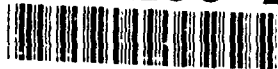


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CRDEC-TR-414

**APPLICATION OF SILICONE FLUID RHEOGONIOMETER MEASUREMENTS
TO DESPIN MOMENT STUDIES IN A SPINNING AND CONING CYLINDER**

Raymond P. Tytus

RESEARCH DIRECTORATE

September 1992

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PREFACE

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APPLICATION OF SILICONE FLUID RHEOGONIOMETER MEASUREMENTS TO DESPIN MOMENT STUDIES IN A SPINNING AND CONING CYLINDER

1. INTRODUCTION

Liquid filled projectile instability studies by Weber and Miller¹ confirmed that high-viscosity liquid payloads can produce significant despin moments that indicate the presence of a destabilizing moment on the shell. Theoretical studies² for Newtonian liquids have established that the despin moment is a function of the liquid viscosity and has a maximum at a low Reynolds number that corresponds to a liquid of high viscosity. The liquids used by Weber and Miller¹ in their test fixture were Dow Corning 200 silicone fluids manufactured by the Dow Chemical Company (Midland, MI). These liquids are considered viscosity standards in many applications and can be obtained in specific viscosities. They may also be blended to obtain a wide viscosity range. However, studies presented by other workers^{3,4} have shown that silicone fluids exhibit viscoelastic behavior. Weber and Miller's test results for silicone fluids¹ showed good agreement with the theory developed for Newtonian fluids at a high Reynolds number (i.e., low-viscosity liquids); however, anomalies were seen at low Reynolds number for higher-viscosity liquids.

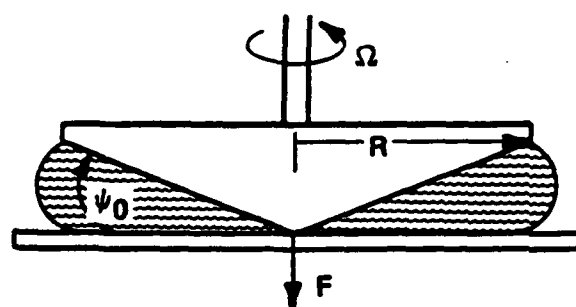
To determine the possible effect of non-Newtonian liquid behavior of Dow Corning 200 silicone fluids on the despin moment, rheology analysis was performed. A Weissenberg rheogoniometer was used to measure the viscosity and normal stress of the silicone fluids as a function of shear rate. These data were then used to compute the resulting moments for these fluids in a spinning and coning cylinder (simulating Weber and Miller's experiment¹). The results indicate the presence and influence of non-Newtonian viscoelastic effects.

2. WEISSENBERG RHEOGONIOMETER

A Weissenberg Rheogoniometer, Model R18, was used to measure the rheological properties of the Dow Corning 200 silicone fluids. Only a brief description of the Weissenberg unit will be given here. A more in-depth description can be found in the instrument's instructional manual.⁵ An excellent review of the Weissenberg unit has also been made by Walters⁶ in which he discusses the instrument and its limitations.

In this study, the unit was used in the cone and plate steady rotational configuration (Figure 1). In this mode, stress measurements are theoretically possible for shear stress (σ_{12}) and normal stress (N_1) at constant shear rates ($\dot{\gamma}$) up to $5,000/s^{-1}$. However, in practice, the maximum shear rate at which one can obtain reliable data is much lower and dependent on inertia and temperature effects of the liquid under test. Rheology data was obtained for 10 silicone fluids. The fluids were usually identified in terms of kilo centistokes (kcSt) (e.g., 600 kcSt = 600,000 cSt). The kinematic viscosities tested included 0.1, 1, 4.2, 6, 10, 32, 60, 100, 300, and 600 kcSt fluids, encompassing the complete range of viscosities used in the Weber and Miller experiments.¹

CONE AND PLATE VISCOMETER



$$\sigma_{12} = 3\tau/2\pi R \quad \dot{\gamma} = \Omega/\psi_0$$

$$\eta = \sigma_{12}/\dot{\gamma}$$

$$N_1 = \sigma_{11} - \sigma_{22} = 2F/\pi R^2$$

Figure 1. Weissenberg Configuration

3. WEISSENBERG TEST RESULTS

Viscosity and normal stress test results for the Dow Corning 200 silicone fluids are shown in Figures 2 and 3, respectively. The start of shear thinning (Figure 2) is indicated at shear rates between 10 and 100/s⁻¹ for higher viscosity fluids. Viscosity data for these fluids dropped dramatically (not shown in Figure 2 for clarity, but will be shown later on individual plots of predictive equations) at higher shear rates. This was attributed to inertial or temperature effects. A normal stress was also measured (Figure 3) for fluid viscosities as low as 4.2 kcSt. The normal stress for higher viscosity fluids also changed dramatically (not shown in Figure 3 for same reason as stated for Figure 2), approaching a constant stress at higher shear rates. Based on this data, it was concluded that non-Newtonian effects were significant for higher viscosity silicone fluids, which may be responsible for the reported anomalies in despin moments for these fluids. To verify this, the effect of viscoelastic fluid behavior on despin moment was investigated.

4. VISCOELASTIC EFFECTS ON DESPIN MOMENT

Previous experiments⁷ and theoretical studies⁸ included the effect of viscoelastic liquid properties on the despin moment. The theoretical studies made by Rosenblat, Gooding, and Engleman⁸ calculated the despin moment for simple viscoelastic models using two approaches. The more rigorous, but more complex, technique involved calculations using a finite element method. The other technique, which was the one used in this study, involved calculations based on assuming an infinitely long cylinder. This method was also used by Herbert² for calculating theoretical despin moments for Newtonian liquids. The calculations do not give exact results for all test conditions. However, good accuracy is obtained when applied to cylinders with small coning to spin rate ratios, which was the case in Weber and Miller's test fixture.¹ A Basic Language computer program was written using Rosenblat, Gooding, and Engleman's derived equation⁸ for the non-Newtonian despin moment. This computer program was then used to determine the viscoelastic effect of high-viscosity Dow Corning 200 silicone fluids on the despin moment. Appropriate parameters for simple viscoelastic models used by Rosenblat, Gooding, and Engleman⁸ were obtained from the Weissenberg test data.

5. VISCOELASTIC MODELS

Rosenblat, Gooding, and Engleman⁸ indicated the difficulty in determining the correct model to use for describing the non-Newtonian flow. There is no constitutive relationship that can be applied to all flows of all non-Newtonian liquids. However, a constitutive equation describing specific flows may be applicable for a wide range of fluids. Rosenblat, Gooding, and Engleman⁸ also indicated that "it is not known whether shear thinning, normal stress differences, elongational viscosity, stress relaxation, or some combination of all or some of these" is significant in any real-flow problem.

SILICONE-200 VISCOSITY RESULTS

- 1- .1KCS
- 2- 1KCS
- 3- 4.2KCS
- 4- 6KCS
- 5- 10KCS
- 6- 32KCS
- 7- 60KCS
- 8- 100KCS
- 9- 300KCS
- 10- 600KCS

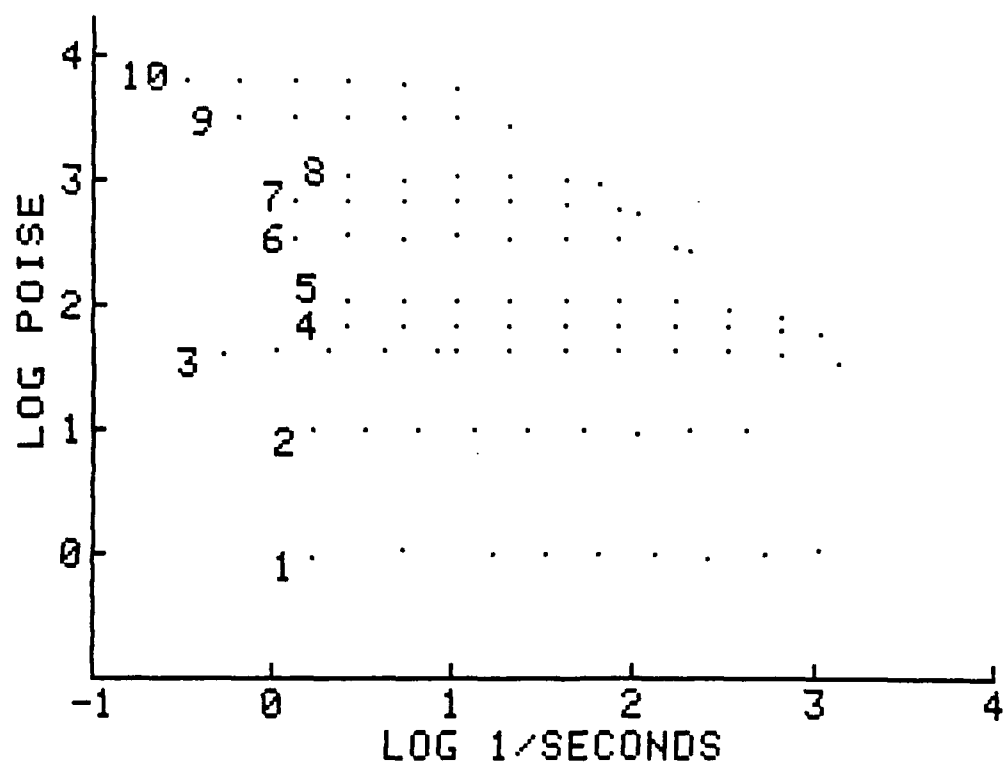


Figure 2. Dow Corning 200 Viscosity Results

SILICONE-200 NORMAL STRESS RESULTS

- 1 - 4.2KCS
- 2 - 4KCS
- 3 - 10KCS
- 4 - 32KCS
- 5 - 60KCS
- 6 - 100KCS
- 7 - 300KCS
- 8 - 600KCS

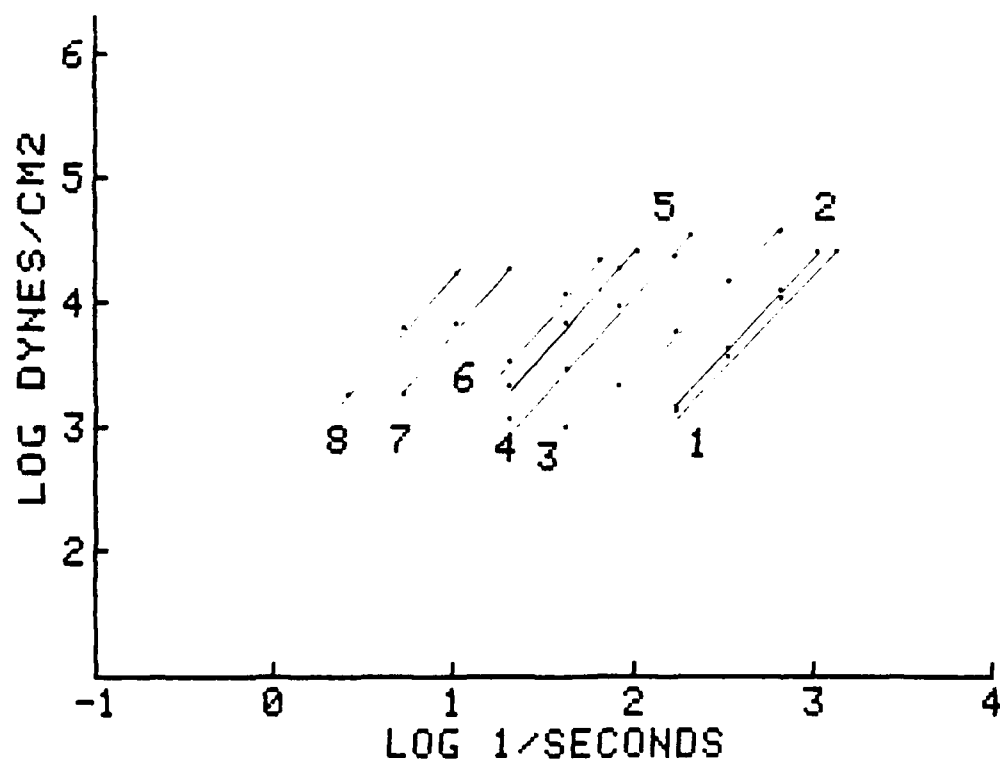


Figure 3. Dow Corning 200 Normal Stress Results

Therefore, Rosenblat, Gooding, and Engleman⁸ restricted themselves to testing and comparing simple constitutive relationships to experimental data.

Rosenblat, Gooding, and Engleman⁸ selected two viscoelastic models to test; a "second order fluid" and a "differential model." In a second order fluid, the following relationships are valid:

$$\eta(\dot{\gamma}) = \eta_0$$

$$N_1(\dot{\gamma}) = 2\lambda\eta_0\dot{\gamma}^2$$

η_0 is the zero shear viscosity, and λ is a relaxation time constant for the fluid. As seen, shear thinning is not predicted, and normal stress is a quadratic function of shear rate. Weissenberg data for higher-viscosity, silicone fluids at high-shear rates did indicate shear thinning; therefore, this model does not appear to be applicable.

For the differential model, a "3 constant modified" version of the "Oldroyd 8 constant model"⁹ was used. The 3 constant modified model exhibits both shear thinning and normal stress behavior. The 3 constant modified model includes a zero-shear viscosity η_0 , a relaxation-time constant λ , and a retardation-time constant λ_r , where ϵ defines the $\frac{\lambda_r}{\lambda}$ ratio.

The pertinent equations are:

$$\eta(\dot{\gamma}) = \eta_0 \left(\frac{1 + \lambda^2 \epsilon \dot{\gamma}^2}{1 + \lambda^2 \dot{\gamma}^2} \right)$$

$$N_1(\dot{\gamma}) = 2\eta_0 \lambda \frac{(1 - \epsilon) \dot{\gamma}^2}{(1 + \lambda^2 \dot{\gamma}^2)}$$

A Basic Language computer program was written (Appendix A) to calculate the fluid relaxation time for four of the Dow Corning 200 silicone fluids. The four silicone fluids corresponded to fluids used extensively by Weber and Miller¹ and included 600, 300, 100, and 10 kcSt fluids. The relaxation-time constant for each fluid was determined using the Weissenberg-zero shear viscosity and normal stress versus shear rate data. The zero-shear viscosity is calculated directly from the Weissenberg measurements. Normal stress data at the lower shear rates were substituted into the normal stress equation, which was then solved for λ at assumed values of $\epsilon = 0, .2, \text{ and } .4$. An average value for λ was then obtained from these results. An exact determination of ϵ for silicone fluids could not be made because of limitations in Weissenberg measurements at the high-shear rates. Therefore, assumed values of ϵ were used to determine fluid relaxation times. Table 1 shows the results of these calculations.

Table 1. Calculated Silicone Fluid Relaxation Times

<u>Viscosity</u> kcSt	<u>Relaxation Time</u>		
	$\epsilon = 0$	$\epsilon = .2$	$\epsilon = .4$
600	.0144	.018	.0244
300	.0099	.0124	.0166
100	.003	.0038	.0051
10	.00138	.00173	.00233

Predictions of viscosity and normal stress obtained for the 3 constant modified model as a function of shear rate are shown in Figures 4-7 for $\epsilon = 0$. (NOTE: The viscosity prediction for the other values of ϵ indicates a constant viscosity of lower magnitude after a short-shear, thinning interval. The predicted values of normal stress also become constant after this interval.) All test data points are included in the plots; a good data fit is indicated. These fluid constants were then used to calculate the despin moment using the equation developed by Rosenblat, Gooding, and Engleman⁸ for the differential model.

6. DESPIN MOMENT CALCULATIONS

The despin moment equation is shown below:

$$M = \frac{M_z}{A^2 8\pi B C^2} = REAL \left\{ \frac{i\eta^1(1)}{S} \right\}$$

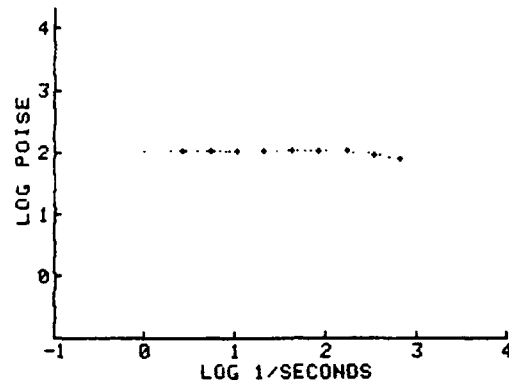
where

M = normalized despin moment

M_z = actual despin moment

A = coning rate to spin rate ratio

10 KCS SILICONE FLUID
PREDICTED VISCOSITY VERSUS SHEAR RATE
+ -TEST DATA POINTS



10 KCS SILICONE FLUID
PREDICTED NORMAL STRESS VERSUS SHEAR RATE
+ -TEST DATA POINTS

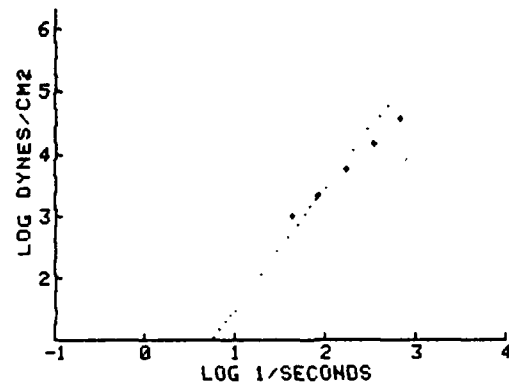
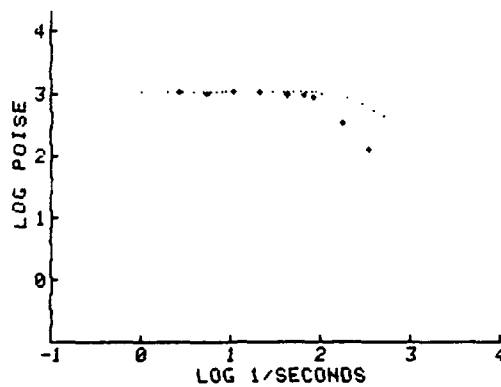


Figure 4. 10 kcSt Rheology Predictions

100 KCS SILICONE FLUID
 PREDICTED VISCOSITY VERSUS SHEAR RATE
 + -TEST DATA POINTS



100 KCS SILICONE FLUID
 PREDICTED NORMAL STRESS VERSUS SHEAR RATE
 + -TEST DATA POINTS

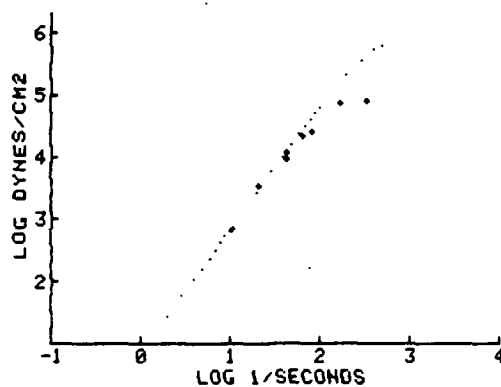
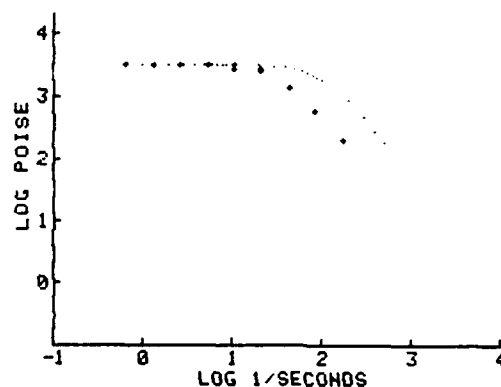


Figure 5. 100 kcSt Rheology Predictions

300 KCS SILICONE FLUID
 PREDICTED VISCOSITY VERSUS SHEAR RATE
 + -TEST DATA POINTS



300 KCS SILICONE FLUID
 PREDICTED NORMAL STRESS VERSUS SHEAR RATE
 + -TEST DATA POINTS

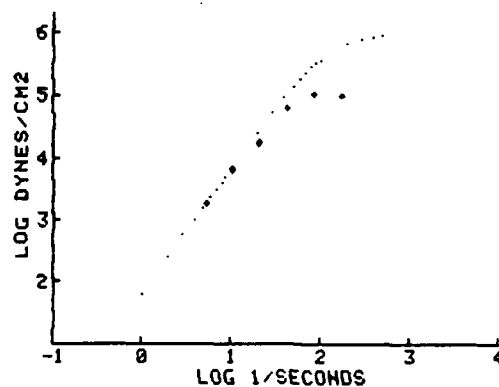
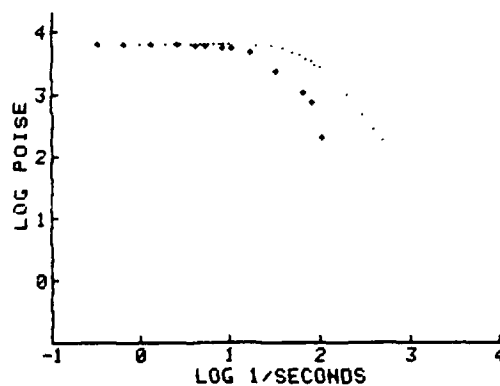


Figure 6. 300 kcSt Rheology Predictions

600 KCS SILICONE FLUID
 PREDICTED VISCOSITY VERSUS SHEAR RATE
 + -TEST DATA POINTS



600 KCS SILICONE FLUID
 PREDICTED NORMAL STRESS VERSUS SHEAR RATE
 + -TEST DATA POINTS

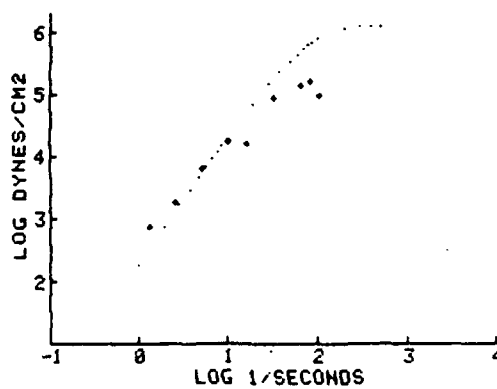


Figure 7. 600 kcSt Rheology Predictions

B = cylinder aspect ratio (4.5 for the reported tests)

C = sine of the coning angle

The term in brackets is a solution of the differential equation for the fluid flow field, which is a function of the fluid model specified by the variable S. The variable S for the various models is shown below:

$S = Re$ -- Newtonian model

$S = Re / (1 + iDeRe)$ -- second order fluid model

$S = (1 - iDeRe)Re / (1 - iDeRe)$ -- differential model

Where Re is a Reynolds number and De is a Deborah number, both dimensionless parameters defined by Rosenblat, Gooding, and Engleman.⁸ Reynolds number is proportional to the spin rate of the cylinder and inversely proportional to the fluid zero-shear viscosity. The Deborah number is proportional to the product of the fluid relaxation time and zero-shear viscosity.

A Basic Language computer program (Appendix B) was written using the despin moment equation. The software was written in a user-friendly format that required information be entered as input data on request by the program. The first input request is the type of fluid model (i.e., Newtonian, second order, or differential). The fluid name and Deborah number are then requested for viscoelastic fluids in the next two user inputs. Table 2 shows the calculated Deborah numbers for the various silicone fluids.

Table 2. Calculated Silicone Fluid Deborah Number

Viscosity kcSt	Deborah Number		
	$\epsilon = 0$	$\epsilon = .2$	$\epsilon = .4$
600	2.96	3.70	5.01
300	1.01	1.26	1.69
100	0.105	0.133	0.179
10	0.0048	0.0061	0.008

If a differential fluid model is being used, the program then asks for the ϵ value for the model equation. At this point, all required fluid specifics have been entered into the program.

The next information requested is the type of despin moment to be calculated (i.e., linear or generalized). This requires simple multiplication by an appropriate factor. For a linearized moment, the factor is equal to four times the coning rate to the spin rate ratio. For the generalized moment, the factor is equal to four times the square of the cosine of the coning angle. The Reynolds number range and increments for making the calculations are then requested. These requests were included in the program for two reasons. First, the Apple IIe computer used in this study has insufficient memory (64K) to perform calculations over the full range of Reynolds numbers used by Rosenblat, Gooding, and Engleman.⁸ Second, and more significant, the calculated values of despin moment would cover only the range of Reynolds number used in the test program. The test data determined by Weber and Miller¹ was obtained over a limited range of Reynolds number because of limitations in the spin rate of their test fixture. The remaining program requests information pertaining to obtaining copies of the calculated despin moments.

7. DISCUSSION OF DESPIN MOMENT RESULTS

Figure 8 shows the test results obtained by Weber and Miller¹ for various silicone fluids. Theoretical curves obtained by Herbert² and Rosenblat, Gooding, and Engleman⁸ for the despin moments are included in Figure 8. The data points that deviate from the theoretical curve at the low Reynolds numbers correspond to silicone viscosities of 600, 300, and 100 kcSt, from left to right. If curves are drawn through the data points for each viscosity, a family of curves can be established for these three silicone viscosities at the low Reynolds numbers. The 10 kcSt data points, as well as other lower silicone viscosity fluids tested, appear to be close to the theoretical prediction of despin moment.

Figures 9, 10, and 11 show the predicted despin moments using the differential model parameters shown in Tables 1 and 2. The three curves correspond to ϵ equal to 0, 0.2, and 0.4. Included in each Figure is the despin moment response for a Newtonian fluid. (NOTE: The response for the Newtonian fluid indicates a maximum at approximately a Reynolds number of 15 compared to a Reynolds number of approximately 40 in Figure 8 for the theoretical curves by Herbert² and Rosenblat, Gooding, and Engleman.⁸ This difference is due to the infinite cylinder approximation used in this analysis. However, the general shapes of the curves are the same).

For $\epsilon = 0$ (Figure 9), the despin moment response for the 600 kcSt fluid rises sharply near a Reynolds number of unity and returns to an approximate value of 0.2 at Reynolds number 3 (this range of 1-3 corresponds to the actual Reynolds number range used in the study). The 300 kcSt fluid has two peaks in the 2-8 Reynolds numbers range; whereas, the 100 kcSt fluid has one peak in the 5-20 Reynolds numbers range. In all three cases, the peaks extend well beyond the value of despin moment obtained for a Newtonian fluid. The 10 kcSt fluid results appear somewhat higher than the Newtonian prediction. However, it is decreasing as expected in this Reynolds number range (50-100). These results agree with the trend in the experimental data,

which show significantly larger despin moments for the higher viscosity fluids; whereas, Newtonian theory predicts much lower despin moments.

For the other two values of ϵ , $\epsilon = 0.2$ (Figure 10) and $\epsilon = 0.4$ (Figure 11), the peaks mentioned in the above paragraph are significantly reduced. The resultant curve for the 100 kcSt fluid qualitatively approaches that of the test data, whereas, the curves for the 300 and 600 kcSt exhibit lower despin moments than the experimental test data. However, in all cases, the differential model predictions are higher than the despin moments for a Newtonian fluid.

It appears that, based on the above analysis, a differential model can be used to predict the qualitative differences in despin moment for the high-viscosity, Dow Corning 200 silicone fluids at a low Reynolds number. However, precise quantitative agreement with test data is not indicated.

Much better agreement with test data can be found if one substitutes a Deborah number equal to 0.3 times the calculated values obtained for $\epsilon = 0$. Figure 12 shows the predicted despin moments for this condition. Comparison of the despin moments for the 300 and 600 kcSt fluids with Weber and Miller's test data¹ (Figure 8) shows a sharp increase with increasing the Reynolds number. The 100 kcSt fluid shows a rise and peak at a Reynolds number of about 20. The 10 kcSt shows a decreasing trend that is very close to the Newtonian prediction. All these fluids behave similarly to the actual test results.

8. CONCLUSIONS

A Weissenberg rheogoniometer was used to measure the rheological properties for a series of Dow Corning 200 silicone fluids. The following information was found from these measurements:

- Non-Newtonian behavior was indicated for the higher viscosity silicone fluids in the form of shear thinning and normal stress at high shear rates.
- "Differential model" viscoelastic parameters could be determined from rheogoniometer measurements. A "second order fluid model" was found to be inappropriate because fluid shear-thinning effects are not predicted by this model.
- The "differential model" qualitatively predicted the despin moment behavior of the silicone fluids. However, quantitative agreement was not achieved.
- Much better agreement with test data was found for all fluids if the "differential model" viscoelastic parameter for Deborah number was made equal to 0.3 times the calculated value obtained for $\epsilon = 0$.

COMPARISON BETWEEN THEORY AND EXPERIMENT

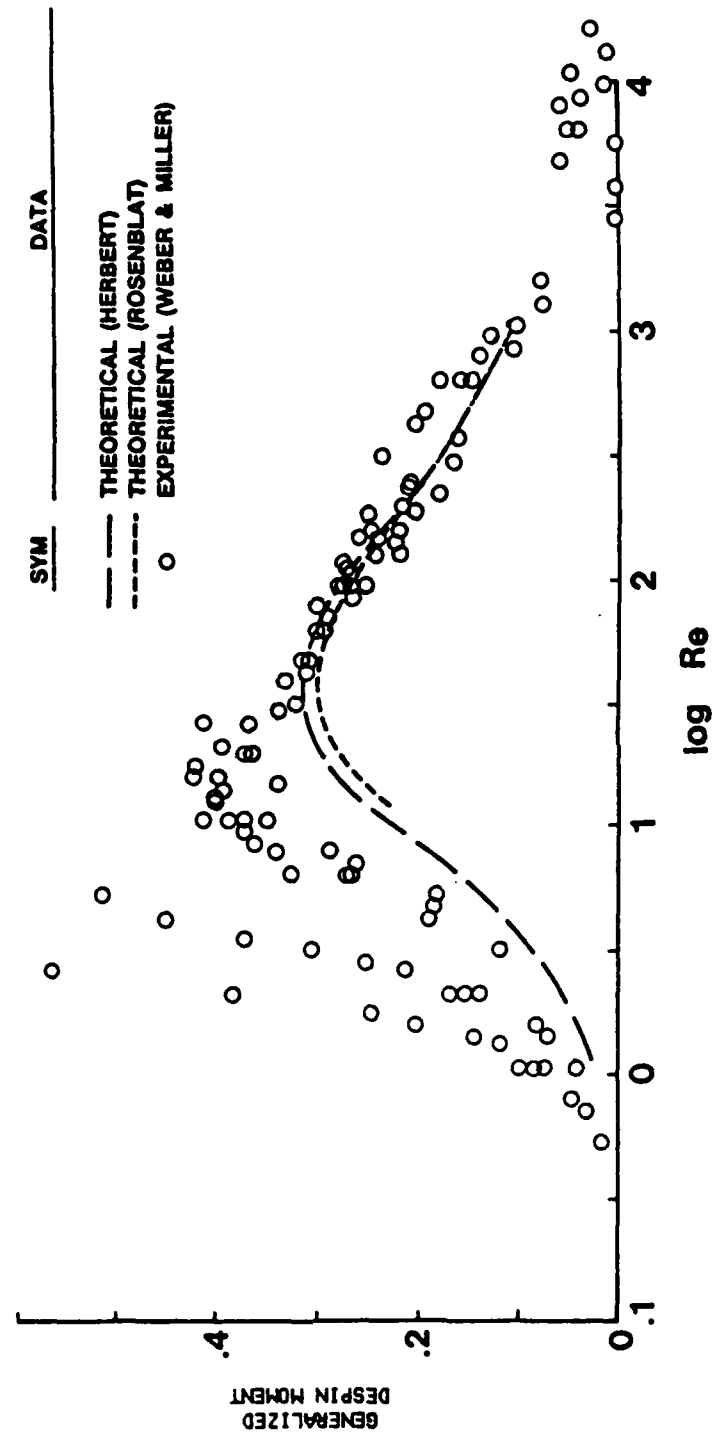


Figure 8. Weber and Miller Despin Moment Results

GENERALIZED DESPIN MOMENT
DIFFERENTIAL MODEL

CONING ANGLE=15

1-NEWTONIAN		
2-KCS600-DEBORAH #	=2.96	E=0
3-KCS300-DEBORAH #	=1.01	E=0
4-KCS100-DEBORAH #	= .105	E=0
5-KCS10-DEBORAH #	=4.8E-03	E=0

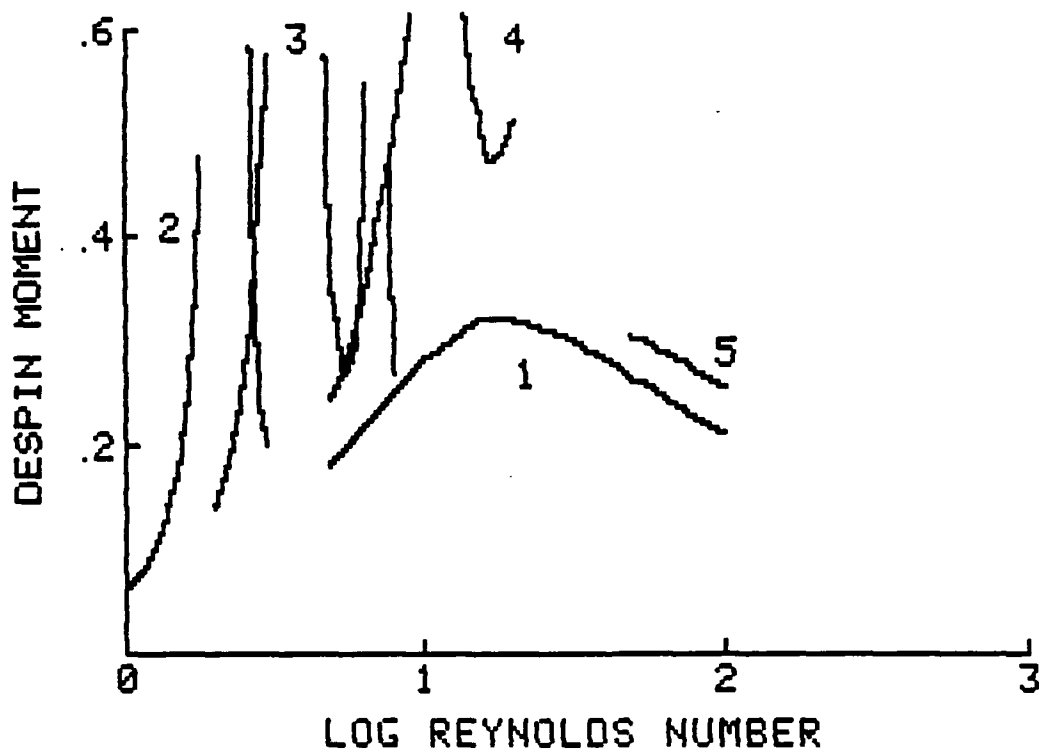


Figure 9. Predicted Despin Moment ($\epsilon = 0$)

GENERALIZED DESPIN MOMENT
DIFFERENTIAL MODEL

CONING ANGLE=15

1-NEWTONIAN
2-KCS400-DEBORAH # =3.7 E=.2
3-KCS300-DEBORAH # =1.26 E=.2
4-KCS100-DEBORAH # =.133 E=.2
5-KCS10-DEBORAH # =6.1E-03 E=.2

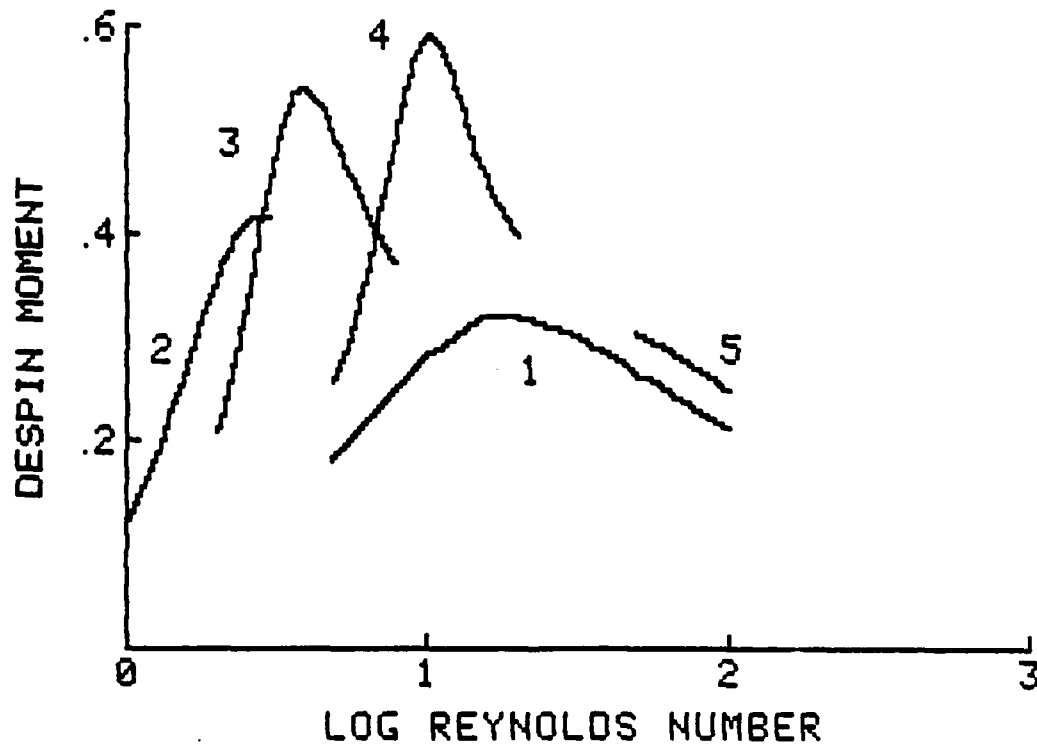


Figure 10. Predicted Despin Moment ($\epsilon = .2$)

GENERALIZED DESPIN MOMENT
DIFFERENTIAL MODEL

CONING ANGLE=15

1-NEWTONIAN		
2-KCS600-DEBORAH # =5.01	E=.4	
3-KCS300-DEBORAH # =1.69	E=.4	
4-KCS100-DEBORAH # =.179	E=.4	
5-KCS10-DEBORAH # =8.2E-03	E=.4	

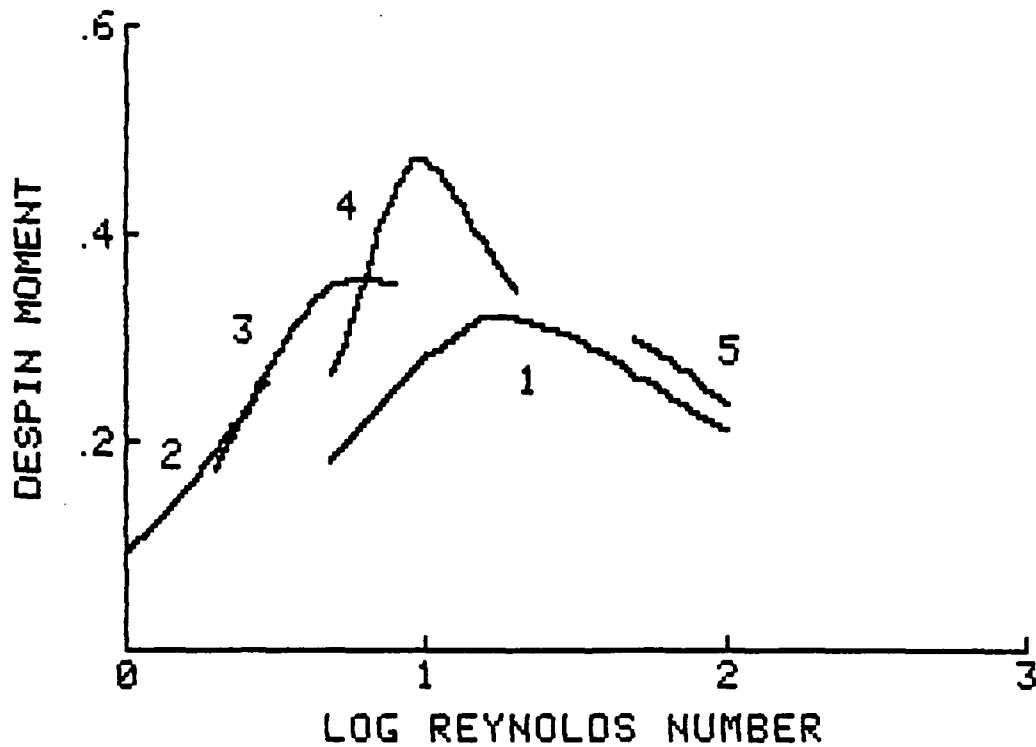


Figure 11. Predicted Despin Moment ($\epsilon = .4$)

• From the analysis performed in this study, it appears that the differences between the despin moment test results for the higher viscosity Dow Corning 200 silicone fluids and the theoretical predictions for Newtonian fluids can be attributed to the viscoelastic properties of the silicone fluids.

GENERALIZED DESPIN MOMENT DIFFERENTIAL MODEL

CONING ANGLE=15

1-NEWTONIAN
2-KCS600-DEBORAH # =.89 E=0
3-KCS300-DEBORAH # =.303 E=0
4-KCS100-DEBORAH # =.032 E=0
5-KCS10-DEBORAH # =1.44E-03 E=0

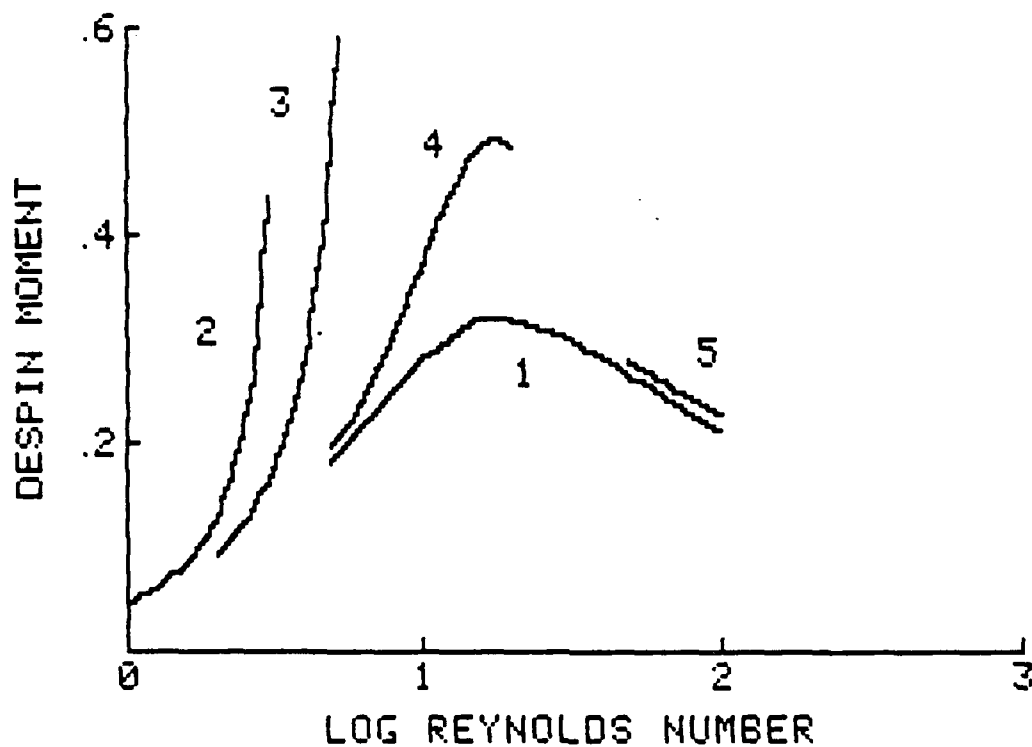


Figure 12. Predicted Despin Moment ($\epsilon = 0$) X 0.3

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LITERATURE CITED

1. Weber, D.J., and Miller, M.C., "Liquid Induced Rolling and Yawing Moment Coefficients for Viscous Newtonian Fluids in a Spinning and Coning Cylinder," In Proceedings of the U.S. Army Chemical Research, Development and Engineering Center Scientific Conference on Chemical Defense Research held in Aberdeen, Maryland, on 15-18 November 1988. Volume I, CRDEC-SP-013, U.S. Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD, August 1989, UNCLASSIFIED Report (AD B137 716).
2. Herbert, T., Fluid Motion in a Rotating and Nutating Container, CRDC-CR-84087, U.S. Army Chemical Research and Development Center, Aberdeen Proving Ground, MD, July 1984, UNCLASSIFIED Report (AD A146 175).
3. Boger, D.V., and Binnington, R., "Separation of Elastic and Shear Thinning Effects in the Capillary Rheometer," Trans. Soc. Rheol. Vol. 21 (4), pp 515-534 (1977).
4. Boger, D.V., and Nguyen, H., "A Model Viscoelastic Fluid," Polym. Eng. Sci. Vol. 18 (13), pp 1037-1043 (1978).
5. The Weissenberg Rheogoniometer Instruction Manual, Model R18, Sangamo Control, Limited, Sussex, England.
6. Walters, K., Rheometry, John Wiley and Sons, New York, NY, 1975.
7. Miller, M.C., and Weber, D.J., "Measurement of Despin Moment Produced by a Viscoelastic Fluid in a Spinning and Coning Cylinder," In Proceedings of the U.S. Army Chemical Research, Development and Engineering Center Scientific Conference on Chemical Defense Research held in Aberdeen, Maryland, on 18-21 November 1986. Volume I, CRDEC-SP-87008, U.S. Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD, June 1987, UNCLASSIFIED Report (AD B113 947).
8. Rosenblat, S., Gooding, A., and Engleman, M.S., Finite Element Calculations of Viscoelastic Fluid Flow in a Spinning and Nutating Cylinder, CRDEC-CR-87021, U.S. Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD, December 1986, UNCLASSIFIED Report (Not Sent to DTIC).
9. Oldroyd, J.G., "Non-Newtonian Effects in Steady Motion of Some Idealized Elastico-Viscous Liquids," Proc. R. Soc. London Vol. A245, pp 278-297 (1958).

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APPENDIX A

FLUID RELAXATION TIME - BASIC LANGUAGE PROGRAM

```

0 TEXT : HOME
2 ONERR GOTO 77
5 INPUT "VISCOSITY";N0
7 INPUT "N1,R1 ";N1,R1
8 INPUT "N2,R2 ";N2,R2
10 INPUT "ENTER E VALUE ";E
11 Z = 2 - (2 * E)
12 INPUT "R,S,T ";R,S,T
15 FOR K = R TO S STEP T
16 A1 = 1:A2 = 1
18 B1 = - ((Z * N0) / (N1 * K))
19 C1 = 1 / (K * R1 * R1)
20 Y1 = - B1 + ((B1 * B1) - (4 *
    A1 * C1)) ^ .5
30 Y1 = Y1 / (2 * A1)
40 X1 = - B1 - ((B1 * B1) - (4 *
    A1 * C1)) ^ .5
50 X1 = X1 / (A1 * 2)
52 B2 = - ((Z * N0) / (N2 * K))
53 C2 = 1 / (K * R2 * R2)
60 Y2 = - B2 + ((B2 * B2) - (4 *
    A2 * C2)) ^ .5
64 Y2 = Y2 / (2 * A2)
66 X2 = - B2 - ((B2 * B2) - (4 *
    A2 * C2)) ^ .5
68 X2 = X2 / (A2 * 2)
69 PRINT K
70 PRINT Y1,X1: PRINT Y2,X2
72 PRINT
73 INPUT A$
75 NEXT K
77 INPUT "HIT KEY FOR NEXT K RAN
    GE ";A$
80 GOTO 12

```

Blank

APPENDIX B

DESPIN MOMENT - BASIC LANGUAGE PROGRAM

```

1  V = 0:K = 0:PW = .5
5  DIM T1(100)
10 TEXT : HOME : VTAB (5): PRINT
    "SELECT FLUID MODEL (1,2 OR
    3) "
12  VTAB (10)
13  PRINT TAB( 6)"1. NEWTONIAN F
    LUID": PRINT
14  PRINT TAB( 6)"2. SECOND ORDE
    R FLUID": PRINT
15  PRINT TAB( 6)"3. DIFFERENTIA
    L MODEL FLUID": PRINT : PRINT
    : PRINT
16  PRINT : INPUT AZ$
17  IF AZ$ = "1" THEN DE$ = "0":E
    $ = "0":AZ$ = "NEWTONIAN FLU
    ID":DE = VAL (DE$):E = VAL
    (E$):NF$ = "NEWTONIAN": GOTO
    50
18  IF AZ$ = "2" THEN E$ = "0":PW
    = - PW:E = VAL (E$): GOTO
    30
19  IF AZ$ = "3" THEN GOTO 30
20  GOTO 16
30  PRINT : INPUT "ENTER FLUID NA
    ME ";NF$
31  PRINT : INPUT "ENTER DEBORAH
    NUMBER ";DE$:DE = VAL (DE$)

32  IF AZ$ = "2" THEN AZ$ = "SECO
    ND ORDER FLUID": GOTO 50
34  PRINT : INPUT "ENTER E VALUE
    ";E$:E = VAL (E$)
36  AZ$ = "DIFFERENTIAL MODEL FLUI
    D"
50  PRINT : INPUT "LINEAR OR GENE
    RAL DESPIN MOMENT (L OR G) ?
    ";AX$
52  IF AX$ = "L" THEN AY$ = "LINE
    ARIZED": GOTO 60
54  IF AX$ = "G" THEN AY$ = "GENE
    RALIZED": GOTO 60
56  GOTO 50
60  PRINT : INPUT "ENTER LOWER RE
    YNOLDS NUMBER ";SL$:SL = VAL
    (SL$)
65  PRINT : INPUT "ENTER UPPER RE
    YNOLDS NUMBER ";SU$:SU = VAL
    (SU$)
70  PRINT : INPUT "ENTER REYNOLDS
    NUMBER INCREMENT ";SI$:SI =
    VAL (SI$)

```

```

72 PRINT : INPUT "DO YOU WANT A
   HARDCOPY OF THE DATA? (Y OR
   N) ";A$
73 IF A$ = "Y" THEN PRINT CHR$
   (4);"PR#1": GOTO 75
74 IF A$ < > "N" THEN GOTO 72
75 HOME
80 C$ = AZ$: GOSUB 600
81 IF DE < > 0 THEN C$ = NF$: GOSUB
   600
82 IF DE < > 0 AND LEN (AZ$) =
   24 THEN PRINT TAB( 9)"DEBO
   RAH #="DE" E="E
83 IF DE < > 0 AND LEN (AZ$) =
   18 THEN PRINT TAB( 14)"DEB
   ORAH #="DE
85 C$ = AY$: GOSUB 600
87 IF AX$ = "G" THEN PRINT TAB(
   12)"DESPIN MOMENT FOR": PRINT
   TAB( 12)"CONING ANGLE=": GOTO
   90
89 PRINT TAB( 12)"DESPIN MOMENT
   FOR T="
90 PRINT TAB( 8)"-----"
   "-----"
91 IF AX$ = "G" THEN GOSUB 500
92 IF AX$ = "G" THEN GOTO 96
93 PRINT "RE #"; TAB( 8)"0.2"; TAB(
   16)"0.15"; TAB( 24)"0.1"; TAB(
   32)"0.05"
95 PRINT "-----"; TAB( 8)"---"; TAB(
   16)"-----"; TAB( 24)"---"; TAB(
   32)"-----"
96 PRINT
99 WP = 0:RN = 0:IN = 0:RD = 0:ID
   = 0
100 FOR S = SL TO SU STEP SI
105 V = V + 1
120 P = LOG ((2 * K) + 4) / LOG
   (10):R = ((2 * K) + 1) * LOG
   (2) / LOG (10)
122 X = ((DE * DE * S * S) + 1) ^
   PW
123 X = S * X
125 Y = ((DE * DE * S * S * E * E
   ) + 1) ^ .5
127 Q = K * LOG (X / Y) / LOG (
   10)
130 IF K = 0 THEN O = 0:WW = 0: GOTO
   170
140 O = K * ( - 1.57 - ATN (DE *
   S) + ATN (E * DE * S))

```

```

150 WW = WP + ( LOG (K) / LOG (1
    0))
170 ZZ = WW + ( LOG (K + 1) / LOG
    (10))
175 NN = Q - (P + R + WW + ZZ):DD
    = Q - (R + WW + ZZ)
176 N = 10 ^ NN:D = 10 ^ DD
185 RR = N * COS (0):II = N * SIN
    (0)
187 RS = D * COS (0):IS = D * SIN
    (0)
210 RN = RN + RR:IN = IN + II
220 RD = RD + RS:ID = ID + IS
221 IF RN = R1 AND RD = R2 THEN
    K = K - 1: GOTO 240
222 IF K < 4 THEN GOTO 224
223 IF RN = R1 AND RD = R2 THEN
    K = K - 1: GOTO 240
224 R1 = RN:R2 = RD:I1 = IN:I2 =
    ID
225 K = K + 1
227 WP = WW
230 GOTO 120
240 SN = ((RN * RN) + (IN * IN)) ^
    .5
245 IF RN < 0 AND IN < 0 THEN OD
    = - 3.14 + ATN (IN / RN):
    GOTO 260
247 IF RN < 0 AND IN > 0 THEN RN
    = - RN:OD = 3.14 - ATN (I
    N / RN): GOTO 260
250 OD = ATN (IN / RN)
260 SD = ((RD * RD) + (ID * ID)) ^
    .5
265 IF RD < 0 AND ID < 0 THEN OD
    = - 3.14 + ATN (ID / RD):
    GOTO 280
267 IF RD < 0 AND ID > 0 THEN RD
    = - RD:OD = 3.14 - ATN (I
    D / RD): GOTO 280
270 OD = ATN (ID / RD)
280 ST = SN / SD:OT = (OD - OD)
290 IM = ST * SIN (OT)
300 RE = 1 * IM
310 REM (-J*J=1)
315 IF AX$ = "G" THEN GOSUB 550
317 IF AX$ = "G" THEN GOTO 325

```

```

320 PRINT S; TAB( 8) INT (8000 *
    RE) / 10000; TAB( 16) INT (6
    000 * RE) / 10000; TAB( 24) INT
    (4000 * RE) / 10000; TAB( 32
    ) INT (2000 * RE) / 10000
325 T1(V) = RE
330 WP = 0:RN = 0:IN = 0:RD = 0:I
    D = 0
335 K = 0
340 NEXT S
345 IF A$ = "Y" THEN PRINT CHR$
    (4);"PR#0"
350 INPUT "DO YOU WANT TO SAVE D
    ATA TO DISK (Y OR N)? ";A$
355 IF A$ = "N" THEN END
360 IF A$ < > "Y" THEN GOTO 35
    0
362 PRINT : INPUT "ENTER DRIVE N
    UMBER FOR DATA DISK";DN$:DN =
    VAL (DN$)
363 IF DN = 2 OR DN = 1 THEN GOTO
    365
364 GOTO 362
365 IF DE = 0 AND E = 0 THEN F$ =
    NF$ + "-" + SL$ + "-" + SU$ +
    "-" + SI$: GOTO 380
367 IF MID$ (AZ$,1,1) = "S" THEN
    F$ = NF$ + "-" + DE$ + "-" +
    SL$ + "-" + SU$ + "-" + SI$:
    E = - 1: GOTO 380
370 F$ = NF$ + "-" + DE$ + "-" +
    E$ + "-" + SL$ + "-" + SU$ +
    "-" + SI$
380 POKE 43624,DN
385 D$ = CHR$ (4)
390 PRINT D$;"OPEN "F$
400 PRINT D$;"WRITE "F$
405 PRINT NF$
410 PRINT V
412 PRINT DE
414 PRINT E
416 PRINT SL
420 PRINT SU
430 PRINT SI
440 FOR K = 1 TO V
450 PRINT T1(K)
470 NEXT K
480 PRINT D$;"CLOSE "F$
485 POKE 43624,1
490 END

```

```

500 PRINT "RE #"; TAB( 8)"20"; TAB(
    16)"15"; TAB( 24)"10"
510 PRINT "-----"; TAB( 8)"---"; TAB(
    16)"---"; TAB( 24)"---"
520 RETURN
550 PRINT S; TAB( 8) INT (35300 *
    RE) / 10000; TAB( 16) INT (3
    7300 * RE) / 10000; TAB( 24)
    INT (38800 * RE) / 10000
590 RETURN
600 XX = LEN (C$)
610 YY = (40 - XX) / 2:YY = INT
    (YY)
620 PRINT TAB( YY)C$
630 RETURN

```