APPENDIX D

DESIGN PROGRAM

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C     TURBINE DESIGN STUDY PROGRAM
C
C     THIS PROGRAM USES BOYACK RESULTS AS INPUT AND CALCULATES TURBINE
C         PERFORMANCE.
C     FROM BOYACK RESULTS, UO,NRE, EFFICIENCY, AND RI ARE ENTERED,
C         ALSO, THE HEAD (FEET OF WATER) IS ENTERED.
C         THE PROGRAM YIELDS Q, OMEGA, POWER, NO. OF DISKS,ETC.
C
C
      DIMENSION  FLUID(5)
    1 READ 2,FLUID
      READ 3, FNU,RHO
      IF(RHO) 1000, 1000, 5
    5 READ 10,UO,VO,RE,RI,ETA,PT,T
      READ 3,RO
      CON= 1.0
      D=.015
      RMIN=1.
      RMAX = 24.
      ROBAR = RO
      HEAD=0.
   15 HEAD = HEAD + 20.
      IF(HEAD-220.) 25,25,1
   25 PTBAR = HEAD / 2.31
      ALPHA = ATAN2(UO,VO)*360./6.283185
      PRINT 30
      PRINT 40
      PRINT 60,FLUID
      PRINT 65,FNU,RHO
      PRINT 70,UO,VO,RE
      PRINT 75,RI,ETA,PT,T
      PRINT 12, ALPHA
      PRINT 11,D
      PRINT 80, PTBAR, HEAD
      PRINT 90
      PRINT 95
      IF (RO) 26,26,27
   26 CONTINUE
      DR=1.
      ROBAR = RMIN - DR
  120 ROBAR = ROBAR + DR
      IF(ROBAR.GE.2.) DR=2.
      IF (ROBAR - RMAX) 130, 130, 15
   27 CONTINUE
  130 OMEG = PTBAR * 32.2 * 144. * 144. / (PT*RHO*ROBAR*ROBAR)
      OMEG = SQRT (OMEG)
      OMEGA = OMEG * 60. / (6.2831853072)
      H = RE * FNU / OMEG
      H = SQRT(H)
      Q = 6.28318530/2 * UO * ROBAR * ROBAR * OMEG * H * 60. / 1728.
      TBAR = T * RHO * ROBAR * ROBAR * ROBAR * ROBAR * OMEG * OMEG * H
      TBAR = TBAR / (32.2*1728.*144.)
      RIBAR = RI * ROBAR
```

```
      CON=.0
   24 CON=CON+1.
      FL = ROBAR * CON
  200 FN = FL / (D*H)
      TOR = FN * TBAR
      QQ = FN * Q
      POW = TOR * OMEG / 550.
      PRINT 110,ROBAR,RIBAR,FL,H,FN,TOR,POW,QQ,OMEGA
      IF(CON.EQ.2.) GO TO 28
      IF (RO) 28,28,29
      GO TO 24
   28 CONTINUE
      GO TO 120
   29 CONTINUE
      PRINT 41
      PRINT 91
      PRINT 96
      PI2=6.2831853072
      DPT=PTBAR/20.
      KONT=0
      PTOF=PTBAR+(DPT*5.)
   36 PTOF=PTOF-DPT
      KONT=KONT+1
      OMEG = PTOF  * 32.2 * 144. * 144. / (PT*RHO*ROBAR*RO)
      OMEG = SQRT (OMEG)
      Q = 6.2831853072 * UO * ROBAR * ROBAR * OMEG * H * 60. / 1728.
      TBAR = T * RHO * ROBAR * ROBAR * ROBAR * ROBAR * OMEG * OMEG * H
      TBAR = TBAR / (32.2*1728.*144.)
      TOR = FN * TBAR
      POW = TOR * OMEG / 550.
      OMEGA = OMEG * 60. / (6.2831853072)
      EFF=TBAR*OMEG*60./(Q*PTOF*144.)
      QQ=FN*Q
      PRINT 111, QQ ,OMEGA,POW,TOR,EFF,PTOF
      IF(KONT.EQ.11) GO TO 15
      GO TO 36
 1000 CALL EXIT
    2 FORMAT(5A5)
    3 FORMAT(2F15.0)
   10 FORMAT(7F10.0)
   11 FORMAT(5X,4H D =F8.4,2X,2HIN)
   12 FORMAT(5X,15H NOZZLE ANGLE =F6.2,5H DEG.)
   30 FORMAT (1H1)
   40 FORMAT(5X,35H MULTIPLE DISK TURBINE DESIGN STUDY,/,5X,24H BASED ON
     1 BOYACK RESULTS,//)
   60 FORMAT(5X,5A5)
   65 FORMAT(5X,22H KINEMATIC VISCOSITY =F9.4,1X,8HINSQ/SEC,/,5X,10H DEN
     1SITY =F9.4,8H LB/FTCU,/)
   70 FORMAT(5X,5H UO =F6.2,3X,5H VO =F6.2,3X,5H RE =F6.2)
   75 FORMAT(5X,5H RI =F7.3,2X,6H ETA =F6.3,2X,4HPT =F10.6,2X,3HT =F10.6
     1,/)
   80 FORMAT(5X,8H PTBAR =F8.2,1X,8HLBF/INSQ,3X,6HHEAD =F8.0,1X,2HFT,/)
   90 FORMAT(7X,2HRO,5X,2HRI,5X,1HL,6X,1HH,5X,1HN,5X,3HTOR,6X,2HHP,3X,6H
```

```
     1VOL FL,5X,3HRPM)
  95 FORMAT(6X,4H(IN),3X,4H(IN),3X,4H(IN),3X,4H(IN),7X,7H(FT-LB),8X,10H
     1(FTCU/MIN),/)
 110 FORMAT(5X,F5.2,2X,F5.2,2X,F5.2,2X,F5.4,1X,F5.0,1X,F7.2,1X,F7.2,1X,
     1F7.2,2X,F6.0)
  41 FORMAT(//,5X,21H OFF DESIGN OPERATION,/,5X,17HWITH HEAD VARYING,/)
  91 FORMAT(5X,6HVOL FL,5X,3HRPM,6X,2HHP,6X,3HTOR,5X,3HETA,       3X,5H
     1PTBAR)
  96 FORMAT(4X,10H(FTCU/MIN),17X,7H(FT-LB),/)
 111 FORMAT(5X,F7.3,1X,F7.1,1X,F7.2,2X,F7.2,2X,F5.4,2X,         F6.2)
     END
```

APPENDIX E

DESIGN PROGRAM OUTPUT SHEETS

MULTIPLE DISK TURBINE DESIGN STUDY
BASED ON BOYACK RESULTS

LIQ HYDROGEN
KINEMATIC VISCOSITY = 0.0002 INSQ/SEC
DENSITY = 4.3600 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA =79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 17.32 LBF/INSQ HEAD = 40. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0009	63.	0.01	0.02	0.313	12592.
3.00	0.90	3.00	.0015	182.	0.35	0.28	4.688	4197.
5.00	1.50	5.00	.0019	295.	2.05	0.98	16.380	2518.
7.00	2.10	7.00	.0023	405.	6.51	2.23	37.212	1799.
9.00	2.70	9.00	.0026	512.	15.42	4.11	68.538	1399.
11.00	3.30	11.00	.0029	616.	30.05	6.68	111.460	1145.
13.00	3.90	13.00	.0031	718.	54.24	10.00	166.909	969.
15.00	4.50	15.00	.0033	818.	88.38	14.13	235.693	839.
17.00	5.10	17.00	.0036	916.	135.37	19.09	318.547	741.
19.00	5.70	19.00	.0038	*13.	197.03	24.94	416.105	663.
21.00	6.30	21.00	.0040	*08.	277.67	31.71	528.963	600.
23.00	6.90	23.00	.0041	*02.	378.11	39.42	657.664	547.

LIQ HYDROGEN
KINEMATIC VISCOSITY = 0.0002 INSQ/SEC
DENSITY = 4.3600 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA = 79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 34.63 LBF/INSQ HEAD = 80. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0007	64.	0.01	0.04	0.375	17808.
3.00	0.90	3.00	.0013	185.	0.60	0.68	5.657	5936.
5.00	1.50	5.00	.0016	301.	3.51	2.38	19.839	3562.
7.00	2.10	7.00	.0019	414.	11.19	5.42	45.202	2544.
9.00	2.70	9.00	.0022	524.	26.55	10.00	83.459	1979.
11.00	3.30	11.00	.0024	632.	52.89	16.30	136.013	1619.
13.00	3.90	13.00	.0026	738.	93.78	24.46	204.063	1370.
15.00	4.50	15.00	.0028	842.	153.06	34.60	288.655	1187.
17.00	5.10	17.00	.0030	945.	234.81	46.83	390.727	1048.
19.00	5.70	19.00	.0032	*46.	343.31	61.27	511.126	937.
21.00	6.30	21.00	.0033	*46.	483.01	77.99	650.627	848.
23.00	6.90	23.00	.0035	*45.	658.54	97.08	809.943	774.

MULTIPLE DISK TURBINE DESIGN STUDY
BASED ON BOYACK RESULTS

LIQ HYDROGEN
KINEMATIC VISCOSITY = 0.0002 INSQ/SEC
DENSITY = 4.3600 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA = 79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 51.95 LBF/INSQ HEAD = 120. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0007	64.	0.32	0.07	0.417	21811.
3.00	0.90	3.00	.0011	186.	0.82	1.13	6.307	7270.
5.00	1.50	5.00	.0015	304.	4.80	3.99	22.164	4362.
7.00	2.10	7.00	.0017	418.	15.33	9.09	50.576	3116.
9.00	2.70	9.00	.0020	531.	36.43	16.81	93.504	2423.
11.00	3.30	11.00	.0022	641.	72.66	27.43	152.555	1983.
13.00	3.90	13.00	.0024	749.	128.95	41.19	229.110	1678.
15.00	4.50	15.00	.0025	855.	210.66	58.32	324.379	1454.
17.00	5.10	17.00	.0027	960.	323.45	79.01	439.449	1283.
19.00	5.70	19.00	.0029	*64.	473.26	103.44	575.304	1148.
21.00	6.30	21.00	.0030	*67.	666.31	131.76	732.845	1039.
23.00	6.90	23.00	.0031	*68.	909.08	164.14	912.907	948.

LIQ HYDROGEN
KINEMATIC VISCOSITY = 0.0002 INSQ/SEC
DENSITY = 4.3600 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA = 79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 69.26 LBF/INSQ HEAD = 160. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0006	64.	0.02	0.11	0.449	25185.
3.00	0.90	3.00	.0011	187.	1.02	1.63	6.811	8395.
5.00	1.50	5.00	.0014	306.	5.99	5.75	23.965	5037.
7.00	2.10	7.00	.0016	421.	19.16	13.12	54.741	3598.
9.00	2.70	9.00	.0018	535.	45.58	24.28	101.290	2798.
11.00	3.30	11.00	.0020	646.	90.95	39.65	165.383	2290.
13.00	3.90	13.00	.0022	756.	161.53	59.58	248.541	1937.
15.00	4.50	15.00	.0024	864.	264.04	84.41	352.103	1679.
17.00	5.10	17.00	.0025	971.	405.63	114.42	477.273	1481.
19.00	5.70	19.00	.0027	*76.	593.81	149.86	625.142	1326.
21.00	6.30	21.00	.0028	*80.	836.45	191.00	796.713	1199.
23.00	6.90	23.00	.0029	*83.	1141.71	238.03	992.914	1095.

LIQ HYDROGEN
KINEMATIC VISCOSITY = 0.0002 INSQ/SEC
DENSITY = 4.3600 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA =79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTRAR = 86.58 LBF/INSQ HEAD = 200. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0006	64.	0.03	0.14	0.476	28157.
3.00	0.90	3.00	.0010	188.	1.21	2.17	7.227	9386.
5.00	1.50	5.00	.0013	307.	7.11	7.63	25.455	5631.
7.00	2.10	7.00	.0015	424.	22.77	17.44	58.188	4022.
9.00	2.70	9.00	.0017	538.	54.20	32.28	107.737	3129.
11.00	3.30	11.00	.0019	650.	108.22	52.74	176.006	2569.
13.00	3.90	13.00	.0021	761.	192.29	79.38	264.635	2166.
15.00	4.50	15.00	.0022	870.	314.47	112.39	375.071	1877.
17.00	5.10	17.00	.0024	978.	483.29	152.41	508.615	1656.
19.00	5.70	19.00	.0025	*85.	707.77	199.71	666.448	1482.
21.00	6.30	21.00	.0026	*90.	997.32	254.61	849.659	1341.
23.00	6.90	23.00	.0028	*95.	1361.76	317.42	*59.254	1224.

LIQ SODIUM
KINEMATIC VISCOSITY = 0.0004 INSQ/SEC
DENSITY = 51.2000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA =79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTRAR = 17.32 LBF/INSQ HEAD = 40. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0020	59.	0.02	0.01	0.198	3675.
3.00	0.90	3.00	.0035	162.	0.73	0.17	2.345	1225.
5.00	1.50	5.00	.0045	257.	4.14	0.58	9.671	735.
7.00	2.10	7.00	.0053	345.	12.90	1.27	21.520	525.
9.00	2.70	9.00	.0060	428.	30.35	2.34	38.973	408.
11.00	3.30	11.00	.0067	508.	58.97	3.74	62.473	334.
13.00	3.90	13.00	.0072	585.	102.08	5.54	92.333	283.
15.00	4.50	15.00	.0078	659.	165.26	7.73	129.002	245.
17.00	5.10	17.00	.0083	730.	251.33	10.34	172.591	216.
19.00	5.70	19.00	.0088	800.	363.55	13.39	223.375	193.
21.00	6.30	21.00	.0092	868.	506.48	16.87	281.555	175.
23.00	6.90	23.00	.0096	934.	684.26	20.82	347.310	160.

LIQ SODIUM
KINEMATIC VISCOSITY = 0.0004 INSQ/SEC
DENSITY = 51.2000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA =79.500 PT = 1.525100 T = 0.152000

NOZZLE ANGLE = 1.14 DEG.
D = 0.0150 IN
PTRAR = 34.63 LBF/INSQ HEAD = 80. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0017	60.	0.13	0.03	0.240	5197.
3.00	0.90	3.00	.0029	167.	1.27	0.42	3.487	1732.
5.00	1.50	5.00	.0038	266.	7.23	1.43	11.939	1039.
7.00	2.10	7.00	.0045	360.	22.04	3.20	26.703	742.
9.00	2.70	9.00	.0051	449.	52.14	5.82	48.560	577.
11.00	3.30	11.00	.0056	534.	104.19	9.36	78.116	472.
13.00	3.90	13.00	.0061	616.	182.47	13.89	115.864	400.
15.00	4.50	15.00	.0065	696.	294.78	19.44	162.224	346.
17.00	5.10	17.00	.0070	774.	448. 4	26.09	217.558	306.
19.00	5.70	19.00	.0074	850.	649.50	33.84	282.185	274.
21.00	6.30	21.00	.0077	924.	916.04	42.72	356.398	247.
23.00	6.90	23.00	.0081	996.	1227.13	52.79	440.423	226.

LIQ SODIUM
KINEMATIC VISCOSITY = 0.0004 INSQ/SEC
DENSITY = 51.2000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA = 79.500 PT = 1.525.00 T = 0.152000

NOZZLE ANGLE = 1.14 DEG.
U = 0.0150 IN
PTBAR = 51.95 LBF/INSQ HEAD = 120. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TQK (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0015	61.	0.14	0.09	0.269	6365.
3.00	0.90	3.00	.0026	170.	1.75	0.71	3.921	2122.
5.00	1.50	5.00	.0034	272.	10.00	2.42	13.474	1273.
7.00	2.10	7.00	.0040	368.	31.79	5.43	30.221	909.
9.00	2.70	9.00	.0046	460.	73.55	9.90	55.082	707.
11.00	3.30	11.00	.0051	548.	144.19	15.94	88.776	579.
13.00	3.90	13.00	.0055	634.	254.45	23.71	131.895	490.
15.00	4.50	15.00	.0059	717.	411.39	33.29	184.944	424.
17.00	5.10	17.00	.0063	798.	626.02	44.65	248.358	374.
19.00	5.70	19.00	.0067	878.	909.19	57.99	322.524	335.
21.00	6.30	21.00	.0070	955.	1270.55	73.37	407.787	303.
23.00	6.90	23.00	.0073	1031.	1721.44	90.71	504.453	277.

LIQ SODIUM
KINEMATIC VISCOSITY = 0.0004 IN**2/SEC
DENSITY = 51.2000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 1.00
RI = 0.300 ETA = 79.500 PT = 1.525100 T = 0.152010

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 69.26 LBF/INSQ HEAD = 160. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TQR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0014	61.	0.05	0.01	0.290	7349.
3.00	0.90	3.00	.0025	172.	2.19	1.04	4.258	2450.
5.00	1.50	5.00	.0032	275.	12.06	3.52	14.667	1470.
7.00	2.10	7.00	.0038	373.	39.53	7.91	32.959	1050.
9.00	2.70	9.00	.0043	467.	92.77	14.42	60.165	817.
11.00	3.30	11.00	.0047	558.	182.98	23.28	97.096	668.
13.00	3.90	13.00	.0051	646.	321.05	34.67	144.420	565.
15.00	4.50	15.00	.0055	732.	520.93	48.61	202.711	490.
17.00	5.10	17.00	.0059	815.	793.54	65.32	272.465	432.
19.00	5.70	19.00	.0062	897.	1152.70	84.89	354.124	387.
21.00	6.30	21.00	.0065	976.	1612.38	107.42	448.082	350.
23.00	6.90	23.00	.0068	1055.	2185.71	132.96	554.696	320.

LIQ SODIUM
KINEMATIC VISCOSITY = 0.0004 INSQ/SEC
DENSITY = 51.2000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.01
RI = 0.300 ETA = 79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 86.58 LBF/INSQ HEAD = 200. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0013	61.	0.16	0.09	0.500	6217.
3.00	0.90	3.00	.0023	173.	2.61	1.54	4.537	2739.
5.00	1.50	5.00	.0030	278.	14.99	4.69	15.687	1643.
7.00	2.10	7.00	.0036	377.	47.24	19.56	35.283	1174.
9.00	2.70	9.00	.0040	473.	111.04	49.38	64.390	913.
11.00	3.30	11.00	.0045	565.	219.15	91.17	104.015	747.
13.00	3.90	13.00	.0048	655.	385.57	166.40	154.844	632.
15.00	4.50	15.00	.0052	743.	621.42	295.15	217.597	548.
17.00	5.10	17.00	.0055	828.	952.62	457.67	292.559	483.
19.00	5.70	19.00	.0059	911.	1384.14	714.01	380.474	432.
21.00	6.30	21.00	.0062	993.	1937.57	1044.35	481.697	391.
23.00	6.90	23.00	.0064	073.	2628.33	1478.79	596.630	357.

GLYCERIN
KINEMATIC VISCOSITY = 0.0323 INSQ/SEC
DENSITY = 79.3000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA =79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTPAR = 17.32 LBF/INSQ HEAD = 40. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0204	28.	0.08	0.03	0.778	2953.
3.00	1.90	3.00	.0354	60.	2.73	0.51	8.529	984.
5.00	1.50	5.00	.0457	82.	13.14	1.52	25.395	591.
7.00	2.10	7.00	.0541	101.	38.42	3.10	51.754	422.
9.00	2.70	9.00	.0613	118.	84.24	5.20	87.804	326.
11.00	3.30	11.00	.0678	133.	156.75	8.01	133.672	268.
13.00	3.90	13.00	.0737	147.	252.55	11.35	189.449	227.
15.00	4.50	15.00	.0792	159.	408.10	15.30	255.206	197.
17.00	5.10	17.00	.0843	171.	599.86	19.84	330.995	174.
19.00	5.70	19.00	.0891	183.	844.36	24.95	416.665	155.
21.00	6.30	21.00	.0937	193.	1148.13	30.74	512.852	141.
23.00	6.90	23.00	.0980	203.	1517.72	37.19	618.989	128.

GLYCERIN
KINEMATIC VISCOSITY = 0.0323 INSQ/SEC
DENSITY = 79.3000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA = 79.500 PT = 1.525[illegible] T = .152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 34.63 LBF/INSQ HEAD = [illegible] FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TQR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0172	31.	0.25	0.12	1.019	4176.
3.00	0.90	3.00	.0298	67.	5.16	1.37	11.419	1392.
5.00	1.50	5.00	.0384	94.	25.86	4.11	34.319	835.
7.00	2.10	7.00	.0455	116.	74.19	9.43	79.303	597.
9.00	2.70	9.00	.0516	135.	162.45	14.35	119.722	464.
11.00	3.30	11.00	.0570	153.	303.1	21.91	182.776	380.
13.00	3.90	13.00	.0620	169.	508.[illegible]	31.12	259.615	321.
15.00	4.50	15.00	.0666	184.	792.31	42.06	350.356	278.
17.00	5.10	17.00	.0709	198.	1166.[illegible]8	54.55	455.089	246.
19.00	5.70	19.00	.0749	211.	1643.[illegible]	68.79	573.891	220.
21.00	6.30	21.00	.0788	224.	2247.[illegible]2	84.72	706.824	199.
23.00	6.90	23.00	.0824	236.	2961.[illegible]9	102.36	853.942	182.

GLYCERIN
KINEMATIC VISCOSITY = 0.0323 INSQ/SEC
DENSITY = 79.3000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA = 79.500 PT = 1.525100 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 51.95 LBF/INSQ HEAD = 120. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0155	33.	0.22	0.21	1.189	5114.
3.00	0.90	3.00	.0269	72.	7.48	2.43	13.503	1705.
5.00	1.50	5.00	.0347	101.	37.67	7.34	40.799	1023.
7.00	2.10	7.00	.0411	125.	108.42	15.08	83.684	731.
9.00	2.70	9.00	.0466	146.	237.05	25.74	143.187	568.
11.00	3.30	11.00	.0515	165.	444.79	39.37	218.987	465.
13.00	3.90	13.00	.0560	183.	747.69	56.00	311.487	393.
15.00	4.50	15.00	.0602	200.	1165.10	75.67	420.841	341.
17.00	5.10	17.00	.0640	215.	1717.57	98.38	547.172	301.
19.00	5.70	19.00	.0677	230.	2422.75	124.16	690.501	269.
21.00	6.30	21.00	.0712	244.	3300.91	153.03	851.153	244.
23.00	6.90	23.00	.0745	257.	4369.86	185.09	*28.962	222.

GLYCERIN
KINEMATIC VISCOSITY = 0.0323 INSQ/SEC
DENSITY = 79.3000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA =79.50 RT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 69.26 LBF/INSQ HEAD = 160. FT

RO (IN)	RI (IN)	L (IN)	h (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0146	34.	0.26	.32	1.324	5995.
3.00	0.90	3.00	.0251	75.	9.71	3.64	15.186	1968.
5.00	1.50	5.00	.0323	106.	49.12	11.05	46.074	1181.
7.00	2.10	7.00	.0382	131.	141.74	22.77	94.967	844.
9.00	2.70	9.00	.0434	154.	311.41	38.93	162.369	656.
11.00	3.30	11.00	.0479	175.	583.24	59.62	248.683	537.
13.00	3.90	13.00	.0521	194.	941.46	84.89	354.096	454.
15.00	4.50	15.00	.0560	211.	1531.34	114.79	478.819	394.
17.00	5.10	17.00	.0596	228.	2250.13	149.35	623.003	347.
19.00	5.70	19.00	.0630	244.	3187.43	188.61	786.773	311.
21.00	6.30	21.00	.0662	259.	4344.36	232.59	970.234	281.
23.00	6.90	23.00	.0693	273.	5754.56	281.32	1173.475	257.

GLYCERIN
KINEMATIC VISCOSITY = 0.0323 INSQ/SEC
DENSITY = 79.3000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA =79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 86.58 LBF/INSQ HEAD = 200. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
1.00	0.30	1.00	.0137	35.	0.34	0.43	1.438	6602.
3.00	0.90	3.00	.0237	78.	11.39	4.96	16.621	2201.
5.00	1.50	5.00	.0306	110.	60.30	15.15	50.593	1320.
7.00	2.10	7.00	.0362	137.	174.35	31.31	104.488	943.
9.00	2.70	9.00	.0410	161.	383.85	53.61	178.918	734.
11.00	3.30	11.00	.0453	182.	719.22	82.19	274.285	600.
13.00	3.90	13.00	.0493	202.	1211.30	117.13	390.879	508.
15.00	4.50	15.00	.0529	221.	1891.25	158.50	528.923	440.
17.00	5.10	17.00	.0564	238.	2790.47	206.32	688.595	388.
19.00	5.70	19.00	.0596	255.	3940.06	260.72	870.040	347.
21.00	6.30	21.00	.0626	270.	5373.28	321.62	*73.384	314.
23.00	6.90	23.00	.0656	286.	7120.53	389.15	*98.730	287.

LIQ HYDROGEN
KINEMATIC VISCOSITY = 0.0002 INSQ/SEC
DENSITY = 4.3600 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA =79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTRAR = 86.58 LBF/INSQ HEAD = 200. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
2.00	0.60	2.00	.0008	126.	0.30	0.50	2.65	11079.

OFF DESIGN OPERATION
WITH HEAD VARYING

VOL FL (FTCU/MIN)	RPM	HP	TOR (FT-LB)	ETA	PTRAR
2.906	15422.4	1.05	0.36	.7932	103.96
2.845	15097.7	0.98	0.34	.7932	99.57
2.782	14765.9	0.92	0.33	.7932	95.24
2.719	14426.4	0.86	0.31	.7932	90.91
2.653	14078.7	0.80	0.30	.7932	86.58
2.586	13722.2	0.74	0.28	.7932	82.25
2.517	13356.2	0.68	0.27	.7932	77.92
2.446	12979.9	0.62	0.25	.7932	73.59
2.373	12592.4	0.57	0.24	.7932	69.26
2.298	12192.5	0.52	0.22	.7932	64.94
2.220	11779.1	0.47	0.21	.7932	60.61

LIQ SODIUM
KINEMATIC VISCOSITY = 0.0004 INSQ/SEC
DENSITY = 51.2000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA =79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 86.58 LBF/INSQ HEAD = 200. FT

RO (IN)	RI (IN)	L (IN)	A (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
4.00	1.20	4.00	.0027	226.	6.99	2.73	9.12	2054.

OFF DESIGN OPERATION
WITH HEAD VARYING

VOL FL (FTCU/MIN)	RPM	HP	TOR (FT-LB)	ETA	PTBAR
9.994	2250.3	3.59	8.39	.7932	103.90
9.784	2202.9	3.37	8.04	.7932	99.57
9.569	2154.5	3.15	7.69	.7932	95.24
9.349	2104.9	2.94	7.34	.7932	90.91
9.123	2054.2	2.73	6.99	.7932	86.58
8.892	2002.2	2.53	6.64	.7932	82.25
8.655	1948.8	2.33	6.29	.7932	77.92
8.411	1893.9	2.14	5.94	.7932	73.59
8.160	1837.3	1.96	5.59	.7932	69.26
7.901	1779.0	1.78	5.24	.7932	64.94
7.633	1718.7	1.60	4.89	.7932	60.61

MULTIPLE DISK TURBINE DESIGN STUDY
BASED ON BOYACK RESULTS

GLYCERIN
KINEMATIC VISCOSITY = 0.0323 INSQ/SEC
DENSITY = 79.3000 LB/FTCU

UO = 0.02 VO = 1.10 RE = 4.00
RI = 0.300 ETA =79.500 PT = 1.525000 T = 0.152000

NOZZLE ANGLE = 1.04 DEG.
D = 0.0150 IN
PTBAR = 86.58 LBF/INSQ HEAD = 200. FT

RO (IN)	RI (IN)	L (IN)	H (IN)	N	TOR (FT-LB)	HP	VOL FL (FTCU/MIN)	RPM
10.00	3.00	10.00	.0432	172.	533.88	87.11	223.96	660.

OFF DESIGN OPERATION
WITH HEAD VARYING

VOL FL (FTCU/MIN)	RPM	HP	TOR (FT-LB)	ETA	PTBAR
245.341	723.3	88.22	640.66	.7932	103.96
240.175	708.0	82.77	613.96	.7932	99.57
234.896	692.5	77.43	587.27	.7932	95.24
229.495	676.5	72.21	560.57	.7932	90.91
223.964	660.2	67.11	533.88	.7932	86.58
218.294	643.5	62.14	507.19	.7932	82.25
212.471	626.4	57.30	480.49	.7932	77.92
206.485	608.7	52.59	453.80	.7932	73.59
200.320	590.5	48.02	427.10	.7932	69.26
193.959	571.8	43.59	400.41	.7932	64.94
187.382	552.4	39.31	373.72	.7932	60.61

BIOGRAPHICAL SKETCH

Major Michael John Lawn, Jr., was born in Auburn, New York on 1 January 1939. He received his elementary and secondary education in the Auburn Public Schools. In 1958 he entered the United States Military Academy, graduating in 1963 with a Bachelor of Science degree. Upon graduation he was commissioned as a Second Lieutenant in the United States Army. From 1963 to 1970 he attended various Army schools and served in a number of field positions. Under the Department of the Army advanced education program he entered Arizona State University in January 1970. He completed the requirements for a Master of Science in Engineering degree in Mechanical Engineering in January 1972. He is married and the father of two children.