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12



COMPUTER PROGRAM FOR CALCULATION OF INTEGRAL-MEAN-SLOPE CORRELATION PARAMETER

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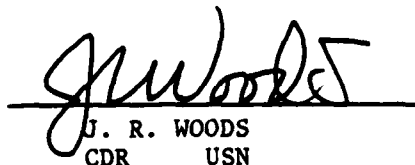
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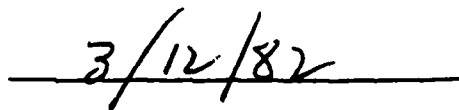
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Aerodynamic Characteristics Correlation Parameter Aft-End Boattail Integral-Mean-Slope Computer Program		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) → A computer program has been developed which calculates an aircraft integral-mean-slope geometrical parameter from detailed information of aft-fuselage area distribution. The IMS parameter correlates with high subsonic and transonic drag measurements and is utilized as a measure of aircraft performance.		

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S U M M A R Y

This report describes a computer code which calculates a geometry parameter from inputs of an air vehicle aft end area distribution. This parameter, called the "Integral-Mean-Slope" or IMS, was found to correlate well with high subsonic and transonic aft end drag measurements and is used as a predictor of pressure drag.

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INTRODUCTION AND BACKGROUND

The NAVAIRDEVCON was tasked with an assignment from the Naval Air Systems Command to develop an accurate method of predicting aft-end fuselage drag of twin nozzle "fighter" type aircraft. A computer program (reference (a)) and several supporting documents (references (b), (c) and (d)) were developed, in addition to this report, as a result of the aft-end drag analysis methods. During the methodology development, it was clear that one of the major parameters which correlates well with the aft-end drag was the Integral Mean Slope (IMS).

This report presents a computer code which allows the user to compute the IMS from inputs of the vehicle geometry. The input format is compatible with other in-house graphics utility codes such as reference (g), so the user may preview the inputs before execution.

The IMS parameter is calculated by integration of the normalized rate of change of fuselage area as defined by the following equation.

$$IMS = \frac{1.0 \int_{A_E/A_{MAX}}^{d(A/A_{MAX})} \frac{d(A/A_{MAX})}{d(X/D_{EQ})} d(A/A_{MAX})}{1.0 - A_E/A_{MAX}} \quad (1)$$

where,

A_E represents the aft area integration limit

A_{MAX} represents the maximum fuselage area

D_{EQ} represents the maximum equivalent fuselage diameter,

$$D_{EQ} = \left(\frac{4 A_{MAX}}{\pi} \right)^{1/2}$$

The IMS parameter was originally introduced by Pratt & Whitney Aircraft in reference (e) as a correlation parameter relating fuselage area distribution with the variation of aftbody drag coefficient. Another variant of the IMS is the truncated IMS or IMST which was formulated by Boeing in reference (f). The truncated IMS parameter is a recent variation of the basic IMS calculation which utilizes empirical data associated with probable streamline separation as a function of aftbody curvature and Mach number. The calculation procedure involves testing the local

aftbody slope at a given free stream Mach condition for the possibility of separation and the modification of the aftbody slope to conform to the separation streamline when appropriate. The empirical data associated with the truncated IMS parameter is presented in Figure 1 and was extracted from reference (f).

CODE OPERATION

The code consists of a main program, IMS, and two subroutines, SPLNQ1 and SLOPE1. IMS processes the input data to create an array of the normalized area distribution versus normalized aftbody length (see equation (1)). An integration is performed in accordance with equation (1) above in steps of .01 of the normalized aftbody length to arrive at the IMS and IMST.

The subroutines SPLNQ1 and SLOPE1 associated with this computer code utilize a spline fit curve through the input data to produce a piecewise cubic with continuous first and second derivatives. The aftbody area distribution is curve fitted using the SPLNQ1 subroutine for interpolation of data values and the calculated aftbody slope is obtained in a similar manner using the SLOPE1 subroutine.

OPERATING INSTRUCTIONS

The IMS parameter correlates well with high subsonic and transonic aftend drag measurements (see references (a) and (b)) if sufficient care is exercised in the precision of input data. The numerical calculation procedure necessitates a smooth input data curve of aftend area distribution for maximum precision of calculated IMS parameter. Therefore, it is advisable to plot the area distribution prior to use of this program to insure a smooth input curve. The data input format is compatible with the NAVAIRDEVCEEN plotting computer codes (reference (g)) to facilitate the input of analytically smooth data curves.

The program input data requirements are specified in Table I, where a minimum of nine data cards are required for execution. The maximum integration limit (XMAX) is input in the first ten columns of card 1 and can represent either fuselage station directly or can be normalized with the maximum equivalent fuselage diameter. The number of Mach numbers (XNOMACH) is input in the next ten columns and the maximum fuselage area (AMAX) is entered in columns 21 thru 30.

The fuselage area distribution (input on card 7) can be specified in dimensional units of either square feet or square inches by setting the parameter (ADIMEN) in columns 31 thru 40 to either 0. or 1., respectively. The user may also input the normalized area distribution as a function of normalized aftbody length X/DEC , provided AMAX is input as 0. Detailed integration steps during the process of calculation of the overall IMS parameter can be printed by insertion of a value of 1. in columns 41 thru 50.

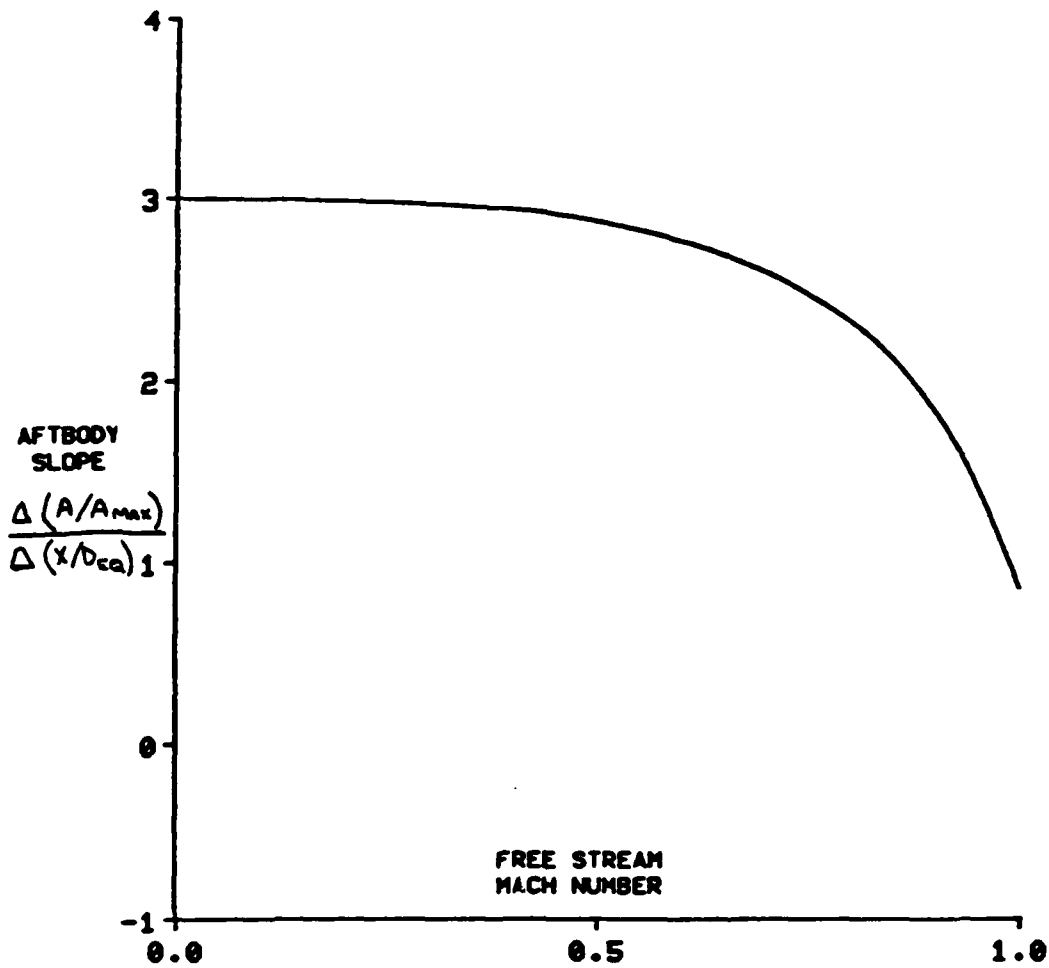


FIGURE 1 AFTBODY SEPARATION CRITERIA

TABLE I
INPUT DATA FORMAT FOR IMS PROGRAM

CARD	QUANTITY	MODE	COLUMNS	DESCRIPTION
1	XMAX	REAL	1-10	MAXIMUM INTEGRATION LIMIT, EITHER X/D (BODY DIAMETERS) OR FUSELAGE STATION - INCHES
	XNOMACH	REAL	11-20	NUMBER OF MACH NUMBERS
	AMAX	REAL	21-30	MAXIMUM OR REFERENCE AREA
	ADIMEN	REAL	31-40	CUE FOR DIMENSION OF AREA, 0. = SQ. FT., 1. = SQ. IN.
	XPRINT	REAL	41-50	CUE FOR DIAGNOSTIC PRINT, 0. = NO, 1. = YES
2	XM	REAL	1-10 11-20 . . . 71-80	MACH NUMBERS
3	IDENT	ALPHA-NUMERIC	2-80	CASE IDENTIFICATION TITLE
4	BLANK CARD			
5	BLANK CARD			
6	NPP	INTEGER	5-7	NUMBER OF X/DMAX DATA VALUES
	FX	REAL	11-20 21-30 . . . 71-80	X/DMAX DATA VALUES

TABLE I (CONT'D)
INPUT DATA FORMAT FOR IMS PROGRAM

CARD	QUANTITY	MODE	COLUMNS	DESCRIPTION
6 (CONT'D)	FX	REAL	11-20 21-30 . . .	ADDITIONAL X/DMAX DATA VALUES AS REQUIRED (FOR MORE THAN 14 DATA VALUES, CONTINUE KEYPUNCHING ADDITIONAL CARDS IN THE SAME MANNER)
7	NPP	INTEGER	5-7	NUMBER OF A/AMAX DATA VALUES
	FX	REAL	11-20 21-30 . . .	A/AMAX DATA VALUES
7a	FX	REAL	11-20 21-30 . . .	ADDITIONAL A/AMAX DATA VALUES AS REQUIRED (FOR MORE THAN 14 DATA VALUES, CONTINUE KEYPUNCHING ADDITIONAL CARDS IN THE SAME MANNER)
8	BLANK CARD		71-80	
9	BLANK CARD		71-80	

REPEAT CARDS 1 THROUGH 8 FOR EACH ADDITIONAL CASE

The second data card is reserved for input of the Mach number values (XM) as real numbers in fields of 10 columns starting in column 1. The third data card allows the input of a case identification or title (IDENT) with cards four and five input with blank fields. The number of fuselage data stations (NPP) is input on card 6 as an integer value right-adjusted in columns 5 thru 7 with the fuselage data values (FX) input as monotonically increasing real numbers in fields of ten, starting in column 11. If necessary, additional fuselage data values can be continued on subsequent cards, starting each in column 11. The number of fuselage area data values (NPP) is input on card seven as a right-adjusted integer in columns 5 thru 7, and must correspond with the value input on card 6. The fuselage area data values (FX) are input in correspondence with the previously input fuselage values as real numbers in fields of ten starting in column 11. Additional fuselage data values can be entered on subsequent cards, starting each in column 11. The final card for each case is input with blank fields and additional cases can be included by repeating the input format of cards 1 through 8 followed by a blank stop card.

The output provided by the program consists of the standard IMS parameter calculation and the truncated IMS parameter for each Mach number specified by the user.

A sample case is included in Appendix A, together with the resulting sample output. A listing of the IMS source program and required subroutines are included in Appendix B.

R E F E R E N C E S

- (a) Franz, J. J. and Lee, K. W., "Modified Twin Nozzle/Afterbody Drag and Nozzle Internal Performance Computer Program," NADC Report No. NADC-76405-30
- (b) Franz, J. J., and Lee, K. W., "An Aftend Drag Data Base and Prediction Technique for Twin Jet Fighter Type Aircraft," NADC Report No. NADC-77021-30
- (c) Franz, J. J., "Computer Program for Calculation of Airfoil Pressure and Turbulent Friction Drag," NADC Report No. NADC-77037-30
- (d) Franz, J. J., "Analysis of Covariance Computer Program with Multiple Covariates and Forecast Capability," NADC Report No. NADC-77036-30
- (e) Herrick, P. W., "Twin Jet Fighter Installed Nozzle Performance - A General Prediction Technique," Pratt & Whitney Aircraft, PWA-SMR-FR-3110, 22 Jan 1969
- (f) Ball, W. H., "Propulsion System Installation Corrections," Air Force Flight Dynamics Laboratory, AFFDL-TR-72-147-Vol. IV, Dec 1972
- (g) Caddy, M. J., "GPPR - A Multipurpose Comptuer Code for Data Plotting," NADC Report No. NADC-76367-30

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APPENDIX A

SAMPLE INPUT/OUTPUT

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In this sample problem, the inputs on page A-5 show that the aft body area distribution was input in normalized form using 17 data sets terminating at a normalized aft body length of 2.611 equivalent diameters. From the inputs, we can see that the IMS was to be determined at 5 Mach numbers (.5, .6, .7, .8, and .9) from the maximum area station +. a length of 2.611 diameters. The IMS computation can be terminated at a more forward body station by specifying the parameter XMAX to be less than 2.611 in this case.

The output, on page A-6 shows the value of IMS and IMST to be .63665 over the Mach number range indicating no probable separation by the criterion discussed in the introduction section.

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2.611 5. 0.0 1.
 .5 0.6 0.7 0.8 0.9

SAMPLE 1MST CALCULATION - AMAA TO NOZZLE EXIT STATIONS

Z 1 0.

V 1 0.

X/DM 17 0. .182 .41 .637 .865 .976 1.024

1.07 1.206 1.434 1.662 1.889 2.108 2.231

2.344 2.458 2.611

A/AM 17 1. .9857 .9786 .9489 .9063 .8782 .8660

.8346 .82002 .7889 .7193 .6440 .5696 .4942

.403 .3028 .1017

EDT

.0

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SAMPLE IM51 CALCULATION - AREA TO NOZZLE EXIT STATIONS

2.61100	0.00000	1.00000						
.50000	.60000	.70000	.80000	.90000	0.00000	0.00000	0.00000	
17.0000								
0.0000	.1820	.4100	.6270	.8650	.9780	1.0240		
1.0700	1.2060	1.4340	1.6620	1.8890	2.1080	2.2310		
2.3440	2.4580	2.6110						
1.0000	.9957	.9788	.9489	.9063	.8782	.8660		
.8566	.8300	.7809	.7193	.6448	.5686	.4942		
4030	.2828	.1017						

MACH NO	TRUNCATED IM5	STD IM5
.5000	.63662	.63662
.6000	.63662	.63662
.7000	.63662	.63662
.8000	.63662	.63662
.9000	.63662	.63662

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APPENDIX B

COMPUTER LISTING

The listing provided herein includes the IMS program with subroutines SPLNQ1 and SLOPE1 which are currently operational on the NAVAIRDEVCEM CDC 6600 computer system.

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SUBROUTINE SPLNQ1	B-5
SUBROUTINE SLOPE1	B-6

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B - 4

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```

C STORAGE LOCATIONS ARE REQUIRED FOR THE DATA AND THE COEFFICIENTS SPLN000
C NEW FEATURE IS QUICK LOOK-UP FOR LARGE ARRAYS SPLN000
C DIMENSION G(100),SB(100),X(1) SPLN000
X=X*INDEX SPLN000
NS=NLOC SPLN000
NOPTS=X(NS) SPLN001
ID=NS-NOPTS SPLN001
NSP1=NS-1 SPLN001
NSP2=NS-2 SPLN001
NS2=NOPTS+2+NSP1 SPLN001
L=X(NS2) SPLN001
LSC=NS2-1 SPLN001
IQMODE=X(LSC) SPLN001
K=L SPLN001
NL=NSP1 SPLN001
NH=ID SPLN002
NTRAP=-1 SPLN002
IF(NOPTS.LE.1) GO TO 120 SPLN002
IF(XIN=X(ID))120,130,10 SPLN002
10 NTRAP=0 SPLN002
GO TO 130 SPLN002
20 IF(XIN=X(NSP1))130,40,50 SPLN002
30 NTRAP=1 SPLN002
40 K=NSP2 SPLN002
GO TO 140 SPLN002
50 IF(L)110,110,60 SPLN002
60 IF(XIN=X(K))170,140,90 SPLN003
70 NH=K SPLN003
K=K-1 SPLN003
80 IF(XIN=X(K))100,140,90 SPLN003
90 NL=K SPLN003
GO TO 110 SPLN003
100 NH=K SPLN003
110 K=(NH-NL)/2+NL SPLN003
IF(XIN=X(K))180,130,80 SPLN003
120 YOUT=X(NSP2) SPLN004
GO TO 240 SPLN004
130 K=NH SPLN004
140 M=K SPLN004
X1=NS2+M SPLN004
M=M+NOPTS SPLN004
IF(L=IQMODE.GT.0) GO TO 210 SPLN004
150 X2=X(NSP1) SPLN004
X3=X(NSP2) SPLN004
X32=X3-X2 SPLN004
Y3=X(ID+2) SPLN005
Y32=X32+(Y3-X(ID+1))/X32 SPLN005
G(1)=0. SPLN005
SB(1)=5. SPLN005
NH=NOPTS-1 SPLN005
IF(NH.LT.2) GO TO 170 SPLN005
DO 160 I=2,NH SPLN005
J=NSP1-1 SPLN005
K1=J+NOPTS SPLN005
X1=X2 SPLN005
X2=X3 SPLN006
X3=X32 SPLN006
X3=X1(J) SPLN006
X32=X3-X2 SPLN006
Y2=Y3 SPLN006
Y3=X(K1) SPLN006
Y2=X2+Y32X32 SPLN006
Y32X32=(Y3-Y2)/X32 SPLN006
W1=(1/2)*(X3-X1)-X2+SB(1-1) SPLN006
SB(1)=X32+W1 SPLN006
160 G(1)=W1*(6*(Y32X32-Y2X2)-X2+G(1-1)) SPLN007
170 EM1=G(1)/(2+SB(NH)) SPLN007
IF(L.GT.0) GO TO 180 SPLN007
ID=NOPTS SPLN007
KQAS=NOPTS+LSC SPLN007
X(KQAS)=EM1 SPLN007
GO TO 190 SPLN007
180 ID=ID+2-M SPLN007
DO 200 I=2,ID1 SPLN007
EM2=EM1 SPLN007
EM1=G(NH)-SB(NH)+EM2 SPLN007
X(NH-LSC)=EM1 SPLN008
200 NH=NH-1 SPLN008
IF(L.GT.0) GO TO 220 SPLN008
210 NSM=NS2+M-NS+1 SPLN008
EM1=X(NSM-1) SPLN008
EM2=X(NSM) SPLN008
220 S=X(NH)-X(M-1) SPLN008
IF(NTRAP.LT.0) GO TO 230 SPLN008
IX=M-NTRAP SPLN008
IY=IX+NOPTS SPLN009
X5=XIN SPLN009
XIN=XIX SPLN009
Z1=X(M)-XIN SPLN009
Z2=XIN-X(M-1) SPLN009
YOUT=((EM2+Z2+Z2-EM1+Z1+Z1+5*(XIN-X(M-1)))/S
1-(EM2-EM1)/S/6.)*(15-XIN+X(IY)
GO TO 240 SPLN009
230 Z2=XIN-X(M-1) SPLN009
YOUT=((EM2-EM1)+Z2+2*(S+EM1)+Z2+6*(XIN-X(M-1))-5*S*(EM1-EM1-
(EM2)+Z2/(6+S)-X(M-1) SPLN010
240 SPLNQ=YOUT SPLN010
RETURN SPLN010
END SPLN010
FUNCTION SLOPE1 (NLOC,X,INDEX,YOUT2) 000
CUBIC SPLINE FIT REVISED 10/21/71 M CADDY 000
THIS VERSION HAS QAO OPTION WHERE ALL OF THE SPLINE COEFFICIENTS 000
ARE COMPUTED AND STORED IN THE ARRAY FOR M DATA POINTS 3NN=3 000
STORAGE LOCATIONS ARE REQUIRED FOR THE DATA AND THE COEFFICIENTS 000
NEW FEATURE IS QUICK LOOK-UP FOR LARGE ARRAYS 000
C DIMENSION G(100),SB(100),X(1) 000
X=X*INDEX 000
NS=NLOC 000
NOPTS=X(NS) 000
ID=NS-NOPTS 000
NSP1=NS-1 000
NSP2=NS-2 000
NS2=NOPTS+2+NSP1 000
L=X(NS2) 000
LSC=NS2-1 000
IQMODE=X(LSC) 000
K=L 000
NL=NSP1 000
NH=ID 000
NTRAP=-1 002

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10 IF (NOPTS-1) 130, 130, 10
11 IF (XIN-X(ID)) 130, 140, 20
20 NTRAP=0
30 GO TO 140
31 IF (XIN-X(NSP1)) 40, 50, 60
40 NTRAP=1
50 N=NSP2
60 GO TO 150
70 IF (L) 120, 120, 70
71 IF (XIN-X(K)) 180, 150, 100
80 N=K
90 IF (XIN-X(K)) 110, 150, 100
100 N=K
110 GO TO 120
120 N=K
130 IF (XIN-X(K)) 180, 140, 90
140 YOUT=X(NSP2)
150 GO TO 260
160 N=EM
170 N=K
180 X(NS2)=N
190 N=NOPTS
200 IF (L) 180, 160, 220
210 X2=X(NSP1)
220 X3=X(NSP2)
230 X3=X3-X2
240 Y3=X(ID+2)
250 Y32=Y3-X(ID+1)
260 G(1)=0
270 S(1)=1
280 N1=NOPTS-1
290 DO 170 I=2, N1
300 J=NSP1-1
310 K1=J-NOPTS
320 K1=K2
330 K2=K3
340 K3=X32
350 X3=X32
360 J32=X3-X2
370 Y2=Y3
380 Y3=X32
390 Y21=Y32
400 Y32=Y3-Y2
410 W=(X3-X1)/2 - X2*(S(1)-1)/8
420 S(1)=X32/(W*8)
430 G(11)=Y32/X32-Y21/X21-X21*(G(1)-1)/8 - 1/W
440 EM1=G(11)/(2 - S(11))
450 IF (L) 180, 180, 180
460 ID1=NOPTS
470 HQAS=NOPTS-LSC
480 X(HQAS)=EM1
490 GO TO 260
500 ID1=ID+2-N
510 DO 210 I=2, ID1
520 EM2=EM1
530 EM1=G(N1)-S(11)*EM2
540 X(N1-LSC)=EM1
550 N1=N1-1
560 IF (L) 220, 220, 230
570 NSM=NS2-N-NS+1
580 EM1=X(NSM-1)
590 EM2=X(NSM)
600 S=X(M)-X(N-1)
610 IF (NTRAP) 250, 240, 240
620 IS=N-NTRAP
630 IV=IS-NOPTS
640 AS=XIN
650 XIN=X(IN)
660 Z1=X(M)-XIN
670 Z2=XIN-X(N-1)
680 YOUT=1-((EM2+Z2+Z2-EM1+Z1+Z1)/2 + X(N)-X(N-1))/S
690 1-(EM2-EM1)/S/8)
700 YOUT2 = 0
710 GO TO 260
720 Z2=XIN-X(N-1)
730 Z1=X(M)-XIN
740 YOUT=1-((EM2+Z2+Z2-EM1+Z1+Z1)/2 + X(N)-X(N-1))/S
750 1-(EM2-EM1)/S/8)
760 YOUT2 = 1-(EM2+Z2-EM1+Z1)/S
770 SLOPE=YOUT
780 RETURN
790 END

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