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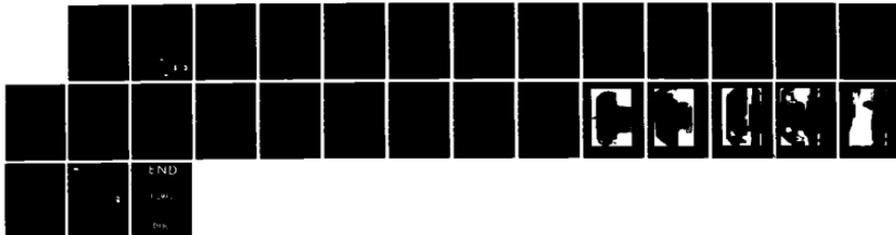
EVALUATION OF POLYISOBUTYLENE (PIB) FORMULATIONS IN  
JP-5 JET FUEL: THE EF. (U) NAVAL RESEARCH LAB  
WASHINGTON DC R C LITTLE ET AL. 30 SEP 83 NRL-MR-5195

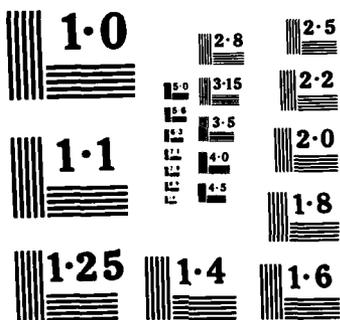
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# Evaluation of Polyisobutylene (PIB) Formulations in JP-5 Jet Fuel: The Effect of PIB Concentration on Fuel Mist Flammability

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September 30, 1983

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| 1. REPORT NUMBER<br>NRL Memorandum Report 5195                                                                                                                                                                                                                                                                                                                                                     | 2. GOVT ACCESSION NO.<br>AD-A155474                                                                    | 3. RECIPIENT'S CATALOG NUMBER                                                                                                                                                                                                                                                                                                          |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
| 4. TITLE (and Subtitle)<br>EVALUATION OF POLYISOBUTYLENE (PIB)<br>FORMULATIONS IN JP-5 JET FUEL: THE EFFECT<br>OF PIB CONCENTRATION ON FUEL MIST<br>FLAMMABILITY                                                                                                                                                                                                                                   | 5. TYPE OF REPORT & PERIOD COVERED<br>Technical report                                                 |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                    | 6. PERFORMING ORG. REPORT NUMBER                                                                       |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
| 7. AUTHOR(s)<br>R.C. Little, S. Pande,* and J.B. Romans**                                                                                                                                                                                                                                                                                                                                          | 8. CONTRACT OR GRANT NUMBER(s)                                                                         |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Naval Research Laboratory<br>Washington, DC 20375                                                                                                                                                                                                                                                                                                   | 10. PROGRAM ELEMENT, PROJECT, TASK<br>AREA & WORK UNIT NUMBERS<br>62765N; WF65-572-000;<br>61-0085-0-3 |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
| 11. CONTROLLING OFFICE NAME AND ADDRESS                                                                                                                                                                                                                                                                                                                                                            | 12. REPORT DATE<br>September 30, 1983                                                                  |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                    | 13. NUMBER OF PAGES<br>26                                                                              |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)                                                                                                                                                                                                                                                                                                                        | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED                                                   |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
|                                                                                                                                                                                                                                                                                                                                                                                                    | 15a. DECLASSIFICATION/DOWNGRADING<br>SCHEDULE                                                          |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
| 16. DISTRIBUTION STATEMENT (of this Report)<br><br>Approved for public release; distribution unlimited.                                                                                                                                                                                                                                                                                            |                                                                                                        |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
| 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)                                                                                                                                                                                                                                                                                                         |                                                                                                        |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |
| 18. SUPPLEMENTARY NOTES<br>*Present address: GEO Centers, Inc., Newton Upper Falls, MA 02164<br>**Present address: Hughes Associates, Inc., Kensington, MD 20895                                                                                                                                                                                                                                   |                                                                                                        | <table border="1"> <tr> <td colspan="2">Accession For</td> </tr> <tr> <td>NTIS GRA&amp;I</td> <td><input checked="" type="checkbox"/></td> </tr> <tr> <td>DTIC TAB</td> <td><input type="checkbox"/></td> </tr> <tr> <td>Unannounced</td> <td><input type="checkbox"/></td> </tr> <tr> <td>Justification</td> <td></td> </tr> </table> |  | Accession For |               | NTIS GRA&I | <input checked="" type="checkbox"/> | DTIC TAB           | <input type="checkbox"/> | Unannounced | <input type="checkbox"/> | Justification |     |  |  |
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| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br>Antimisting<br>Polymer<br>JP-5<br>Polyisobutylene                                                                                                                                                                                                                                                            |                                                                                                        | <table border="1"> <tr> <td>By</td> <td colspan="2">Distribution/</td> </tr> <tr> <td></td> <td colspan="2">Availability Codes</td> </tr> <tr> <td>Dist</td> <td>Avail and/or</td> <td>Special</td> </tr> <tr> <td>A/1</td> <td></td> <td></td> </tr> </table>                                                                         |  | By            | Distribution/ |            |                                     | Availability Codes |                          | Dist        | Avail and/or             | Special       | A/1 |  |  |
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>The antimisting fire suppressive effect of a high molecular weight polyisobutylene (6.3 million daltons), in JP-5, an aviation jet fuel, was investigated as a function of concentration. At the concentration level of 1000 ppm, polyisobutylene of this molecular weight is an effective antimisting agent. |                                                                                                        |                                                                                                                                                                                                                                                                                                                                        |  |               |               |            |                                     |                    |                          |             |                          |               |     |  |  |

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EVALUATION OF POLYISOBUTYLENE (PIB) FORMULATIONS IN JP-5 JET FUEL:  
THE EFFECT OF PIB CONCENTRATION ON FUEL MIST FLAMMABILITY

INTRODUCTION

Disastrous consequences have occurred from aircraft crash landings and aircraft combat related to fuel mist flammability. In crash-related situations involving the fuel tank increased atomization of fuel-in-air mixtures occurs, thereby increasing the fire hazard. This hazard aspect of fuel mist flammability has been addressed by the investigation of antimisting agents [1].

Found to be effective as antimisting fire suppressive agents are high molecular weight polymers [2,3]. The leading contenders include polyisobutylene, and a proprietary material designated FM-9, developed by Imperial Chemical Industries (ICI), England. However, fuel filtration problems have been identified [4] with FM-9. In the case of polyisobutylene, a previous solubilization problem in the jet fuel without accompanying loss of its antimisting effectiveness, has recently been resolved by General Technology Applications, Inc. (GTA) [5]. This led to the discovery [6] that polyisobutylene was more effective than FM-9. Also, the efficacy of polyisobutylene was found to increase with increasing molecular weight [3, 6-9] and with concentration [3]. These results, in conjunction with the proprietary aspect of FM-9 suggest polyisobutylene to be both a promising candidate and an excellent material for fire suppression studies.

The purpose of this investigation was to evaluate on a laboratory scale the flammability characteristics of anti-misting fuel (AMF) formulations prepared by GTA. As shown in Fig. 1 this constitutes the penultimate phase of the generalized work scheme for the evaluation of additive-fuel combinations.

EXPERIMENTAL: Formulation and Ignition Test Method.

Formulation

The GTA formulations contained polyisobutylene (PIB) of molecular weight 6.3 million as the AMF additive in JP-5 jet fuel. The concentrations tested were 0, 50, 100, 200, 500, and 1000 ppm PIB/JP-5. Selection of this concentration range is related to previous work [8,9] which indicated PIB to be effective at concentration levels below 100 ppm for molecular weights above 8 million.

The viscosity and shear rate data for the PIB solutions used in the flammability test experiments are reported in Table 1. The data show the typical viscosity-building effects of

Manuscript approved August 4, 1983.

high molecular weight polymers such as PIB. These data are presented for comparison purposes as part of the overall test plan developed by the Naval Air Systems Command for the GTA-supplied polymer solutions in JP-5 jet fuel. These data may be useful to determine whether or not significant degradation of the polymer occurred during transportation and handling procedures.

### Ignition Test Method

A schematic of the flammability test apparatus is shown in Fig. 2. A spinning disk atomizer (diameter, 4.5 inches), patterned after one used by Mannheimer [10], was employed to dispense the fuel, forming a mist. Rotational speed of the disk was variable. Previous work [3] had shown that increasing disk speed resulted in decreasing mist droplet size. A propane burner was used as the flame source. Ignition of the fuel mist and propagation of the flame were monitored as a function of disk speed and fuel additive concentration. These flammability characteristics were detected with a photocell (not shown in Fig. 2) and recorded on a dual pen strip-chart recorder as well as by camera and by video cassette recorder. The speed of the disk was calibrated with a digital photoelectric tachometer as a function of power supply voltage, and the voltage recorded simultaneously with the photocell data. Further details of the apparatus have been described in previous reports [3,11].

The mist flammability test was conducted using a decreasing series of disk speeds for each jet fuel formulation (0-1000 ppm PIB/JP-5). The procedure involved an initial disk speed of 12,000 revolutions per minute (rpm) decreasing at 1000 rpm intervals, to 3000-4000 rpm or until no further effect of disk speed was observed. Each test was then repeated in a similar manner but with the initial disk speed changed to 11,500 rpm. Staggering the initial disk speed by 500 rpm has the advantage of checking the precision of the data at 500 rpm intervals. The rate of fuel delivery to the center of the spinning disk was 400 ml/min.

### RESULTS AND DISCUSSION

Results of the mist flammability tests of the GTA formulations (0-1000 ppm PIB/JP-5) are given in Tables 2-7. Disk speed is also represented in terms of the more basic measurement of tangential velocity, meters per second (m/s). This makes it possible to relate disk speeds with aircraft landing speeds in crash situations.

Some scatter in the data is noted. However, Figures 3-5 are representative of the trends observed in mist flammability with respect to increasing tangential velocity of the disk, and increasing polyisobutylene concentration.

### Effect of Disk Speed/Tangential Velocity of Disk on Fuel Mist Flammability

In general, the photocell output increased with increasing disk speed for the neat JP-5 fuel as well as for all polyisobutylene formulations (see Figures 3-5). This increase in fuel flammability with increasing disk speed is consistent with the phenomenon of mist flammability i.e., the mass median diameter of fuel droplet sizes decreases with increasing disk speed [3].

As shown in Figures 3-5, there appears to be a minimum disk speed for ignition, which is termed critical disk speed or critical tangential velocity. This parameter reflects the susceptibility of the fuel to ignite under mist flammability conditions. There also appears to be an optimum disk speed above which no increase in flame propagation occurs as measured by the photocell. Further testing at disk speeds greater than 12,000 rpm (tangential velocity 67.8 m/s), the upper limit for the apparatus, is required to confirm this. The maximum photocell output value reflects the degree of flame propagation.

Fuel mist flammability can be expressed as a function of both critical ignition tangential velocity of the disk and maximum photocell output. Since misting of the fuel increases with increasing tangential velocity of the disk, for an effective antimisting fire suppressive additive, the critical ignition tangential velocity of the disk should be high. Also, at the high tangential disk velocity e.g., 67.85 meters per second, the maximum photocell output should be low. These parameters are useful in characterizing the degree of fuel mist flammability, and are discussed further in relation to their effects on polyisobutylene concentration.

### Effects of Polyisobutylene (PIB) Concentration on Fuel Mist Flammability of JP-5

The effect of polyisobutylene concentration on fuel ignition and flame propagation is clearly demonstrated in Figures 6 and 7 respectively. These figures indicate that as an antimisting fire suppressive additive, the efficacy of the polyisobutylene tested is dependent on concentration levels greater than 500 ppm. The flammability characteristics of the various concentration levels evaluated are discussed subsequently.

Within the concentration range of 50-500 ppm PIB, virtually no change in the maximum photocell output is observed with increasing PIB concentration (Figure 7). Furthermore, the maximum photocell output of JP-5 was not significantly higher than that of JP-5 containing 500 ppm PIB. This similarity in the degree of flame propagation between JP-5 and JP-5 containing 500 ppm PIB, at the highest tangential velocity employed, is further illustrated in Figures 8 and 9 respectively.

As described earlier, ignition of the fuel and propagation of the flame are related to the tangential velocity of the disk. Consequently, the tangential velocity serves as an excellent index for comparative evaluations of the various PIB concentrations at the various stages of flame development, viz., ignition of the fuel, transition from ignition to propagation, and propagation of the flame. On such a comparison, no significant differences in critical tangential velocity of the disk were observed between JP-5 and JP-5 containing 500 ppm PIB at the ignition stage (Figure 6), the transition stage (c.f., Figures 10 and 11), and at maximum photocell output (c.f., Figures 3 and 4). These results indicate that the lower concentration levels of 50-500 ppm PIB, apparently did not sufficiently increase the mass median diameter of the fuel droplet size to the point where ignition was effectively suppressed. Consequently, concentration levels of 50-500 ppm of the polyisobutylene screened are not effective as antimisting fire suppressive additives for JP-5 as measured in the NRL flammability apparatus.

The efficacy of PIB as an antimisting fire suppressive additive was observed at 1000 ppm concentration under the test conditions. Figure 12 clearly demonstrates no flame propagation from the propane burner to the spinning disk at the highest disk speed employed. Further evidence of the antimisting fire-suppressive characteristics of PIB at 1000 ppm concentration is indicated by its high critical ignition tangential velocity of 62.2 meters per second (Figure 6) and its low "maximum photocell output" (Figure 7). The development of fire-suppressive behavior is probably linked to the fuel drop size distribution within the fuel/air mixture. Since it has been shown that the mass median diameter of PIB solutions in JP-5 is affected by both molecular weight and concentration [3] it is presumed that the fire-suppressive behavior of the 1000 ppm PIB sample of the present report may be linked to the production of very large droplet sizes in the air/fuel mixture. More research, however, is required to delineate the role of drop size distributions in fuel/air mixtures to overall fuel ignition characteristics.

Results of attempts to relate the effect of PIB concentration with a delay from the time of fuel delivery to the spinning disk for the time of fuel ignition, were inconclusive.

## CONCLUSION

At low concentration levels of 500 ppm or less, the high molecular weight polyisobutylene (6.3 million daltons) that was screened does not appear to be an effective antimisting fire suppressive additive for JP-5 jet fuel. At the 1000 ppm PIB concentration level however, the formulation appears promising. Consequently, further study at higher concentrations is

warranted. Other areas to be investigated include rheological and turbulent flow characteristics, as well as other physical properties of selected formulations.

ACKNOWLEDGEMENT

The authors wish to thank Susan Phippen for the viscosity measurements of the fuel formulations. This work was sponsored by the Naval Air Systems Command.

Table 1 - Viscosity<sup>(a)</sup> of PIB Formulation in JP-5  
Fuel at 30°C

| PPM              | Efflux <sup>(b)</sup><br>Time<br>(Sec) | Apparent Shear<br>Rate <sub>I</sub><br>(Sec <sup>-1</sup> ) | Viscosity<br>(CS) | Average<br>Viscosity<br>(CS) |
|------------------|----------------------------------------|-------------------------------------------------------------|-------------------|------------------------------|
| 0<br>(neat JP-5) | 808.8                                  | 534.6                                                       | 1.865             | 1.864                        |
|                  | 812.4                                  | 532.2                                                       | 1.873             |                              |
|                  | 803.4                                  | 538.2                                                       | 1.853             |                              |
|                  | 808.8                                  | 534.6                                                       | 1.865             |                              |
| 50               | 841.2                                  | 514.0                                                       | 1.940             | 1.940                        |
|                  | 841.8                                  | 514.0                                                       | 1.941             |                              |
| 100              | 886.8                                  | 487.5                                                       | 2.045             | 2.042                        |
|                  | 883.2                                  | 489.5                                                       | 2.037             |                              |
|                  | 885.6                                  | 488.2                                                       | 2.042             |                              |
|                  | 886.8                                  | 487.5                                                       | 2.045             |                              |
| 200              | 985.2                                  | 438.8                                                       | 2.272             | 2.274                        |
|                  | 987.0                                  | 438.0                                                       | 2.276             |                              |
| 500              | 1328.4                                 | 325.5                                                       | 3.063             | 3.065                        |
|                  | 1326.0                                 | 326.1                                                       | 3.058             |                              |
|                  | 1329.4                                 | 325.2                                                       | 3.066             |                              |
| 1000             | 2120.4                                 | 203.9                                                       | 4.890             | 4.872                        |
|                  | 2105.4                                 | 205.4                                                       | 4.855             |                              |

(a) - ASTM Method D 445

(b) - Measurements made in Cannon-Fenske Viscometer #50-64,  
Constant = 0.002306 CS/sec.

Table 2 - Mist Flammability of JP-5: Maximum Photocell Output at Varying Disk Speeds.

| Run No. | Initial Disk Speed (rpm $\pm$ 1%) | Tangential Velocity of Disk (m/s) | Maximum Photocell Output (millivolts)   |
|---------|-----------------------------------|-----------------------------------|-----------------------------------------|
| 1       | 12,000                            | 67.8                              | 74                                      |
| 2       | 11,000                            | 62.2                              | 69.4                                    |
| 3       | 10,000                            | 56.6                              | 68.7                                    |
| 4       | 9,000                             | 50.9                              | 54.2                                    |
| 5       | 8,000                             | 45.2                              | 43.5; 46.0 <sup>a</sup>                 |
| 6       | 7,000                             | 39.6                              | 49.8                                    |
| 7       | 6,000                             | 33.9                              | 9.7                                     |
| 8       | 5,000                             | 28.3                              | 1.0                                     |
| 9       | 4,000                             | 22.6                              | 1.0                                     |
| 10      | 3,000                             | 12.0                              | 0.8                                     |
| 11      | 11,500                            | 65.0                              | 75.5                                    |
| 12      | 10,500                            | 59.4                              | 80.0, 75 <sup>b</sup>                   |
| 13      | 9,500                             | 53.7                              | 62.5                                    |
| 14      | 8,500                             | 48.1                              | 48.5                                    |
| 15      | 7,500                             | 42.4                              | 38.6; 61 <sup>a</sup> , 51 <sup>b</sup> |
| 16      | 6,500                             | 36.8                              | 49.4                                    |
| 17      | 5,500                             | 31.1                              | -                                       |
| 18      | 4,500                             | 25.4                              | 1.8                                     |
| 19      | 3,500                             | 19.8                              | 0.8                                     |

a - Repeat

b - Next highest value

Table 3 - Mist Flammability of 50 ppm Polyisobutylene  
in JP-5: Maximum Photocell Output at  
Varying Disk Speeds.

| No. | Initial<br>Disk Speed<br>(rpm $\pm$ 1%) | Tangential Velocity<br>of Disk<br>(m/s) | Maximum<br>Photocell Output<br>(millivolts) |
|-----|-----------------------------------------|-----------------------------------------|---------------------------------------------|
| 1   | 12,000                                  | 67.8                                    | 68.8                                        |
| 2   | 11,000                                  | 62.2                                    | 74.8, 68 <sup>a</sup>                       |
| 3   | 10,000                                  | 56.6                                    | 82.8, 64.5 <sup>a</sup>                     |
| 4   | 9,000                                   | 50.9                                    | 58.4                                        |
| 5   | 8,000                                   | 45.2                                    | 51.8                                        |
| 6   | 7,000                                   | 39.6                                    | 47.7                                        |
| 7   | 6,000                                   | 33.9                                    | 1.9                                         |
| 8   | 5,000                                   | 28.3                                    | 0.4                                         |
| 9   | 4,000                                   | 22.6                                    | 1.0                                         |
| 10  | 11,500                                  | 65.0                                    | 84.5; 64.0 <sup>b</sup> ; 68.7 <sup>b</sup> |
| 11  | 10,500                                  | 59.4                                    | 69.2, 65 <sup>a</sup>                       |
| 12  | 9,500                                   | 53.7                                    | 73.5, 59.5 <sup>a</sup>                     |
| 13  | 8,500                                   | 48.1                                    | 55.5                                        |
| 14  | 7,500                                   | 42.4                                    | 48.5                                        |
| 15  | 6,500                                   | 36.8                                    | 25.0                                        |
| 16  | 5,500                                   | 31.1                                    | 0.3                                         |
| 17  | 4,500                                   | 25.4                                    | 0.4                                         |

- Next highest value
- Repeat

Table 4 - Mist Flammability of 100 ppm Polyisobutylene  
in JP-5: Maximum Photocell Output at  
Varying Disk Speeds

| Run No. | Initial<br>Disk Speed<br>(rpm $\pm$ 1%) | Tangential Velocity<br>of Disk<br>(m/s) | Maximum<br>Photocell Output<br>(millivolts) |
|---------|-----------------------------------------|-----------------------------------------|---------------------------------------------|
| 1       | 12,000                                  | 67.8                                    | 65.5                                        |
| 2       | 11,000                                  | 62.2                                    | 64.9;58.7 <sup>a</sup>                      |
| 3       | 10,000                                  | 56.6                                    | 61.0                                        |
| 4       | 9,000                                   | 50.9                                    | 53.6                                        |
| 5       | 8,000                                   | 45.2                                    | 40.0                                        |
| 6       | 7,000                                   | 39.6                                    | 37.8                                        |
| 7       | 6,000                                   | 33.9                                    | 0.8                                         |
| 8       | 5,000                                   | 28.3                                    | 1.1                                         |
| 9       | 4,000                                   | 22.6                                    | 0.4                                         |
| 10      | 11,500                                  | 65.0                                    | 60.7                                        |
| 11      | 10,500                                  | 59.4                                    | 59.8                                        |
| 12      | 9,500                                   | 53.7                                    | 69.0,61.6 <sup>b</sup>                      |
| 13      | 8,500                                   | 48.1                                    | 50.0                                        |
| 14      | 7,500                                   | 42.4                                    | 3.0 <sup>c</sup>                            |
| 15      | 6,500                                   | 36.8                                    | 1.1                                         |
| 16      | 5,500                                   | 31.1                                    | 1.0                                         |

a - Repeat

b - Next highest value

c - Value is questionable



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Fig. 12 — Mist flammability of 1000 ppm polyisobutylene in JP-5. Run 1. 1000 rpm disk speed; tangential velocity 67.5 m/s; propagation at 12000 rpm disk speed; tangential velocity 67.5 m/s.



R-975

Fig. 11 — Mist flammability of 500 ppm polyisobutylene in JP-5. Run 6 - showing the transition from fuel ignition to flame propagation at 7000 rpm disk speed; tangential velocity: 39.58 m/s.

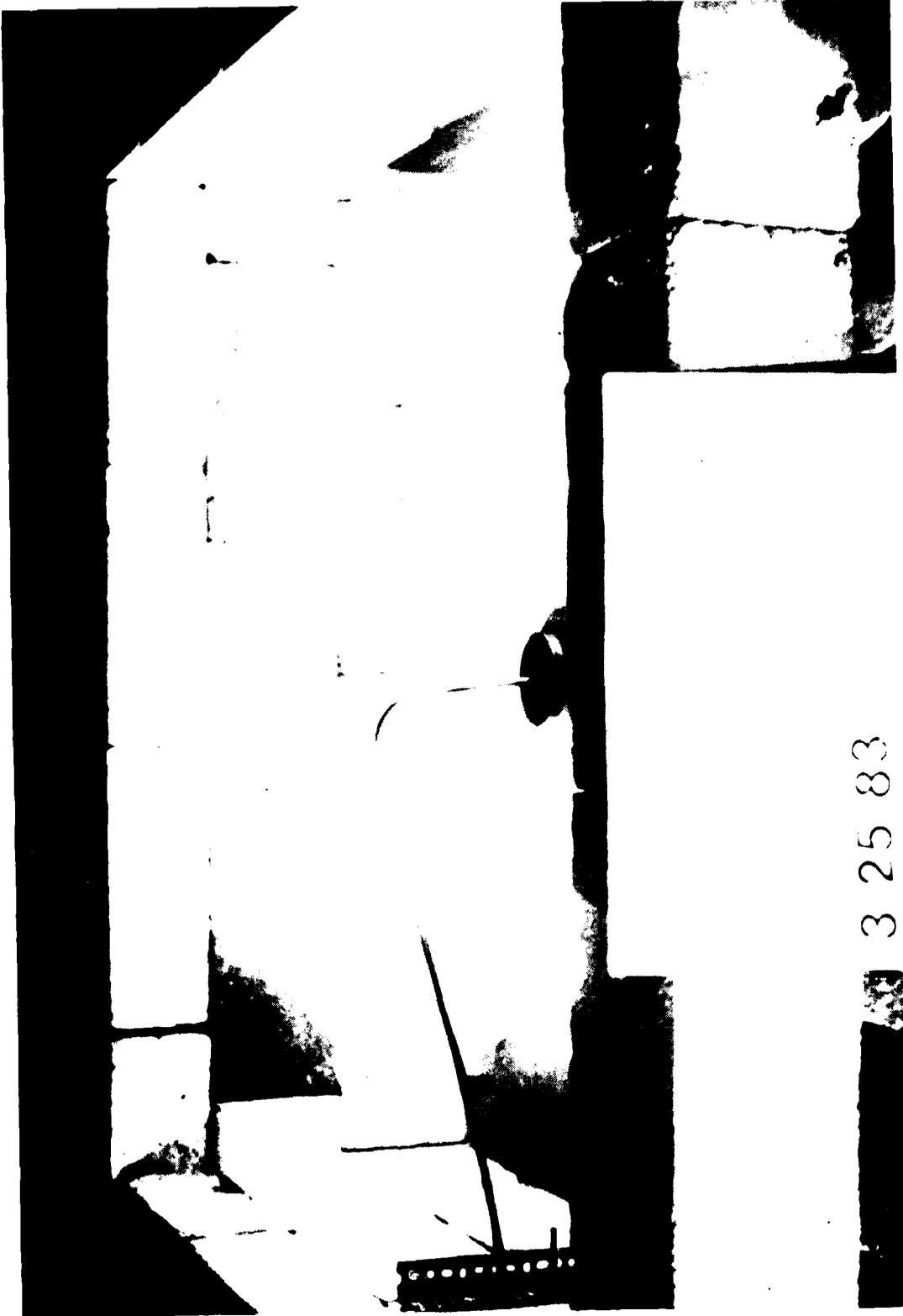
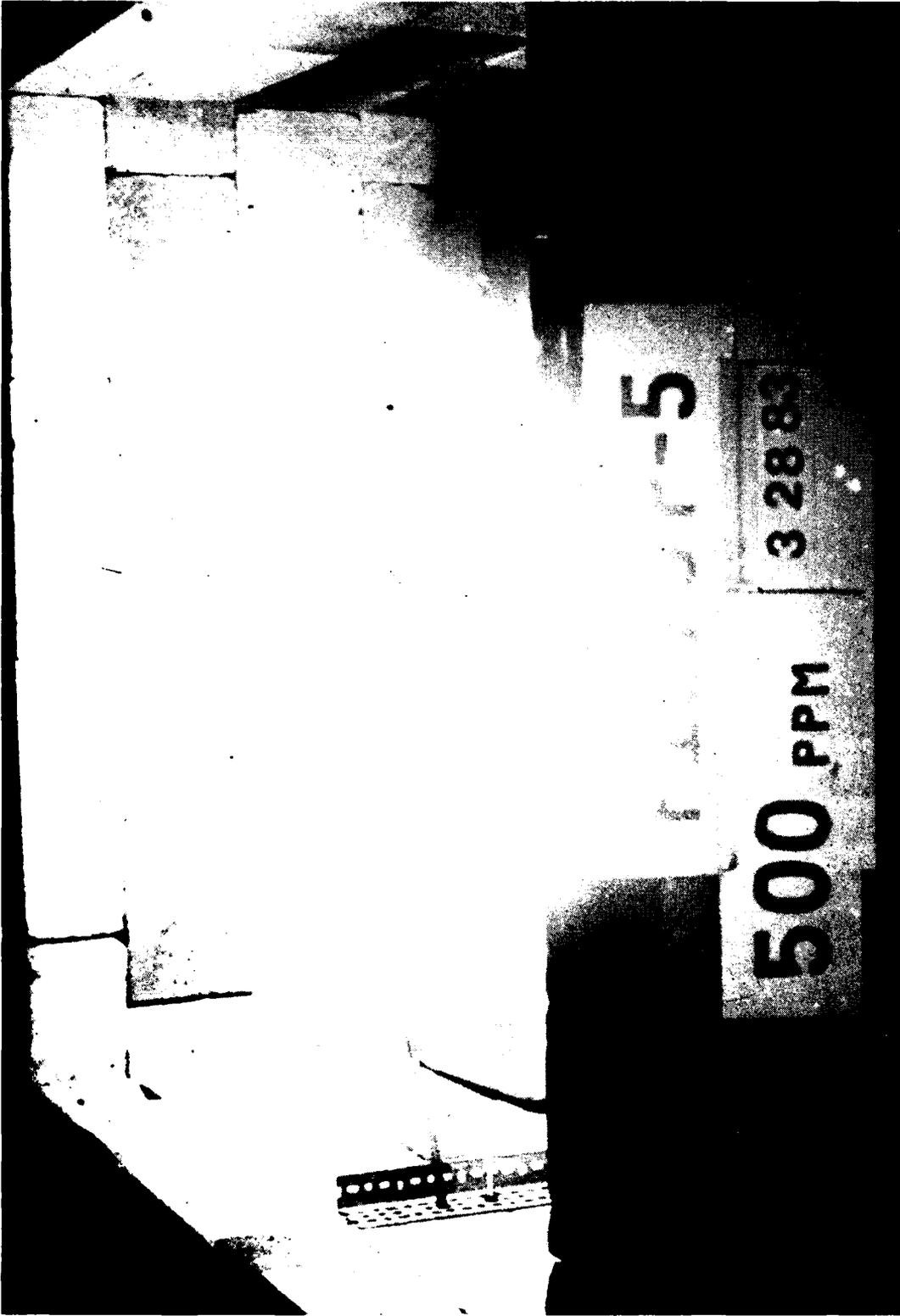


Fig. 10 — Mist flammability of jet fuel JP-5. Run 7 - showing the transition from fuel ignition to flame propagation at disk speed 6000 rpm; tangential velocity of disk: 33.93 m/s.

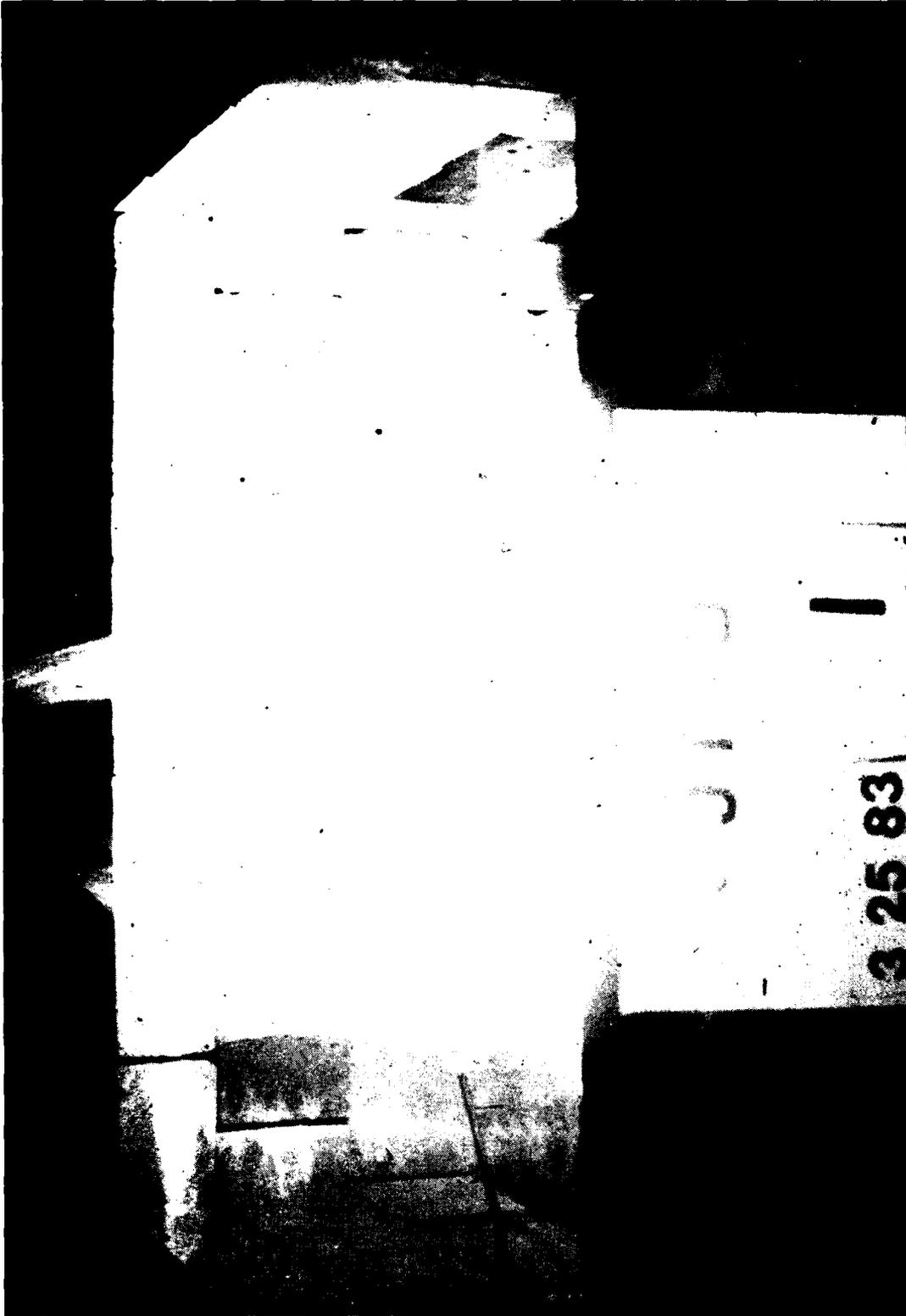
R-976

3 25 83



R-974

Fig. 9 — Mist flammability of 500 ppm polyisobutylene in JP-5. Run 1 - showing maximum flame propagation at 12000 rpm disk speed; tangential velocity of disk: 67.85 m/s.



R-972

Fig. 8 — Mist flammability of jet fuel JP-5. Run 1 - showing maximum flame propagation at 12000 rpm disk speed; tangential velocity of disk: 67.85 m/s.

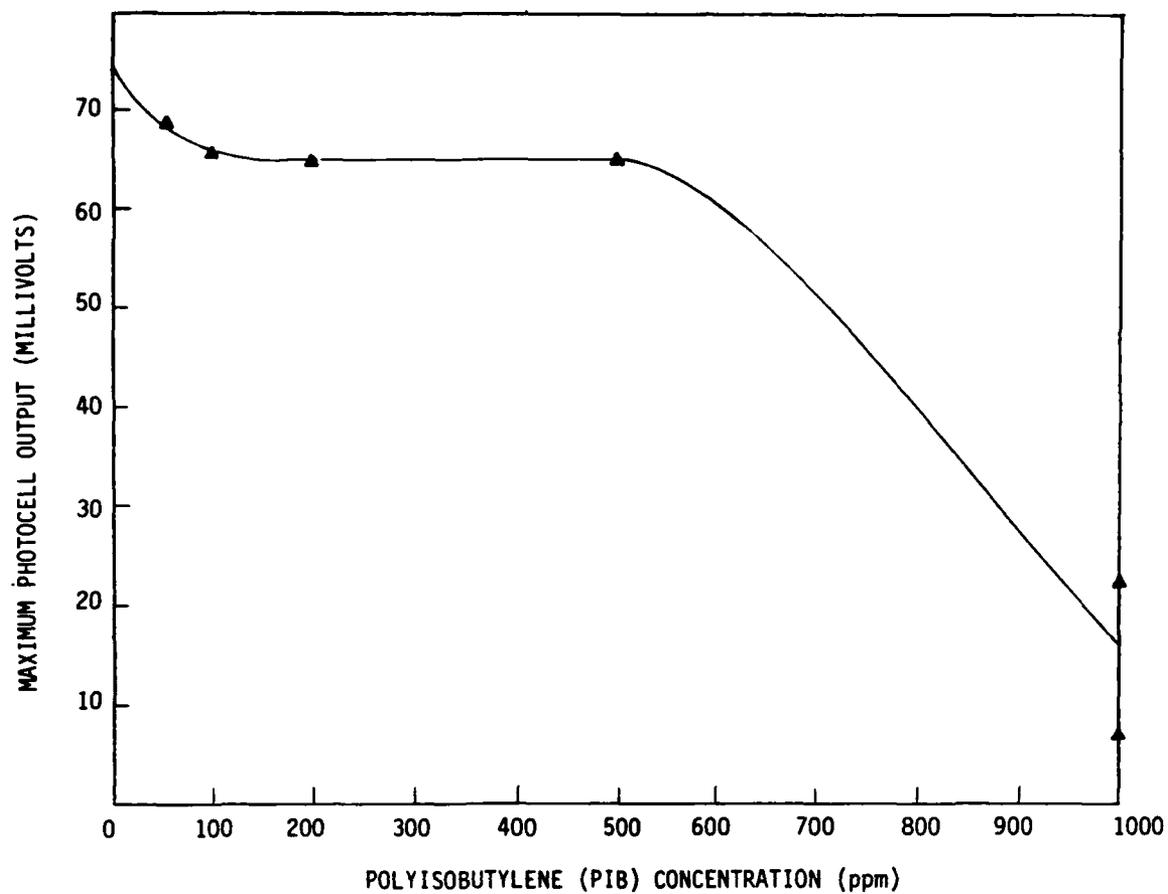


Fig. 7 — Effect of PIB concentration on maximum photocell output

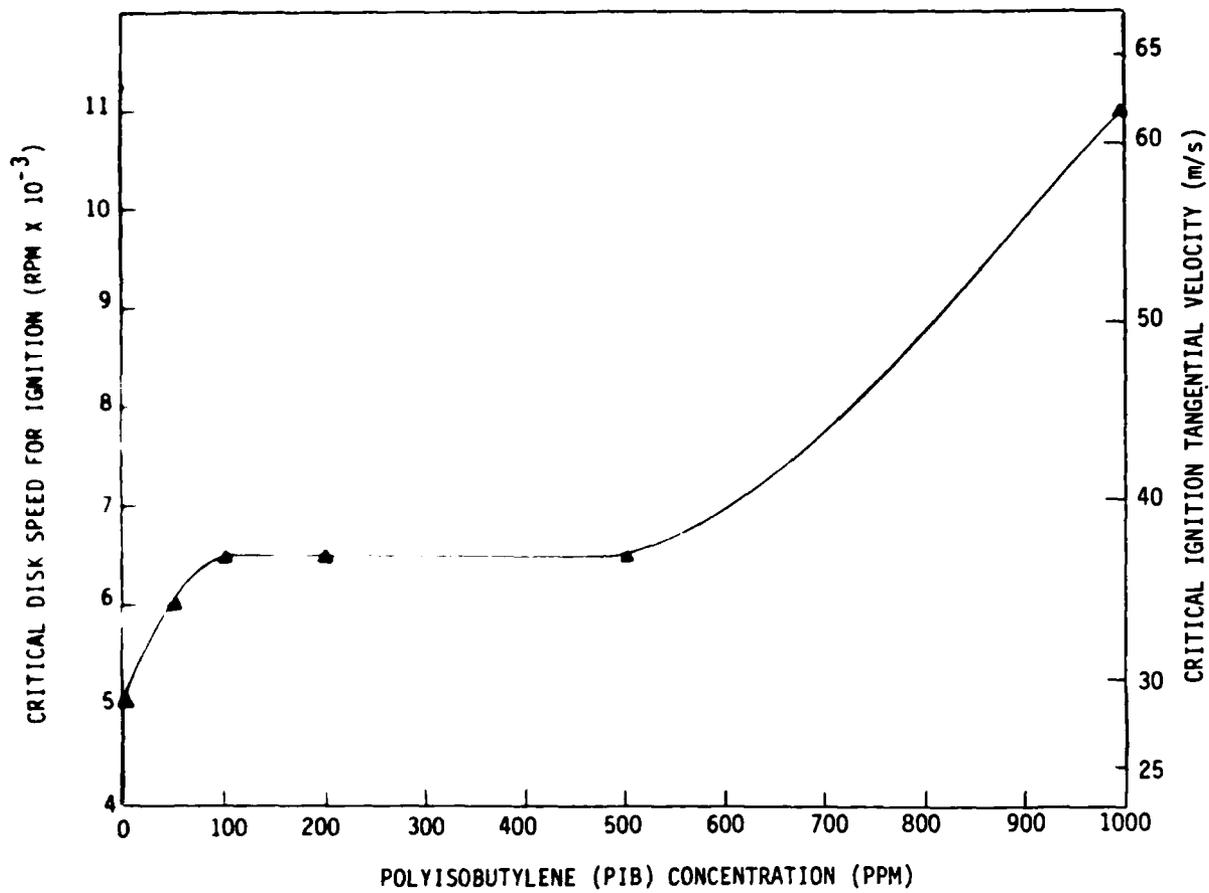


Fig. 6 — Effect of PIB concentration on critical disk speed for ignition

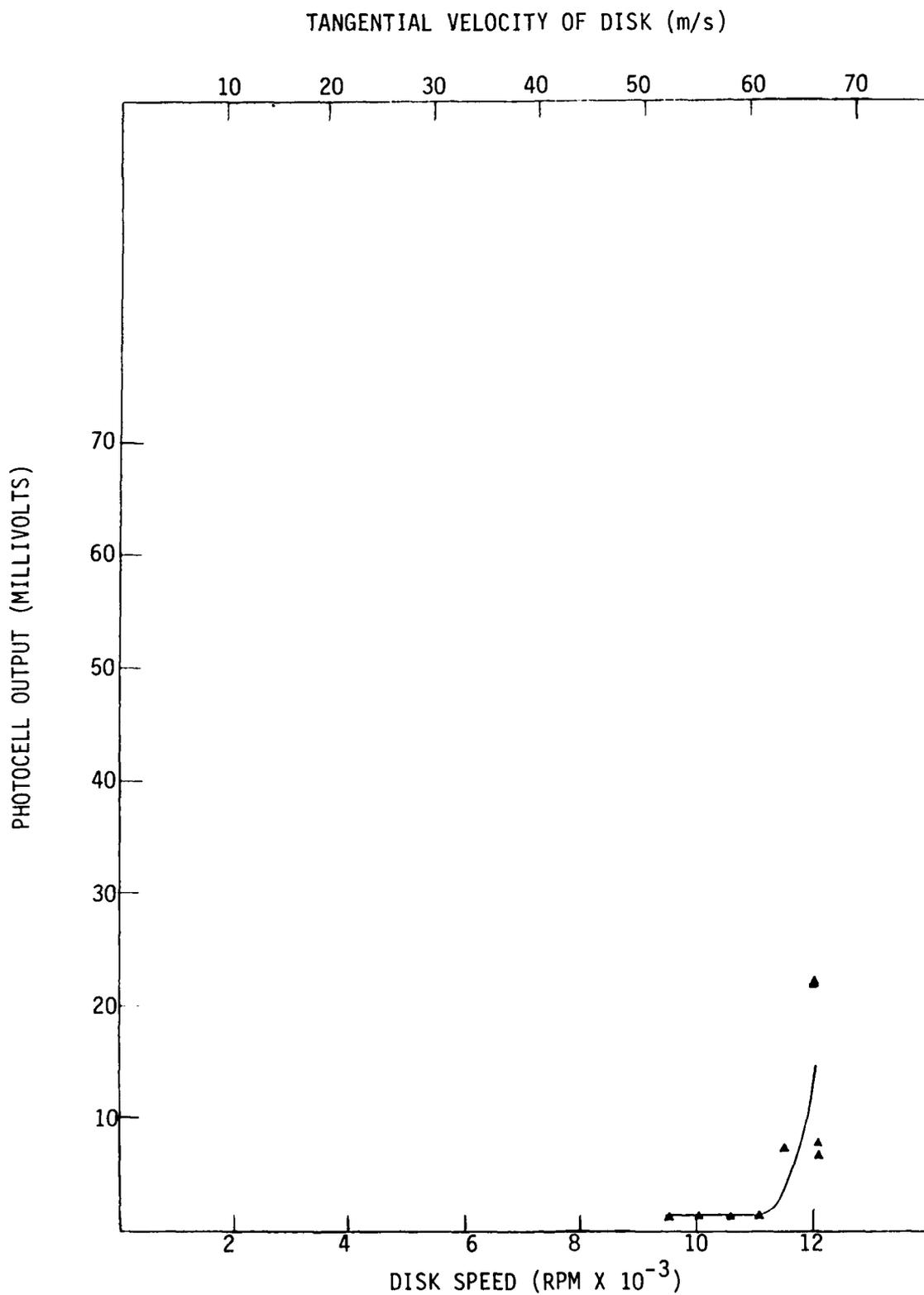


Fig. 5 — Mist flammability of 1000 ppm PIB/JP-5:  
 photocell output as a function of disk RPM

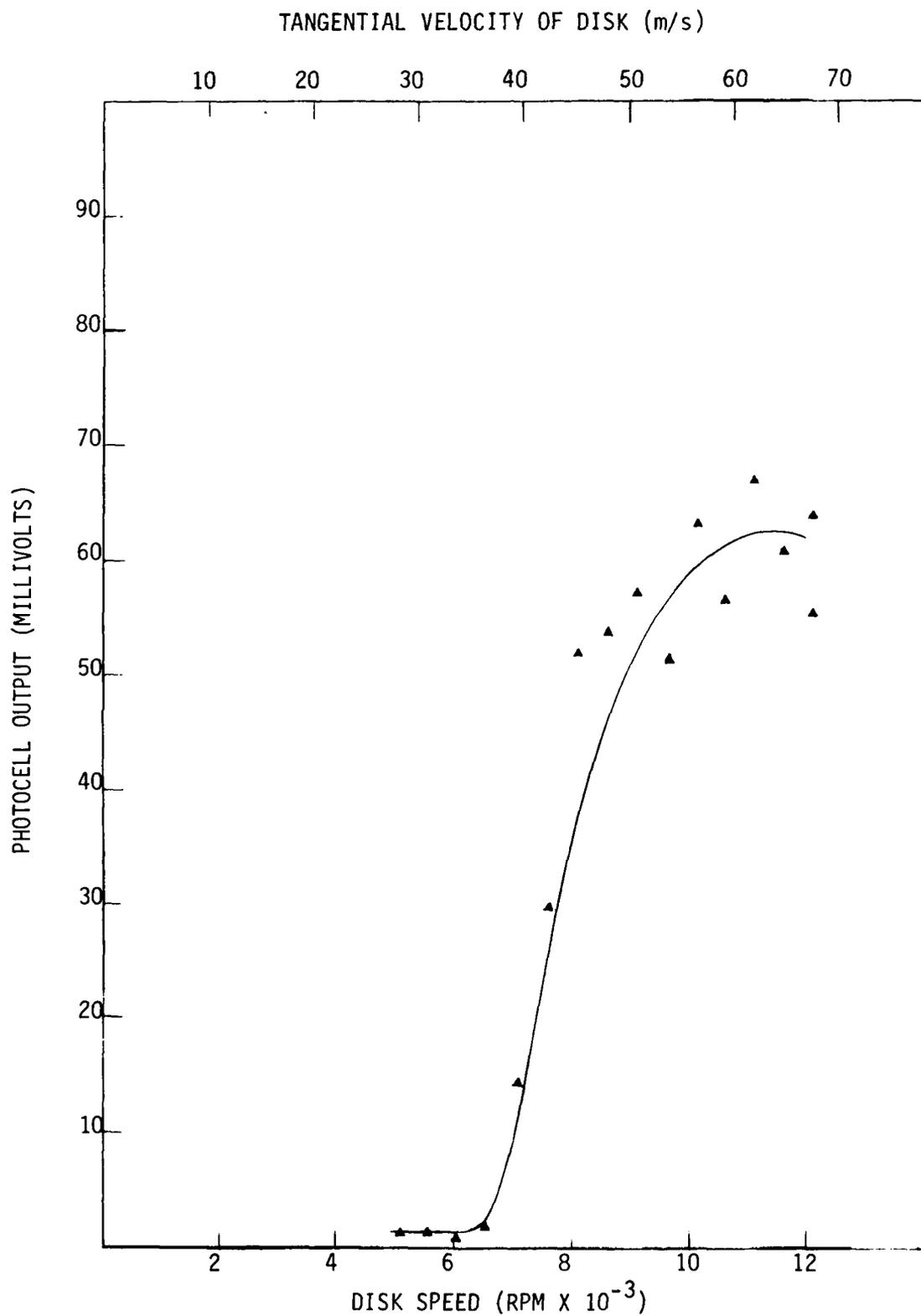


Fig. 4 — Mist flammability of 500 ppm PIB/JP-5:  
 photocell output as a function of disk RPM

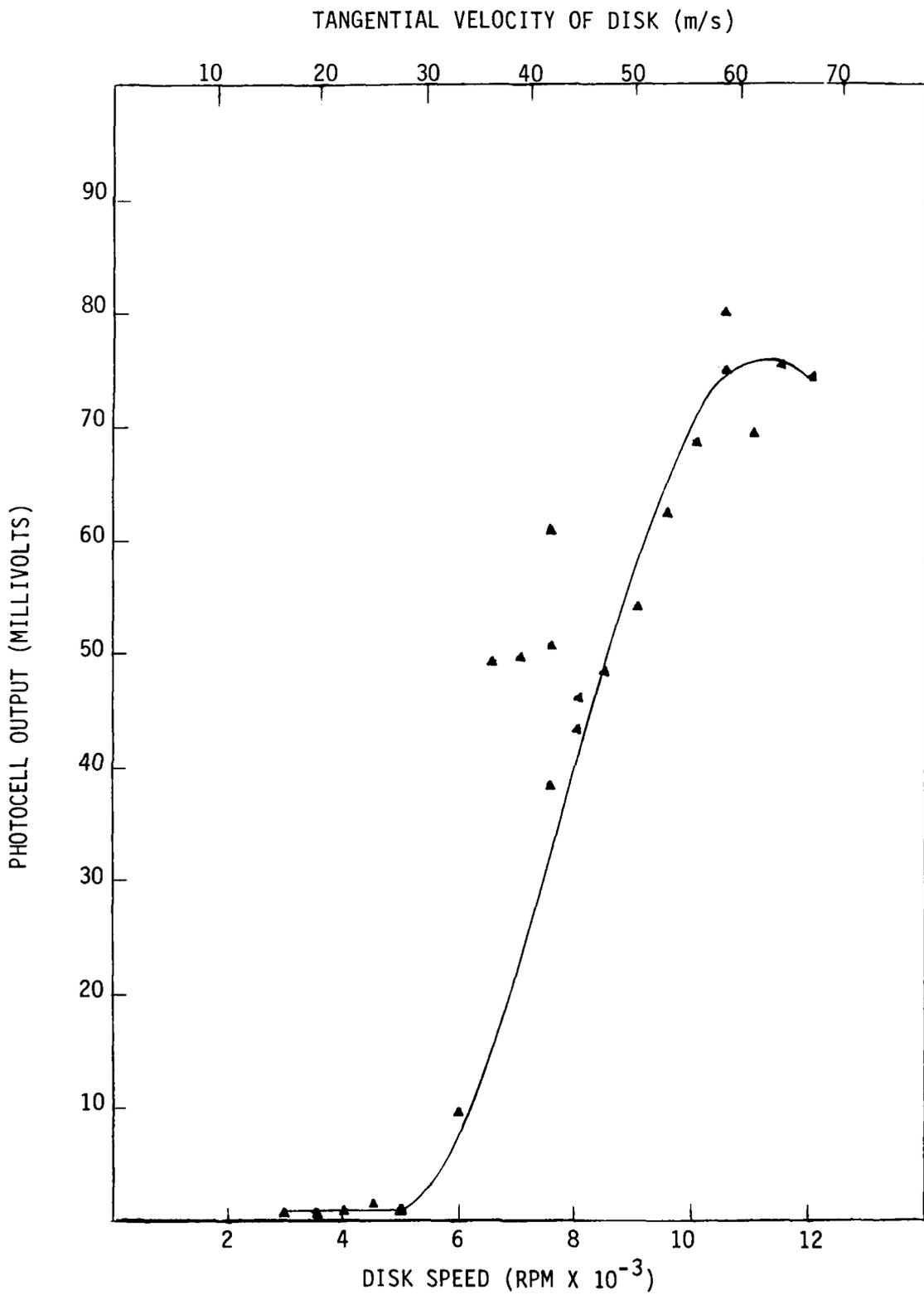


Fig. 3 - Mist flammability of JP-5 (neat fuel):  
 photocell output as a function of disk RPM

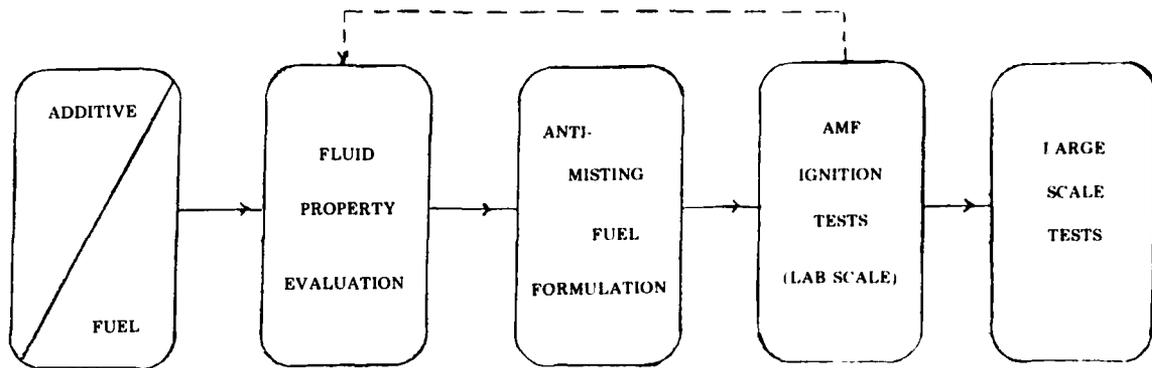


Fig. 1 — Simplified work scheme — NRL

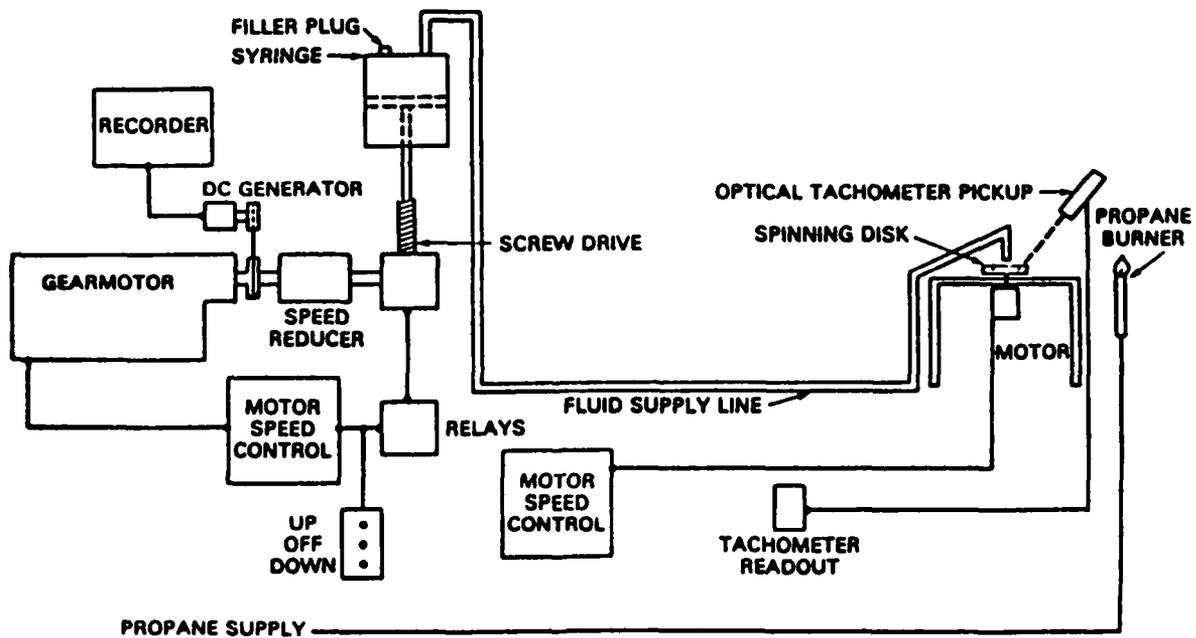


Fig. 2 — Flammability apparatus

Table 7 - Mist Flammability of 1000 ppm Polyisobutylene  
in JP-5: Maximum Photocell Output at  
Varying Disk Speeds.

| Run No. | Initial<br>Disk Speed<br>(rpm $\pm$ 1%) | Tangential Velocity<br>of Disk<br>(m/s) | Maximum<br>Photocell Output<br>(millivolts) |
|---------|-----------------------------------------|-----------------------------------------|---------------------------------------------|
| 1       | 12,000                                  | 67.8                                    | 22.2, 7.0 <sup>a</sup>                      |
| 2       | 11,000                                  | 62.2                                    | 1.5                                         |
| 3       | 10,000                                  | 56.6                                    | 1.5                                         |
| 4       | 12,000                                  | 67.8                                    | 8.2                                         |
| 5       | 11,500                                  | 65.0                                    | 7.5                                         |
| 6       | 10,500                                  | 59.4                                    | 1.4                                         |
| 7       | 9,500                                   | 53.7                                    | 1.3                                         |

a - Next highest value

Table 6 - Mist Flammability of 500 ppm Polyisobutylene  
in JP-5: Maximum Photocell Output at  
Varying Disk Speeds.

| Run No. | Initial<br>Disk Speed<br>(rpm $\pm$ 1%) | Tangential Velocity<br>of Disk<br>(m/s) | Maximum<br>Photocell Output<br>(millivolts) |
|---------|-----------------------------------------|-----------------------------------------|---------------------------------------------|
| 1       | 12,000                                  | 67.8                                    | 55.5; 90.5 <sup>a</sup> , 64.0 <sup>b</sup> |
| 2       | 11,000                                  | 62.2                                    | 67.2                                        |
| 3       | 10,000                                  | 56.6                                    | 63.2                                        |
| 4       | 9,000                                   | 50.9                                    | 57.2                                        |
| 5       | 8,000                                   | 45.2                                    | 52.2                                        |
| 6       | 7,000                                   | 39.6                                    | 14.5                                        |
| 7       | 6,000                                   | 33.9                                    | 0.6                                         |
| 8       | 5,000                                   | 28.3                                    | 0.8; 1.5 <sup>a</sup>                       |
| 9       | 11,500                                  | 65.0                                    | 61.5                                        |
| 10      | 10,500                                  | 59.4                                    | 56.9                                        |
| 11      | 9,500                                   | 53.7                                    | 51.3                                        |
| 12      | 8,500                                   | 48.1                                    | 50.4                                        |
| 13      | 7,500                                   | 42.4                                    | 29.7                                        |
| 14      | 6,500                                   | 36.8                                    | 2.1                                         |
| 15      | 5,500                                   | 31.1                                    | 1.6                                         |

a - Repeat

b - Next highest value

Table 5 - Mist Flammability of 200 ppm Polyisobutylene  
in JP-5: Maximum Photocell Output at  
Varying Disk Speeds.

| Run No. | Initial<br>Disk Speed<br>(rpm $\pm$ 1%) | Tangential Velocity<br>of Disk<br>(m/s) | Maximum<br>Photocell Output<br>(millivolts) |
|---------|-----------------------------------------|-----------------------------------------|---------------------------------------------|
| 1       | 12,000                                  | 67.8                                    | 64.8                                        |
| 2       | 11,000                                  | 62.2                                    | 66.0                                        |
| 3       | 10,000                                  | 56.6                                    | 64.5                                        |
| 4       | 9,000                                   | 50.9                                    | 42.3                                        |
| 5       | 8,000                                   | 45.2                                    | 41.5                                        |
| 6       | 7,000                                   | 39.6                                    | 34.0                                        |
| 7       | 6,000                                   | 33.9                                    | 0.8                                         |
| 8       | 5,000                                   | 28.3                                    | 0.8                                         |
| 9       | 11,500                                  | 65.0                                    | 65.0                                        |
| 10      | 10,500                                  | 59.4                                    | 62.7                                        |
| 11      | 9,500                                   | 53.7                                    | 80.0, 61.0 <sup>a</sup>                     |
| 12      | 8,500                                   | 48.1                                    | 48.5; 42.2 <sup>b</sup>                     |
| 13      | 7,500                                   | 42.4                                    | 2.9                                         |
| 14      | 6,500                                   | 36.8                                    | 1.0                                         |

a - Next highest value

b - Repeat

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