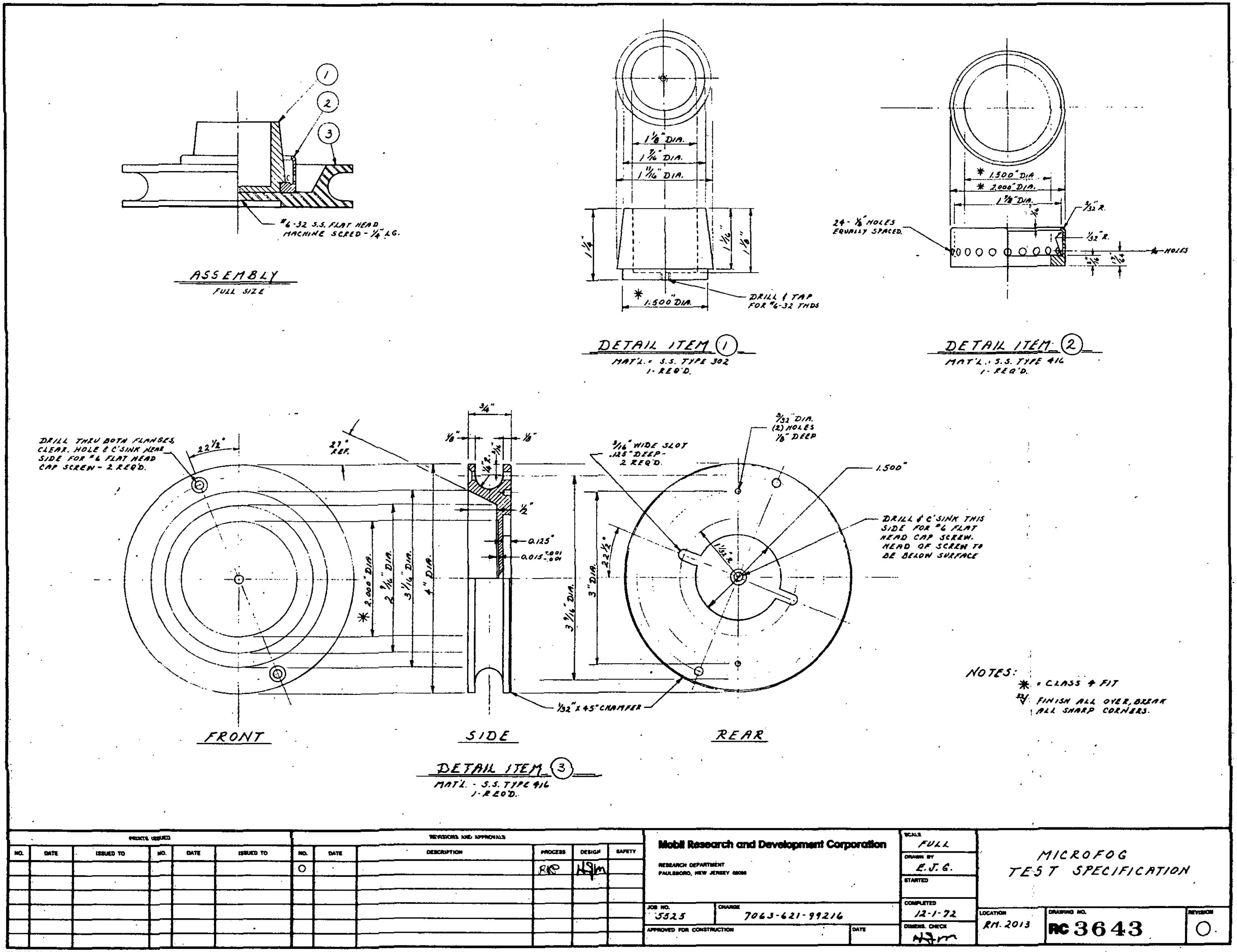

ASSEMBLY
FULL SIZE
#6-32 S.S. FLAT HEAD MACHINE SCRED - 1/4" LG.
DETAIL ITEM 1
MAT'L. - S.S. TYPE 302
1 - REQ'D.
1 1/8" DIA.
1 9/16" DIA.
1 11/16" DIA.
1.500" DIA.
DRILL & TAP FOR #6-32 THDS
DETAIL ITEM 2
MAT'L. - S.S. TYPE 416
1 - REQ'D.
24 - 1/8" HOLES EQUALLY SPACED.
* 1.500" DIA.
* 2.000" DIA.
1 7/8" DIA.
3/32" R.
1/32" R.
DRILL THRU BOTH FLANGES, CLEAR. HOLE & C'SINK NEAR SIDE FOR #6 FLAT HEAD CAP SCREW - 2 REQ'D.
22 1/2°
27° REF.
* 2.000" DIA.
2 9/16" DIA.
3 1/16" DIA.
4" DIA.
3/4"
1/8"
1/2"
0.125"
1/32" X 45° CHAMFER
3 9/16" DIA.
3" DIA.
3/16" WIDE SLOT .125" DEEP - 2 REQ'D.
3/32" DIA. (2) HOLES 1/8" DEEP
1.500"
DRILL & C'SINK THIS SIDE FOR #6 FLAT HEAD CAP SCREW. HEAD OF SCREW TO BE BELOW SURFACE
FRONT
SIDE
REAR
DETAIL ITEM 3
MAT'L. - S.S. TYPE 416
1 - REQ'D.
NOTES:
* = CLASS 4 FIT
FINISH ALL OVER, BREAK ALL SHARP CORNERS.
PRINTS ISSUED
REVISIONS AND APPROVALS
Mobil Research and Development Corporation
RESEARCH DEPARTMENT
PAULSBORO, NEW JERSEY 08066
SCALE FULL
DRAWN BY E.J.G.
COMPLETED 12-1-72
JOB NO. 5525
CHARGE 7063-621-99216
APPROVED FOR CONSTRUCTION
MICROFOG
TEST SPECIFICATION
LOCATION RM. 2013
DRAWING NO. RC 3643
REVISION O

FIGURE 5

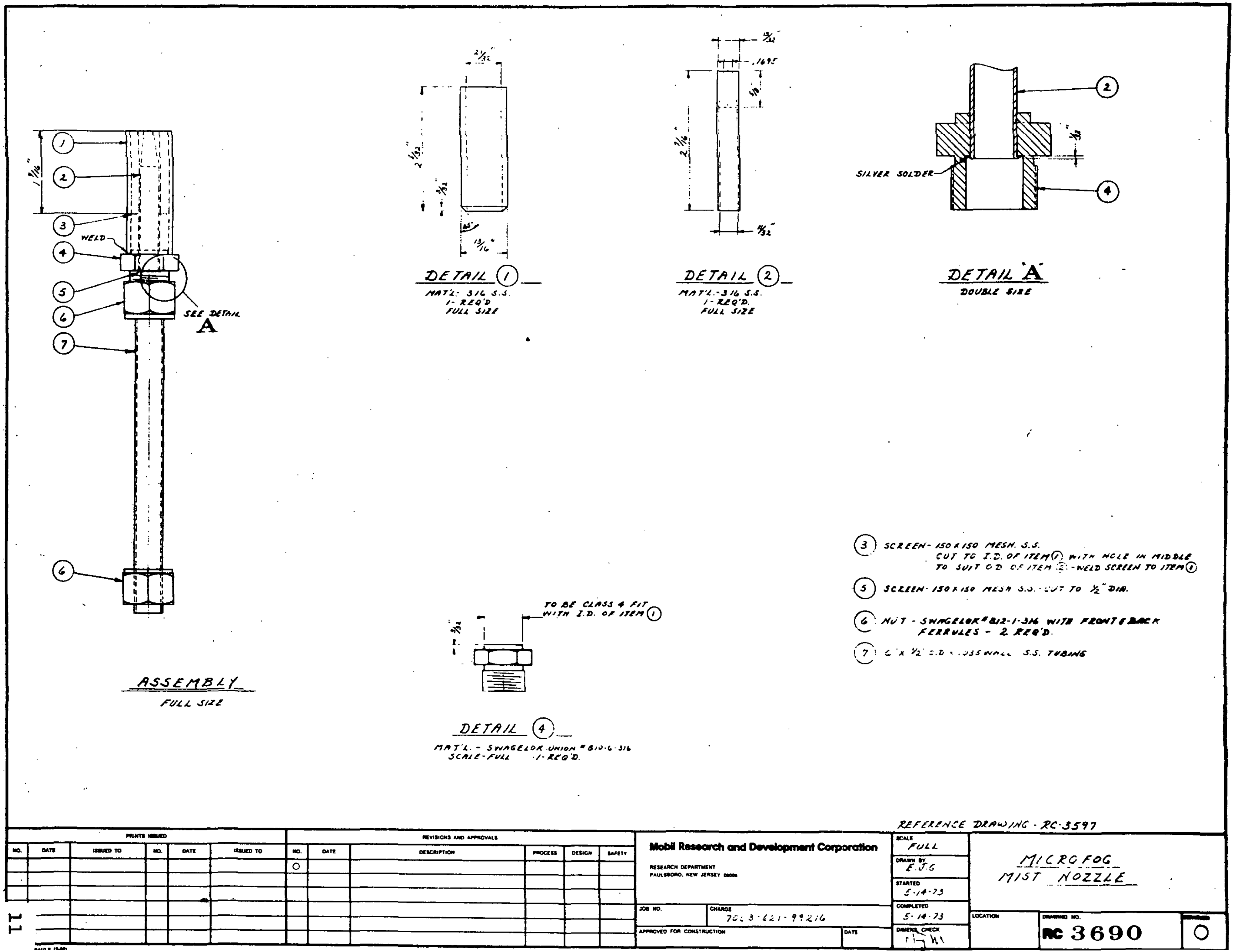
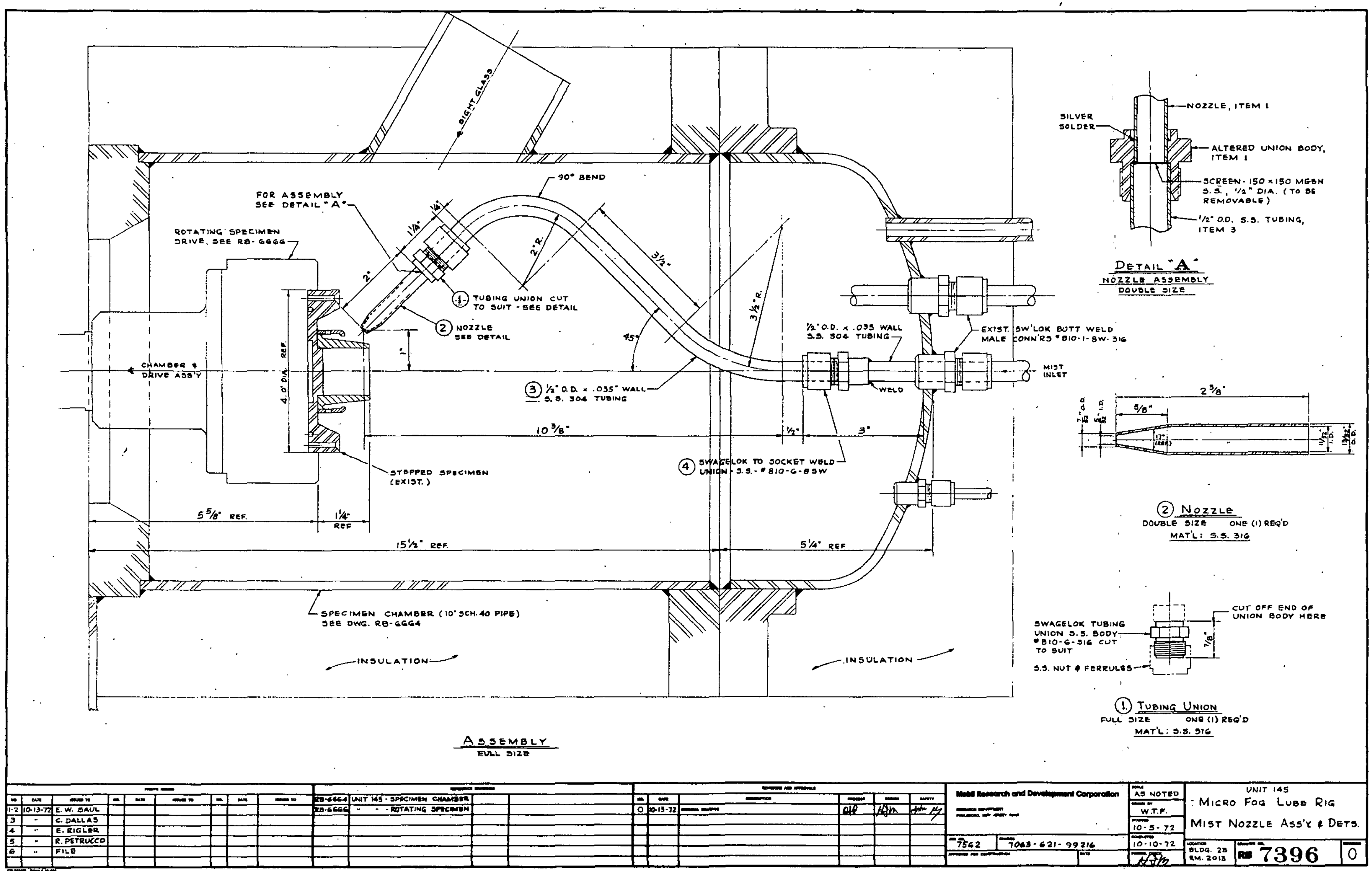

ASSEMBLY
FULL SIZE
WELD
SEE DETAIL A
DETAIL 1
MAT'L: 316 S.S.
1- REQ'D
FULL SIZE
DETAIL 2
MAT'L: 316 S.S.
1- REQ'D.
FULL SIZE
.1695
DETAIL 'A'
DOUBLE SIZE
SILVER SOLDER
DETAIL 4
MAT'L. - SWAGELOK UNION # 810-6-316
SCALE-FULL 1- REQ'D.
TO BE CLASS 4 FIT WITH I.D. OF ITEM 1
3 SCREEN - 150 X 150 MESH. S.S. CUT TO I.D. OF ITEM 1 WITH HOLE IN MIDDLE TO SUIT O.D. OF ITEM 2 - WELD SCREEN TO ITEM 1
5 SCREEN - 150 X 150 MESH S.S. CUT TO ½" DIA.
6 NUT - SWAGELOK # 812-1-316 WITH FRONT & BACK FERRULES - 2 REQ'D.
REFERENCE DRAWING - RC-3597
PRINTS ISSUED
REVISIONS AND APPROVALS
Mobil Research and Development Corporation
RESEARCH DEPARTMENT
PAULSBORO, NEW JERSEY
SCALE FULL
DRAWN BY E.J.G
STARTED 5-14-73
COMPLETED 5-14-73
MICRO FOG
MIST NOZZLE
DRAWING NO.
RC 3690

FIGURE 4



SIGHT GLASS
90° BEND
FOR ASSEMBLY SEE DETAIL "A"
ROTATING SPECIMEN DRIVE, SEE RB-6666
CHAMBER & DRIVE ASS'Y
4.0" DIA. REF.
1 TUBING UNION CUT TO SUIT - SEE DETAIL
2 NOZZLE SEE DETAIL
3 ½" O.D. x .035" WALL S.S. 304 TUBING
½" O.D. x .035 WALL S.S. 304 TUBING
EXIST. SW'LOK BUTT WELD MALE CONN'RS #810-1-8W-316
MIST INLET
WELD
4 SWAGELOK TO SOCKET WELD UNION - S.S. - #810-6-8SW
STEPPED SPECIMEN (EXIST.)
5⅝" REF.
1¼" REF
15½" REF.
5¼" REF
10⅜"
SPECIMEN CHAMBER (10" SCH. 40 PIPE) SEE DWG. RB-6664
INSULATION
ASSEMBLY
FULL SIZE
SILVER SOLDER
NOZZLE, ITEM 1
ALTERED UNION BODY, ITEM 1
SCREEN - 150 x 150 MESH S.S., ½" DIA. (TO BE REMOVABLE)
½" O.D. S.S. TUBING, ITEM 3
DETAIL "A"
NOZZLE ASSEMBLY
DOUBLE SIZE
2⅜"
5/8"
2 NOZZLE
DOUBLE SIZE ONE (1) REQ'D
MAT'L: S.S. 316
CUT OFF END OF UNION BODY HERE
SWAGELOK TUBING UNION S.S. BODY #810-6-316 CUT TO SUIT
S.S. NUT & FERRULES
7/8"
1 TUBING UNION
FULL SIZE ONE (1) REQ'D
MAT'L: S.S. 316
1-2 10-13-72 E. W. SAUL
3 C. DALLAS
4 E. RIGLER
5 R. PETRUCCO
6 FILE
RB-6664 UNIT 145 - SPECIMEN CHAMBER
RB-6666 - - ROTATING SPECIMEN
0 10-13-72
Mobil Research and Development Corporation
AS NOTED
W.T.F.
10-5-72
10-10-72
7562
7063-621-99216
UNIT 145
MICRO FOG LUBE RIG
MIST NOZZLE ASS'Y & DETS.
BLDG. 28 RM. 2013
RB 7396
0

An engineering drawing of the modified unit is contained in Figure 5. The major electronic component added to the existing unit was the substitution of an ECS Model 7627 temperature controller for the disc.

A final modification in the existing unit was the enlargement of the orifices in the two-holed misting head from 0.226 cm to 0.366 cm in diameter. This misting head, which was used in all of the current work, allowed air to pass through the microfog generator at a lower pressure.

1. Wetting Rate Measurements - Plane Disc Specimen

Task I - the wetting rates of the nine test fluids were measured under the following conditions:

Temp, °K	Disc Velocity, rad/s	Air Flow Rates $(m^3/s) \times 10^3$
533.3	104	1.17
533.3	262	1.17
588.8	104	1.98
588.8	262	1.98

Task II - based on the results of Task I, four oils, XRL 850 A, XRL 850 A + Kendall 0839 paraffinic resin, XRM 232 A, and XRM 205 F, were selected for additional wetting rate measurements using the following conditions:

Temp, °K	Disc Velocity, rad/s	Air Flow Rates $(m^3/s) \times 10^3$
477.7	104	0.769
477.7	262	0.769
477.7	104	1.17
477.7	262	1.17
477.7	104	1.98
477.7	262	1.98
533.3	104	0.769
533.3	262	0.769
588.8	104	0.769
588.8	262	1.98

In each case the wetting characteristics of the fluid under test were determined by means of high speed photography, using a Hycam high speed motion picture camera operating at 800 frames/sec with a 25 mm f/2.8 lens. The geometry of the test chamber, camera placement, and lighting were the same as in earlier reports (3, 4).

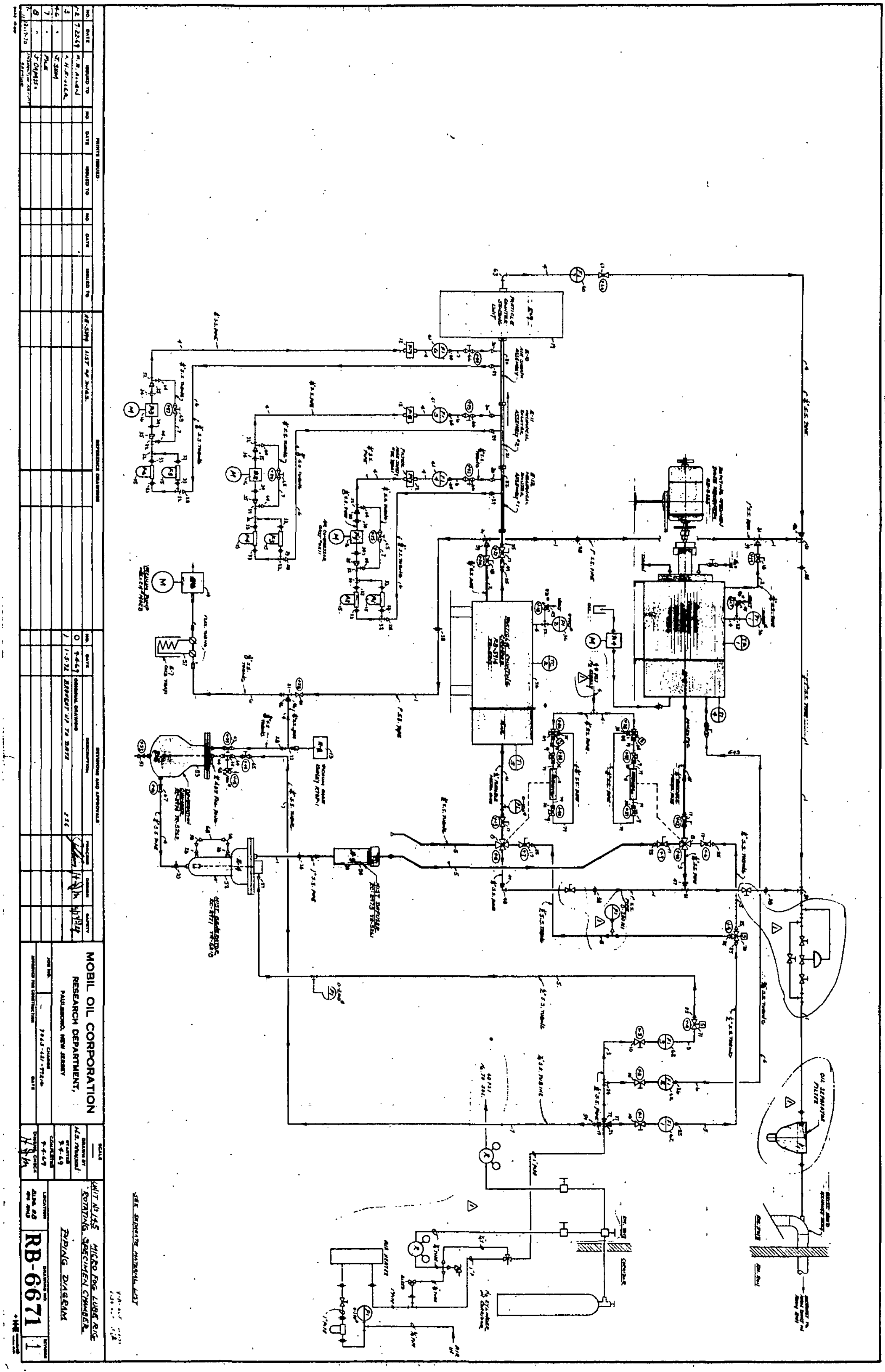

MOBIL OIL CORPORATION
RESEARCH DEPARTMENT,
PAULSBORO, NEW JERSEY
UNIT NO 145 MICRO FOG LUBE RIG
"ROTATING SPECIMEN CHAMBER"
PIPING DIAGRAM
RB-6671
1

FIGURE 5

To begin a typical wetting run measurement, the test chamber was heated to the desired test temperature while the oil reservoir and mist generator were held at a constant temperature of 366.4°K for all measurements. Cooling water is started circulating through the water jacket. Once the test chamber, oil reservoir and air temperature were stabilized, the cleaned plane disc specimen was inserted and fastened to the rotating head. Finally, the reclassifying nozzle was locked in place and the test chamber closed. The disc was then brought to the desired temperature while rotating at the rate required for that specific test with a flow of 0.5×10^{-3} m^3/s of heated (366.4°K) air to the test chamber. When run conditions were reached and stabilized, flow of heated air through the generator and to the exhaust was initiated. When test parameters were stabilized, the plane disc was illuminated as in previous work and the high speed Hycam camera was activated. A programmed time delay of 1.5 seconds was employed in order to allowthe film speed to accelerate and attain a constant filming speed of 800 frames per second. After the 1.5 second period, a relay switch was automatically activated which diverted the chamber air stream to the exhaust and the microfog mist coming from the generator to the plane disc. At the end of twenty seconds, when the entire roll of film was exposed, the wetting run was terminated.

It should be pointed out that during the wetting and deposit runs involving the plane disc, the ECS controller was employed using the automatic control mode. Thus heat was transmitted to the disc as required to maintain it at a constant temperature.

Between wetting runs, a freshly ground and cleaned disc was installed. Also, the spray nozzle and oil delivery line were removed, solvent cleaned, and replaced.

2. <u>Deposit Studies - Plane Disc Specimen</u>

Deposit studies were conducted using the same conditions as in Task I. A procedure identical to that used for the wetting runs was employed with one exception: Whereas wetting runs were completed in twenty seconds, tests for deposit formation were continued for thirty minutes.

To compare the oils, a deposit rating scale was established (Table 1). The numerical rating scale is based on the type (thickness) of deposit and the area covered. A demerit factor is assigned for each type of deposit, and this factor is multiplied by the fraction of area covered by that deposit. The demerits for the entire disc are then summed, and that total is subtracted

Table 1

DEMERIT SCALE FOR MICROFOG RIG DISC DEPOSITS*

Demerit Factor	Deposit Description	General Description
3	Faint Iridescence	
6	Iridescence or Faint Yellow	Very Light
9	Dark Iridescence or Pale Yellow, Highly Transparent	
12	Yellow (Gold), Highly Transparent	Light
16	Dark Yellow, or Orange, or Gray, Highly Transparent	
20	Yellow-Brown or Light Brown, Highly Transparent	
25	Brown, Highly Transparent	Medium
33	Brown, or Brown-Black, or Brown and Black, Transparent	
42	Brown, or Brown-Black, or Brown and Black, Very Little Transparency	
50	(1) Black or Brown, Opaque, Smooth, or (2) Shallow Carbon Streaks, Very Sparse	Heavy
58	Shallow Carbon Streaks, Sparse	
66	Carbon Streaks of Medium Depth, Very Sparse	
75	(1) Black or Brown, Opaque, Somewhat Rough, or (2) Deep Carbon Streaks, Very Sparse, or (3) Shallow Carbon Streaks, Moderately Dense, or (4) Carbon Streaks of Medium Depth, Sparse	
83	(1) Shallow Carbon Streaks, Dense, or (2) Carbon Streaks of Medium Depth, Moderately Dense, or (3) Deep Carbon Streaks, Sparse	
91	(1) Deep Carbon Streaks, Moderately Dense, or (2) Carbon Streaks of Medium Depth, Dense	
100	(1) Black or Brown, Opaque, Quite Rough, or (2) Deep Carbon Streaks, Dense	Very Heavy

*The fraction of the disc area covered by each type of deposit is measured and multiplied by the appropriate demerit factor. The sum of those products is subtracted from 100 to obtain a cleanliness rating.

from a rating of one hundred, which corresponds to a perfectly clean disc. This demerit rating system is based on years of experience with thin film oxidation (TFO) techniques for screening synthetic high temperature lubricants (5).

3. Heat Transfer Studies - Plane and Complex Discs

For heat transfer tests with both the plane and complex discs, the test chamber was heated to the appropriate testing temperature with the misting gas and oil reservoir held at a constant temperature of 366.4°K as with the wetting runs. The plane disc was placed in position and rotated at the appropriate rotating speed. The disc was then heated to temperature with a stream of pure air, equivalent to air in the air/oil mist to be used in the test, passing through the nozzle onto the disc. Concurrently, heated air, at an equivalent flow rate, was passed through the microfog generator to the exhaust. When equilibrium test conditions were established, the solenoid was activated, switching the microfog stream to the disc surface and the pure air to the exhaust. The consequent temperature drop, due to the oil only, was determined as a measure of the cooling ability of the oil. For the heat transfer studies, the ECS controller was used in the manual mode, i.e., with a fixed input of energy. Thus a cooling effect could be observed due to the addition of the oil.

Additional studies were also conducted to establish the cooling effect of air alone. To obtain this information, the chamber was heated to the appropriate temperature. Heated air (366.4°K) was circulated to the exhaust. The disc was inserted into the heated chamber and heated to the test temperature while rotating. When equilibrium conditions were established, the flow of air was directed toward the heated disc and the temperature decrease over a ten-minute period was recorded.

C. Results and Discussion

In general, to simplify discussion, total results and trends pertinent to a particular topic will be considered without discussing each table or graph in detail. Data used to illustrate trends will be tabulated in this section, and all test data appear in Appendices C to F.

1. Wetting Characteristics and Deposit-Forming Tendencies of Test Fluids on Plane Disc

a. XRM 205 F (Vicsous Synthetic Paraffinic Hydrocarbon)

The wetting characteristics of XRM 205 F on the plane disc are depicted graphically in Figures 6 through 11. The data are summarized in Table 2, and complete wetting data for all fluids are reported in Appendix C.

Figure 6

WETTING CHARACTERISTICS OF XRM 205F ON PLANE DISC

477.7°K, 104 rad/s

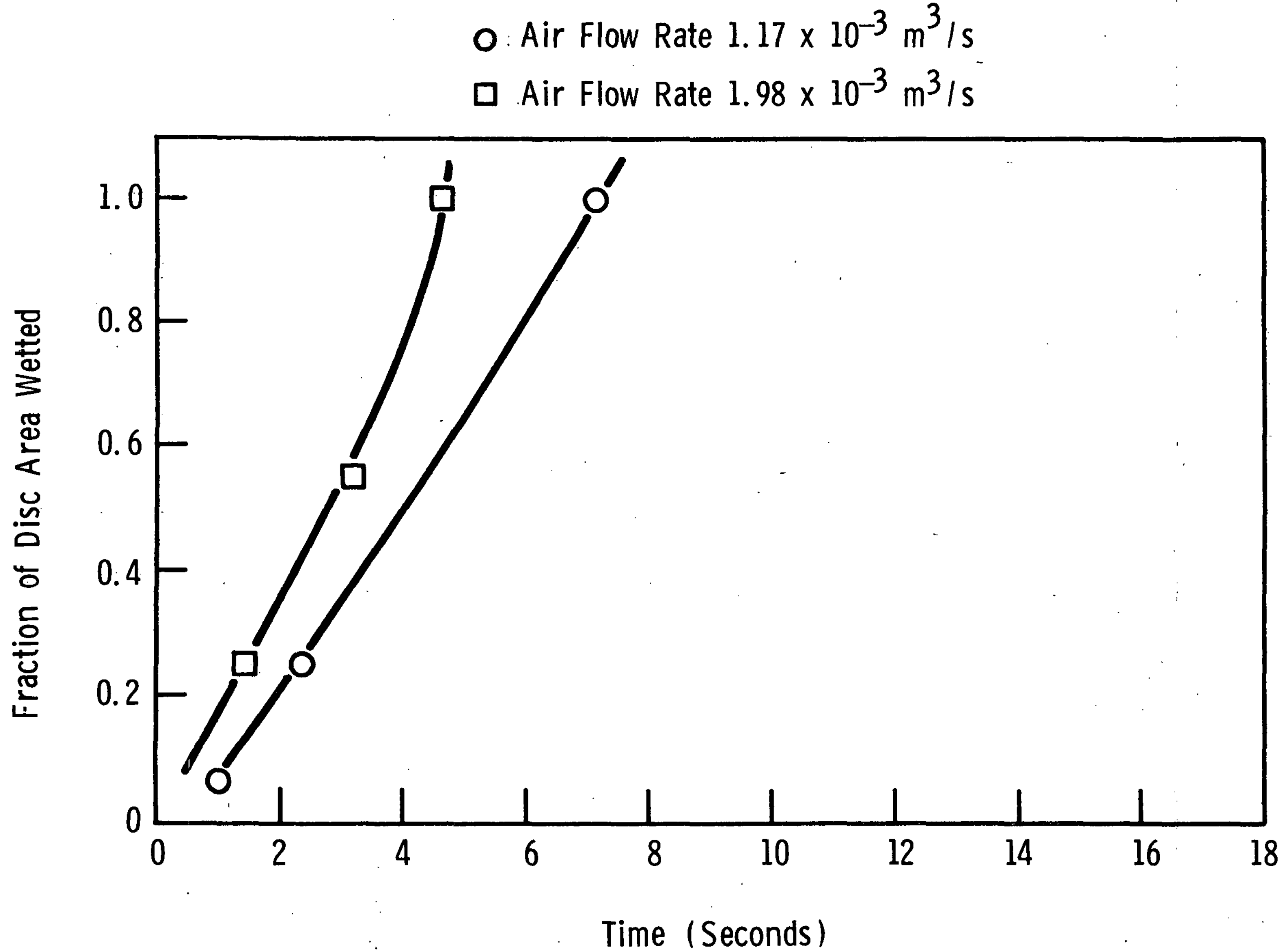


Figure 7

WETTING CHARACTERISTICS OF XRM 205F ON PLANE DISC

477°K, 262 rad/s

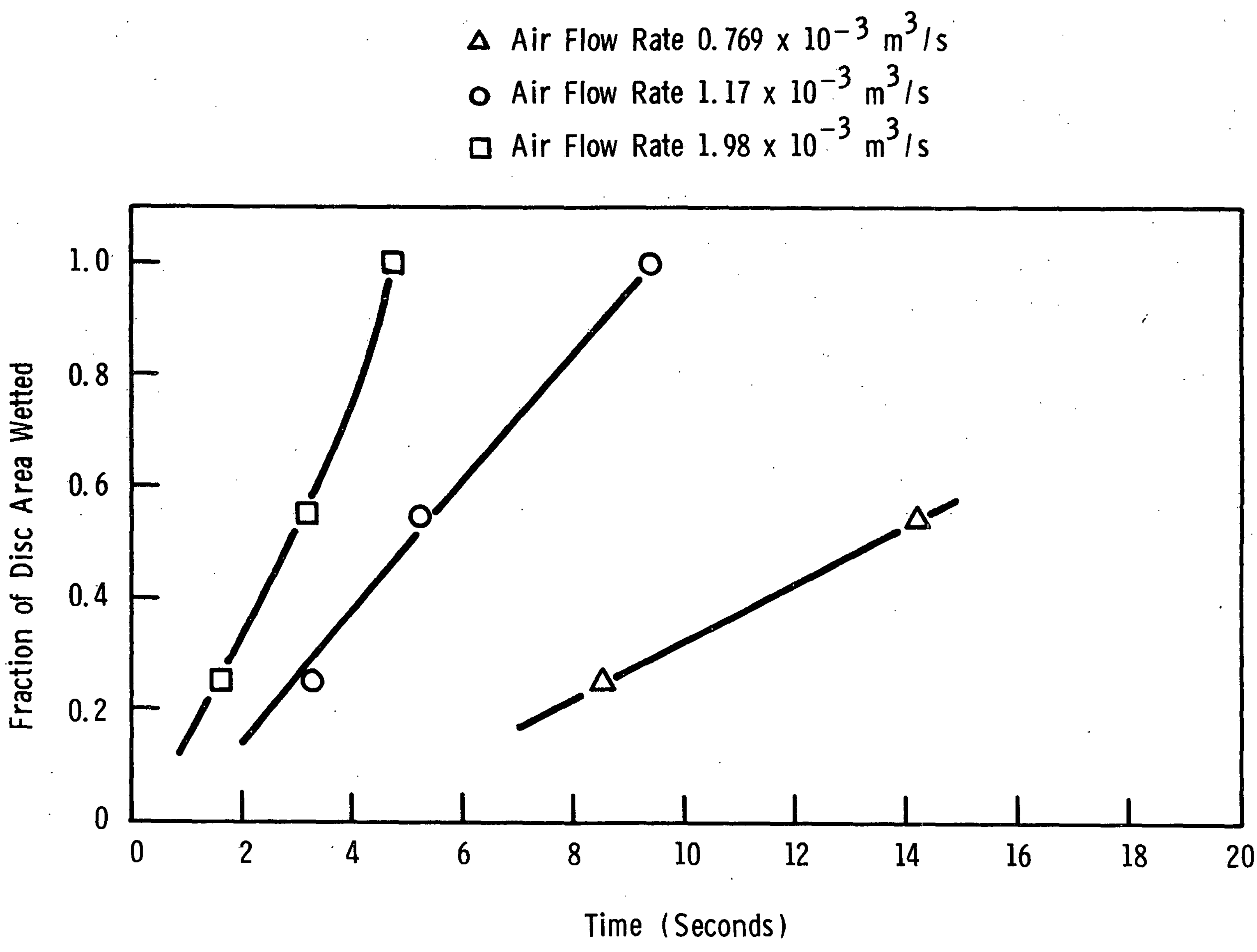


Figure 8

WETTING CHARACTERISTICS OF XRM 205F ON PLANE DISC

533°K, 104 rad/s

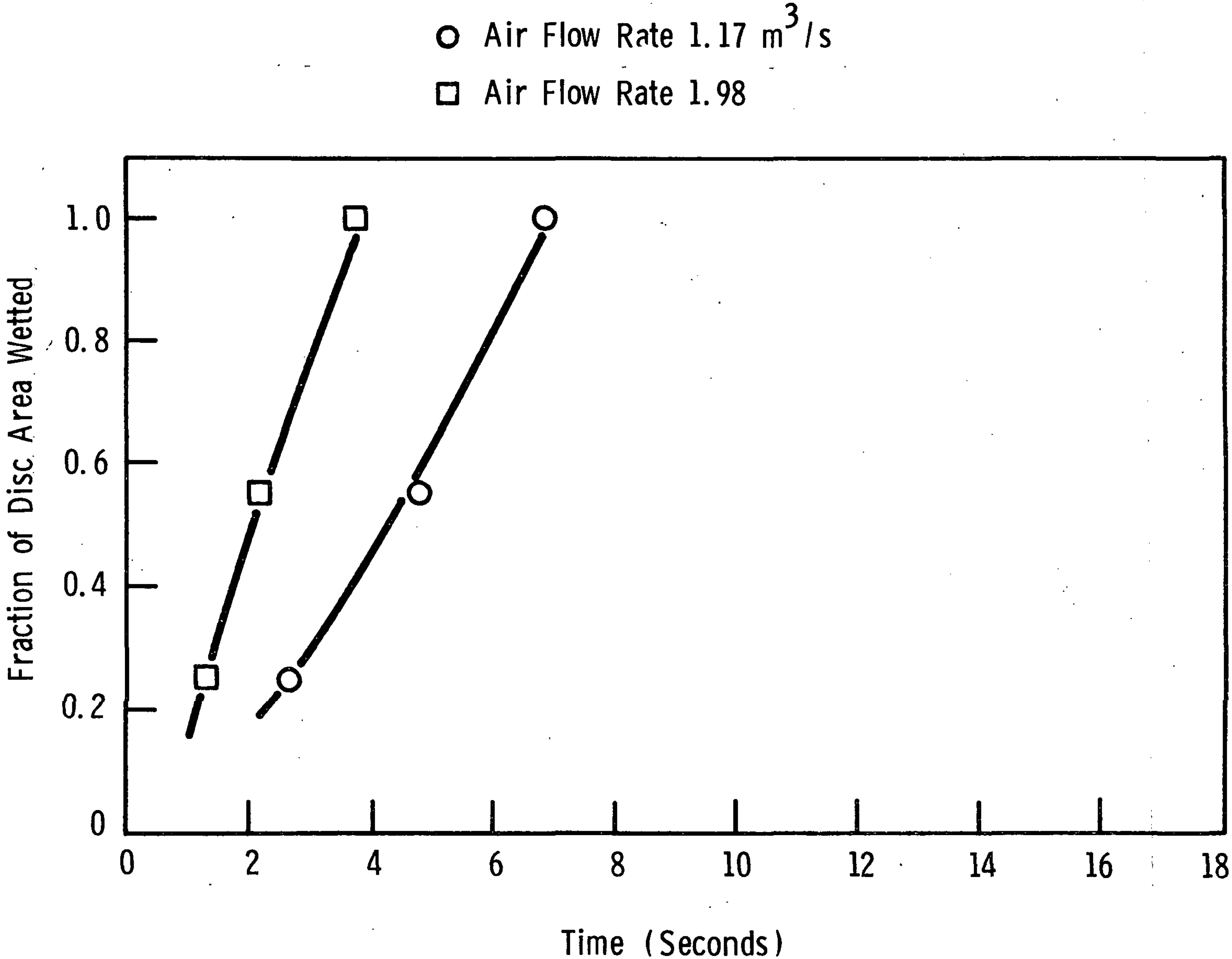


Figure 9

WETTING CHARACTERISTICS OF XRM 205F ON PLANE DISC

533.3°K, 262 rad/s

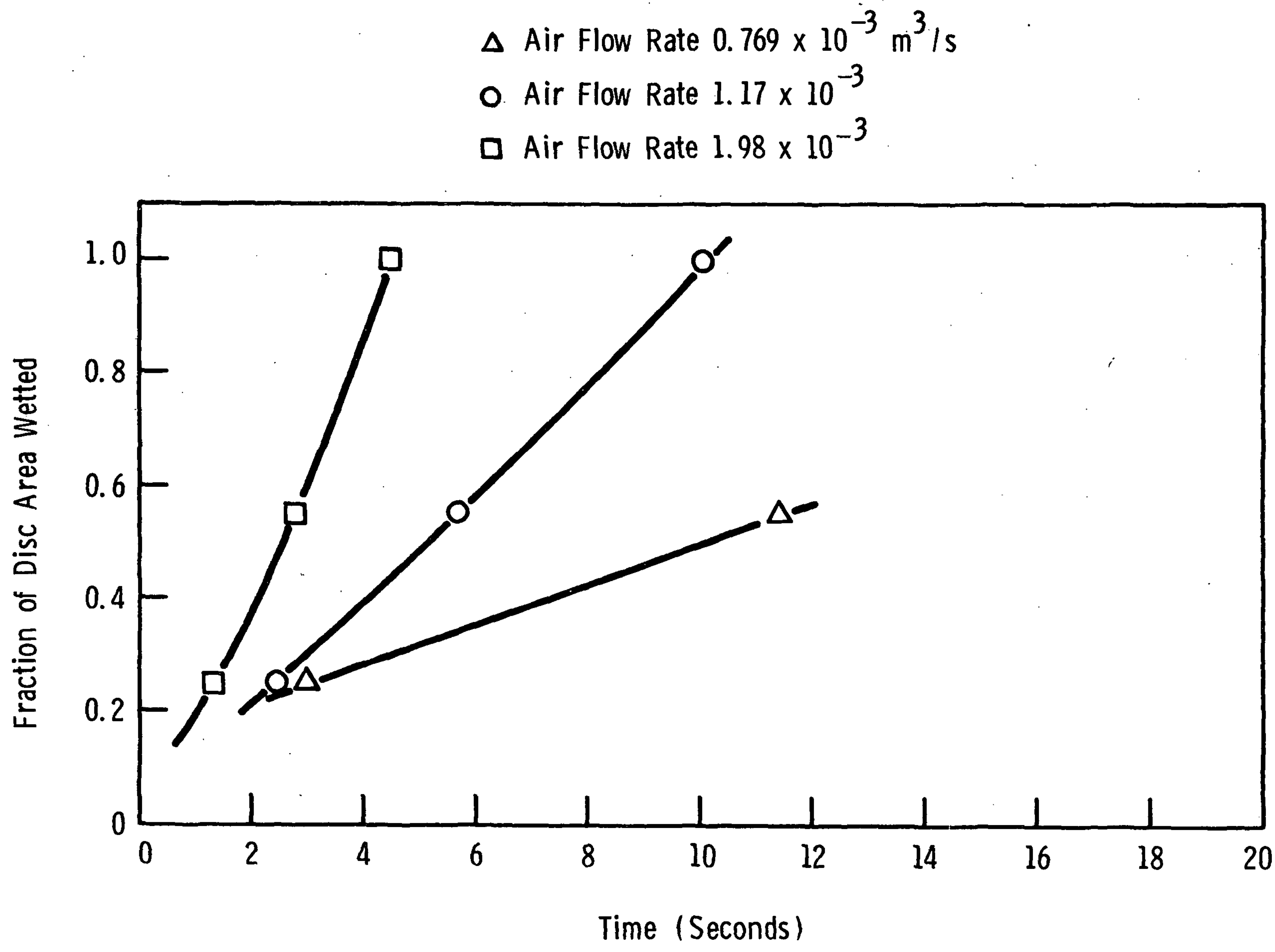


Figure 10

WETTING CHARACTERISTICS OF XRM 205F ON PLANE DISC

588.8°K, 104 rad/s

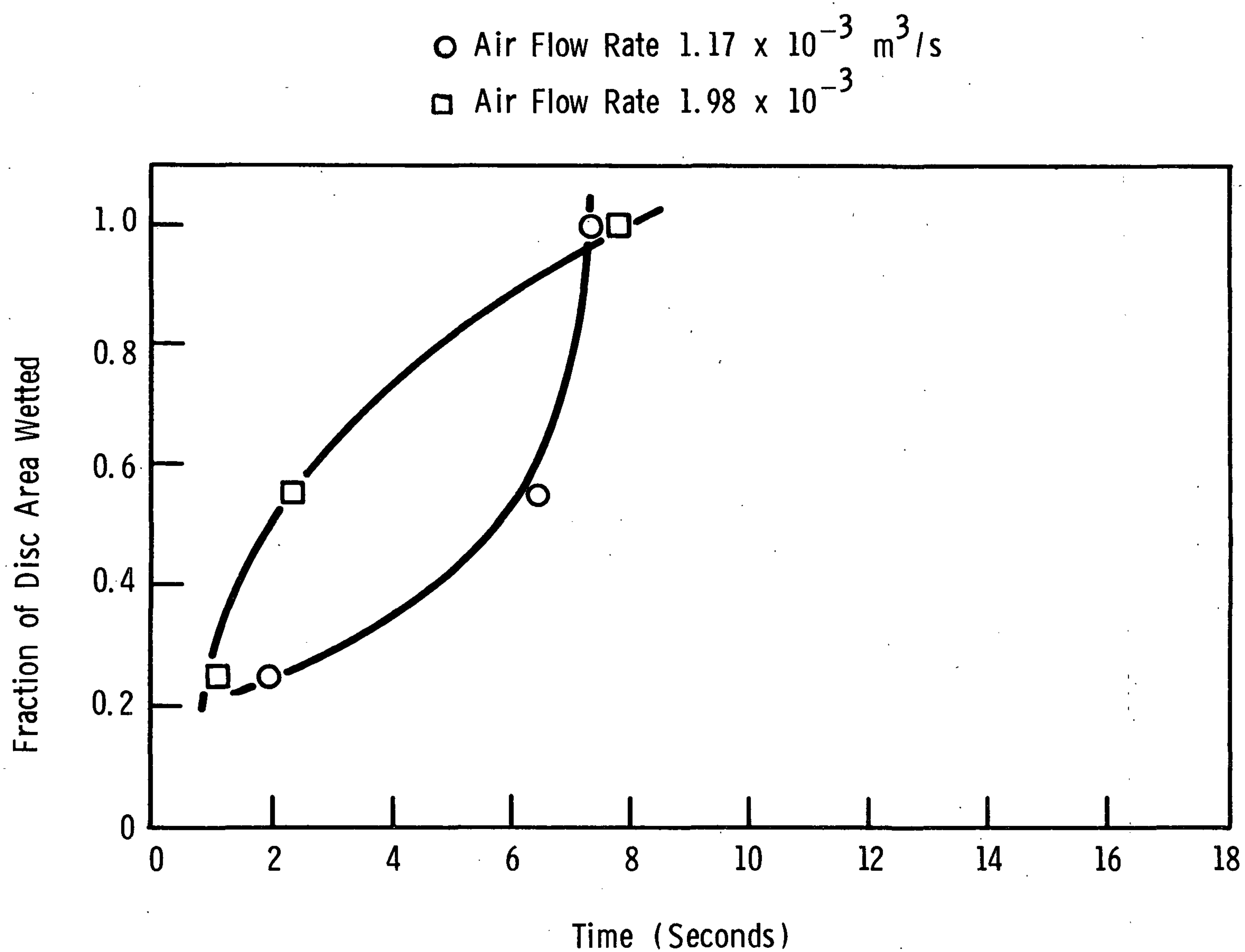


Figure 11

WETTING CHARACTERISTICS OF XRM 205F ON PLANE DISC

588.8°K, 262 rad/s

△ Air Flow Rate 0.769×10^{-3} m^3/s

○ Air Flow Rate 1.17×10^{-3}

□ Air Flow Rate 1.98×10^{-3}

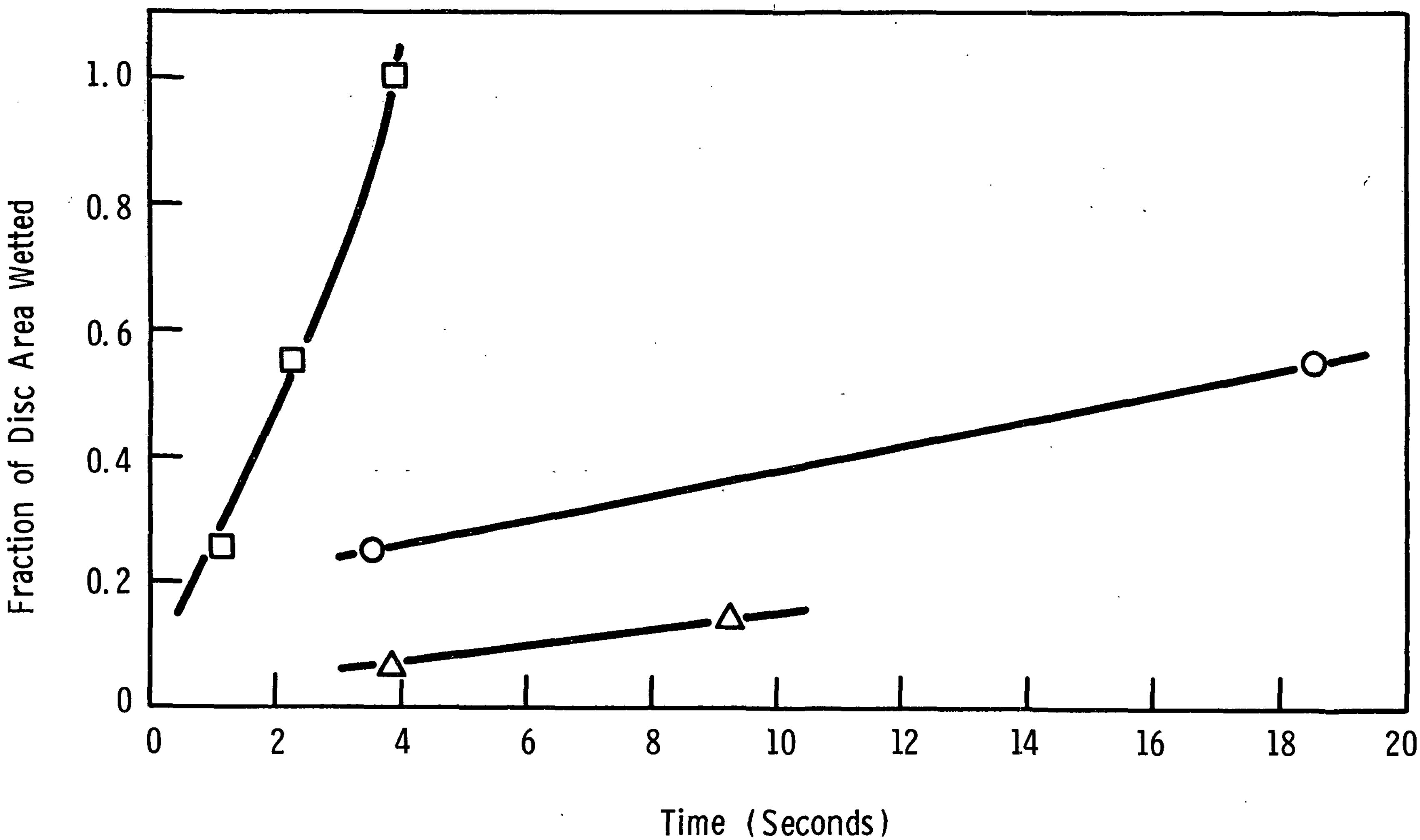


Table 2

Wetting and Deposit Data for XRM 205 F on Plane Disc

Temperature (°K)	477.7	533.3	588.8	477.7	533.3	588.8	477.7	533.3	588.8
Air Flow Rate, (m^3/s) x 10^3 (1)	0.769	0.769	0.769	1.17	1.17	1.17	1.98	1.98	1.98
Wetting Rate, cm^2/s at 104 rad/s	(2)	(2)	(2)	11.33	9.72	7.31	19.02	24.7	10.5
Area Wetted, at 104 rad/s	< 10%	< 10%	< 10%	100	100	55	100	100	100
Wetting Rate, cm^2/s at 262 rad/s	5.13	3.60	1.15	9.24	7.98	2.32	18.7	19.7	21.6
Area Wetted, at 262 rad/s	55	55	14	100	100	55	100	100	100
Oil Consumption, cm^3/s	0.004	0.004	0.004	.0165	.0165	.0165	.042	.042	.042
Cleanliness Rating at 262 rad/s					60	37		74	47

(1) at 366°K and 41 N/m^2.
(2) could not be calculated because of small area wetted.

For XRM 205 F, no wetting rate measurements could be made at the poorest wetting conditions of minimum air flow (0.769 x 10^{-3} m^3/s) and the slowest disc speed (1000 RPM) because the wetted area was too small. The general trends observed in analyzing Figures 6-11 and the data summary are that the wettability of XRM 205 F

- improved with increasing air flow rate,
- improved with increasing disc RPM.

At the highest air flow rate and disc RPM, the increase in temperature had little effect on the wetting rate. The poor wetting at the lowest air flow rate probably is explained by the extremely small amount of oil misted (.004 cm^3/s).

Table 2 also contains data on deposit formation by XRM 205 F, while Appendix D includes all deposit data for all test fluids. The effects of increasing test temperature and air flow rate on the deposit forming tendencies of XRM 205 F are readily apparent from the data in Table 2. As the temperature rose from 533.3°K to 588.8°K, deposit formation increased as expected. At 1.17 x 10^{-3} m^3/s, the cleanliness rating dropped approximately 38% from 60 to 37. At 1.98 x 10^{-3} m^3/s, a smaller decrease of 28% in the cleanliness rating, from 74 to 47, was observed. Thus, at the same temperature, higher ratings are obtained at the higher air and oil flow rates, and the tendency of higher disc temperature to increase deposits seems to be partially offset by higher air and oil flow rates. From previous experience with thin film oxidation techniques (5), this tendency of the higher flow of air and oil to reduce deposits probably can be attributed to increased film thickness and reduced residence time of the oil on the disc.

b. <u>XRL 850 A (Synthetic Paraffinic Hydrocarbon)</u>

The wetting characteristics of XRL 850 A are depicted graphically in Figures 12 to 17, and summarized in Table 3. The wetting characteristics of the oil can be summarized as follows:

- The wetting rate decreased with increasing temperature, except under the most favorable wetting conditions (1.98 x 10^{-3} m^3/s and 262 rad/s) where the wetting rate observed with the oil remained fairly constant.

Figure 12

WETTING CHARACTERISTICS OF XRL 850A ON PLANE DISC

477.7°K, 104 rad/s

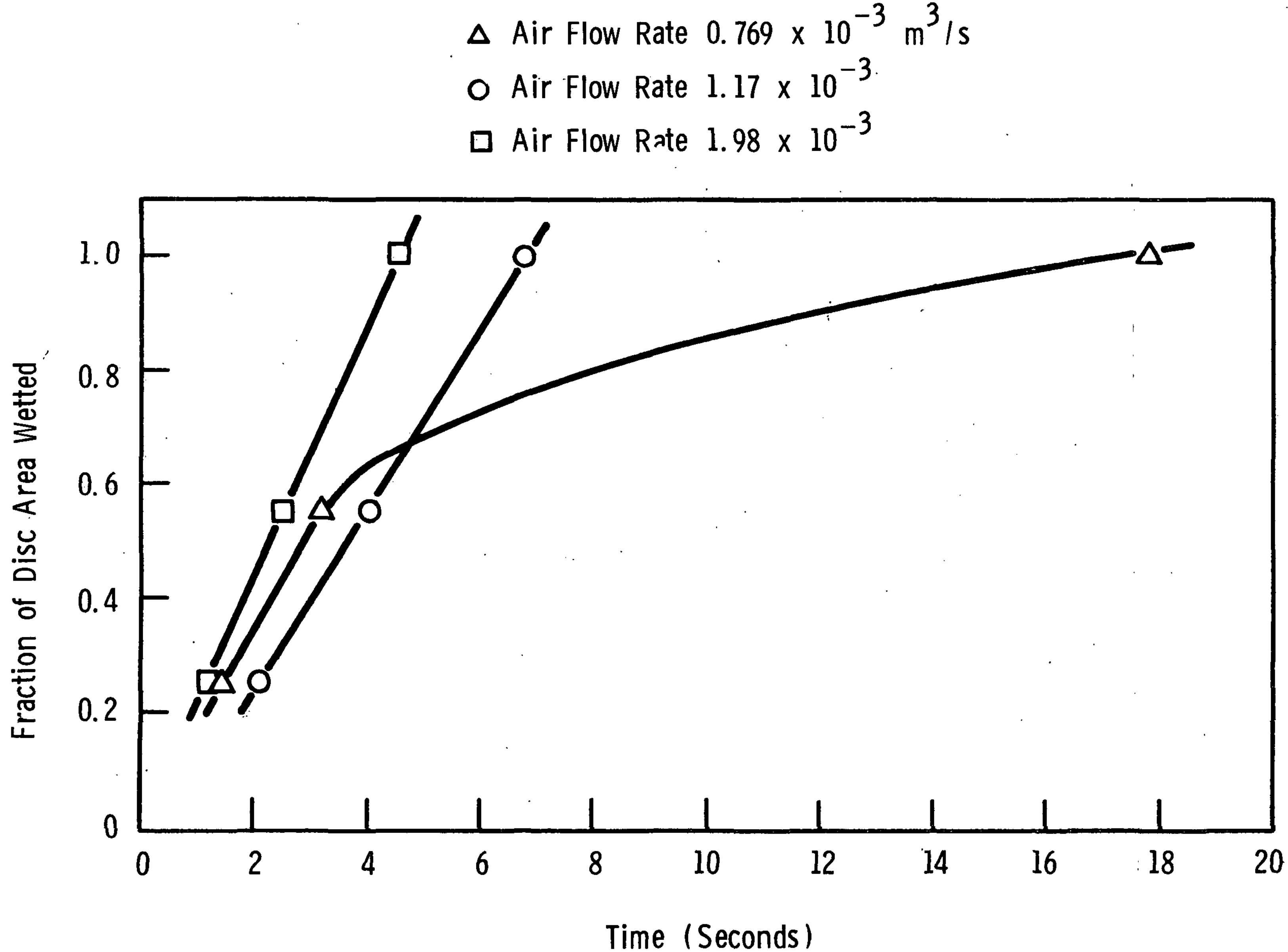


Figure 13

WETTING CHARACTERISTICS OF XRL 850A ON PLANE DISC

477.7°K, 262 rad/s

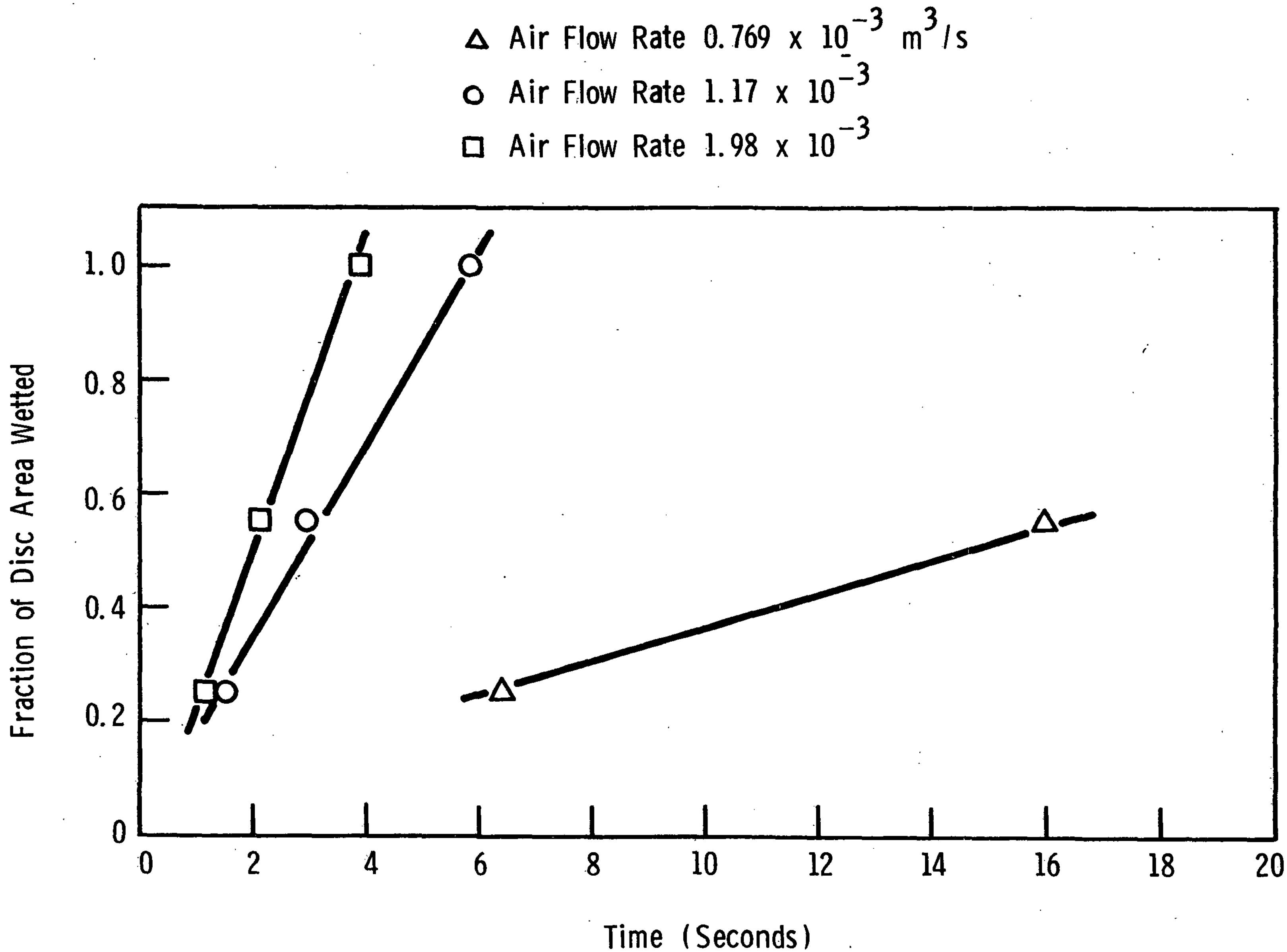


Figure 14

WETTING CHARACTERISTICS OF XRL 850A ON PLANE DISC

533.3°K, 104 rad/s

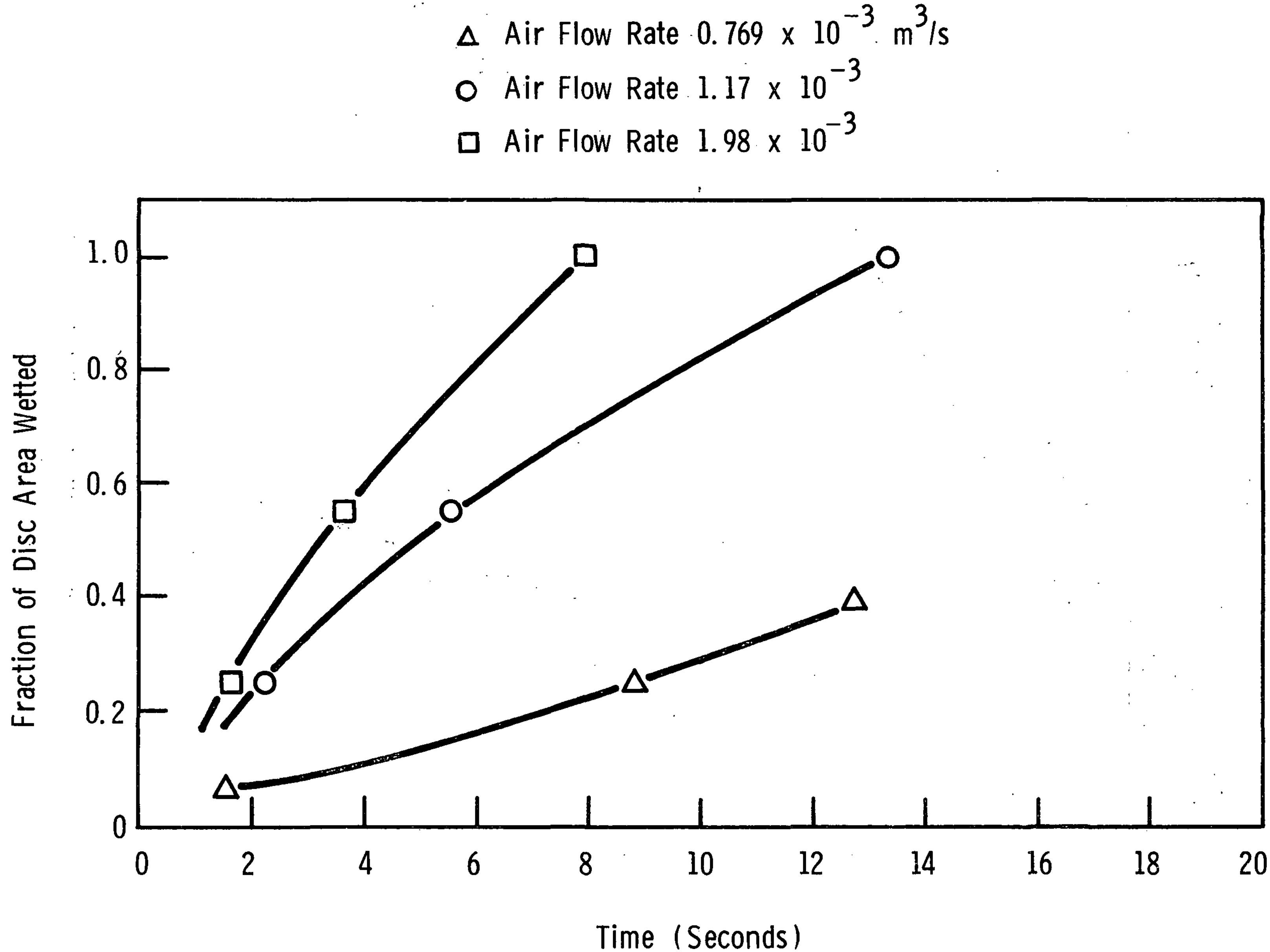


Figure 15

WETTING CHARACTERISTICS OF XRL 850A ON PLANE DISC

533.3°K, 262 rad/s

△ Air Flow Rate 0.769×10^{-3} m^3/s

○ Air Flow Rate 1.17×10^{-3}

□ Air Flow Rate 1.98×10^{-3}

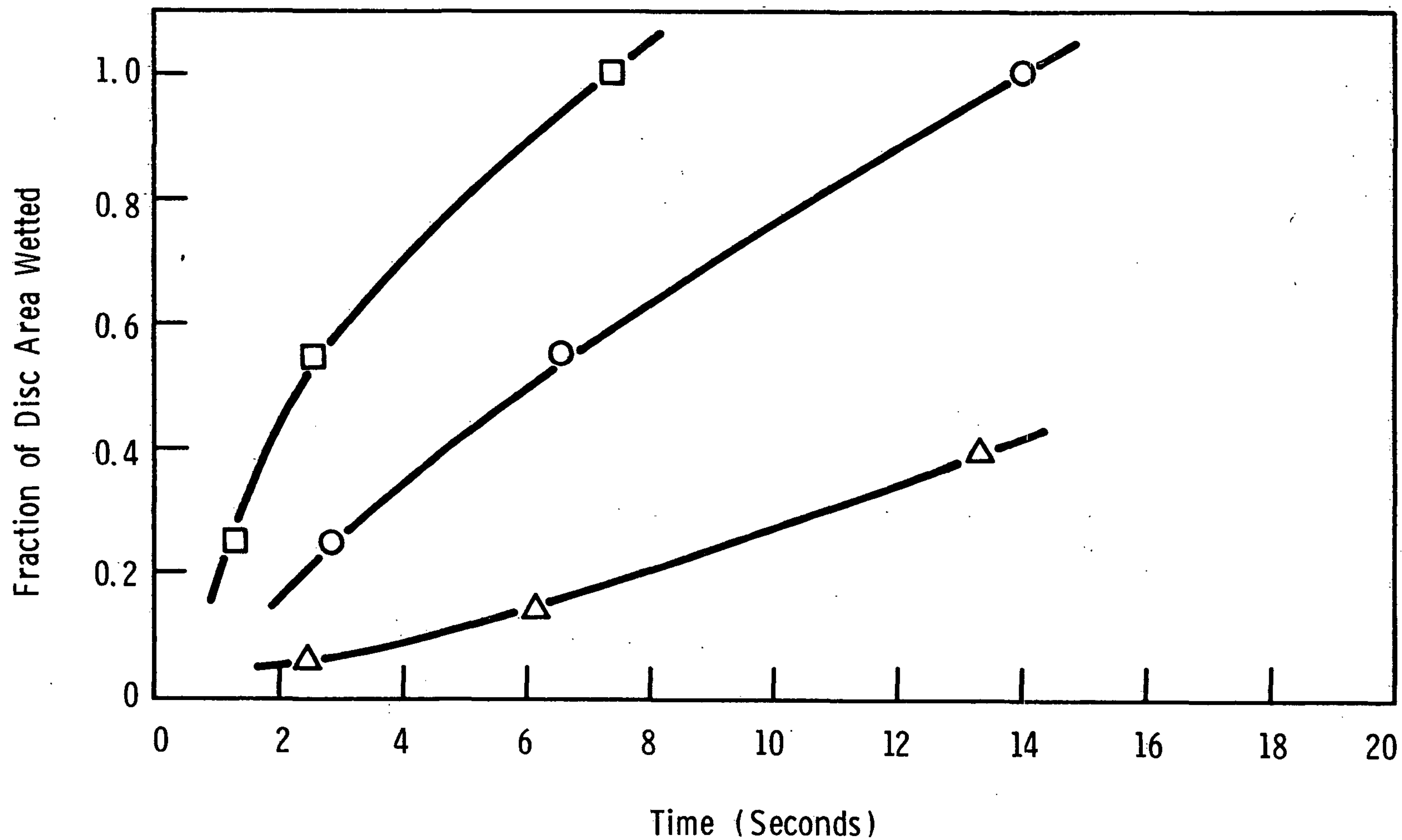


Figure 16

WETTING CHARACTERISTICS OF XRL 850A ON PLANE DISC

588.8°K, 104 rad/s

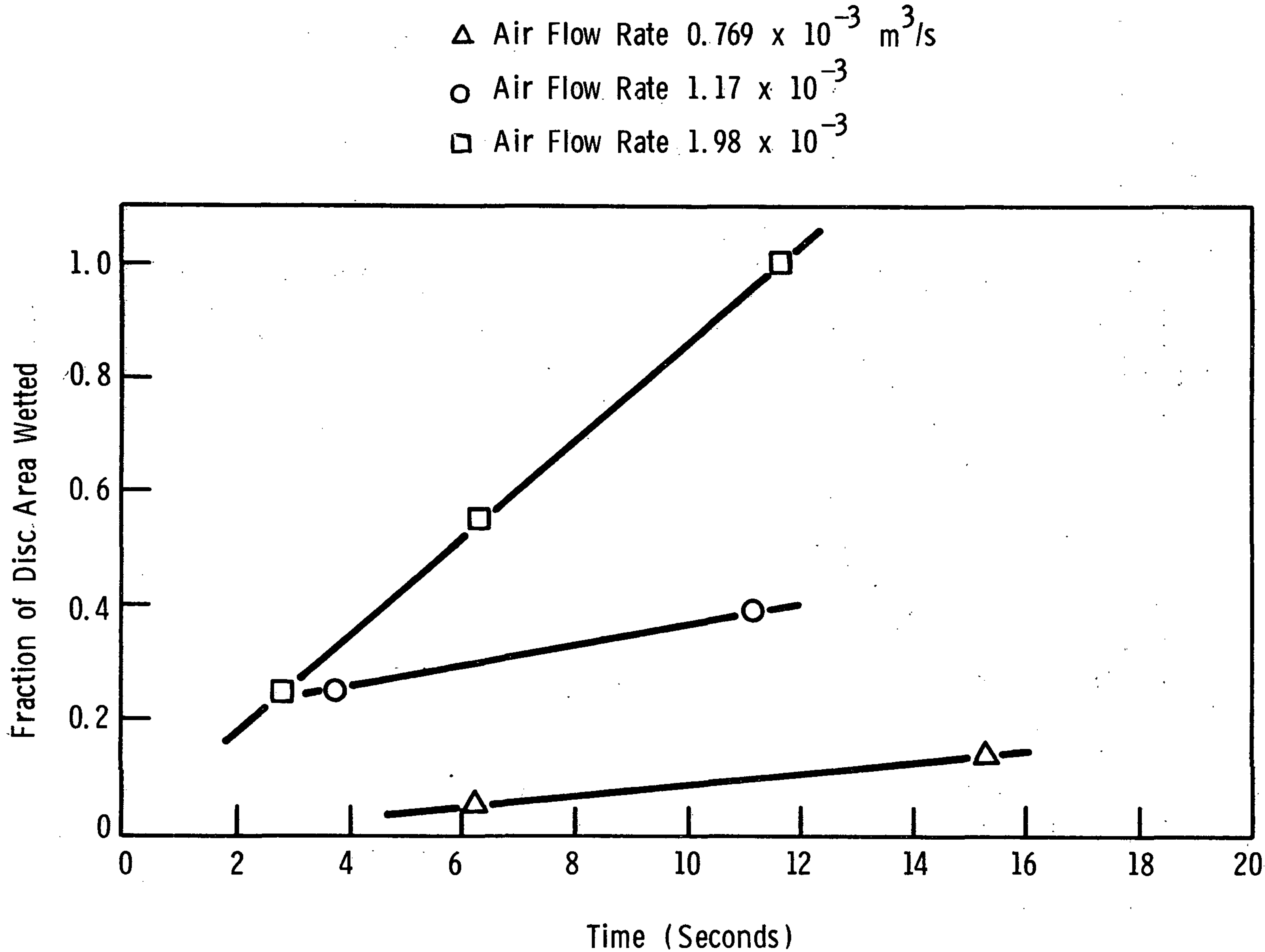


Figure 17

WETTING CHARACTERISTICS OF XRL 850A ON PLANE DISC

588.8°K, 262 rad/s

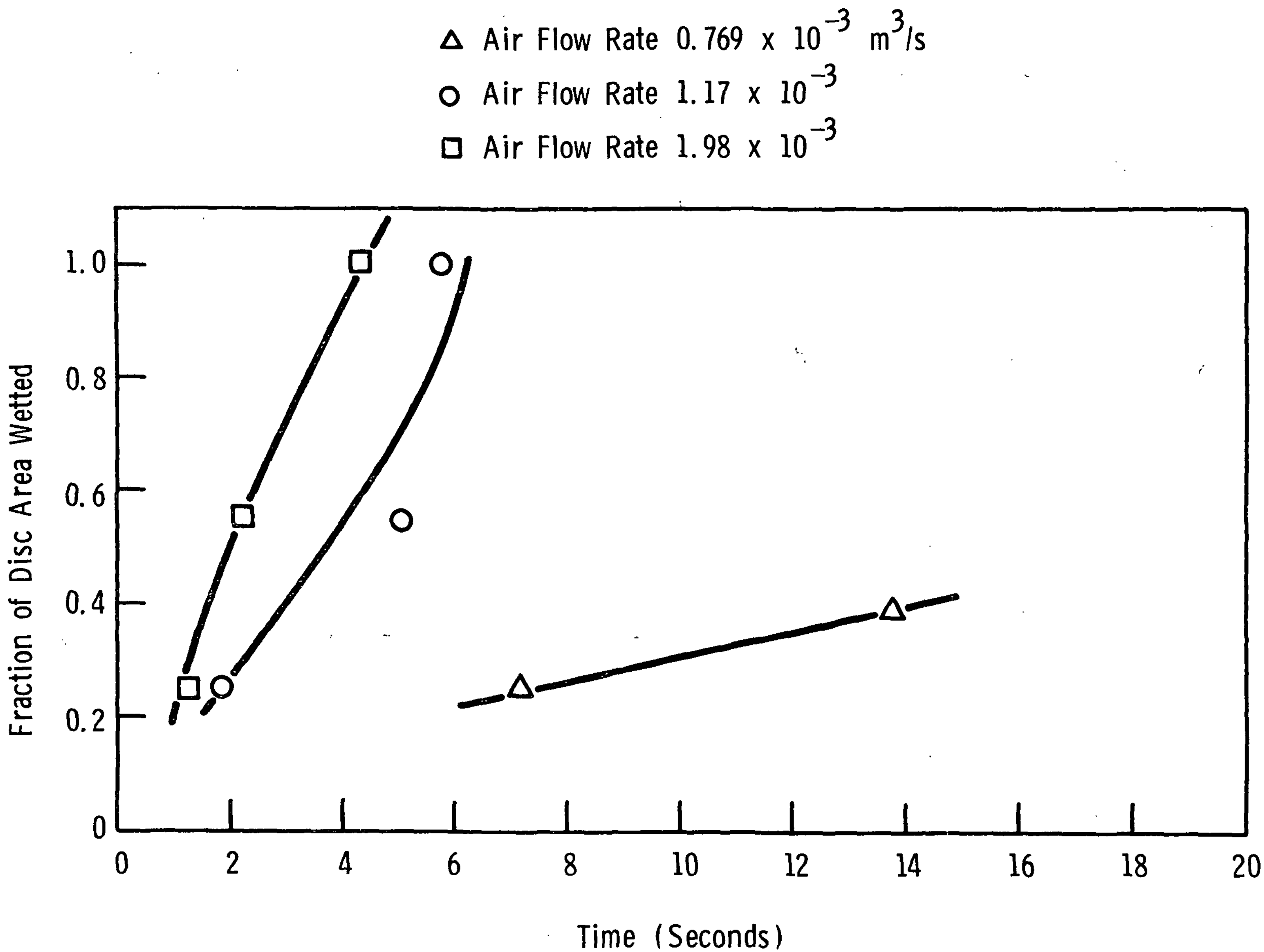


Table 3

Wetting and Deposit Data for XRL 850 A on Plane Disc

Temp (°K)	477.7	533.3	588.8	477.7	533.3	588.8	477.7	533.3	588.8
Air Flow Rate[1] (m^3/s) x 10^3	<——	0.769	——>	<——	1.17	——>	<——	1.98	——>
Wetting Rate (cm^2/s) at 104 rad/s	4.39	2.36	0.37	13.34	6.15	2.52	19.87	10.53	3.68
Area Wetted (%) at 104 rad/s	100	39	14	100	100	39	100	100	55
Wetting Rate (cm^2/s) at 262 rad/s	2.76	2.0	0.45	14.45	5.4	5.6	22.13	14.71	19.7
Area Wetted (%) at 262 rad/s	55	39	39	100	100	100	100	100	100
Oil Consumption (cm^3/s)	<——	0.008	——>	<——	0.0832	——>	<——	0.1708	——>
Cleanliness Rating at 262 rad/s					94	78		94	80

(1) at 366°K and 41 N/m^2.

- The angular velocity of the disc had little effect on the wetting characteristics of XRL 850 A at low air flows but appeared to aid wetting at the higher air flow rates. At 588.8°K and 1.17 x 10^{-3} m^3/s, the wetting rate increased approximately 100% when the rotational speed was increased from 1000 RPM to 2500 RPM. At 1.98 x 10^{-3} m^3/s and 588.8°K, the effect of disc speed was even more dramatic. When the disc speed was increased from 1000 to 2500 RPM, the wetting rate of XRL 850 A increased from 2.68 cm^2/s to 19.7 cm^2/s.

- The wetting rate increased as the air flow rate increased.

As illustrated by Table 3, XRL 850 A yields very little deposits under the test conditions employed in this study. At 533.3°K, both at 1.17 and 1.98 x 10^{-3} m^3/s, the deposit rating was 94. This is an essentially perfect rating since the WB-49 disc develops an iridescent appearance when heated to either test temperature for the 30-minute test time in air alone. Thus, in general, the first six demerits cannot be attributed to the test fluid. At 588.8°K, the cleanliness ratings were still good, but not as high as those observed at 533.3°K.

c. XRL 850 A Containing 5 Wt % Kendall 0839 Heavy Paraffinic Resin

The wetting characteristics of XRL 850 A containing 5 wt % Kendall 0839 Heavy Paraffinic Resin under the various test conditions are depicted graphically in Figures 18 to 23. The data on the lubricant are summarized in Table 4 and can be described as follows:

- The wetting rates increased as the air flow rate increased.

- The wetting rates decreased as the temperature increased.

- The angular velocity of the disc had little effect on the wetting rates.

- The addition of the Kendall resin to XRL 850 A appeared to result in a small improvement in wettability under the poorest wetting conditions. At the higher air flow rates the presence of the Kendall resin had little effect, and in some cases appeared to actually be detrimental to the wetting characteristics of the oil. These same trends are observed

Figure 18

WETTING CHARACTERISTICS OF XRL 850A + 5% KENDALL 0839 RESIN ON PLANE DISC

477.7°K, 104 rad/s

△ Air Flow Rate 0.769×10^{-3} m^3/s

○ Air Flow Rate 1.17×10^{-3}

□ Air Flow Rate 1.98×10^{-3}

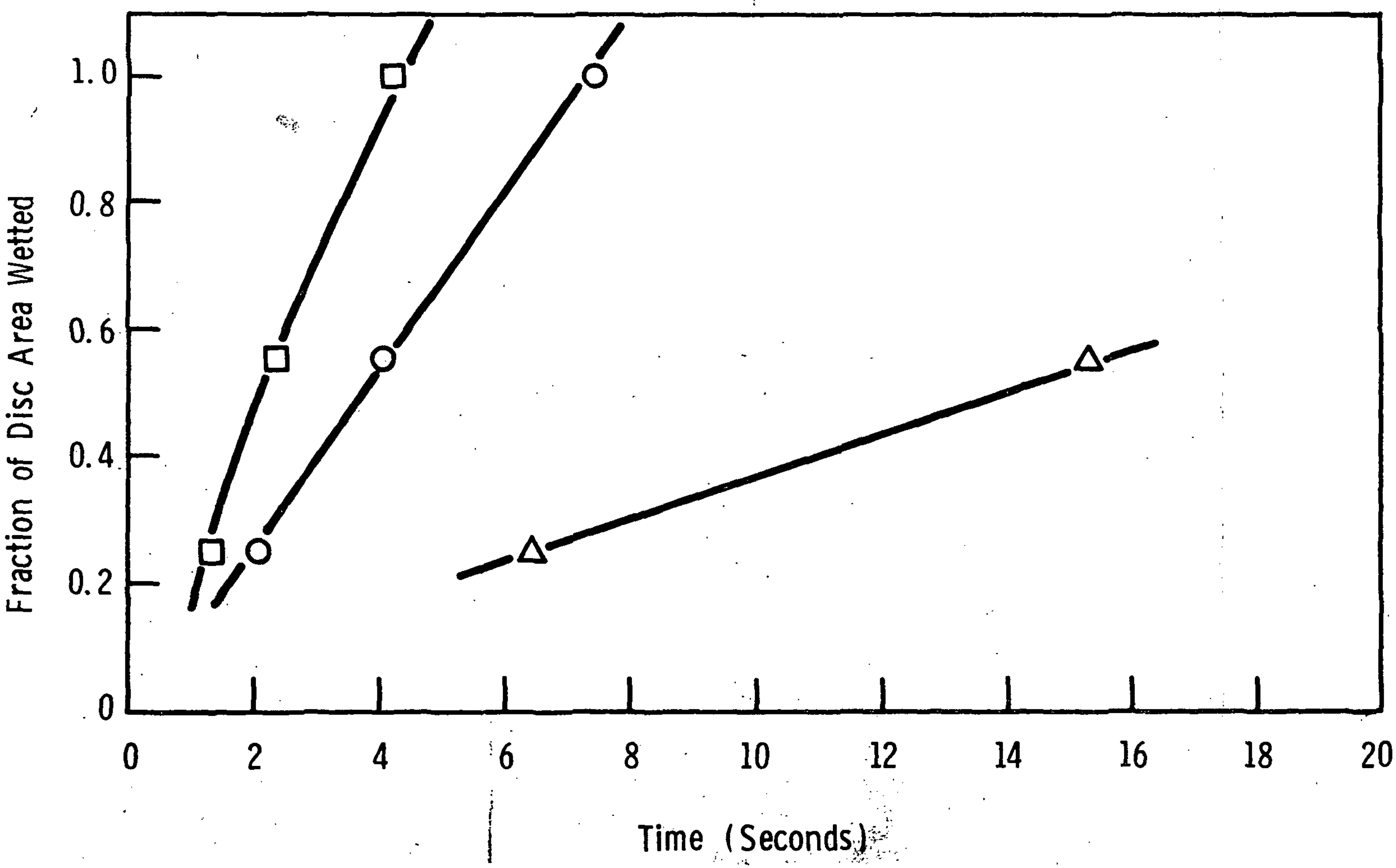


Figure 19

WETTING CHARACTERISTICS OF XRL 850A + 5% KENDALL 0839 RESIN ON PLANE DISC

477.7°K, 262 rad/s

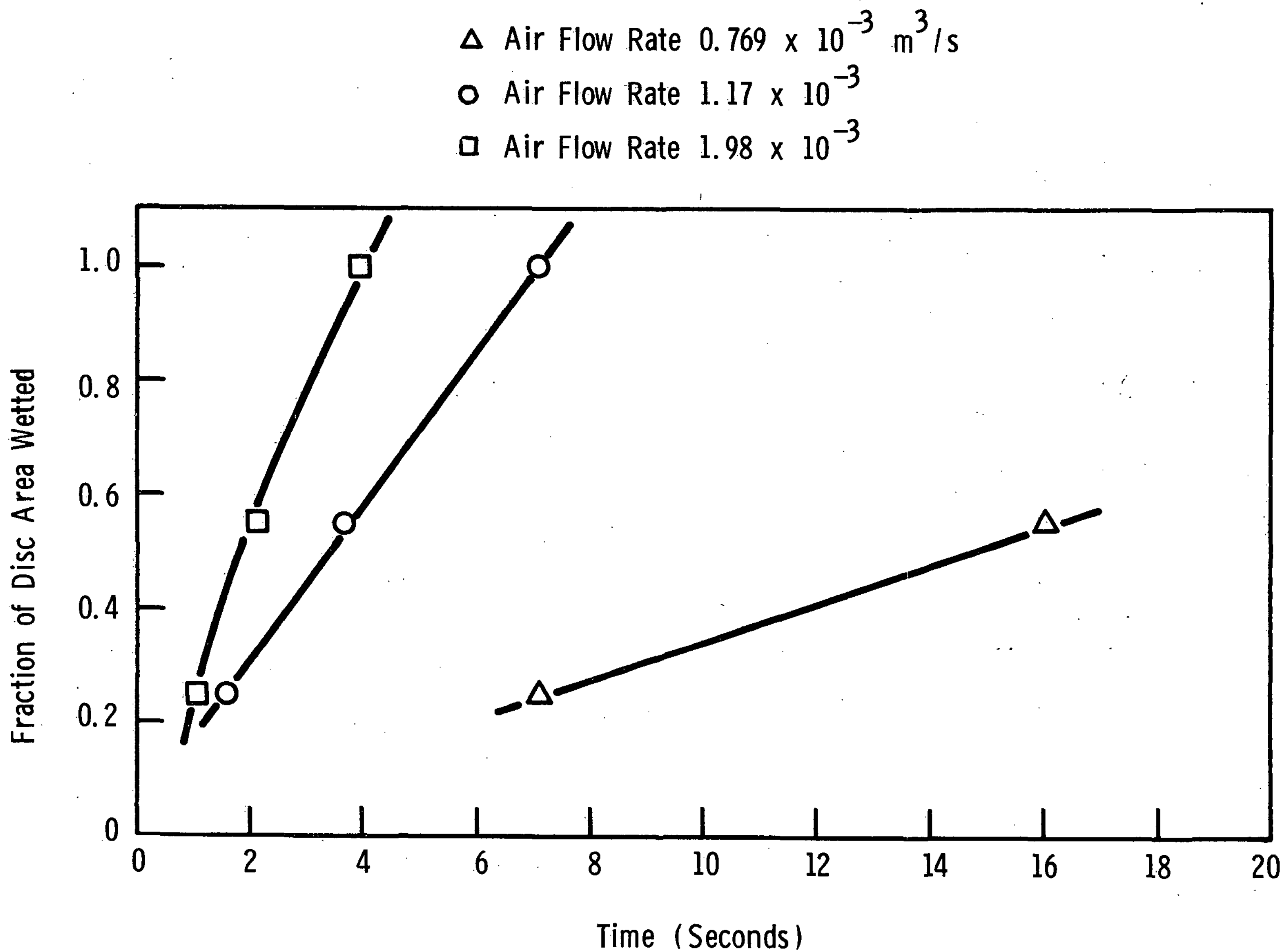


Figure 20

WETTING CHARACTERISTICS OF XRL 850A + 5% KENDALL 0839 RESIN ON PLANE DISC

533.3°K, 104 rad/s

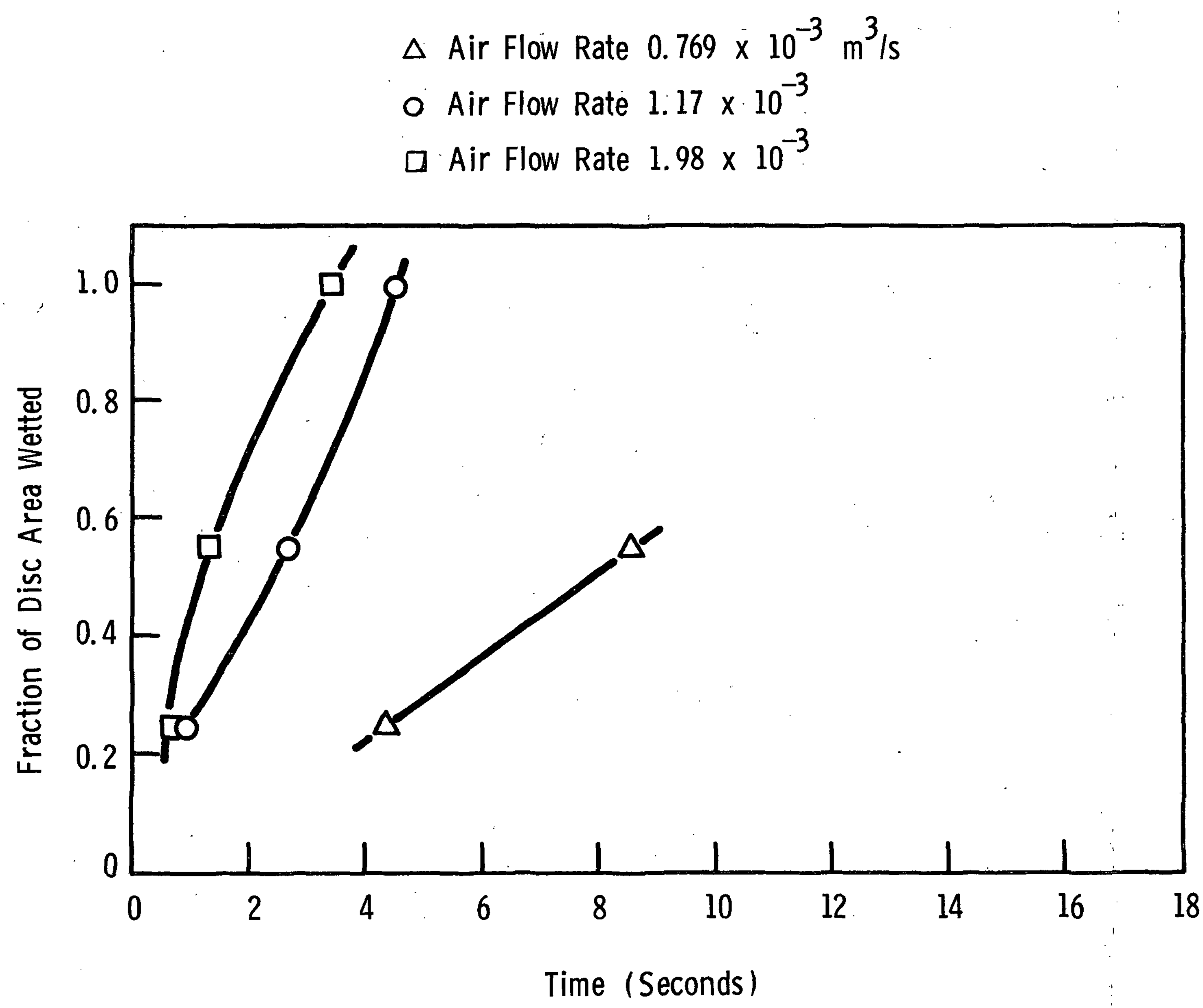


Figure 21

WETTING CHARACTERISTICS OF XRL 850A + 5% KENDALL 0839 RESIN ON PLANE DISC

533°K, 262 rad/s

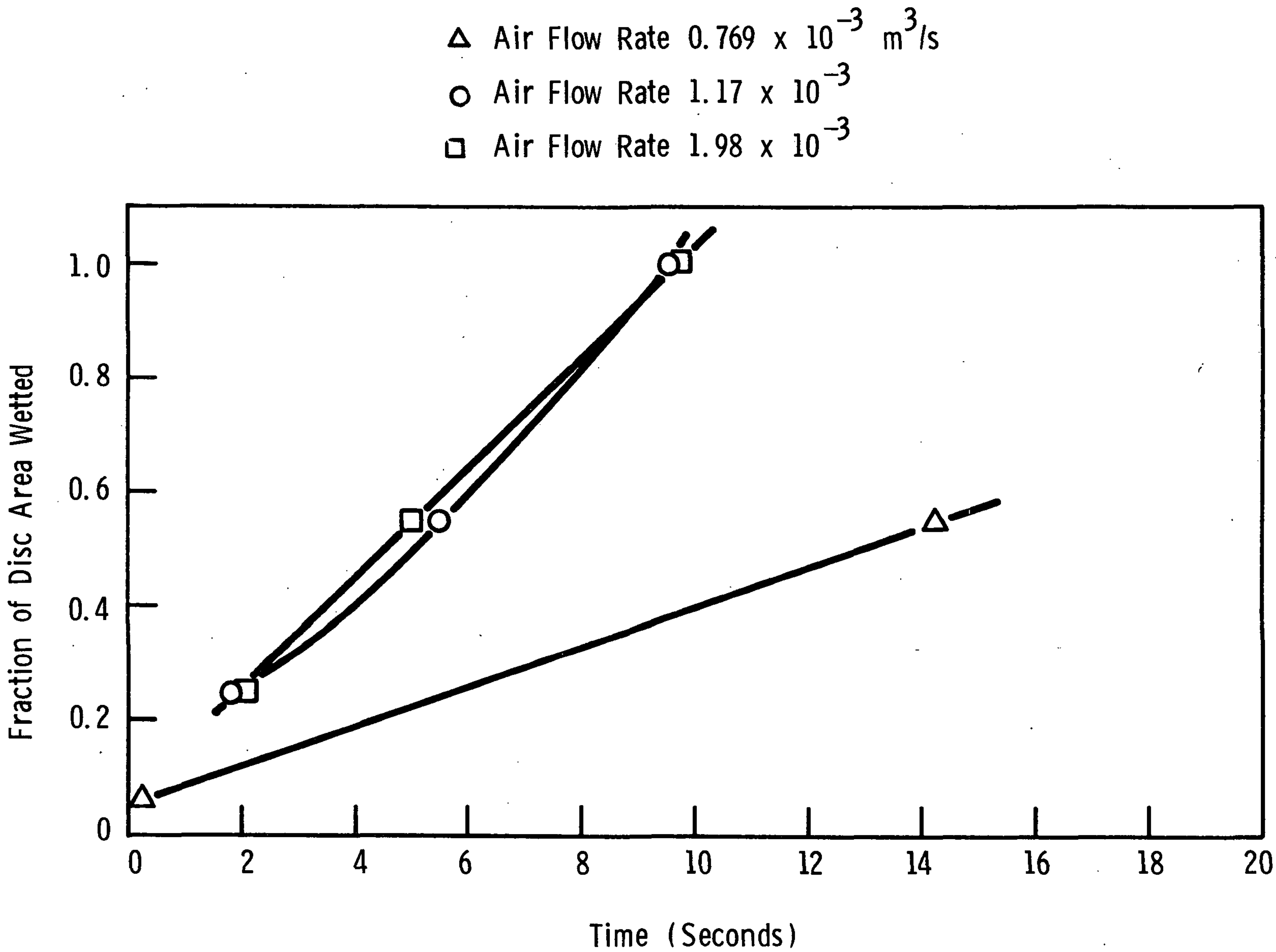


Figure 22

WETTING CHARACTERISTICS OF XRL 850A + 5% KENDALL
0839 RESIN ON PLANE DISC

588.8°K, 104 rad/s

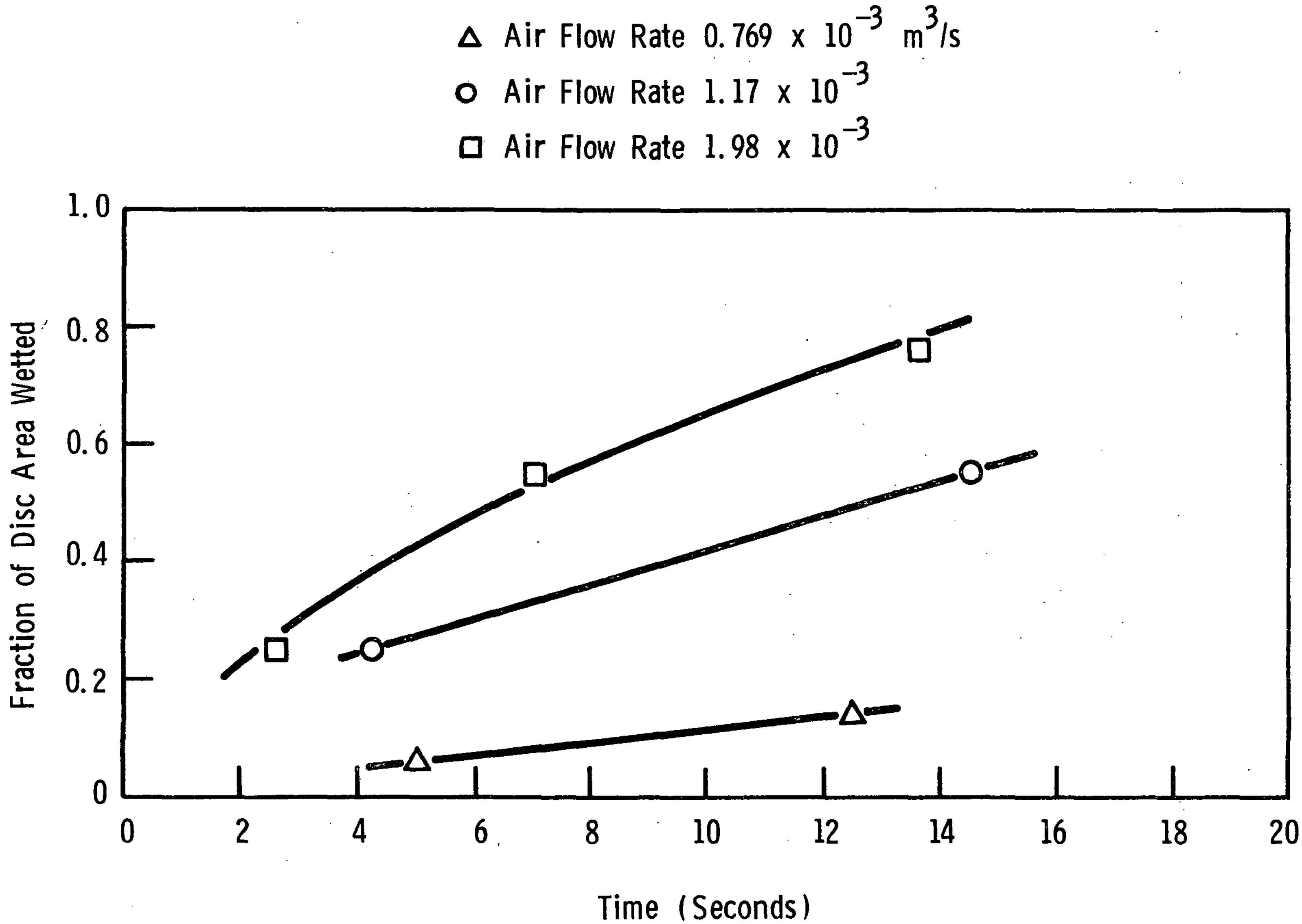


Figure 23

WETTING CHARACTERISTICS OF XRL 850A + 5% KENDALL 0839 RESIN ON PLANE DISC

588.8°K, 262 rad/s

△ Air Flow Rate 0.869×10^{-3} m^3/s

○ Air Flow Rate 1.17×10^{-3}

□ Air Flow Rate 1.98×10^{-3}

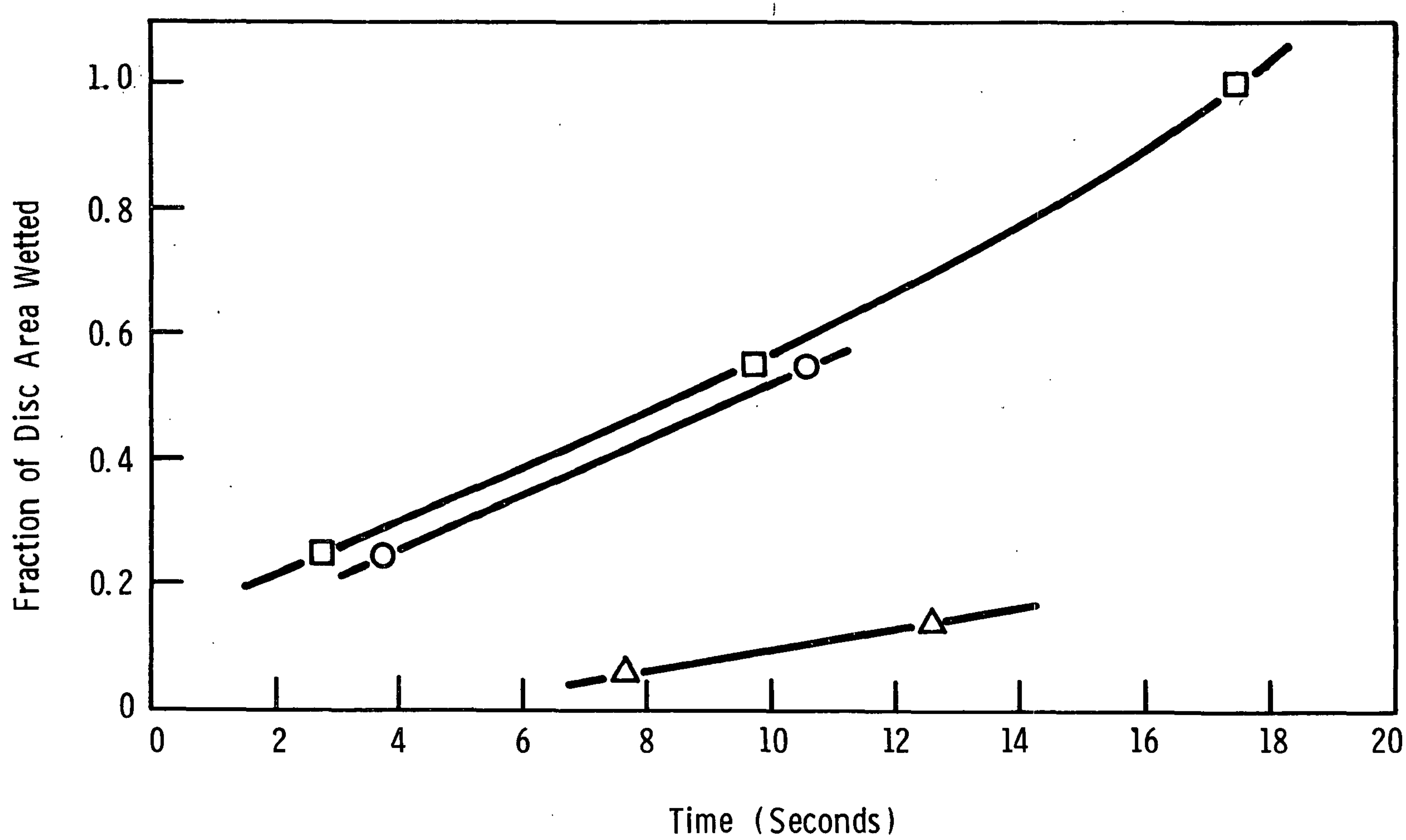


Table 4

Wetting and Deposit Data for XRL 850 A Containing 5 Wt % Kendall 0839 Paraffinic Resin on Plane Disc

Temp (°K)	477.7	533.3	588.8	477.7	533.3	588.8	477.7	533.3	588.8
Air Flow Rate[1] (m^3/s) x 10^3	<——	0.769	——>	<——	1.17	——>	<——	1.98	——>
Wetting Rate (cm^2/s) at 104 rad/s	3.06	5.21	0.83	11.75	7.47	2.96	20.87	8.40	4.42
Area Wetted (%) at 104 rad/s	55	55	14	100	100	55	100	100	77
Wetting Rate (cm^2/s) at 262 rad/s	2.94	5.60	0.62	12.01	7.85	4.09	22.33	7.97	4.12
Area Wetted (%) at 262 rad/s	55	55	14	100	100	55	100	100	100
Oil Consumption (cm^3/s)	<——	0.01	——>	<——	0.0747	——>	<——	0.1347	——>
Cleanliness Rating at 262 rad/s					78	88		90	82

(1) at 366°K and 41 N/m^2.

if one looks at the rate of oil consumption. At a flow rate of 0.769×10^{-3} m^3/s, the Kendall resin increased the rate of oil output about 25%, from 0.008 cm^3/s without the Kendall resin to 0.01 cm^3/s. In both cases at the higher air flow rate, the oil output decreased when the Kendall resin was present. At 1.17×10^{-3} m^3/s, the decrease was approximately 12.5%, while at 1.98×10^{-3} m^3/s, the oil output rate was decreased by about 23%.

The addition of the Kendall resin did not substantially alter the cleanliness of XRL 850 A as evaluated in the 30-minute deposit runs.

d. XRM 232 A (Advanced Type II Ester)

The following observations can be made regarding XRM 232 A, for which wettability data appear in Figures 24 to 39 and in Table 5.

- Wetting rate decreased as test temperature increased.
- The angular velocity of the disc had no effect on the wetting rates.
- Wetting rate increased as the air flow rate increased. An exception to this general statement was observed at 588.8°K, both at 104 and 262 rad/s, where increasing the air flow rate from 1.17×10^{-3} m^3/s to 1.98×10^{-3} m^3/s did not result in a corresponding increase in the wetting rate. At this high temperature the wetting rate either remained essentially constant or slightly decreased as the air flow rate was increased under a specific set of conditions.

With respect to deposit formation, XRM 232 A was among the cleanest of the fluids in the test program, as illustrated by Table 5.

e. XRM 232 A Containing 10 Wt % Freon BF

An objective of the present test program was to determine the effects of volatile components on the wetting characteristics of conventional fluids. In pursuit of this objective, a blend of XRM 232 A containing 10 wt % of Freon BF was tested. Freon BF was chosen as the freon type additive called for by the work statement because it alone of the liquid Freons available had a boiling point sufficiently high to survive the 366°K temperature of the microfog generator sump. The physical properties of Freon BF are attached as Appendix B-2.

Figure 24

WETTING CHARACTERISTICS OF XRM 232A ON PLANE DISC

477.7°K, 104 rad/s

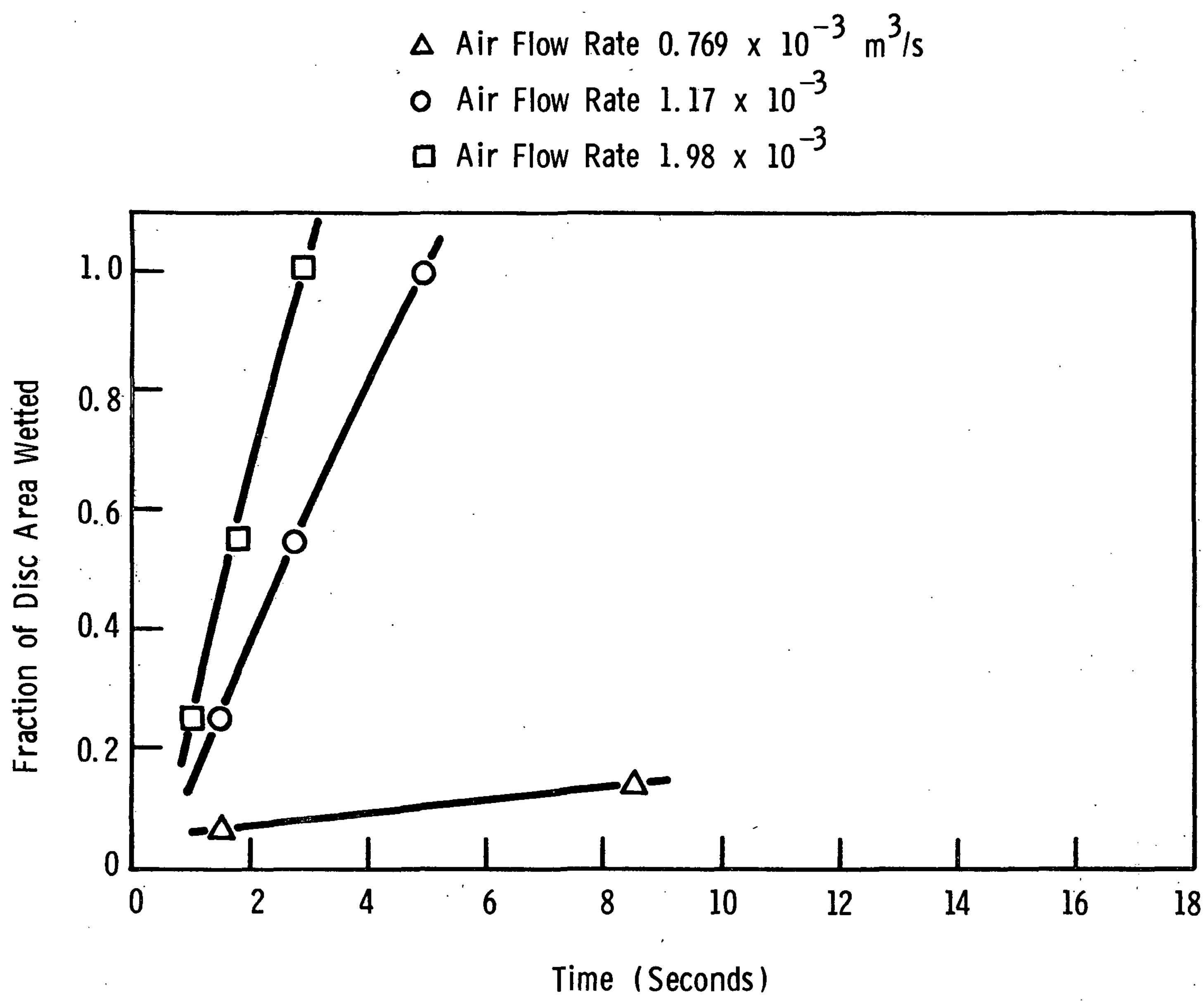


Figure 25

WETTING CHARACTERISTICS OF XRM 232A ON PLANE DISC

477.7°K, 262 rad/s

△ Air Flow Rate $0.769 \times 10^{-3}\ m^3/s$

○ Air Flow Rate 1.17×10^{-3}

□ Air Flow Rate 1.98×10^{-3}

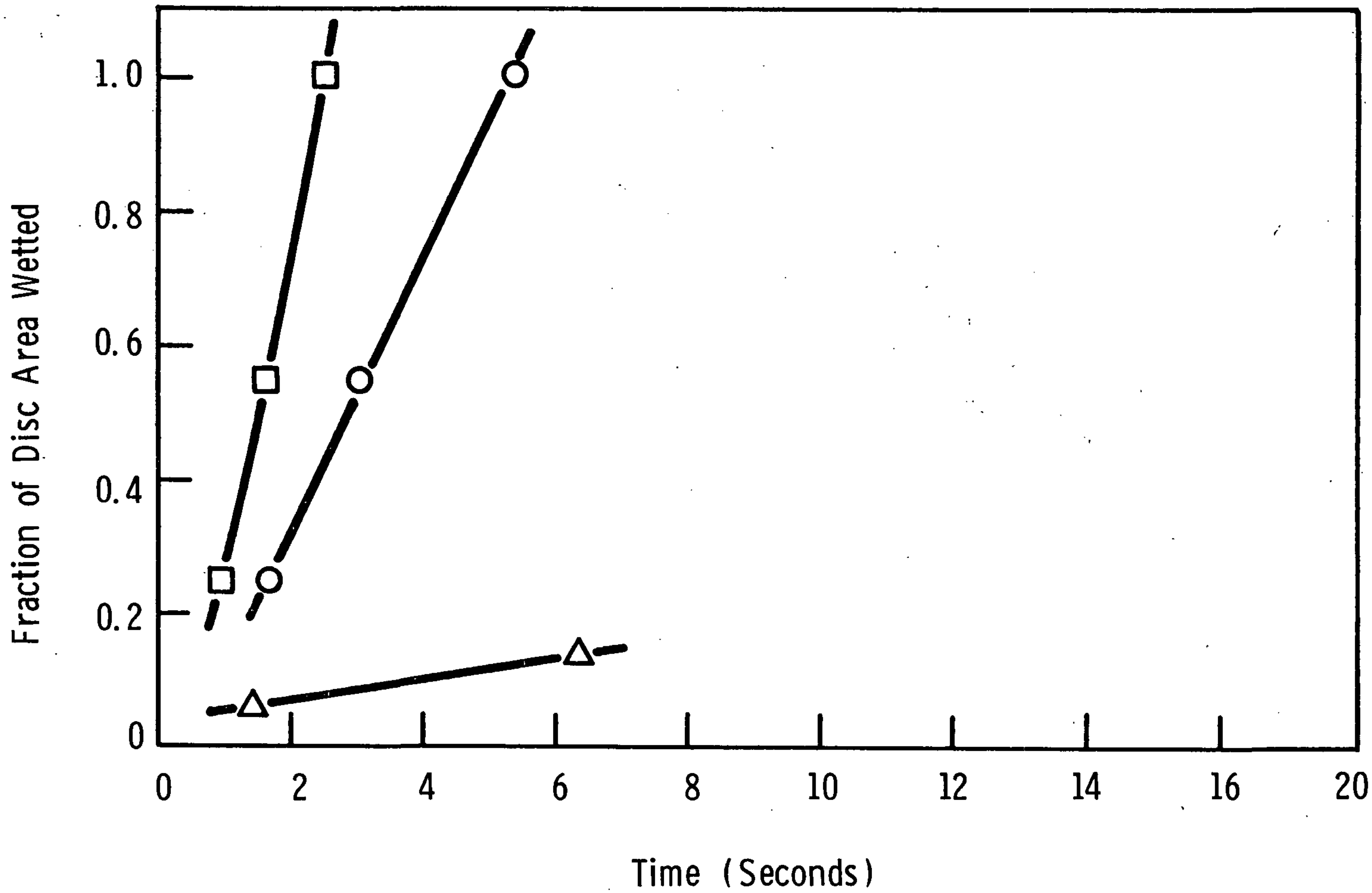


Figure 26

WETTING CHARACTERISTICS OF XRM 282A ON PLANE DISC

533.3°K, 104 rad/s

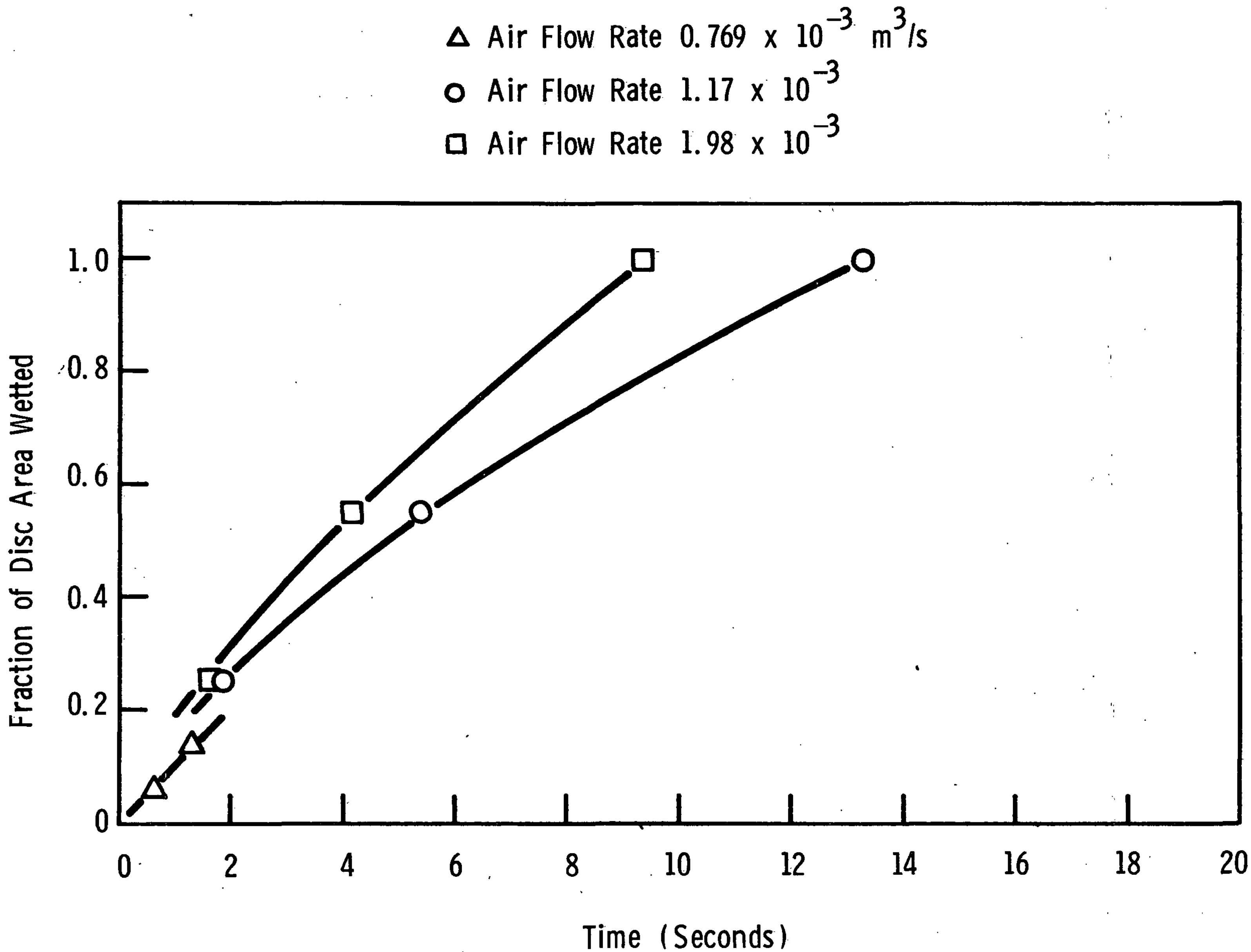


Figure 27

WETTING CHARACTERISTICS OF XRM 232A ON PLANE DISC

533.3°K, 262 rad/s

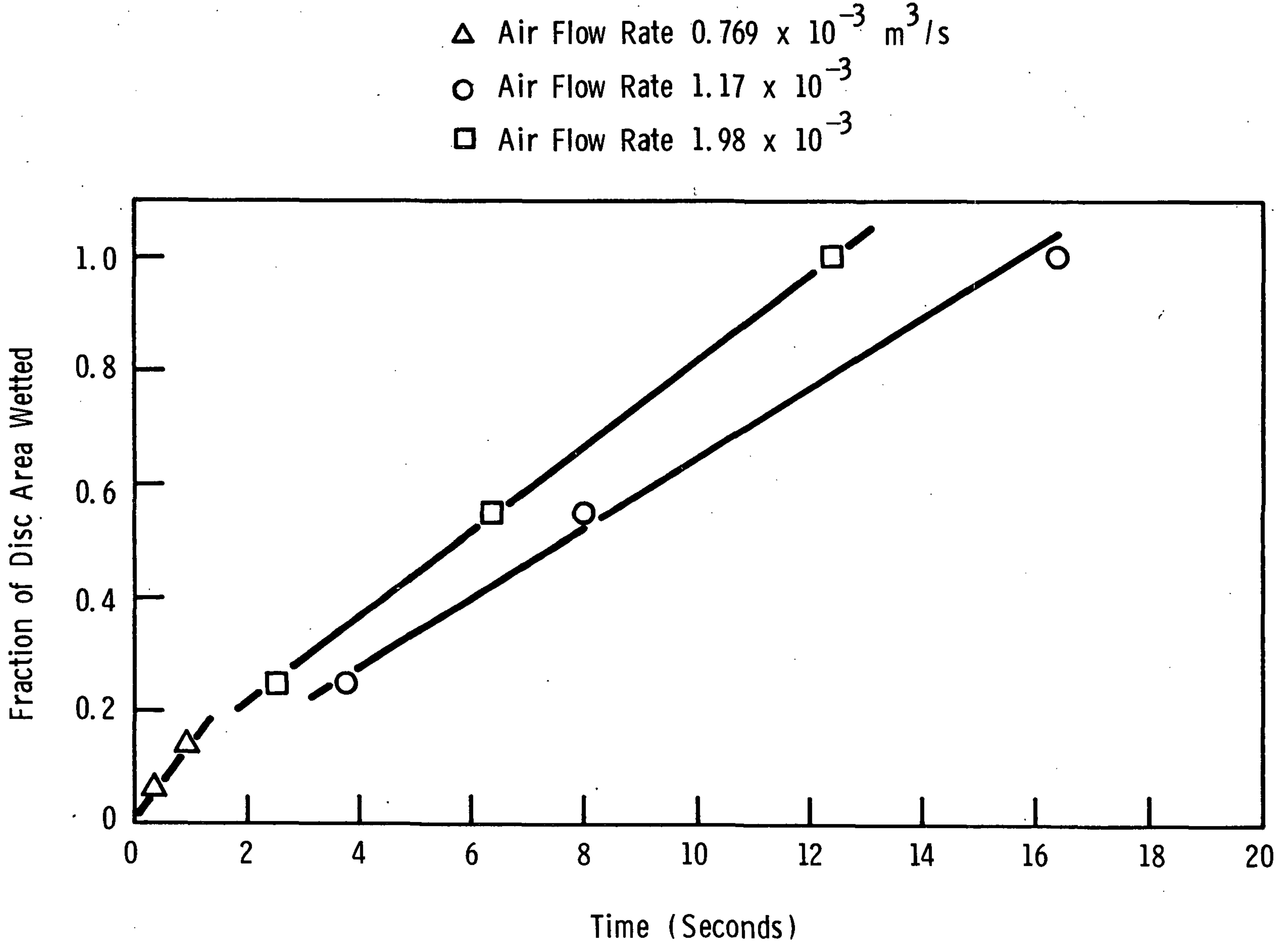


Figure 28

WETTING CHARACTERISTICS OF XRM 232A ON PLANE DISC

588.8°K, 104 rad/s

△ Air Flow Rate $0.769 \times 10^{-3}\ m^3/s$
○ Air Flow Rate 1.17×10^{-3}
□ Air Flow Rate 1.98×10^{-3}

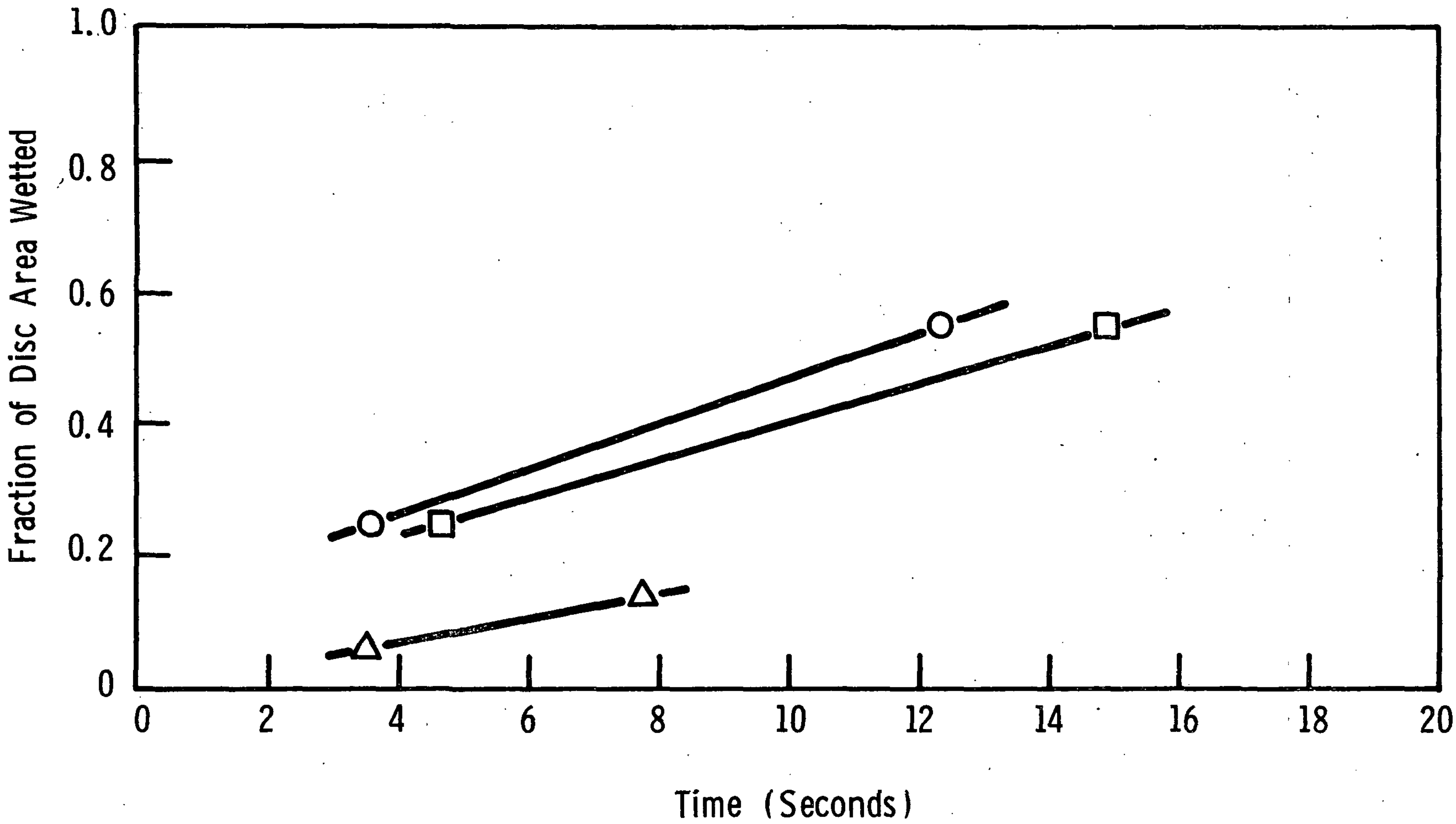


Figure 29

WETTING CHARACTERISTICS OF XRM 232A ON PLANE DISC

588.8°K, 262 rad/s

○ Air Flow Rate 1.17×10^{-3} m^3/s

□ Air Flow Rate 1.98×10^{-3}

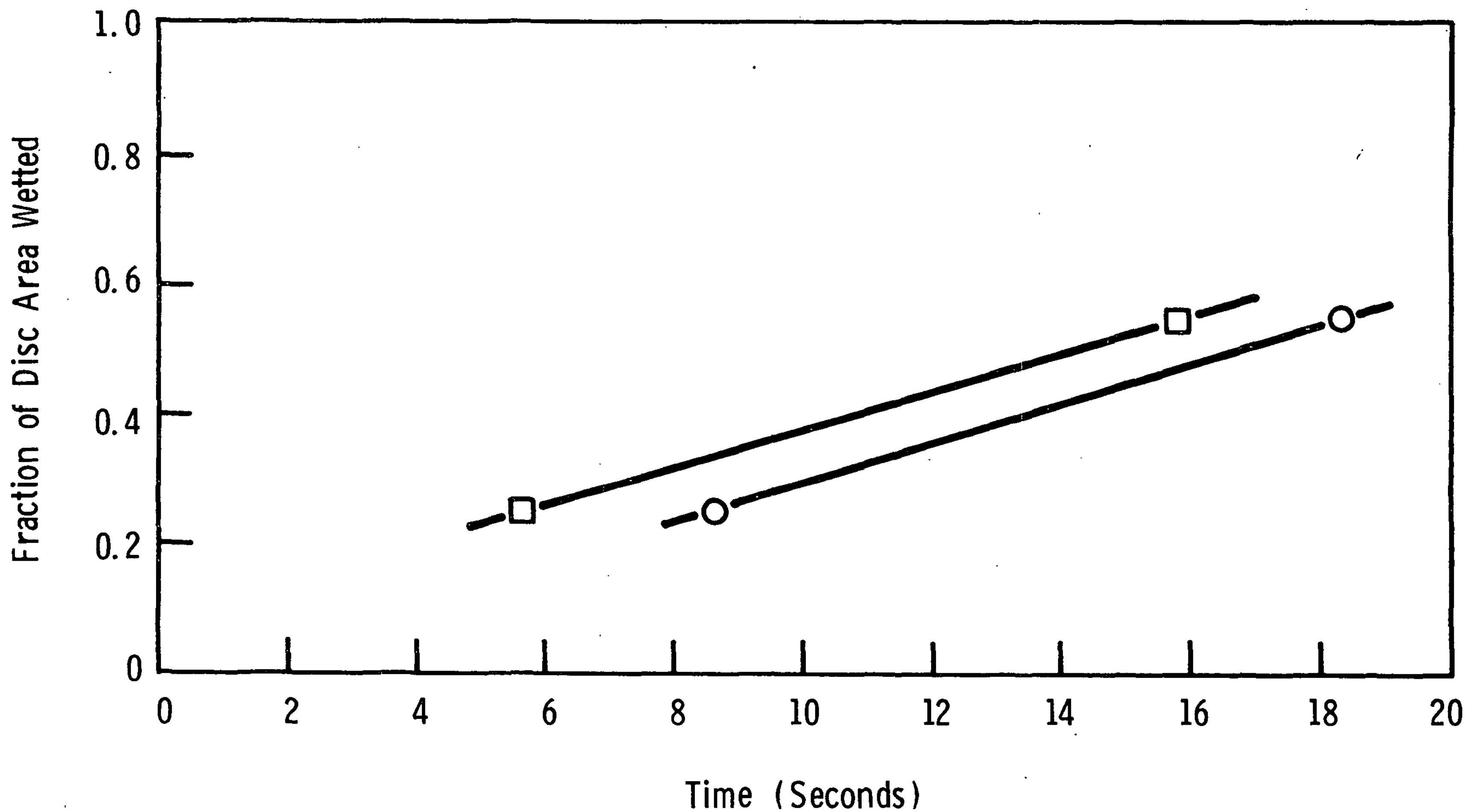


Table 5

Wetting and Deposit Data for XRM 232 A on Plane Disc

Temp (°K)	477.7	533.3	588.8	477.7	533.3	588.8	477.7	533.3	588.8
Air Flow Rate(1) (m^3/s) x 10^3	←	0.769	→	←	1.17	→	←	1.98	→
Wetting Rate (cm^2/s) at 104 rad/s	0.89	2.93	1.46	17.45	5.32	3.11	32.17	7.93	2.09
Area Wetted (%) at 104 rad/s	14	14	14	100	100	55	100	100	55
Wetting Rate (cm^2/s) at 262 rad/s	1.27	1.27	-	18.7	4.79	2.56	36.85	6.15	2.45
Area Wetted (%) at 262 rad/s	14	14	14	100	100	55	100	100	55
Oil Consumption (cm^3/s)	←	0.0056	→	←	0.0611	→	←	0.1267	→
Cleanliness Rating at 262 rad/s					95	89		94	91

(1) at 366°K and 41 N/m^2.

Wettability data for XRM 232 A containing 10 wt % Freon BF appear in Figures 30 and 31 and Table 6. The addition of Freon BF appeared to have a slightly detrimental effect on the wetting characteristics of XRM 232 A. This can be explained from film analyses of the wetting runs. Vaporization of the Freon was initiated as soon as the stream entered the hot chamber and presumably disrupted the microfog stream even before contact with the heated rotating disc. After impinging on the disc, continued evaporation of the Freon appeared to also disrupt and reduce the stability of the liquid film expanding from the center of the disc.

f. Ucon Polyglycol Ether Blend Containing 10 Wt % Water

A second fluid containing a volatile component, and evaluated in the present program, was a blend (G-10) of Ucon polyglycol ethers containing 10 wt % water. The composition of blend G-10 was described earlier in this report.

Unfortunately, misting of the Ucon/Water blend was very erratic, with the microfog particles delivered in intermittent bursts rather than continuously. Probably because of this phenomenon, no film appeared on the disc and wetting rates could not be calculated. The available data are summarized in Table 7.

The erratic misting behavior of blend G-10 is perhaps explained by analysis of the blend after residing in the sump of the mist generator at 366.3°K (200°F) through two 30-minute deposit runs, one at an absolute sump pressure of 3.1 x 10^5 N/cm (40.5 psi), and the other at 5 x 10^5 N/cm (66.5 psi). Water content had been reduced from the original 10% to only 0.1%, indicating selective stripping of the water from the blend in the generator. This behavior is surprising, since at the same sump temperature and pressures (corresponding to the standard air flow rates of 1.17 and 1.98 m^3/s), Freon BF in XRM 232 A exhibited no such behavior, although its boiling point at atmospheric pressure is slightly lower than that of water.

Another possible explanation for the erratic misting of blend G-10 is its relatively high surface tension (Appendix B-1). Subsequent discussion will show that Monsanto MCS-1370, the other fluid with a comparatively high surface tension, also produced mist in intermittent bursts under the conditions of this study.

As indicated by the deposit data in Table 7, the blend of Ucon fluids containing water was extremely clean.

Figure 30

WETTING CHARACTERISTICS OF XRM 232A + 10% FREON BF
ON PLANE DISC

533.3°K, 262 rad/s

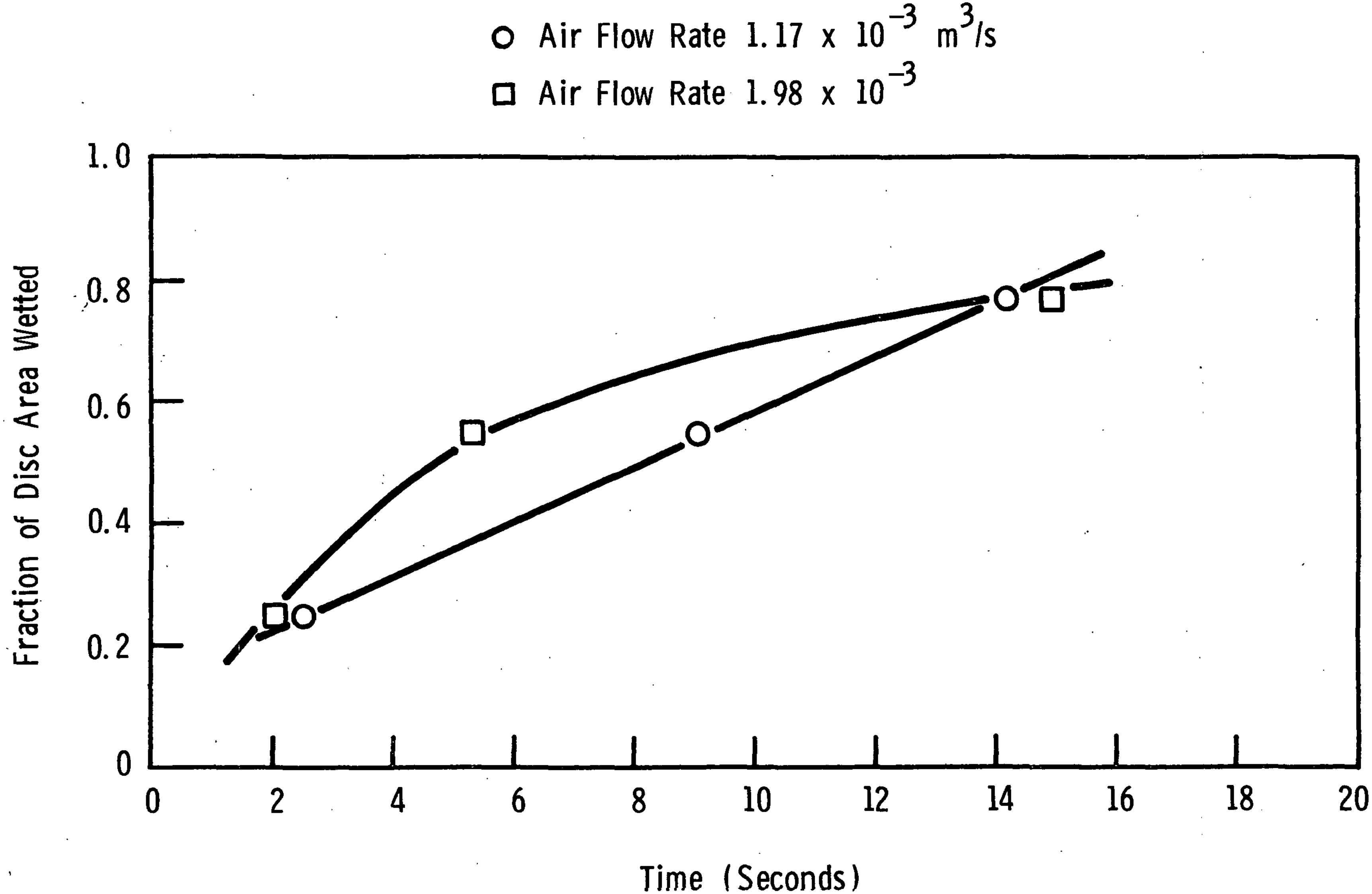


Figure 31

WETTING CHARACTERISTICS OF XRM 232A + 10% FREON BF ON PLANE DISC

588.8°K, 262 rad/s

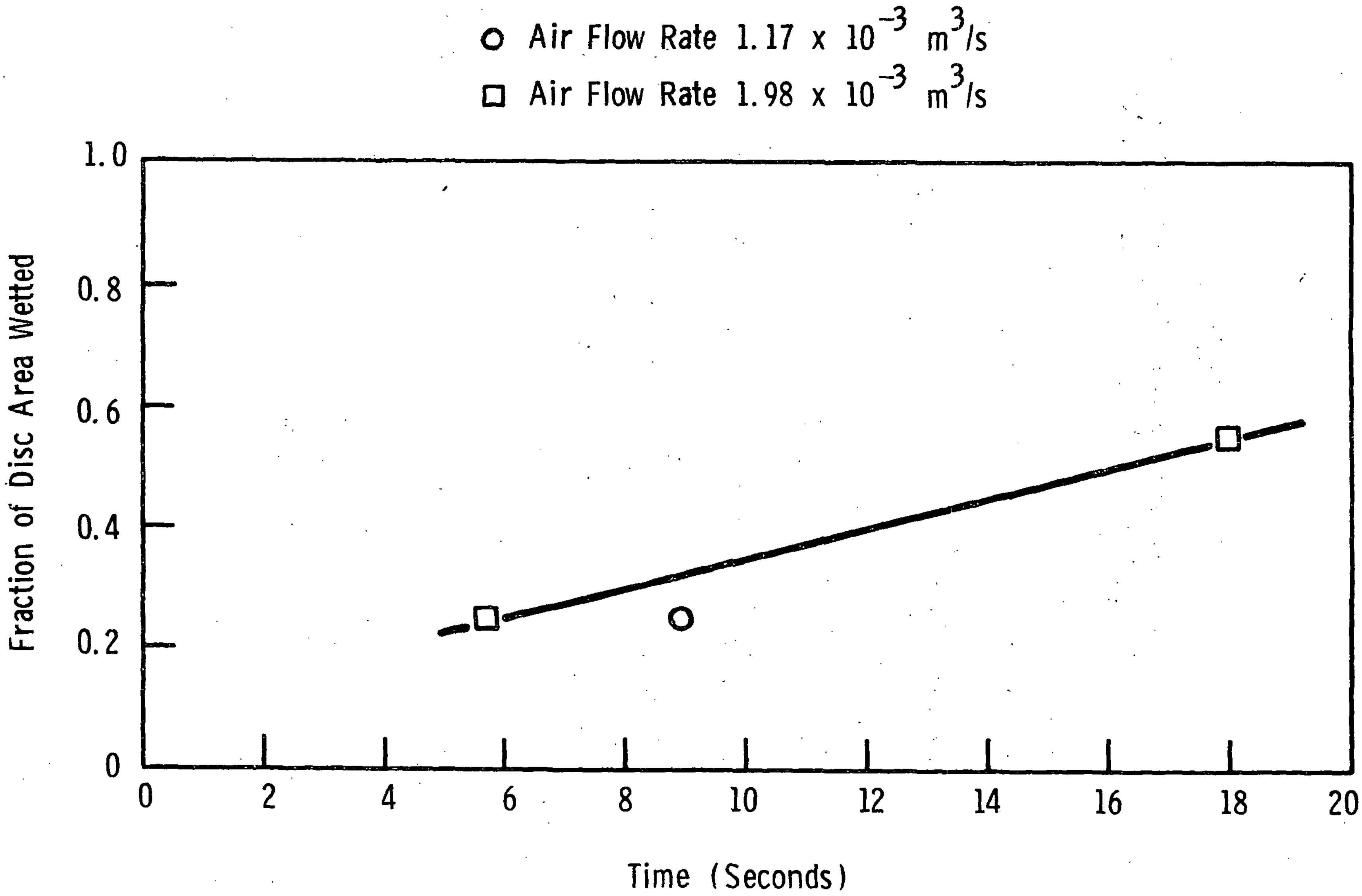


Table 6

Wetting and Deposit Data for XRM 232 A Containing 10 Wt % Freon BF on Plane Disc

Temp (°K)	533.3	588.8	533.3	588.8
Air Flow Rate[(1)] (m^3/s) x 10^3	1.17	1.17	1.98	1.98
Wetting Rate (cm^2/s) at 262 rad/s	3.24	1.93	4.69	2.63
Area Wetted (%) at 262 rad/s	76	100	25	55
Oil Consumption (cm^3/s)	.0862	.0862	.1233	.1233
Cleanliness Rating at 262 rad/s	89	89	86	87

(1) at 366°K and 41 N/m^2.

Table 7

Wetting and Deposit Data for Blend (G-10) of Ucon Fluids Containing 10% Water on Plane Disc

Temp (°K)	533.3	588.8	533.3	588.8
Air Flow Rate(1) (m^3/s) x 10^3	1.17	1.17	1.98	1.98
Wetting Rate (cm^2/s) at 262 rad/s	(2)	(2)	(2)	(2)
Area Wetted (%) at 262 rad/s	< 25	< 25	< 25	< 25
Oil Consumption (cm^3/s)	.0271	.0271	.0871	.0871
Cleanliness Rating at 262 rad/s	90	91	88	89

(1) at 366°K and 41 N/m^2.
(2) Insufficient wetted area for calculation.

g. Conoco DN-600 (Type II Polyalkyl Aromatic Hydrocarbon) and DN-600 Containing 5 Wt % Kendall 0839 Heavy Paraffinic Resin

Tables 8 and 9 summarize the results obtained when DN-600 and DN-600 containing the Kendall resin were evaluated for wettability. Both of these fluids showed relatively poor wetting characteristics under all test conditions listed. This behavior could not be explained in terms of misting rates since the consumption rates for these fluids are roughly intermediate between other fluids with better wettability properties. Comparison of physical properties (Appendix B-1) also reveals no reason for this behavior. Perhaps some property such as surface tension, which is similar for DN-600 and other fluids when measured at low temperature, begins to diverge at the relatively high temperature of the wettability tests.

As illustrated by Tables 8 and 9, both DN-600 and DN-600 containing the Kendall 0839 resin formed light to moderate deposits under most test conditions, but produced heavy deposits under the most severe condition of maximum disc temperature and minimum air flow rate where cleanliness ratings of 40 and 23, respectively, were obtained. The cleanliness rating was reduced at each set of test conditions by the presence of the Kendall 0839 resin.

h. Monsanto Modified C-Ether MCS-1370

MCS-1370 exhibited poor misting behavior, producing microfog in erratic intermittent bursts, and did not form sufficient film on the disc to allow calculation of any wettability data. As previously discussed, the Ucon Polyglycol Ether blend (G-10) containing water exhibited similar misting behavior. Both of these fluids have high surface tensions in comparison with other fluids tested (Appendix B-1), which probably accounts for the erratic nature of their mist formation under the test conditions employed. Previous work also indicated that increasing surface tension decreases mist output (3). The theoretical effects of surface tension on mist generation also were discussed earlier (1).

i. Comparison of Wettabilities and Deposit Forming Tendencies of Test Fluids

To simplify comparison of the test fluids, the wettability and deposit data for all fluids under directly comparable test conditions are summarized in Table 10.

It is readily apparent that XRL 850 A, XRM 205 F, XRL 850 A containing 5% Kendall 0839 resin, and XRM 232 A, in roughly that order, yield the highest overall wetting rates and disc areas wetted.

Table 8

Wetting and Deposit Data for DN-600 on Plane Disc

Temp (°K)	533.3	588.8	533.3	588.8
Air Flow Rate[(1)] (m^3/s) x 10^3	1.17	1.17	1.98	1.98
Wetting Rate (cm^2/s) at 262 rad/s	(2)	(2)	1.47	(2)
Area Wetted (%) at 262 rad/s	< 25	< 25	55	< 25
Oil Consumption (cm^3/s)	.0351	.0351	.1117	.1117
Cleanliness Rating at 262 rad/s	91	40	92	83

(1) at 366°K and 41 N/m^2.
(2) Wetted area insufficient for calculation.

Table 9

Wetting and Deposit Data for DN-600 Containing 5 Wt % Kendall 0839 Resin on Plane Disc

Temp (°K)	533.3	588.8	533.3	588.8
Air Flow Rate[(1)] (m^3/s) x 10^3	1.17	1.17	1.98	1.98
Wetting Rate (cm^2/s) at 262 rad/s	(2)	(2)	1.9	(2)
Area Wetted (%) at 262 rad/s	< 25	< 25	25	< 25
Oil Consumption (cm^3/s)	.0539	.0539	.0969	.0969
Cleanliness Rating at 262 rad/s	79	23	88	68

(1) at 366°K and 41 N/m^2.
(2) Wetted area insufficient for calculation.

Table 10

Summary of Wettabilities and Deposit Forming Tendencies of Various Fluids

Disc Angular Velocity = 262 rad/s

	Fluid Consumption Rate (cm^3/s)		Wetting Rate (cm^2/s)				Area Wetted (%)(1)				Cleanliness Rating(2)			
Conditions														
Temperature (°K)			533.3	533.3	588.8	588.8	533.3	533.3	588.8	588.8	533.3	533.3	588.8	588.8
Air Flow Rate(3) (m^3/s) x 10^3	1.17	1.98	1.17	1.98	1.17	1.98	1.17	1.98	1.17	1.98	1.17	1.98	1.17	1.98
Test Fluids														
XRM 205 F	.0165	.042	8.0	19.7	2.3	21.6	100	100	57	100	60	74	37	47
XRL 850 A	.0832	.1708	5.4	10.0	5.6	19.7	100	100	100	100	94	94	78	80
XRL 850 A + 5 Wt % Kendall 0839 Paraffinic Resin	.0747	.1347	7.9	8.0	4.1	4.1	100	100	57	100	78	90	88	82
DN-600	.0351	.1117	(4)	1.5	(4)	(4)	< 25	57	< 25	< 25	91	92	40	83
DN-600 + 5 Wt % Kendall 0839 Paraffinic Resin	.0539	.0969	(4)	1.9	(4)	(4)	< 25	25	< 25	< 25	79	88	23	68
XRM 232 A	.0611	.1267	4.8	6.2	2.6	2.5	100	100	57	57	95	94	89	91
XRM 232 A + 10 Wt % Freon BF	.0862	.1233	3.24	4.7	1.9	2.6	75	100	57	25	89	91	89	89
G-10 Blend of Ucon Polyglycol Ethers + 10 Wt % Water	.0274	.0871	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	90	88	91	89
Monsanto MCS-1370 Fluid	.0323	.0925	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	87	87	90	91

(1) During 20-second run.
(2) 100 = Perfectly clean; 30-minute test time.
(3) At 366°K and 41 N/m^2.
(4) Insufficient wetted area for rate calculation.

Although in general the fluids with poor wettability properties are characterized by low mist output (fluid consumption), one of the best fluids in terms of wettability (XRM 205 F) had by far the lowest rate of mist output of all fluids tested. In the case of XRM 205 F the low rate of mist output probably is due to its relatively high viscosity, the effects of which have been discussed previously (1, 2, 3). On the other hand, in the cases of the Ucon fluid blend and MCS-1370, the low mist output appears to be related instead to high surface tension (Appendix B-1). Thus, while high surface tension and high viscosity both reduce oil output from the mist generator, high surface tension also adversely affects wetting while high viscosity does not - in fact, high viscosity, or some property associated with high viscosity, such as low volatility, appears to enhance wetting; and thus actually offsets the effects of low mist output. In this connection it is of interest to compare XRM 205 F and XRL 850 A, which chemically are closely related, but have widely different viscosities. Although mist outputs for these oils also are widely different, their wettability characteristics are surprisingly close, suggesting again that while high viscosity suppresses mist output, it (or low volatility) compensates by enhancing wetting.

Since two oils can produce similar wetting data at widely different oil consumption rates, it is obvious that wetting efficiency - i.e., the ability of a given amount of oil misted to produce a liquid oil film - also varies widely. This is illustrated by Table 11, where "wetting efficiencies" are calculated by dividing wetting rates by the oil consumption rates for those oils which produced usable wetting rate data. It is readily apparent that, under the test conditions employed, the wetting efficiency of XRM 205 F is very high, those of XRL 850 A and XRM 232 A intermediate and similar, and that of DN-600 somewhat lower.

Deposit formation by most of the test fluids fell within the range of very light to moderate under the various test conditions of the deposit test procedure (Table 10). Overall, the best cleanliness ratings were obtained with XRM 232 A. Only three test fluids produced cleanliness ratings below 78 at any test condition - XRM 205 F under all test conditions, and DN-600, with or without Kendall 0839 resin, under the most severe set of test conditions which combined the highest temperature with the lowest air flow rate.

2. Surface Cooling Effects of Microfog Streams on Plane Disc

On the basis of their overall performances in the wettability and deposit-forming studies, XRM 232 A and XRL 850 A were selected for evaluation of the heat transfer chracteristics (cooling effects) of microfog streams.

Table 11

Wetting Efficiencies of Various Fluids

Disc Angular Velocity = 262 rad/s

Disc and Chamber Temp, °K	533.3						588.8					
Air Flow Rate[1] (m^3/s) x 10^3	1.17			1.98			1.17			1.98		
	Oil Consumption Rate, cm^3/s	Wetting Rate, cm^2/s	Wetting Efficiency[2]	Oil Consumption Rate, cm^3/s	Wetting Rate, cm^2/s	Wetting Efficiency[2]	Oil Consumption Rate, cm^3/s	Wetting Rate, cm^2/s	Wetting Efficiency[2]	Oil Consumption Rate, cm^3/s	Wetting Rate, cm^2/s	Wetting Efficiency[2]
Test Fluids												
XRM 205 F	0.0165	8.0	4.8	0.042	19.7	4.7	0.0165	2.3	1.4	0.042	21.6	5.1
XRL 850 A	0.0832	5.4	0.65	0.1708	10.0	0.59	0.0832	5.6	0.67	0.1708	19.7	1.2
XRL 850 + 5 Wt % Kendall Resin	0.0747	7.9	1.1	0.1347	8.0	0.59	0.747	4.1	0.55	0.1347	4.1	0.30
DN-600	0.0351	(3)	(3)	0.1117	1.5	0.13	0.0351	(3)	(3)	0.1117	(3)	(3)
DN-600 + 5 Wt % Kendall Resin	0.0539	(3)	(3)	0.0969	1.9	0.19	0.0539	(3)	(3)	0.969	(3)	(3)
XRM 232 A	0.0611	4.8	0.79	0.1267	6.2	0.49	0.0611	2.6	0.42	0.1267	2.5	0.19
XRM 232 A + 10 Wt % Freon BF	0.0862	3.24	0.38	0.1233	4.7	0.38	0.0862	1.9	0.22	0.1233	2.6	0.21

(1) At 366°K and 41 N/m^2.

(2) Wetting Efficiency = $\frac{\text{Disc Wetting Rate } (cm^2/s)}{\text{Oil Consumption Rate } (cm^3/s) \times 10^2}$

(3) Could not be calculated because of insufficient wetted area.

For base line data, the cooling effects of the carrier-gas (air) alone impinging on the heated disc surface were determined. The experimental procedure for this preliminary study differed from the earlier described procedure for determination of the net effect of the oil. The test chamber and rotating disc were held at test temperature with fixed thermal energy to the disc (manual mode of ECS controller), and without air flowing to the disc or test chamber. Meanwhile, air at 366.4°K was circulated, at the specific air flow rate required for the test, directly to the exhaust system, bypassing the mist generator. Once equilibrium was established, the three-way valve was activated, directing the stream of pure air to the disc surface for a test duration of ten minutes.

The total disc temperature changes obtained in ten minutes are plotted in Figures 32 to 34. Results are summarized as follows:

- At disc velocities from 104 to 262 rad/s, disc temperatures from 477.7 to 588.8°K, and air flow rates from 0.769 to 1.98 $m^3/s \times 10^3$, measured temperature drops ranged from 31.7 to 90.5°K.
- Temperature drops increased as the air flow rate increased.
- Temperature drops increased as the initial disc temperature increased.
- The angular velocity of the disc had little influence on the disc temperature change. A consistent (but slight) trend toward larger temperature drops with increasing angular velocity was observed only at the lowest air flow rate (Table 12).

The net cooling effects of XRL 850 and XRM 232 A (by the procedure described under "Apparatus and Procedure") are summarized, respectively, in Tables 13 and 14.

Trends are similar to those observed for the effects of air alone - i.e., drops in disc temperature due to the presence of the liquid phase in the microfog stream tend to increase with rising disc temperature, and with increasing air flow rate, which, of course, also increases the amount of oil misted. However, the disc temperature changes due to the presence of the

Figure 32

HEAT TRANSFER STUDIES
PLANE DISC, AIR ONLY, 477.7°K

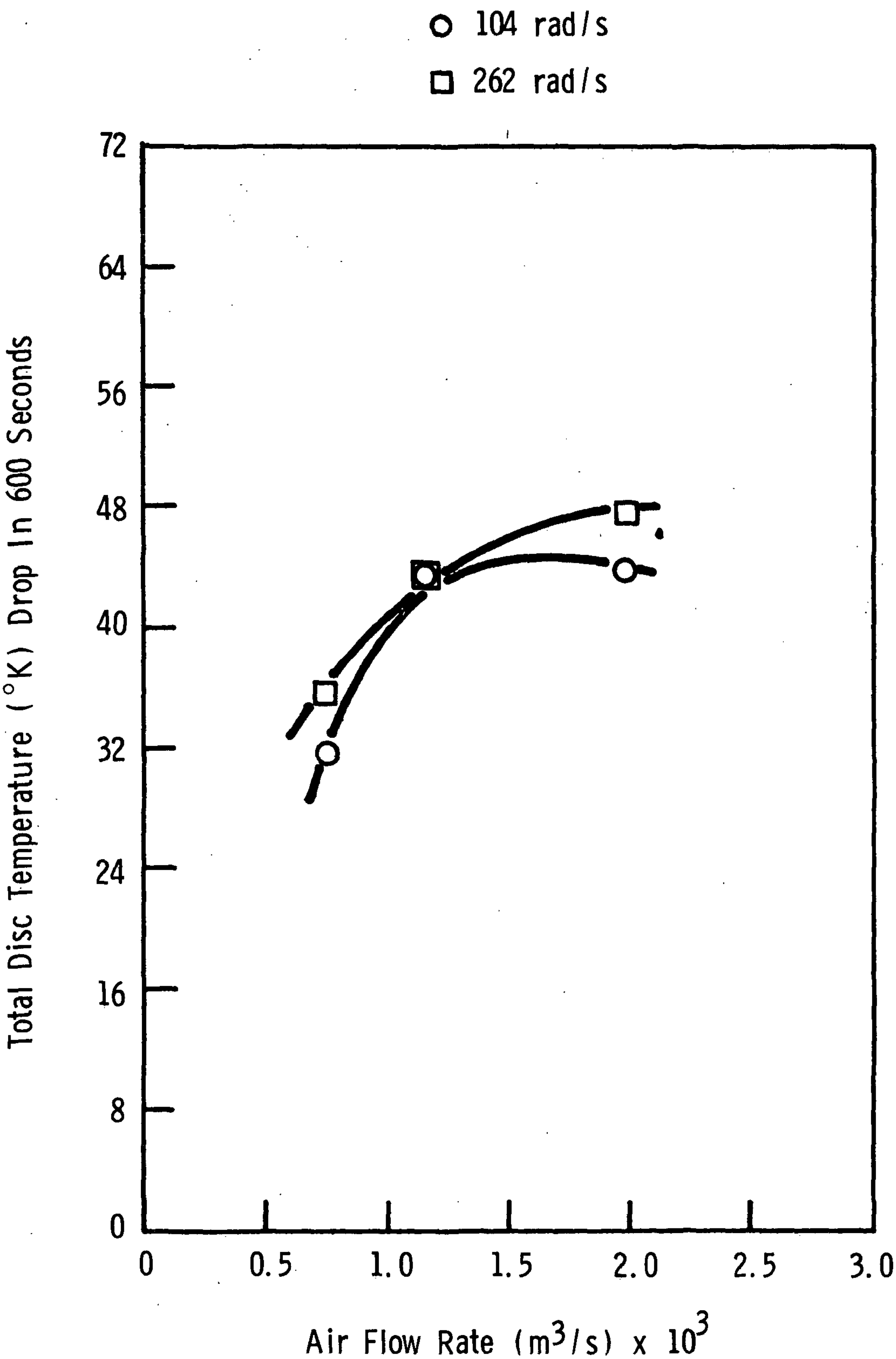


Figure 33

HEAT TRANSFER STUDIES
PLANE DISC, AIR ONLY, 533.3°K

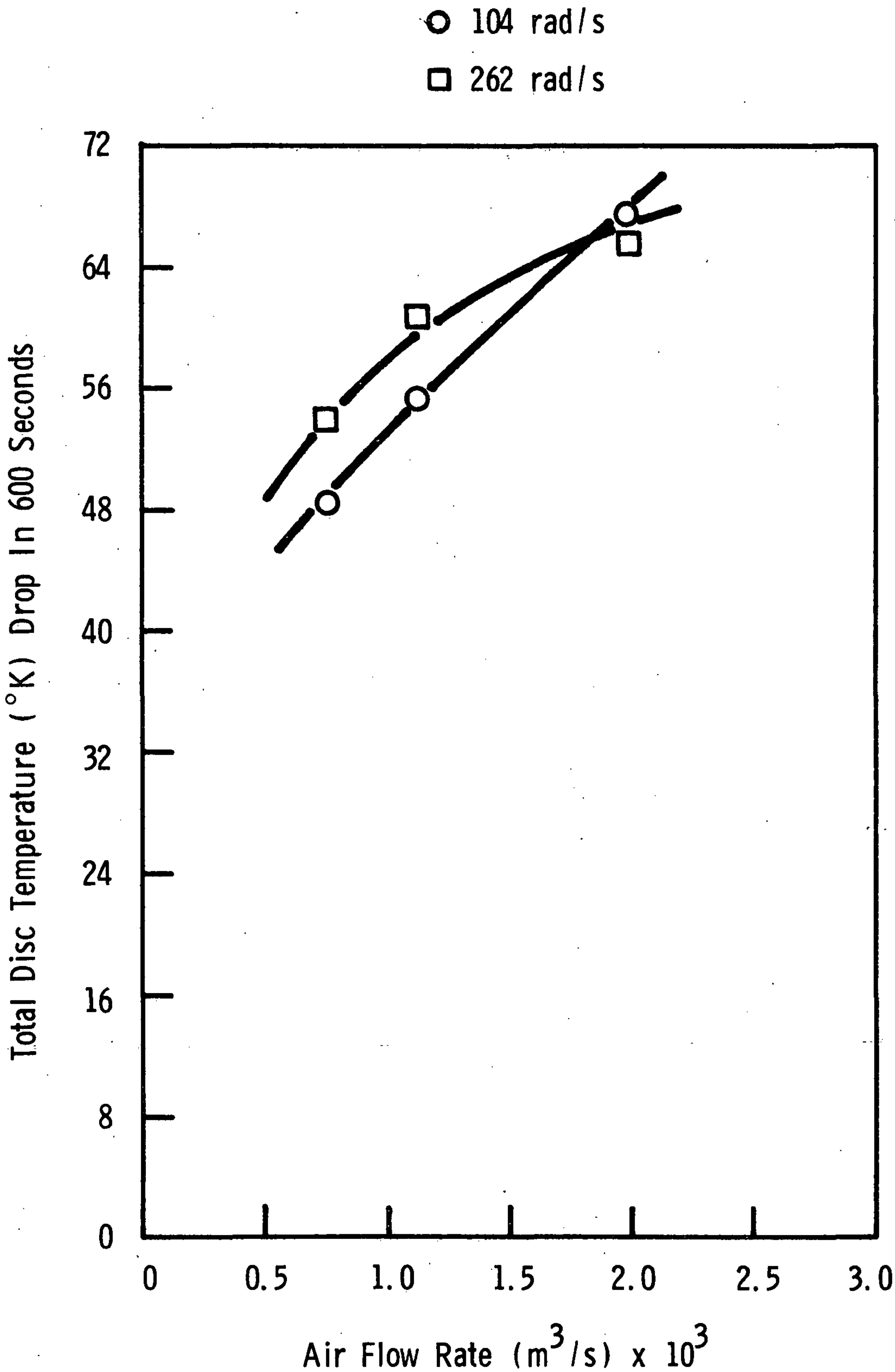


Figure 34

HEAT TRANSFER STUDIES
PLANE DISC, AIR ONLY, 588.8°K

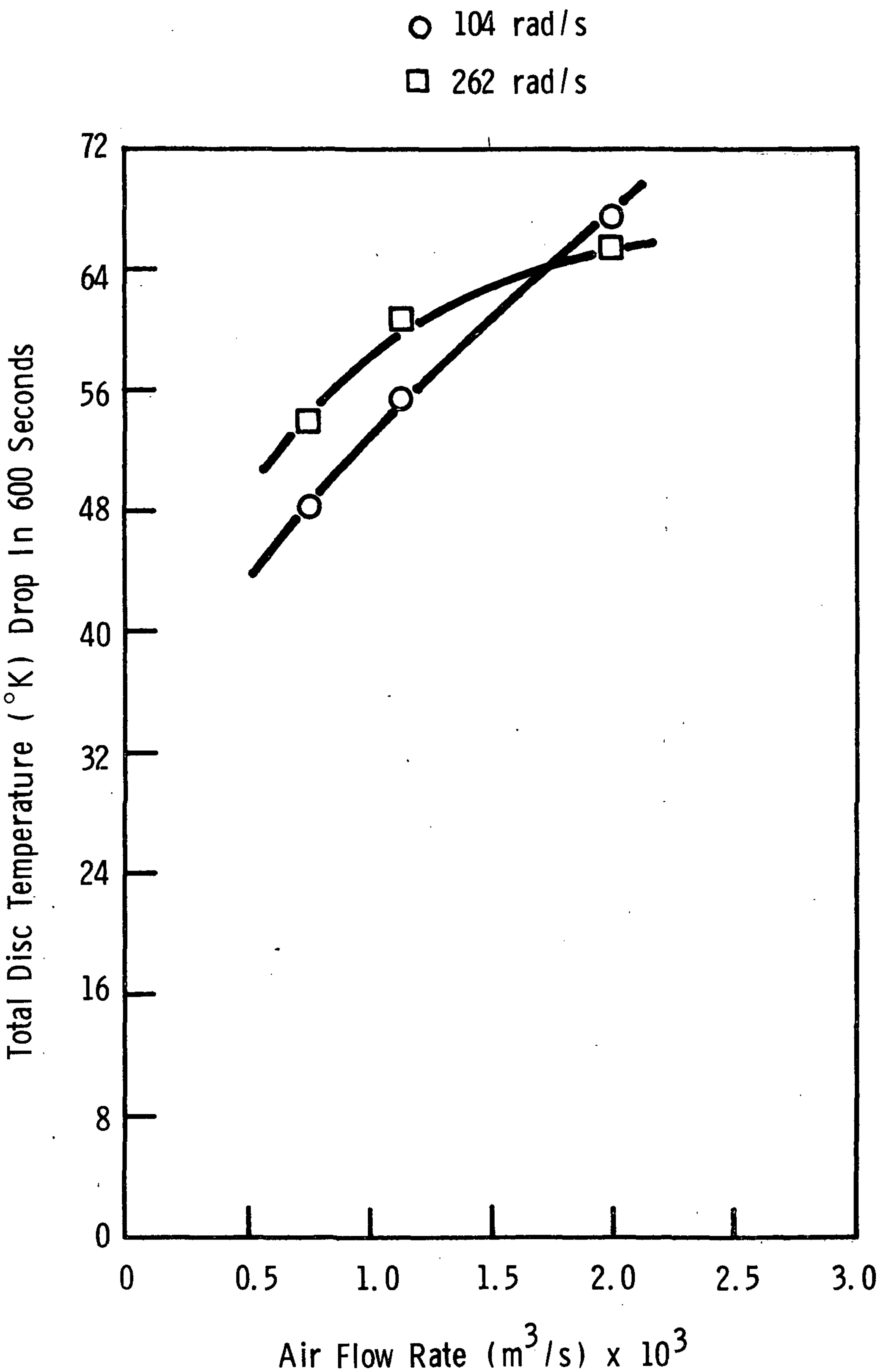


Table 12

Heat Transfer Data - Air Alone on Plane Disc

Test Conditions			
Disc Angular Velocity, (rad/s)	Temp (°K)	Air Flow Rate (m^3/s) x 10^3	Total Temp (°K) Change in 10 Minutes
104	477.7	0.769	31.7
104	533.3	0.769	48.3
104	588.8	0.769	57.8
104	477.7	1.17	43.3
104	533.3	1.17	55.6
104	588.8	1.17	65.0
104	477.7	1.98	43.9
104	533.3	1.98	67.6
104	588.8	1.98	90.5
262	477.7	0.769	35.6
262	533.3	0.769	53.9
262	588.8	0.769	68.8
262	477.7	1.17	43.3
262	533.3	1.17	60.6
262	588.8	1.17	62.8
262	477.7	1.98	47.2
262	533.3	1.98	65.6
262	588.8	1.98	86.6

Table 13

Heat Transfer Data - XRL 850 A on Plane Disc

Test Conditions			
Disc Angular Velocity, (rad/s)	Temp (°K)	Air Flow Rate $(m^3/s) \times 10^3$	Total Temp (°K) Change in 10 Minutes
104	477.7	0.769	None
104	533.3	0.769	None
104	588.8	0.769	None
104	477.7	1.17	None
104	533.3	1.17	1.0
104	588.8	1.17	3.8
104	477.7	1.98	4.6
104	533.3	1.98	9.4
104	588.8	1.98	11.1
262	477.7	0.769	None
262	533.3	0.769	None
262	588.8	0.769	None
262	477.7	1.17	1.8
262	533.3	1.17	3.4
262	588.8	1.17	3.9
262	477.7	1.98	3.4
262	533.3	1.98	4.1
262	588.8	1.98	11.1

Table 14

Heat Transfer Data - XRM 232 A on Plane Disc

Test Conditions			
Disc Angular Velocity, (rad/s)	Temp (°K)	Air Flow Rate (m^3/s) x 10^3	Total Temp (°K) Change in 10 Minutes
104	477.7	0.769	None
104	533.3	0.769	None
104	588.8	0.769	None
104	477.7	1.17	5.0
104	533.3	1.17	4.2
104	588.8	1.17	4.2
104	477.7	1.98	6.1
104	533.3	1.98	5.2
104	588.8	1.98	11.2
262	477.7	0.769	None
262	533.3	0.769	None
262	588.8	0.769	None
262	477.7	1.17	4.2
262	533.3	1.17	4.1
262	588.8	1.17	5.6
262	477.7	1.98	3.0
262	533.3	1.98	7.0
262	588.8	1.98	7.1

oil in the microfog stream are much smaller than those determined for the air alone, and are not measurable at the lowest air flow rate by the procedure employed.

To confirm the observation that the cooling effects of the oil phase were small compared with those of the air phase, a brief series of runs was made with XRL 850 wherein the total surface cooling effect of air and oil in the microfog stream was determined. This was accomplished by the method described for the surface cooling effect of air alone, except that the air was passed through the generator so that a total microfog stream (air/oil) was directed at the disc instead of a pure air stream. The results obtained are listed in the first data column of Table 15.

By subtracting these data from those obtained previously for air alone, the net surface cooling effect of the oil is obtained by a different procedure. Values so calculated are listed in the second data column of Table 15, and can be compared with those obtained earlier by the standard procedure, which are listed in the third data column. Both techniques subtract, in one way or another, the large effect of air from the total surface cooling effect to yield the relatively small effect of the oil. Hence, while groups of such data are useful in revealing trends, individual data may be somewhat inaccurate, and the lack of close agreement on a few points by the two methods is not surprising. Nevertheless, the comparison does confirm the small cooling effect of the oil phase relative to the air phase of the aerosol.

3. Wettability Studies with Complex Disc Simulating Bearing Geometry

A drawing of the disc fabricated for this work was presented in Figure 2, and the microfog delivery system for the disc was depicted in Figure 4. The microfog stream impinges against the external surface of the conical section mounted at the center, which simulates the inner race of a bearing. Aided by centrifugal force and the force of the air stream, the oil wetted out migrates to the collector ring which surrounds the central cone, simulating a bearing cage, and is slung radially through the holes in the collector ring toward the bevelled surface which simulates the outer race of a bearing. The objective of the investigation was to determine whether lubricant delivered as a microfog at the simulated inner race would, under test conditions simulating advanced flight, supply a film of lubricant sufficient for carrying out lubrication functions at the simulated outer race.

Table 15

Surface Cooling Effects of XRL 850 A on Plane Disc

Disc Temperature: 588°K
Disc Angular Velocity: 262 rad/s

Air Flow Rate (m^3/s) x 10^3	Disc Temperature Drop (°K)		
	Air + Oil (1)	Oil Alone, Calculated (2)	Oil Alone, Determined (3)
0.769	60.2	(8.6 gain)	0
1.17	67.8	3.9	4.0
1.98	91.4	11.1	4.8

(1) By method described for air alone.
(2) By subtracting temperature drop for air alone, Table 12, from temperature drop for air + oil, above.
(3) By method described for Net Effect of Oil, data taken from Table 13.

A series of preliminary runs without oil was made to determine optimum photographic conditions for the complex disc. Photography was complicated because the area of interest, the curved and bevelled simulated outer race, presented only one small, weak highlight in contrast to the plane disc, whose entire surface could be strongly highlighted because it lay in one plane. With the complex disc, the planar surfaces were not the areas of interest and, in any event, tended to lie in the shadows cast by the projecting features of the disc face. Best results were obtained with the existing lighting and a film speed of 400 fps as a compromise to maximize exposure of the area of interest at the expense of some loss of resolution.

Conditions selected for the wettability tests with the complex disc were as follows:

Temp (°K)	Air Flow Rate (m^3/s) x 10^3	Disc Angular Velocity, rad/s
477.7	0.769	104
477.7	0.769	262
477.7	1.17	104
477.7	1.17	262
477.7	1.98	104
477.7	1.98	262

The test oil in this series was XRM 232 A. (Advanced Type II Ester).

After a careful analysis of the wetting run films, it was determined that no quantitative measurements of wetting of the simulated outer race could be made, and only a qualitative evaluation of the wetting process would be possible. Beside the problems of limited illuminated field and shadowed disc already cited, the disc was necessarily designed so that essentially the entire surface of the simulated outer race is simultaneously spattered by oil droplets sprayed from the perforated "cage". Hence, there is no readily apparent circular line of demarcation between wet and dry sections as in the plane disc work, where wetting consisted largely of spreading of the oil wetted out at the center of the disc.

Despite the lack of quantitative data, the work with the complex disc led to the following observations and conclusions:

- Absence of the stray mist that usually collects in the test chamber during test runs with a plane disc indicated that collection of the oil particles impinging on the simulated inner race was very efficient. This may have been due in part to the closer proximity of the reclassifying nozzle to the complex disc (0.6 cm) than to the plane disc (2.54 cm), but may also be related to the different geometrical configuration of the nozzle and disc system. In particular, the reclassifying nozzle is oriented at a 45° angle to the surface of impingement on the complex disc, and at 90° to the plane disc.

- Under all test conditions listed, the complex disc was completely wetted with oil when removed after the 20-second run, indicating a plentiful supply of lubricant to the simulated outer race. Moreover, although oil film formation could not be followed, the high speed motion pictures did reveal what appeared to be large numbers of large (individually visible) air-borne oil droplets moving across the shadowed area between the perforated cone and simulated outer race, toward the "outer race".

4. Surface Cooling Effects of Microfog Streams on Complex Disc

Surface cooling studies with the complex disc were conducted by the techniques already described for the effect of air alone, and for the net effect of the oil in the microfog stream. Results with air alone are reported in Figure 35 and Table 16, where comparable results with the plane disc also are included for comparison. The data can be summarized as follows:

- The total temperature change increased as the air flow rate increased.

- Disc angular velocity in the range of 104 to 262 rad/s had little effect on the cooling of the disc.

- Larger temperature changes were observed with the complex disc than with the plane disc, suggesting that complex geometry enhances contact between the air stream and the disc - possibly by eliminating, through turbulance, a stagnant air layer adjacent to the disc.

Figure 35

HEAT TRANSFER STUDIES
COMPLEX DISC, AIR ONLY, 477.7°K

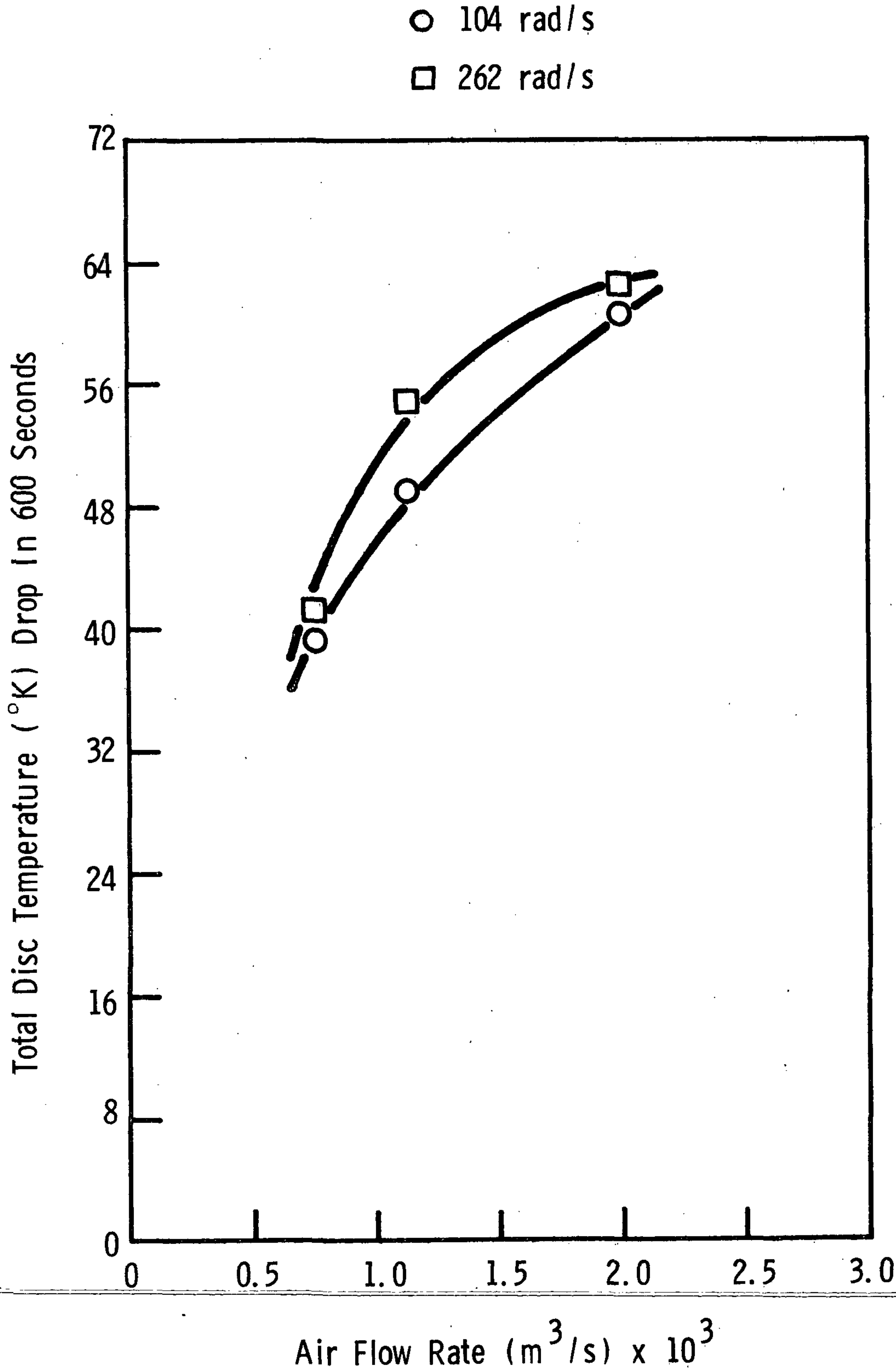


Table 16

Heat Transfer Data for Air Alone on Complex Disc

Test Conditions			Total Temp (°K) Change in 10 Minutes	
Disc Angular Velocity, (rad/s)	Temp (°K)	Air Flow Rate (m^3/s) x 10^3	Complex Disc	Plane Disc
104	477.7	0.769	42.6	31.7
262	477.7	0.769	43.5	35.6
104	477.7	1.17	49.0	43.3
262	477.7	1.17	55.2	43.3
104	477.7	1.98	65.4	43.9
262	477.7	1.98	67.2	47.2

The net surface cooling effects of XRM 232 A as a component of microfog streams impinging on the complex disc are listed in Table 17 for a 477.7°K initial disc temperature, and in Table 18 for a 533.3°K initial disc temperature. Where available, comparable data for the plane disc are included in these tables.

As noted earlier for the plane disc, the temperature changes brought about by the cooling effect of the oil on the complex disc were small compared to those determined previously for the air alone on the complex disc. General trends were similar to those observed with the plane disc:

- Temperature changes were larger at higher air flow rates.
- The angular velocity of the complex disc had little effect on the temperature change brought about by the oil.
- Temperature declines tended to be larger at the higher disc temperature.

Comparing the net effect of the oil on the complex and plane discs (Tables 17 and 18) indicates larger temperature declines on the complex disc. This is in agreement with the earlier observations that collection of the mist particles seemed to be more efficient on the complex disc, and that better contact of the air (and hence particles) seemed to occur on the complex disc.

In the heat transfer work with the complex disc, a broader range of disc angular velocities (from 51 rad/s to 524 rad/s) confirmed that this variable had little influence on the heat transfer processes under the conditions of the investigation (Tables 17 and 18).

Table 17

Heat Transfer Data - XRM 232 A on Complex Disc

Test Conditions			Total Temp (°K) Change in 10 Minutes	
Disc Angular Velocity, (rad/s)	Temp (°K)	Air Flow Rate $(m^3/s) \times 10^3$	Complex Disc	Plane Disc
104	477.7	0.769	None	None
262	477.7	0.769	None	None
52	477.7	1.17	3.0	
104	477.7	1.17	4.8	5.0
262	477.7	1.17	4.8	4.2
524	477.7	1.17	7.2	
52	477.7	1.98	9.6	
104	477.7	1.98	7.0	6.1
262	477.7	1.98	8.4	3.0
524	477.7	1.98	23.4	

Table 18

Heat Transfer Data - XRM 232 A on Complex Disc

Test Conditions			Total Temp (°K) Change in 10 Minutes	
Disc Angular Velocity, (rad/s)	Temp (°K)	Air Flow Rate (m^3/s) x 10^3	Complex Disc	Plane Disc
52	533.3	1.17	4.2	
104	533.3	1.17	4.4	4.2
262	533.3	1.17	5.4	4.1
524	533.3	1.17	5.7	
52	533.3	1.98	12.2	
104	533.3	1.98	10.9	5.2
262	533.3	1.98	10.6	7.0
524	533.3	1.98	12.3	

IV. REFERENCES

1. Shim, J. and S. J. Leonardi; "Microfog Lubricant Application System for Advanced Turbine Engine Components", Task I Report, NASA CR-72291, Sept. (1967).

2. Shim, J. and S. J. Leonardi; "Microfog Lubricant Application System for Advanced Turbine Engine Components", Final Report, NASA CR-72489, Sept. (1968).

3. Shim, J. and S. J. Leonardi; "Microfog Lubricant Application System for Advanced Turbine Engine Components", Task I and II Report, NASA CR-72743, May (1970).

4. Shim, J. and S. J. Leonardi; "Microfog Lubricant Application System for Advanced Turbine Engine Components", Phase II, NASA CR-120843, Aug. (1971).

5. Leonardi, S. J., E. A. Oberright, and L. J. DeBrohun; "Study and Evaluation of the Oxidative and Deposit-Forming Properties of High Temperature Lubricants", Air Force Technical Report, AFAPL-TR-66-87, Oct. (1966).

APPENDIX A

Statement of Work
Contract NAS3-16729

I. SCOPE OF WORK

The Contractor shall furnish the necessary personnel, facilities, services and materials and do all things necessary for, or incident to, the work described below:

A. Task I - Screening of Test Fluids

The Contractor shall perform a series of dynamic screening tests to investigate the residual film forming ability and wettability for each of the nine (9) test lubricants using the rotating disk test rig and equipment described in reference 1*. The lubricants, ambient conditions, and the manner of operation are as prescribed in this task.

1. Test Lubricants

The following nine lubricants shall be used in this investigation:

a. Mobil XRM-177F synthetic paraffinic hydrocarbon plus an antioxidant.

b. Mobil XRL-850A synthetic hydrocarbon.

c. Mobil XRL-850A plus 5 weight percent Kendall 0839 paraffinic heavy resin.

d. Conoco DN-600 (fully formulated) Type II polyalkyl aromatic hydrocarbon.

e. Conoco DN-600 plus 5 weight percent Kendall 0839 paraffinic heavy resin.

f. Monsanto C-ether blend fluid to be selected by the Contractor subject to the approval of the NASA Project Manager.

g. Mobil XRM-232A advanced Type II ester.

h. Mobil XRM-232A plus 10 weight percent of Freon type additive.

i. Blend of Union Carbide UCON50HB polyglycol ether fluids mixed with 10 weight percent water to obtain a viscosity similar to that of Mobil XRM-177F at 210°F.

*Reference No. 1: NASA Contract NAS3-13207, Article I, Exhibit A (June 25, 1969), Task III.

Substitution of items in this list can be made by agreement of the Contractor and the NASA Project Manager pursuant to the Technical Direction Article of the Schedule.

2. Test Procedure and Conditions

Each of the nine (9) test lubricants listed in paragraph 1 of this Task shall be tested in a manner similar to that in reference 1 except that the dropwise oil feed system shall not be used, and the operating conditions shall be as listed below.

a. Test Conditions:

(1) Oil and gas temperature in generator: 200 (±10)°F.

(2) Test Specimen Temperature: all nine (9) of the test lubricants shall be tested at 500 (±10)°F. Four (4) of these fluids, to be selected by the Contractor, subject to the approval of the NASA Project Manager, shall be tested at 600 (±10)°F.

(3) Use air as the mist carrier gas.

(4) Two air flow rates and at one disk rotational speed to be selected by the Contractor with the approval of the NASA Project Manager.

(5) Spray nozzle: the novel pneumatic convergent type with 150 mesh screen insert that was developed in reference 1 - Task V.

(6) Test chamber pressure: constant value (e.g., 5 psig) somewhat higher than maximum back pressure.

(7) Spray distance between nozzle and test disk: one inch horizontal (axial) distance from the disk surface and directed at the center of the disk and normal to that surface.

b. The test lubricants shall not be degassed before running as was done in previous Tasks of this effort.

B. Task II - Fluid/Nozzle Optimization Tests

The Contractor shall perform a series of wettability tests using at least four (4) of the test lubricants screened in Task I and using the plane disk specimen. Also, wettability tests shall be made using two (2) of these test lubricants with a stepped disk specimen with simulated bearing inner race supply collector ring, to be made as shown in Figure 1 attached hereto and made a part hereof. Test conditions for the plane disk runs shall be the same as those specified for Task I.2. except for those additions and changes given below:

1. Three (3) disk specimen temperatures of 400, 500 and 600 ($\pm$10)°F.

2. Two (2) disk rotational speeds and three (3) air flow rates to be selected by the Contractor subject to the approval of the NASA Project Manager.

Test conditions for the stepped disk runs shall be varied within the limits of the plane disk conditions to permit a minimum of twelve (12) different runs as defined by disk temperature, disk rotational speed, and air flow rates. Selection of the lubricants, nozzle, and operating conditions for the stepped disk runs shall be made by the Contractor based on the prior testing, when possible, and these choices shall be subject to the approval of the NASA Project Manager.

C. Task III - Surface Cooling Studies

Using the microfog lubricant applicator test rig specified in Task I, the Contractor shall measure the cooling effect of oil-fog sprays on the heated rotating plane disk and stepped disks for two different oils or formulations. The disks shall be maintained at the required temperature while spraying each of the two test fluids on the disks. After reaching steady state conditions of temperature, pressure, and flow, the rate of heat transfer through the disk shall be measured. Test conditions shall be used as defined in Task II except that the stepped disk shall be studied at only one temperature and tests with the plane disk shall be at each of two temperatures. Test temperatures and fluids shall be as selected by the Contractor from those employed in Task II subject to the approval of the NASA Project Manager.

APPENDIX B-1

Physical Properties of Test Fluids

Fluid	Mobil XRM 205 F	Mobil XRL 850 A	XRL 850 A + 5% Kendall 0839 Resin	Conoco DN 600	Conoco DN 600 + 5% Kendall 0839 Resin	Monsanto C-Ether Blend Fluid MCS-1370	Mobil XRM 232 A	XRM 232 A + 10% Freon Additive	Blend G-10
Chemical Type	Synthetic Paraffinic Hydrocarbon + Antiwear Additive and Antioxidant	Synthetic Hydrocarbon	Synthetic Hydrocarbon + 5 Wt % Kendall Paraffinic Resin	Synthetic Hydrocarbon	Synthetic Hydrocarbon + 5 Wt % Kendall Paraffinic Resin		Advanced Type II Ester Fluid	Advanced Type II Ester Fluid + 10 Wt % Freon BF	Ucon Polyglycol Ester Fluid + 10 Wt % Water
Flash Point. °F (COC)	515	435	455	405	400	470	505	495	(a)
Fire Point. °F (COC)	635	500	515	445	455	525	560	505	(a)
Autogeneous Ignition Point, °F	730	650	690	670	680	840	740	760	700
Kinematic Viscosity (cs)									
@ 400°F	5.76	1.50	1.64	2.38	2.57	.72	1.31	-	-
@ 210°F	39.61	6.12	7.26	9.99	11.26	3.5	5.14	-	43.4
@ 100°F	444	35.10	44.0	56.96	67.36	18.79	51.3	20.89	290
@ 0°F	39064	954	1343	1693	2242	2794	783	513	18717
Density @ 20°C. g/cm^2	.8473	.8307	.8334	.8786	.879	1.1544	.9903	1.0303	1.0572
Surface Tension @ 25°C dynes/cm	32.7	30.4	30.5	31.2	31.2	41.6	30.8	30.8	38.6
Specific Heat cal/GDC									
@ 200°F	.604	.590	.691	.546	.558	.405	.520	.467	.602
@ 400°F	.693	.676	.803	.634	.648	.462	.588	-	-

(a) Could not be determined because of water present.

APPENDIX B-2

PHYSICAL PROPERTIES OF FREON BF

Chemical Formula	CCl_2F-CCl_2F
Molecular Weight	203.84
Boiling Point at One Atmosphere, °F	199.0
°C	92.8
Freezing Point, °F	79
°C	26
Critical Temperature, °F	532
°C	278
Critical Pressure, psia	500
atm	34
Density at 77°F (25°C)	
Liquid, lbs/ft^3	102.1
$grams/cm^3$	1.634
Sat'd Vapor at boiling point, lbs/ft^3	0.438
grams/liter	7.02
Latent Heat of Vaporization at boiling pt, Btu/lb	67
cal/gram	37 (est)
Thermal Conductivity at 70°F (21.1°C), Btu/(hr)(ft^2)(°F/ft), Liquid	0.040
Refractive Index of Liquid at 79.7°F (26.5°C)	1.413
Surface Tension at 86°F (30°C), dynes/cm	2.3
Relative Dielectric Strength (nitrogen = 1)	5 (est)
Dielectric Constant	
Liquid at 77°F (25°C), 100 H_z	2.54
Solubility in water at saturation pressure & 77°F (25°C), % by wt	0.012

APPENDIX C-1

Wetting Data for XRM 205F on Plane Disc

Run No.	Temp. (°K)	Air Flow Rate $(m^3/s) \times 10^3$	Disc Speed (rad/s)	Wetting Time for Indicated Fraction of Disc Area (Seconds)					Wetting Rate (cm^2/s)
				0.0625	0.25	0.55	0.76	1.0	
A-32	477.7	0.769	104	(1)					
A-33	477.7	1.17	104	1.02	2.36			7.13	11.33
A-34	477.7	1.98	104	0.66	1.45	3.20		4.65	19.02
A-35	477.7	0.769	262		8.55	14.19			5.13
A-36	477.7	1.17	262	1.12	3.28	5.18		9.34	9.24
A-37	477.7	1.98	262	0.65	1.62	3.18		4.70	18.7
A-38	533.3	0.769	104	(1)					
A-39	533.3	1.17	104	1.04	2.61	4.79		6.84	9.72
A-40	533.3	1.98	104	0.655	1.29	2.16		3.73	24.7
A-41	533.3	0.769	262	0.578	3.02	11.52			3.60
A-27	533.3	1.17	262	0.8975	2.447	5.615		10.05	7.98
A-26	533.3	1.98	262	0.485	1.37	2.78		4.46	19.7
A-42	588.8	0.769	104	(1)					
A-43	588.8	1.17	104	0.98	1.98	6.45			7.31
A-44	588.8	1.98	104	0.55	1.06	2.37		7.77	10.51
A-45	588.8	0.769	262	3.87	9.26(2)				1.15
A-25	588.8	1.17	262	1.25	3.54	18.59			2.32
A-24	588.8	1.98	262	0.4775	1.14	2.25		3.95	21.6

(1) Wetted fraction less than 0.0625.
(2) For area fraction of 0.14.

APPENDIX C-2

Wetting Data for XRM 232A on Plane Disc

Run No.	Temp. (°K)	Air Flow Rate $(m^3/s) \times 10^3$	Disc Speed (rad/s)	Wetting Time for Indicated Fraction of Disc Area (Seconds)					Wetting Rate (cm^2/s)
				0.0625	0.14	0.25	0.55	1.0	
C-19	477.7	0.769	104	1.56	8.50				0.89
C-20	477.7	1.17	104	0.55		1.44	2.76	4.90	17.45
C-21	477.7	1.98	104	0.54		1.03	1.80	2.90	52.17
C-22	477.7	0.769	262	1.41	6.34				1.27
C-23	477.7	1.17	262	0.833		1.61	3.0	5.40	18.7
C-24	477.7	1.98	262	0.46		0.930	1.60	2.52	36.85
C-17	533.3	0.769	104	0.625	1.34				2.93
C-18	533.3	1.17	104	0.60		1.86	5.35	13.27	5.32
C-15	533.3	1.98	104	0.32		1.69	4.13	9.34	7.93
C-16	533.3	0.769	262	0.35	0.93				1.27
C-2	533.3	1.17	262	1.05		3.73	7.98	16.39	4.79
C-1	533.3	1.98	262	1.11		2.51	6.35	12.37	
C-10	588.8	0.769	104	3.50	7.79				1.46
C-11	588.8	1.17	104	1.13		3.57	12.32		3.11
C-12	588.8	1.98	104	0.94		4.64	14.88		2.09
C-13	588.8	0.769	262	2.68					-
C-4	588.8	1.17	262	1.42		8.62	18.37		2.56
C-3	588.8	1.98	262	1.31		5.64	15.8		2.45

APPENDIX C-3

Wetting Data for XRL 850A on Plane Disc

Run No.	Temp. (°K)	Air Flow Rate $(m^3/s) \times 10^3$	Disc Speed (rad/s)	Wetting Time for Indicated Fraction of Disc Area (Seconds) 0.0625	0.14	0.25	0.39	0.55	0.76	1.0	Wetting Rate (cm^2/s)
B-12	477.7	0.769	104	0.56		1.44		3.19		17.81	4.39
B-13	477.7	1.17	104	1.02		2.07		4.07		6.71	13.34
B-14	477.7	1.98	104	0.71		1.27		2.50		4.53	19.87
B-15	477.7	0.769	262	1.73		6.43		16.0			2.76
B-16	477.7	1.17	262	0.612		1.53		2.95		5.87	14.45
B-17	477.7	1.98	262	0.517		1.23		2.16		3.95	22.13
B-18	533.3	0.769	104	1.54		8.81	12.74				2.36
B-19	533.3	1.17	104	0.9875		2.25		5.56		13.32	6.15
B-20	533.3	1.98	104	0.7375		1.68		3.63		7.95	10.53
B-21	533.3	0.769	262	2.41	6.19		13.36				2.0
B-3	533.3	1.17	262	0.75		2.81		6.54		14.05	5.40
B-4	533.3	1.98	262	0.45		1.34		2.51		7.36	10.04
B-22	588.8	0.769	104	6.23	15.37						0.37
B-23	588.8	1.17	104	0.68		3.77	11.19				2.52
B-24	588.8	1.98	104	0.98		2.83	6.32	11.69			3.68
B-25	588.8	0.769	262	0.65		7.20	13.81				0.45
B-2	588.8	1.17	262	0.59		1.84		5.06		5.71	14.71
B-1	588.8	1.98	262	0.94		1.27		2.24		4.36	19.7

APPENDIX C-4

Wetting Data for XRL 850A + 5 Wt% Kendall 0839 Paraffinic Resin on Plane Disc

Run No.	Temp. (°K)	Air Flow Rate $(m^3/s)x10^3$	Disc Speed (rad/s)	Wetting Time for Indicated Fraction of Disc Area (Seconds) 0.0625	0.14	0.25	0.39	0.55	0.76	1.0	Wetting Rate (cm^2/s)
F-9	477.7	0.769	104	2.49		6.48		15.36			3.06
F-10	477.7	1.17	104	0.98		2.10		4.04		7.44	11.75
F-11	477.7	1.98	104	0.68		1.34		2.38		4.25	20.87
F-12	477.7	0.769	262	2.67		7.16		16.05			2.94
F-13	477.7	1.17	262	0.78		1.60		3.67		7.10	12.01
F-14	477.7	1.98	262	0.59		1.15		2.16		3.99	22.33
F-15	533.3	0.769	104	1.04		4.34		8.60			5.21
F-16	533.3	1.17	104	0.39		0.92		2.65		4.50	7.47
F-17	533.3	1.98	104	0.29		0.84		1.34		3.40	8.40
F-18	533.3	0.769	262	0.25				14.28			2.80
F-2	533.3	1.17	262	0.6825		1.82		5.46		9.55	7.85
F-1	533.3	1.98	262	0.553		2.03		5.01		9.64	7.97
F-20	588.8	0.769	104	5.01	12.52						0.62
F-22	588.8	1.17	104	1.3		4.24		14.55			2.96
F-23	588.8	1.98	104	0.89		2.60		7.06	13.66		4.42
F-21	588.8	0.769	262	7.62	12.60						0.83
F-4	588.8	1.17	262	0.717		3.77		10.55			4.09
F-3	588.8	1.98	262	0.727		2.72		9.77		17.44	4.12

APPENDIX C-5

Wetting Data for XRM 232A + 10 wt % Freon BF on Plane Disc

Run No.	Temp. (°K)	Air Flow Rate $(m^3/s)x10^3$	Disc Speed (rad/s)	Wetting Time for Indicated Fraction of Disc Area (Seconds)					Wetting Rate (cm^2/s)
				0.0625	0.25	0.55	0.76	1.0	
H-3	533.3	1.17	262	0.973	2.54	9.07	14.19		3.24
H-2	533.3	1.98	262	0.762	2.06	5.3		14.99	4.69
H-5	588.8	1.17	262	1.1	8.94				1.93
H-4	588.8	1.98	262	1.1	5.72	18.0			2.63

APPENDIX C-6

Wetting Data for Blend of Polyglycol Ethers Containing 10 wt % Water on Plane Disc

Run No.	Temp. (°K)	Air Flow Rate $(m^3/s)x10^3$	Disc Speed (rad/s)	Wetting Time for Indicated Fraction of Disc Area (Seconds) 0.0625	0.25	0.55	0.76	1.0
G-3	533.3	1.17	262	(1)				
G-4	533.3	1.98	262	(1)				
G-6	588.8	1.17	262	(1)				
G-5	588.8	1.98	262	(1)				

(1) Insufficient wetting for wetting time or rate determination

APPENDIX C-7

Wetting Data for Monsanto MCS-1370 Fluid on Plane Disc

Run No.	Temp. (°K)	Air Flow Rate $(m^3/s)x10^3$	Disc Speed (rad/s)	Wetting Time for Indicated Fraction of Disc Area (Seconds) 0.0625	0.25	0.55	0.76	1.0
I-1	533.3	1.17	262	(1)				
I-2	533.3	1.98	262	(1)				
I-3	588.8	1.17	262	(1)				
I-4	588.8	1.98	262	(1)				

(1) Insufficient wetting for wetting time or rate determination

APPENDIX C-8

Wetting Data for DN-600 on Plane Disc

Run No.	Temp. (°K)	Air Flow Rate $(m^3/s) \times 10^3$	Disc Speed (rad/s)	Wetting Time for Indicated Fraction of Disc Area (Seconds) 0.0625	0.25	0.55	0.76	1.0	Wetting Rate (cm^2/s)
D-2	533.3	1.17	262	3.51	(1)				
D-1	533.3	1.98	262	0.42	0.91	18.07			1.47
D-4	588.8	1.17	262	9.59	(1)				
D-3	588.8	1.98	262	9.80	(1)				

(1) Insufficient wetting for wetting time or rate determination

APPENDIX C-9

Wetting Data for DN-600 + 5 wt % Kendall 0839 Paraffinic Resin

Run No.	Temp. (°K)	Air Flow Rate $(m^3/s) \times 10^3$	Disc Speed (rad/s)	Wetting Time for Indicated Fraction of Disc Area (Seconds)					Wetting Rate (cm^2/s)
				0.0625	0.25	0.55	0.76	1.0	
E-2	533.3	1.17	262	(1)					
E-1	533.3	1.98	262	0.46	8.58				1.9
E-4	588.8	1.17	262	(1)					
E-3	588.8	1.98	262	(1)					

(1) Insufficient wetting for wetting time or rate determination

APPENDIX D

Deposit Data for Various Fluids on Plane Disc

Test Fluid	Run No.	Temp. (°K)	Air Flow Rate $(m^3/s) \times 10^3$	Disc Speed (rad/s)	Cleanliness Rating
XRM 205F	A-31	533.3	1.98	262	60
	A-30	533.3	1.98	262	74
	A-29	588.8	1.17	262	37
	A-28	588.8	1.98	262	47
XRL 850A	B-10	533.3	1.17	262	94
	B-9	533.3	1.98	262	94
	B-7	588.8	1.17	262	78
	B-6	588.8	1.98	262	80
XRM 232A	C-6	533.3	1.17	262	95
	C-7	533.3	1.98	262	94
	C-9	588.8	1.17	262	89
	C-8	588.8	1.98	262	91
Conoco DN-600	D-7	533.3	1.17	262	91
	D-6	533.3	1.98	262	92
	D-8	588.8	1.17	262	40
	D-5	588.8	1.98	262	83
Conoco DN-600 +5 Wt.% Kendall 0839 Resin	E-7	533.3	1.17	262	79
	E-6	533.3	1.98	262	88
	E-8	588.8	1.17	262	23
	E-5	588.8	1.98	262	68
XRL 850A + 5 wt.% Kendall 0839 Resin	F-8	533.3	1.17	262	78
	F-7	533.3	1.98	262	90
	F-6	588.8	1.17	262	88
	F-5	588.8	1.98	262	82
Blend of Ucon Polyglycol Ethers + 10 Wt.% Water	G-8	533.3	1.17	262	90
	G-7	533.3	1.98	262	88
	G-6	588.8	1.17	262	91
	G-5	588.8	1.98	262	89
XRM 232A + 10 Wt.% Freon BF	H-8	533.3	1.17	262	89
	H-9	533.3	1.98	262	86
	H-5	588.8	1.17	262	89
	H-6	588.8	1.98	262	87
Monsanto MCS-1370	I-6	533.3	1.17	262	87
	I-5	533.3	1.98	262	87
	I-8	588.8	1.17	262	90
	I-7	588.8	1.98	262	91

APPENDIX E-1

Heat Transfer Data for Air Only on Plane Disc at 477.7°K

Run No.	T-1	T-2	T-3	T-4	T-5	T-6
Temp (°K)	477.7	477.7	477.7	477.7	477.7	477.7
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.98	1.98
Disc Speed (rad/s)	104	262	104	262	104	262
Temperature (°K) Change						
@ 1.0 Minute	7.8	7.8	13.3	13.9	13.1	16.1
@ 2.0 Minutes	15.0	16.1	23.3	22.2	25.6	26.7
@ 3.0 "	20.6	21.7	29.4	28.9	32.8	33.3
@ 4.0 "	23.4	25.7	33.9	33.3	36.7	37.8
@ 5.0 "	26.2	28.9	37.8	36.6	39.0	41.1
@ 6.0 "	28.9	31.1	39.4	38.9	41.1	43.3
@ 7.0 "	30.0	33.4	41.1	40.5	42.3	45.0
@ 8.0 "	31.2	33.9	42.2	42.2	43.4	46.1
@ 9.0 "	31.7	34.5	42.8	42.8	43.9	46.7
@10.0 "	31.7	35.6	43.3	43.3	43.9	47.2
Total Temperature (°K) Change During 10 Minute Run	31.7	35.6	43.3	43.3	43.9	47.2

APPENDIX E-2

Heat Transfer Data for Air Only on Plane Disc at 533.3°K

Run No.	T-7	T-8	T-9	T-10	T-11	T-12
Temp (°K)	533.3	533.3	533.3	533.3	533.3	533.3
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.98	1.98
Disc Speed (rad/s)	104	262	104	262	104	262
Temperature (°K) Change						
@ 1.0 Minute	13.3	13.4	16.7	19.5	20.8	24.4
@ 2.0 Minutes	23.8	23.9	30.0	32.8	35.5	37.8
@ 3.0 "	30.0	31.7	37.8	41.1	45.5	45.0
@ 4.0 "	35.5	37.8	43.9	47.3	51.1	51.1
@ 5.0 "	39.4	42.2	47.8	51.7	56.1	55.5
@ 6.0 "	42.8	46.1	52.8	55.6	59.4	58.9
@ 7.0 "	45.0	48.9	54.5	57.3	62.6	61.1
@ 8.0 "	46.6	51.1	55.0	58.9	63.9	63.3
@ 9.0 "	47.8	52.8	55.6	60.6	65.5	64.4
@10.0 "	48.3	53.9	55.6	60.6	67.6	65.5
Total Temperature (°K) Change During 10 Minute Run	48.3	53.9	55.6	60.6	67.6	65.5

APPENDIX E-3

Heat Transfer Data for Air Only on Plane Disc at 588.8°K

Run No.	T-13	T-14	T-15	T-16	T-17	T-18
Temp (°K)	588.8	588.8	588.8	588.8	588.8	588.8
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.98	1.98
Disc Speed (rad/s)	104	262	104	262	104	262
Temperature (°K) Change						
@ 1.0 Minute	16.0	22.2	18.9	18.9	26.1	21.1
@ 2.0 Minutes	26.6	36.6	32.8	32.8	45.7	38.9
@ 3.0 "	36.0	45.5	42.3	42.2	57.2	50.5
@ 4.0 "	41.1	52.8	48.9	49.5	66.6	58.9
@ 5.0 "	46.1	57.3	53.4	54.5	73.3	65.0
@ 6.0 "	50.0	61.0	56.7	60.0	78.9	72.0
@ 7.0 "	52.8	63.8	60.0	61.1	83.3	77.8
@ 8.0 "	55.0	66.0	61.7	61.7	85.5	81.6
@ 9.0 "	56.6	67.2	63.9	62.2	88.3	85.0
@10.0 "	57.8	68.8	65.0	62.8	90.5	86.6
Total Temperature (°K) Change During 10 Minute Run	57.8	68.8	65.0	62.8	90.5	86.6

APPENDIX E-4

Heat Transfer Data for XRM 232 A on Plane Disc at 477.7°K

Run No.	C-25	C-26	C-27	C-28	C-43	C-44
Temp (°K)	477.7	477.7	477.7	477.7	477.7	477.7
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.98	1.98
Disc Speed (rad/s)	104	262	104	262	104	262
Temperature (°K) Change	NONE	NONE				
@ 1.0 Minute			1.1	1.7	1.8	0.6
@ 2.0 Minutes			2.3	3.4	2.4	1.7
@ 3.0 "			3.4	4.6	3.0	2.4
@ 4.0 "			3.9	5.8	3.7	2.4
@ 5.0 "			4.5	6.4	4.2	3.0
@ 6.0 "			4.5	6.4	4.2	3.0
@ 7.0 "			4.5	6.4	4.2	3.0
@ 8.0 "			5.0	7.0	4.2	3.0
@ 9.0 "			5.0	7.0	4.2	3.0
@10.0 "			5.0	7.0	4.2	3.0
Total Temperature (°K) Change During 10 Minute Run			5.0	7.0	4.2	3.0

APPENDIX E-5

Heat Transfer Data for XRM 232 A on Plane Disc at 533.3°K

Run No.	C-31	C-32	C-35	C-36	C-33	C-34
Temp (°K)	533.3	533.3	533.3	533.3	533.3	533.3
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.98	1.98
Disc Speed (rad/s)	104	262	104	262	104	262
Temperature (°K) Change	NONE	NONE				
@ 1.0 Minute			1.2	1.2	0.6	1.2
@ 2.0 Minutes			1.8	2.4	1.1	2.9
@ 3.0 "			3.0	2.9	2.3	4.1
@ 4.0 "			3.0	3.5	4.0	4.6
@ 5.0 "			3.6	4.1	4.6	5.8
@ 6.0 "			4.2	4.1	5.2	6.4
@ 7.0 "			4.2	4.1	5.2	6.4
@ 8.0 "			4.2	4.1	5.2	7.0
@ 9.0 "			4.2	4.1	5.2	7.0
@10.0 "			4.2	4.1	5.2	7.0
Total Temperature (°K) Change During 10 Minute Run			4.2	4.1	5.2	7.0

APPENDIX E-6

Heat Transfer Data for XRM 232 A on Plane Disc at 588.8°K

Run No.	C-38	C-39	C-40	C-42	C-37	C-41
Temp (°K)	588.8	588.8	588.8	588.8	588.8	588.8
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.98	1.98
Disc Speed (rad/s)	104	262	104	262	104	262
Temperature (°K) Change	NONE	NONE				
@ 1.0 Minute			1.2	1.1	1.7	1.1
@ 2.0 Minutes			1.7	2.2	2.9	2.2
@ 3.0 "			1.7	3.3	5.8	3.3
@ 4.0 "			2.3	3.9	7.0	4.4
@ 5.0 "			2.9	4.5	8.2	5.0
@ 6.0 "			2.9	5.1	8.8	5.6
@ 7.0 "			2.9	5.6	10.0	5.6
@ 8.0 "			2.9	5.6	11.2	7.1
@ 9.0 "			2.9	5.6	11.2	7.1
@10.0 "			2.9	5.6	11.2	7.1
Total Temperature (°K) Change During 10 Minute Run			2.9	5.6	11.2	7.1

APPENDIX E-7

Heat Transfer Data for XRL 850 A on Plane Disc at 477.7°K

Run No.	B-26	B-27	B-30	B-31	B-28	B-32
Temp (°K)	477.7	477.7	477.7	477.7	477.7	477.7
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.98	1.98
Disc Speed (rad/s)	104	262	104	262	104	262
Temperature (°K) Change	NONE	NONE	NONE			
@ 1.0 Minute				0	2.2	0.6
@ 2.0 Minutes				0.6	3.9	1.2
@ 3.0 "				1.2	4.5	2.3
@ 4.0 "				1.8	5.5	2.9
@ 5.0 "				1.8	6.1	3.4
@ 6.0 "				1.8	6.3	3.4
@ 7.0 "				1.8	6.3	3.4
@ 8.0 "				1.8	6.3	3.4
@ 9.0 "				1.8	6.3	3.4
@10.0 "				1.8	6.3	3.4
Total Temperature (°K) Change During 10 Minute Run				1.8	6.3	3.4

APPENDIX E-8

Heat Transfer Data for XRL 850 A on Plane Disc at 533.3°K

Run No.	B-33	B-34	B-35	B-36	B-37	B-38
Temp (°K)	533.3	533.3	533.3	533.3	533.3	533.3
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.98	1.98
Disc Speed (rad/s)	104	262	104	262	104	262
Temperature (°K) Change	NONE	NONE		NONE		
@ 1.0 Minute			0		2.9	1.2
@ 2.0 Minutes			0		5.2	2.9
@ 3.0 "			0		7.0	3.5
@ 4.0 "			0		8.2	4.1
@ 5.0 "			0.6		8.7	4.1
@ 6.0 "			0.6		9.4	4.1
@ 7.0 "			0.6		9.4	4.1
@ 8.0 "			0.6		9.4	4.1
@ 9.0 "			0.6		9.4	4.1
@10.0 "			0.6		9.4	4.1
Total Temperature (°K) Change During 10 Minute Run			0.6		9.4	4.1

APPENDIX E-9

Heat Transfer Data for XRL 850 A on Plane Disc at 588.8°K

Run No.	B-39	B-44	B-46	B-47	B-40	B-45
Temp (°K)	588.8	588.8	588.8	588.8	588.8	588.8
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.98	1.98
Disc Speed (rad/s)	104	262	104	262	104	262
Temperature (°K) Change	NONE	NONE				
@ 1.0 Minute			1.1	1.1	1.1	2.3
@ 2.0 Minutes			1.6	1.7	3.3	3.4
@ 3.0 "			2.2	1.7	6.1	5.6
@ 4.0 "			2.7	2.2	7.2	7.3
@ 5.0 "			3.3	2.8	8.8	8.4
@ 6.0 "			3.3	2.8	10.0	9.5
@ 7.0 "			3.8	3.3	11.1	10.0
@ 8.0 "			3.8	3.9	11.1	10.6
@ 9.0 "			3.8	3.9	11.1	10.6
@10.0 "			3.8	3.9	11.1	11.2
Total Temperature (°K) Change During 10 Minute Run			3.8	3.9	11.1	11.2

APPENDIX F-1

Heat Transfer Data for Air Only on Complex Disc

Run No.	S-15	S-16	S-11	S-12	S-13	S-14
Temp (^oK)	477.7	477.7	477.7	477.7	477.7	477.7
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.98	1.98
Disc Speed (rad/s)	104	262	104	262	104	262
Temperature (^oK) Change						
@ 1.0 Minute	6.11	6.6	3.9	9.0	13.9	14.4
@ 2.0 Minutes	14.4	15.5	20.6	19.4	28.9	28.3
@ 3.0 "	20.6	23.3	28.3	29.4	39.4	38.3
@ 4.0 "	25.5	25.5	35.0	34.4	46.6	43.9
@ 5.0 "	29.4	31.6	38.3	40.0	50.0	49.4
@ 6.0 "	32.8	33.0	41.6	43.3	53.3	53.3
@ 7.0 "	35.0	36.2	44.4	46.1	56.6	56.6
@ 8.0 "	36.6	37.4	46.6	48.9	59.4	58.9
@ 9.0 "	38.3	38.9	47.8	52.0	60.6	60.6
@10.0 "	39.4	41.3	49.0	55.0	60.6	62.6
Total Temperature (^oK) Change During 10 Minute Run	39.4	41.3	49.0	55.0	60.6	62.6

APPENDIX F-2

Heat Transfer Data for XRM 232 A on Complex Disc

Run No.	S-18	S-17	S-21	S-9	S-10	S-24	S-22	S-7	S-8	S-23
Temp (^{o}K)	477.7	477.7	477.7	477.7	477.7	477.7	477.7	477.7	477.7	477.7
Air Flow Rate (m^3/s) x 10^3	0.769	0.769	1.17	1.17	1.17	1.17	1.98	1.98	1.98	1.98
Disc Speed (rad/s)	104	262	52	104	262	524	52	104	262	524
Temperature (^{o}K) Change	NONE	NONE								
@ 1.0 Minute			0.5	0.6	1.1	1.7	1.1	0.6	1.1	2.8
@ 2.0 Minutes			1.7	1.7	1.7	2.8	3.3	3.9	2.8	7.2
@ 3.0 "			2.2	2.8	3.3	4.4	6.1	5.0	4.4	12.2
@ 4.0 "			2.2	3.9	3.9	5.6	7.2	5.6	5.6	15.5
@ 5.0 "			2.2	4.4	4.4	6.1	7.8	6.1	6.1	17.8
@ 6.0 "			2.8	4.4	4.4	6.7	8.3	6.7	7.2	19.4
@ 7.0 "			2.8	4.4	4.4	6.7	8.9	7.2	7.8	20.6
@ 8.0 "			2.8	4.4	4.4	6.7	8.9	7.2	7.8	21.7
@ 9.0 "			2.8	4.4	4.4	6.7	8.9	7.2	7.8	21.7
@10.0 "			2.8	4.4	4.4	6.7	8.9	7.2	7.8	21.7
Total Temperature (^{o}K) Change During 10 Minute Run			2.8	4.4	4.4	6.7	8.9	7.2	7.8	21.7

APPENDIX F-3

Heat Transfer Data for XRM 232 A on Complex Disc

Run No.	S-25	S-26	S-27	S-28	S-29	S-30	S-31	S-32
Temp (^oK)	533.3	533.3	533.3	533.3	533.3	533.3	533.3	533.3
Air Flow Rate (m^3/s) x 10^3	1.17	1.17	1.17	1.17	1.98	1.98	1.98	1.98
Disc Speed (rad/s)	52	104	262	524	52	104	262	524
Temperature (^oK) Change								
@ 1.0 Minute	0.6	1.1	1.1	0.6	1.7	1.1	2.2	2.2
@ 2.0 Minutes	1.7	2.2	2.8	1.1	3.3	1.7	5.0	3.3
@ 3.0 "	2.8	3.3	3.3	1.7	5.0	2.8	7.2	3.3
@ 4.0 "	2.8	3.9	3.9	2.2	6.1	3.9	8.9	3.3
@ 5.0 "	2.8	3.9	3.9	2.2	7.2	4.4	9.4	3.3
@ 6.0 "	3.3	4.4	4.4	2.2	8.3	4.4	10.0	3.3
@ 7.0 "	3.9	5.0	5.0	2.2	10.0	4.4	10.6	3.3
@ 8.0 "	3.9	5.0	5.0	2.2	12.2	4.4	10.6	3.3
@ 9.0 "	3.9	5.0	5.0	2.2	12.2	4.4	10.6	3.3
@10.0 "	3.0	5.0	5.0	2.2	12.2	4.4	10.6	3.3
Total Temperature (^oK) Change During 10 Minute Run	3.9	5.0	5.0	2.2	5.6	4.4	6.4	3.3

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