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MASTER

MASFLO: A Computer Code to Calculate Mass Flow Rates in the THTF

M. D. White

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CONTENTS

	Page
PREFACE	v
ABSTRACT	1
1. INTRODUCTION — MASFLO CODE DESCRIPTION	1
2. MASFLO SUBROUTINE DESCRIPTION	6
2.1 MAIN	6
2.2 INPUT	6
2.3 EUTAPE	6
2.4 FMTAPE	7
2.5 FLOCAL	7
2.6 FIXIT	8
2.7 REYNLD	8
2.8 DDCAL	9
2.9 MASCAL	9
2.10 OUTPUT	9
2.11 PROP, SATUR8, FIND, THEPY	9
REFERENCES	10
APPENDIX. MASFLO INPUT AND OUTPUT INFORMATION	13

PREFACE

The MASFLO computer code was developed at Oak Ridge National Laboratory (ORNL) to analyze data from the Thermal-Hydraulic Test Facility (THTF) and produce a calculated quantity: mass flow rate. The code is intended primarily for internal use; its sole function is the combination of measured data to produce calculated quantities. This report documents the techniques employed in performing this calculation. It is intended as a user's guide for those using the code at ORNL and as an account of the methods used for those who access data and/or results that are influenced by this calculation.

MASFLO: A COMPUTER CODE TO CALCULATE MASS FLOW RATES IN THE THTF

M. D. White

ABSTRACT

This report documents a modular data interpretation computer code. The MASFLO code is a FORTRAN code used in the Oak Ridge National Laboratory Blowdown Heat Transfer Program to convert measured quantities of density, volumetric flow, and momentum flux into a calculated quantity: mass flow rate. The code performs both homogeneous and two-velocity calculations. The homogeneous models incorporate various combinations of the Thermal-Hydraulic Test Facility instrumented spool piece turbine flow meter, gamma densitometer, and drag disk readings. The two-velocity calculations also incorporate these instruments, but in models developed by Aya, Rouhani, and Popper. Each subroutine is described briefly, and input instructions are provided in the appendix along with a sample of the code output.

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1. INTRODUCTION — MASFLO CODE DESCRIPTION

The MASFLO code is a FORTRAN code used in the Oak Ridge National Laboratory (ORNL) Blowdown Heat Transfer (BDHT) Program to convert measured quantities of density, volumetric flow, and momentum flux into a calculated quantity: mass flow rate. The code performs both homogeneous and two-velocity calculations. The homogeneous models incorporate various combinations of the Thermal-Hydraulic Test Facility (THTF) instrumented spool piece turbine flow meter, gamma densitometer, and drag disk readings. The two-velocity calculations also incorporate readings from these instruments but use models developed by Aya, Rouhani, and Popper.[1–7] The actual two-velocity quantities used are calculated in the Aya model and then applied to the equations developed by Rouhani and Popper. Additional instruments used to obtain thermophysical properties are spool piece thermocouples and absolute-pressure transducers. Models are also included to allow for drag disk temperature-dependent zero-shift correction and Reynolds number calibration to compensate for phenomena that were observed for the original drag disk probes.

The code is divided into subroutines, each of which is designed to perform a specific function. The organization of the subroutines with respect to each other is shown in Fig. 1. Input data are read in, and certain input flags are examined. These input flags indicate matters such as (1) whether only an Engineering Units data tape (EU tape) or both an EU and analog data tape (FM tape) are to be mounted and read,* (2) whether there are corrections or additional calculations that need to be performed on the data, and (3) how the vertical inlet and outlet instrument spool piece pressures are to be determined. Once these flags have been read and examined and the other input data concerning the drag disks have been read, the scan table record is read on each data tape that has been mounted. A scan table search is then performed to determine the scan table entry numbers of interest. If both an EU tape and an FM tape are mounted, they are aligned to correspond in time. Data records are read and needed signals extracted. A thermophysical property calculation is performed. These properties and a quality-weighted viscosity are used to calculate a drag disk Reynolds number. Next a calibration factor for the drag disk is determined. The drag disk signal is then zero-shift corrected and calibrated.† This signal is used with the turbine flow meter velocity and gamma densitometer readings to calculate the homogeneous and two-velocity mass flow models. The various mass flow model equations employed in this total calibration/calculation scheme are shown in Fig. 2. Once these and several peripheral calculations (such as total bundle power and time rates of change of output variables) are performed, the results

---

*An EU tape is generated using the Computer Controlled Data Acquisition System (CCDAS) and is composed of data records containing 500 instrument signals, each data scan being performed every 50 ms. An FM tape is generated using the digitized signals from an FM tape recorder and is composed of data records containing 24 instrument signals, each data scan being performed every 1.25 ms. These methods of data acquisition are documented in Ref. 8, and the format of the data record is documented in Ref. 9. Future modifications to the CCDAS will entail enlargement of the number of instruments monitored and will require modification of MASFLO to handle the data or the writing of a new code.

†The rationale for such a calibration procedure is documented in Refs. 10 through 12.

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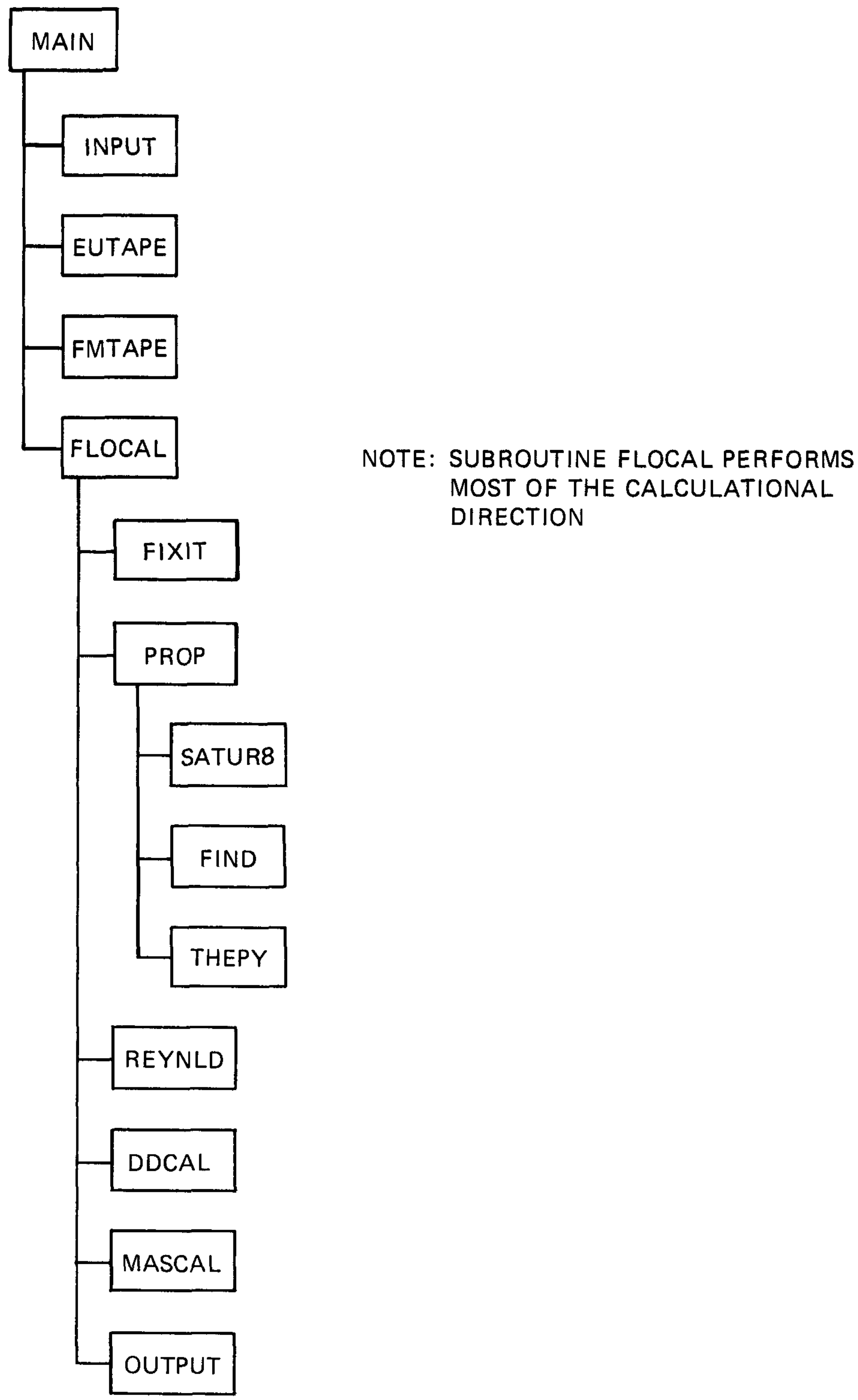

Fig. 1. MASFLO subroutine organization.

ORNL–DWG 79–16980 ETD

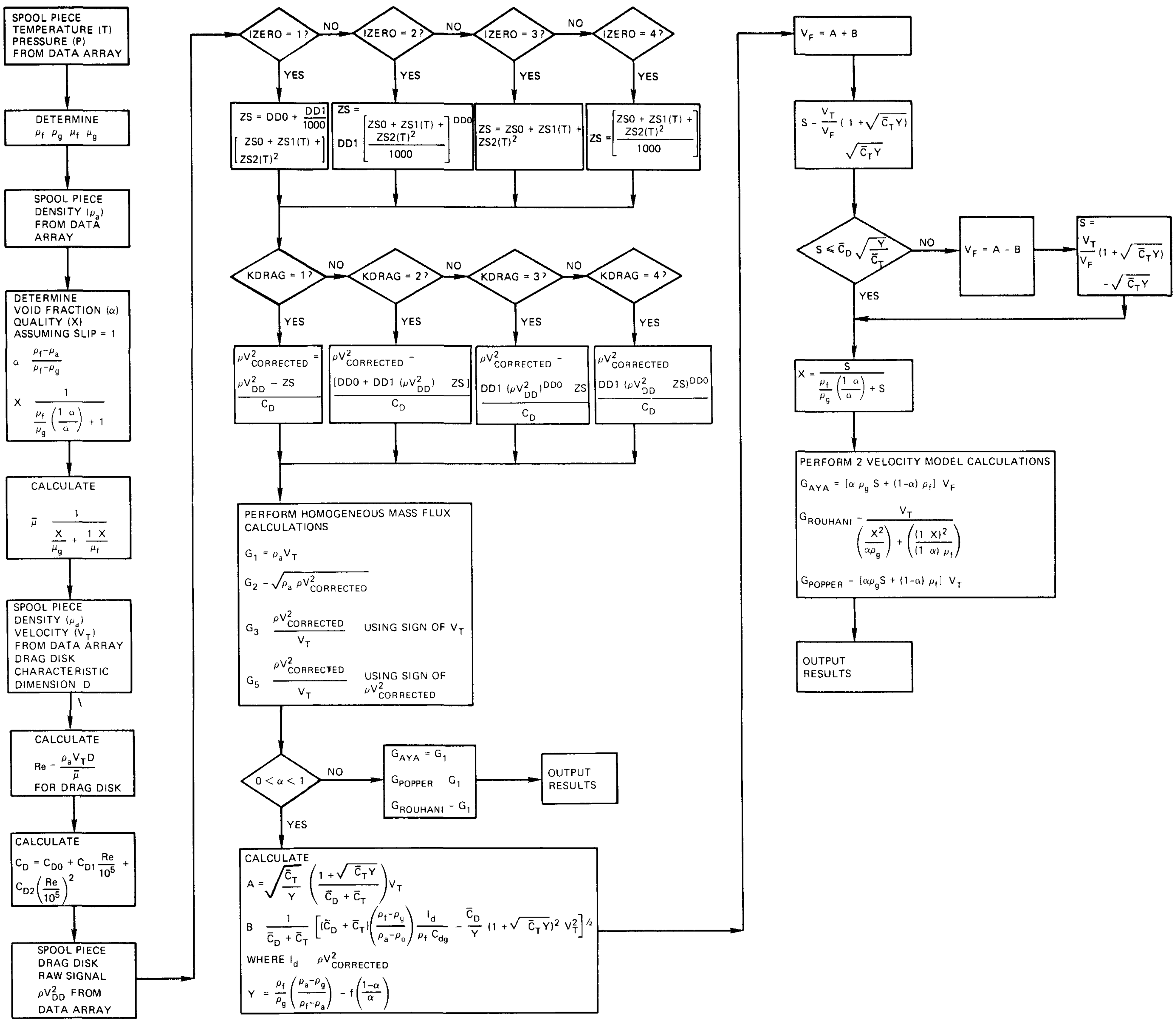

Fig. 2. Flowchart of calculation procedure (as directed in FLOCAL).

are loaded in a data array and written on an output tape. Selected results are printed out during time intervals of interest. These calculations are performed for each spool piece each time a data scan is taken. After a data scan has been performed, the process is repeated until all the scans have been processed.

2. MASFLO SUBROUTINE DESCRIPTION

MASFLO is divided into subroutines, each designed to perform a specific function. This modular programming approach was employed to facilitate modification as the THTF instrumentation is changed and as approaches to combining signals of interest change. A description of the function of each subroutine follows. The organization of the subroutines with respect to each other is shown in Fig. 1. The actual calculational procedure, including equations employed, is shown in Fig. 2.

2.1 MAIN

This portion of the code calls the INPUT subroutine and examines the input flags to determine if an EU tape only is to be read or if both an EU tape and an FM tape are to be read. It then calls the EUTAPE subroutine and the FMTAPE subroutine (if needed), which perform scan table searches to locate data array entry numbers for signals of interest. Control is transferred to the FLOCAL subroutine, which performs the bulk of the remaining data manipulation and subroutine calls.

2.2 INPUT

This subroutine reads input data necessary to control the tapes to be read and also reads calibration information for the THTF drag disks.

2.3 EUTAPE

The purpose of this subroutine is to determine the location of signals of interest (such as instrumented spool piece temperature, pressure, fluid density, volumetric flow rate, and momentum flux) within the data array on an EU tape. These locations are termed "data array entry numbers." This subroutine reads the first record on the EU tape and extracts the scan table from this record. The scan table contains the sequence in which the channel numbers of THTF instruments are scanned during the data-taking process; these channel numbers are used to identify the instruments of interest. The data array entry numbers are determined by comparing channel numbers of instruments of interest with the channel numbers in the scan table.

2.4 FMTAPE

This subroutine reads the first record on the analog tape (if there is one mounted). From this record the scan table is extracted and compared with channel numbers of interest, just as in EUTAPE. This comparison is used to determine the data array entry numbers of the signals of interest.

2.5 FLOCAL

This subroutine performs the bulk of the calculations and controls subroutine calls for the mass flow rate calculation and peripheral calculations. FLOCAL generates the mass flow tape scan table, which has the entry numbers equal to the channel numbers. It aligns the EU tape and FM tape if both are being used. It then writes the header information record on the mass flow output tape. FLOCAL extracts information of interest from the EU tape and FM tape (if there is one). If an FM tape is mounted, FLOCAL then performs interpolation of EU data necessary to perform the calculations of interest, because the FM tape has much more frequent data scans than the EU tape.

Once the necessary information has been extracted from a data scan, the input flags are examined to determine if there is need for correction of any data (e.g., erroneous signs due to known polarity reversals in turbine meters or substitutions for failed instruments). Correction is performed by calling the subroutine FIXIT. Once FIXIT has been called and control is returned to FLOCAL, the thermophysical properties ρ_f, ρ_g, μ_f, μ_g, and T_{sat} are determined by calling the subroutine PROP. These properties are used in the subroutine REYNLD, which is called next and which performs a Reynolds number calculation. Next FLOCAL calls the subroutine DDCAL, which performs a calibration and zero-shift correction of the spool-piece drag disks. Finally, these corrected drag disk readings are used in the subroutine call to MASCAL, which actually performs the mass flow calculation. After the return from MASCAL, peripheral calculations are performed, and the IFIXIT flag to call FIXIT is checked to determine whether postcalibration and calculation corrections are necessary. Such a call would be indicated, for example, for temporary use of a flow model not currently in the code without major revisions in the code or for temporarily changing the manner in which a calculation is performed. The data are then loaded in the data array, where the IFIXIT flag is checked again to see if corrections or substitutions are to be made. For example, such a call would be used to output an instrument signal not previously examined, without changing the output routine of the code. Finally, the output data are written on tape, and, for specific time intervals and record intervals, the subroutine OUTPUT is called to provide a printout of results. Then the process is repeated for each data record until the end of the data tape is read. The actual calculational procedure employed as directed by FLOCAL is shown in Fig. 2.

2.6 FIXIT

This subroutine has all the common blocks that FLOCAL has and thus has access to all the data that FLOCAL has. Normally the executable statements in this subroutine will be provided by the user, depending on what, if any, corrections or substitutions are needed. This subroutine can also be used to incorporate temporary model changes into the code without other modifications to the code.

2.7 REYNLD

This subroutine performs a quality-weighted viscosity calculation and then uses this to calculate the Reynolds number that is used in the subroutine DDCAL to calibrate the drag disks. The Reynolds number employs a characteristic dimension of the drag disk target, usually its diameter. If a drag disk having a noncircular cross-sectional area such as a cross is used, then the dimension should be consistent with the characteristic dimension used in calibrating the drag disk probe.

2.8 DDCAL

This subroutine performs zero-shift and calibration factor calculations and provides a zero-shift-corrected and calibrated drag disk reading that is used in the mass flow calculation subroutine MASCAL. This step was necessary because of the behavior of drag disks that were used during the early stages of THTF testing. Details are given in Refs. 10 through 12.

2.9 MASCAL

This subroutine employs the drag disk, turbine meter, and gamma densitometer readings along with other thermal properties to perform both homogeneous and two-velocity model mass flow rate calculations. The equations employed are found in Refs. 1 through 7 and are shown in the calculational flow sheet (Fig. 2.).

2.10 OUTPUT

This subroutine performs printout of selected quantities of interest for each spool piece at specific time intervals.

2.11 PROP, SATUR8, FIND, THEPY

These subroutines are standard water property search subroutines used in thermal-hydraulic analysis codes at ORNL. The subroutines were taken from the computer code BLAST, and the techniques used are discussed in Ref. 13.

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Appendix

MASFLO INPUT AND OUTPUT INFORMATION

A.1. Input Instructions for MASFLO

MASFLO requires the input of three flags and then the input of zero-shift and calibration factors for each of the four spool pieces in the THTF-MOD1.

Card	Variable	Format	Remarks
1	IFM	I10	Flag to indicate if analog (FM) tape is to be mounted (0 — no tape, 1 — tape)
2	IFIXIT	I10	Flag to indicate if there are data or calculational corrections to be made (0 — no corrections, 1 — data corrections, 2 — preoutput array loading corrections, 3 — postoutput array loading corrections)
3	IPFLAG	I10	Flag to indicate how vertical spool-piece pressures are to be determined (0 — spool-piece transducers used, 1 — test section transducers and DP cell used)
4	ZS0, ZS1, ZS2	3F10.0	Drag disk zero-shift correction factors[a]
5	CD0, CD1, CD2	3F10.0	Drag disk calibration factors for first Reynolds number range[b]
6	CD0, CD1, CD2	3F10.0	Drag disk calibration factors for second Reynolds number range[b]
7	CD0, CD1, CD2	3F10.0	Drag disk calibration factors for third Reynolds number range[b]
8	REC1, REC2, REC3, REC4	4F10.0	Drag disk calibration ($Re/10^5$) values used to determine Reynolds number range Range 1 REC1 < ($RE/10^5$) < REC2 Range 2 REC2 < ($RE/10^5$) < REC3 Range 3 REC3 < ($RE/10^5$) < REC4 (If $RE/10^5$ < REC1, $RE/10^5$ is set equal to REC1. If $RE/10^5$ > REC4, $RE/10^5$ is set equal to REC4)
9	DD0, DD1, KDRAGE, KDRAGF, IZERO	2F10.0 3I10	Drag disk conversion factors, and flags determining method of drag disk and zero-shift conversion and calibration[c]

Cards 4 through 9 are provided for each spool piece in the sequence: horizontal inlet, vertical inlet, vertical outlet, horizontal outlet.

A.2. Explanation of Input Constants

The coefficients ZS0, ZS1, and ZS2 were obtained by fitting equations to data taken at different temperatures during calibration runs. Because the drag disk zero-shift and calibration have been performed using various equation forms, they are explained below.

[a]Drag disk zero-shift correction, ZS (T is spool piece temperature):

IZERO = 1 (zero-shift coefficients in millivolts)

$$ZS = DD0 + DD1 \left[\frac{ZS0 + (ZS1 \cdot T) + (ZS2 \cdot T^2)}{1000}\right]$$

IZERO = 2 (zero-shift coefficients in millivolts)

$$ZS = DD1 \left[\frac{ZS0 + (ZS1 \cdot T) + (ZS2 \cdot T^2)}{1000}\right]^{DD0}$$

IZERO = 3 (zero-shift coefficients in $lb_m/ft\text{-}s^2$)

$$ZS = ZS0 + (ZS1 \cdot T) + (ZS2 \cdot T^2)$$

IZERO = 4 (zero-shift coefficients in millivolts — for this case, KDRAGE or KDRAGF must also be set to 4)

$$ZS = \frac{ZS0 + (ZS1 \cdot T) + (ZS2 \cdot T^2)}{1000}$$

[b]Drag disk calibration factor C_D (Re is Reynolds number):

$$C_D = CD0 + CD1(Re/10^5) + CD2(Re/10^5)^2$$

Note: The rationale for these zero-shift and calibration factors is found in discussion in Refs. 10 through 12.

[c]Drag disk voltage to engineering units (given variable name DRAG in code) conversion and/or calibration and zero-shift correction for values of the input flags KDRAGE (EU data) and KDRAGF (FM data) (DATA is data from EU or FM tape):

KDRAGE (or KDRAGF) = 1 (data in $lb_m/ft\text{-}s^2$)

$$DRAG = \frac{DATA - ZS}{C_D} = \rho V^2_{corrected}$$

KDRAGE (or KDRAGF) = 2 (data in volts)

$$DRAG = \frac{DD0 + DD1(DATA) - ZS}{C_D} = \rho V^2_{corrected}$$

KDRAGE (or KDRAGF) = 3 (data in volts)

$$\text{DRAG} = \frac{\text{DD1(DATA)}^{\text{DDO}} - \text{ZS}}{C_D} = \rho V^2{}_{\text{corrected}}$$

KDRAGE (or KDRAGF) = 4 (data in volts)

$$\text{DRAG} = \frac{\text{DD1(DATA} - \text{ZS)}^{\text{DDO}}}{C_D} = \rho V^2{}_{\text{corrected}}$$

A.3. Sample Input

Card	Column				
	1–10	11–20	21–30	31–40	50
1	0				
2	0				
3	1				
4	99.6	0.139	–0.004		
5	0.95	0.0	0.0		
6	1.047	–0.053	–0.037		
7	0.66	0.0	0.0		
8	0.0	1.17	2.9	100.0	
9	0.	33400.	2	2	3
10	–178.0	–0.954	–0.02		
11	1.1	0.0	0		
12	0.755	0.639	–0.294		
13	0.72	0.0	0.0		
14	0.0	1.1	2.3	100.0	
15	1.0126	4100.	3	2	3
16	740.75	–5.099	0.016		
17	0.9	0.0	0.0		
18	2.028	–1.263	0.335		
19	0.66	0.0	0.0		
20	0.0	1.4	2.6	100.0	
21	0.	32000.0	2	2	3
22	390.73	–1.281	0.0		
23	1.0	0	0.0		
24	1.604	–0.8	0.174		
25	0.67	0	0.0		
26	0.0	0.9	2.4	100.0	
27	0.	34000.	2	2	3

A.4. Sample Output

```
EU DATA ARRAY INDICES ARE:

EEE9=  462
EEE10=  463
EEE11=  464
EEE12=  465
EIE9=  458
EIE10=  459
EIE11=  460
EIE12=  461
IFMF22=  354
IFE19=  351
IDE20=  352
ITE24=  356
IPE26=  353
IFM170=  360
IFE166=  357
IDE168=  358
ITE172=  362
IPE174=*****
IFM220=  366
IFE216=  363
IDE218=  364
ITE222=  368
IPE224=*****
IFMF38=  372
IFE34=  369
IDE36=  370
ITE40=  374
IPE42=  371
NBLDNI=  401
NBLDNO=  402
IPE201=  376
IPD217=  367
IPD204=  359

STIME=   -64.999985  BDREC= 1301  ISEQEU=    1
```

```
RECORD 1307
TIME SINCE TRANSIENT=       0.303059 SEC
BREAKWIRE VOLTAGES: INLET=   0.07000    OUTLET=    3.72750    TOTAL BUNDLE POWER=.45033E 01MW

HORIZONTAL INLET SPOOL PIECE
VEL          DEN          DRAG         T            P            TSAT         AL           RHOF         RHOG
 0.1337E 02   0.4693E 02   0.7477E 04   0.5444E 03   0.1944E 04   0.5317E 03   0.0           0.3942E 02   0.5099E 01
MASSFLOW1    MASSFLOW2    MASSFLOW3    MASSFLOWAYA  MASSFLOW5    MASSFLOWP    MASSFLOWR
 0.4193E 02   0.3958E 02   0.3736E 02   0.4193E 02   0.3736E 02   0.4193E 02   0.4193E 02
G1           G2           G3           GAYA         G5           GPOPPER      GROUHANI
 0.6276E 03   0.5924E 03   0.5591E 03   0.6276E 03   0.5591E 03   0.6276E 03   0.6276E 03
ZRSHFT       CD           RE/100000    MU           QUAL         ISFLAG
-0.1530E 04   0.6600E 00   0.4044E 01   0.2328E 00   0.0                     1.
GRATIO       DVDT         DMDT         DXDT         DALDT        DSDT         DRHODT       DPDT         DTDT         S
 0.1000E 01 -0.6000E 02 -0.6000E 00   0.0          0.0          0.0          0.1876E 01 -0.6300E 03   0.0          0.1000E 01
TOTAL MASS FLOW1      TOTAL MASSFLOW AYA      TOTAL MASS FLUX1       TOTAL MASS FLUX AYA      RHOV**2 DRAG DISK/RHOVT**2
    0.1750E 02            0.1750E 02              0.2619E 03               0.2619E 03                0.8909E 00

VERTICAL INLET SPOOL PIECE
VEL          DEN          DRAG         T            P            TSAT         AL           RHOF         RHOG
 0.1371E 02   0.4688E 02   0.9473E 04   0.5452E 03   0.1989E 04   0.6350E 03   0.0           0.3907E 02   0.5268E 01
MASSFLOW1    MASSFLOW2    MASSFLOW3    MASSFLOWAYA  MASSFLOW5    MASSFLOWP    MASSFLOWR
 0.4293E 02   0.4453E 02   0.4618E 02   0.4293E 02   0.4518E 02   0.4293E 02   0.4293E 02
G1           G2           G3           GAYA         G5           GPOPPER      GROUHANI
 0.6426E 03   0.6664E 03   0.6912E 03   0.6426E 03   0.6912E 03   0.6426E 03   0.6426E 03
ZRSHFT       CD           RE/100000    MU           QUAL         ISFLAG
-0.9227E 04   0.7200E 00   0.4145E 01   0.2326E 00   0.0                     1.
GRATIO       DVDT         DMDT         DXDT         DALDT        DSDT         DRHODT       DPDT         DTDT         S
 0.1000E 01 -0.6000E 02 -0.2500E 00   0.0          0.0          0.0          0.6071E 01 -0.8480E 03   0.0          0.1000E 01
TOTAL MASS FLOW1      TOTAL MASSFLOW AYA      TOTAL MASS FLUX1       TOTAL MASS FLUX AYA      RHOV**2 DRAG DISK/RHOVT**2
    0.1789E 02            0.1789E 02              0.2678E 03               0.2678E 03                0.1076E 01

VERTICAL OUTLET SPOOL PIECE
VEL          DEN          DRAG         T            P            TSAT         AL           RHOF         RHOG
 0.1487E 02   0.4446E 02   0.6728E 04   0.6138E 03   0.1914E 04   0.6295E 03   0.0           0.3964E 02   0.4987E 01
MASSFLOW1    MASSFLOW2    MASSFLOW3    MASSFLOWAYA  MASSFLOW5    MASSFLOWP    MASSFLOWR
 0.4418E 02   0.3654E 02   0.3022E 02   0.4418E 02   0.3022E 02   0.4418E 02   0.4418E 02
G1           G2           G3           GAYA         G5           GPOPPER      GROUHANI
 0.6613E 03   0.5469E 03   0.4524E 03   0.6613E 03   0.4524E 03   0.6613E 03   0.6613E 03
ZRSHFT       CD           RE/100000    MU           QUAL         ISFLAG
 0.5514E 04   0.6600E 00   0.4930E 01   0.2012E 00   0.0                     1.
GRATIO       DVDT         DMDT         DXDT         DALDT        DSDT         DRHODT       DPDT         DTDT         S
 0.1000E 01   0.4000E 03 -0.1250E 01   0.0          0.0          0.0          0.1219E 02 -0.5080E 03   0.0          0.1000E 01
TOTAL MASS FLOW1      TOTAL MASSFLOW AYA      TOTAL MASS FLUX1       TOTAL MASS FLUX AYA      RHOV**2 DRAG DISK/RHOVT**2
    0.1855E 02            0.1855E 02              0.2777E 03               0.2777E 03                0.6841E 00

HORIZONTAL OUTLET SPOOL PIECE
VEL          DEN          DRAG         T            P            TSAT         AL           RHOF         RHOG
-0.4082E 02   0.4218E 02 -0.6870E 05   0.6045E 03   0.1905E 04   0.6288E 03   0.0           0.3971E 02   0.4954E 01
MASSFLOW1    MASSFLOW2    MASSFLOW3    MASSFLOWAYA  MASSFLOW5    MASSFLOWP    MASSFLOWR
-0.1150E 03 -0.1137E 03 -0.1124E 03 -0.1150E 03 -0.1124E 03 -0.1150E 03 -0.1150E 03
G1           G2           G3           GAYA         G5           GPOPPER      GROUHANI
-0.1722E 04 -0.1702E 04 -0.1683E 04 -0.1722E 04 -0.1593E 04 -0.1722E 04 -0.1722E 04
ZRSHFT       CD           RE/100000    MU           QUAL         ISFLAG
-0.5727E 03   0.6700E 00   0.1255E 02   0.2057E 00   0.0                     1.
GRATIO       DVDT         DMDT         DXDT         DALDT        DSDT         DRHODT       DPDT         DTDT         S
 0.1000E 01 -0.4800E 03 -0.5000E 01   0.0          0.0          0.0          0.5493E 01 -0.3300E 03 -0.3377E 02   0.1000E 01
TOTAL MASS FLOW1      TOTAL MASSFLOW AYA      TOTAL MASS FLUX1       TOTAL MASS FLUX AYA      RHOV**2 DRAG DISK/RHOVT**2
   -0.2653E 02           -0.2653E 02             -0.3972E 03              -0.3972E 03                0.9775E 00
```

A.5. Output Variable Meaning and Units

VEL — Instrumented spool piece turbine meter velocity, ft/s.

DEN — Instrumented spool piece gamma densitometer density, lb_m/ft^3.

DRAG — Instrumented spool piece drag disk momentum flux, $lb_m/ft\text{-}s^2$.

T — Instrumented spool piece temperature, °F.

P — Instrumented spool piece pressure, psig.

TSAT — Saturation temperature for the indicated spool piece pressure, °F.

AL — Instrumented spool piece void fraction, dimensionless.

RHOF — Saturated liquid density, lb_m/ft^3.

RHOG — Saturated vapor density, lb_m/ft^3.

MASSFLOW1 — Mass flow rate calculated using turbine meter velocity and gamma densitometer density, lb_m/s.

MASSFLOW2 — Mass flow rate calculated using drag disk momentum flux and gamma densitometer density, lb_m/s.

MASSFLOW3 — Mass flow rate calculated using turbine meter velocity and drag disk momentum flux with sign of turbine meter, lb_m/s.

MASSFLOWAYA — Mass flow rate calculated using the Aya model, lb_m/s.

MASSFLOW5 — Mass flow rate calculated using turbine meter velocity and drag disk momentum flux with sign of drag disk, lb_m/s.

MASSFLOWP — Mass flow rate calculated using the Popper model, lb_m/s.

MASSFLOWR — Mass flow rate calculated using the Rouhani model, lb_m/s.

G1 — Mass flux calculated using turbine meter velocity and gamma densitometer density, $lb_m/s\text{-}ft^2$.

G2 — Mass flux calculated using drag disk momentum flux and gamma densitometer density, $lb_m/s\text{-}ft^2$.

G3 — Mass flux calculated using turbine meter velocity and drag disk momentum flux with sign of turbine meter, $lb_m/s\text{-}ft^2$.

GAYA — Mass flux calculated using the Aya model, $lb_m/s\text{-}ft^2$.

G5 — Mass flux calculated using turbine meter velocity and drag disk momentum flux with sign of drag disk, $lb_m/s\text{-}ft^2$.

GPOPPER — Mass flux calculated using the Popper model, $lb_m/s\text{-}ft^2$.

GROUHANI — Mass flux calculated using the Rouhani model, $lb_m/s\text{-}ft^2$.

ZRSHFT — Drag disk zero-shift correction, $lb_m/ft\text{-}s^2$.

CD — Drag disk Reynolds number—based calibration factor, dimensionless.

RE/100000 — Drag disk target Reynolds number divided by 100000, dimensionless.

MU — Quality-weighted viscosity, $lb_m/h\text{-}ft$.

QUAL — Spool piece quality, dimensionless.

ISFLAG — Flag to indicate whether data permit use of Aya model. If ISFLAG = 1, Aya model used; if ISFLAG is some number other than 1, homogeneous model calculations have been substituted for the Aya calculation, dimensionless.

GRATIO — Ratio of GAYA to G1, dimensionless.

DVDT — Time rate of change of turbine meter velocity between data scans, ft/s^2.

DMDT — Time rate of change of drag disk momentum flux between data scan, $lb_m/ft\text{-}s^3$.

DXDT — Time rate of change of quality between data scans, s^{-1}.

DALDT — Time rate of change of void fraction between data scans, s^{-1}.

DSDT — Time rate of change of slip between data scans, s^{-1}.

DRHODT — Time rate of change of gamma densitometer density between data scans, $lb_m/ft^3\text{-}s$.

DPDT — Time rate of change of spool piece pressure between data scans, psig/s.

DTDT — Time rate of change of spool piece temperature between data scans, °F/s.

S — Slip ratio, dimensionless.

TOTAL MASS FLOW1 — Total integrated mass using turbine meter velocity and gamma densitometer density, lb_m.

TOTAL MASSFLOW AYA — Total integrated mass using Aya model, lb_m.

TOTAL MASS FLUX1 — Total integrated mass per unit area using turbine meter velocity and gamma densitometer density, lb_m/ft^2.

TOTAL MASS FLUX AYA — Total integrated mass per unit area using Aya model, lb_m/ft^2.

RHOV**2 DRAG DISK/RHOVT**2 — Ratio of drag disk measured momentum flux to momentum flux, calculated by combining turbine meter velocity and gamma densitometer density, dimensionless.

A.6. Output Data Array Locations of Output Variables

Variable name	Entry number by spool piece and type of data (EU or FM)							
	Horizontal inlet		Vertical inlet		Vertical outlet		Horizontal outlet	
	EU	FM	EU	FM	EU	FM	EU	FM
VEL	1	51	101	151	201	251	301	351
DEN	2	52	102	152	202	252	302	352
DRAG	3	53	103	153	203	253	303	353
T	4	54	104	154	204	254	304	354
P	5	55	105	155	205	255	305	355
TSAT	6	56	106	156	206	256	306	356
AL	7	57	107	157	207	257	307	357
RHOF	8	58	108	158	208	258	308	358
RHOG	9	59	109	159	209	259	309	359
MASSFLOW1	10	60	110	160	210	260	310	360
MASSFLOW2	11	61	111	161	211	261	311	361
MASSFLOW3	12	62	112	162	212	262	312	362
MASSFLOWAYA	13	63	113	163	213	263	313	363
MASSFLOW5	14	64	114	164	214	264	314	364
MASSFLOWP	15	65	115	165	215	265	315	365
MASSFLOWR	16	66	116	166	216	266	316	366
G1	17	67	117	167	217	267	317	367
G2	18	68	118	168	218	268	318	368
G3	19	69	119	169	219	269	319	369
GAYA	20	70	120	170	220	270	320	370
G5	21	71	121	171	221	271	321	371
GPOPPER	22	72	122	172	222	272	322	372
GROUHANI	23	73	123	173	223	273	323	373
ZRSHFT	24	74	124	174	224	274	324	374
CD	25	75	125	175	225	275	325	375
RE/100000	26	76	126	176	226	276	326	376
MU	27	77	127	177	227	277	327	377
QUAL	28	78	128	178	228	278	328	378
GRATIO	29	79	129	179	229	279	329	379
DVDT	30	80	130	180	230	280	330	380
DMDT	31	81	131	181	231	281	331	381
DXDT	32	82	132	182	232	282	332	382
DALDT	33	83	133	183	233	283	333	383
DSDT	34	84	134	184	234	284	334	384
DRHODT	35	85	135	185	235	285	335	385
DPDT	36	86	136	186	236	286	336	386
DTDT	37	87	137	187	237	287	337	387
S	38	88	138	188	238	288	338	388
TOTAL MASS FLOW1	39	89	139	189	239	289	339	389
TOTAL MASS FLOW AYA	40	90	140	190	240	290	340	390
TOTAL MASS FLUX1	41	91	141	191	241	291	341	391
TOTAL MASS FLUX AYA	42	92	142	192	242	292	342	392
RHOV**2 DRAG DISK/ RHOVT**2	43	93	143	193	243	293	343	393
ISFLAG	44	94	144	194	244	294	344	394

Other variables	Data array entry number
Generator 9 power, kW	401
Generator 10 power, kW	402
Generator 11 power, kW	403
Generator 12 power, kW	404
Total bundle power, MW	405
Inlet breakwire voltage, V	406
Outlet breakwire voltage, V	407

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