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A COMPUTER PROGRAM FOR THE ANALYSIS OF WIND TUNNEL CONTROL SURFACE DATA

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SUMMARY

The Report describes a computer program for the analysis of data derived by the Five-Component Wind Tunnel Dynamometer described in Ref.1.

The program is written in Interactive Basic; it incorporates the dynamometer five-component interaction matrix and correction formulae, and includes corrections for wind tunnel boundary effects. Output is in the form of coefficients of lift, drag and normal force and centre of pressure for varying angle of attack of rudder and/or skeg; the cases of rudder plus skeg, rudder alone and skeg alone are included in the output.

The program variables are defined and the program described. A program listing and examples of typical data input and program output are given.

CONTENTS PAGE

1. INTRODUCTION

Derivation of the five force and moment components using the raw data measured by the dynamometer described in Ref.1 requires the solution of five interaction equations. Each equation contains five terms involving, in total, twenty-five coefficients. Calculation by hand calculator, whilst not impossible, is extremely time consuming and it was a logical step, following the construction and calibration of the dynamometer, to write a short computer program to handle the data analysis.

After writing the program to derive the five components it was further logical, and not difficult, to include the extra corrections for the rudder alone case, the resolution of the components as required, necessary wind tunnel boundary corrections and to present the results in the desired coefficient form.

2. REQUIREMENTS OF ANALYSIS AND PROGRAM

The requirments of the analysis and hence computer program are outlined in this SECTION. The nomenclature defined in Ref.1 (and repeated at end of this Report) is used in this SECTION in order to provide a link between the program, the analysis and Ref.1.

The measured data consist of Betz manometer reading (H), mean test air temperature and atmospheric pressure (hence mean air density (ρ_A) and kinematic viscosity (ν)), lift bridge voltage (Vo), and meter reading R for each of the five components at particular angles of attack for rudder (δ) and skeg (β). Rudder data required for the analysis is mean chord ($\bar{c}$), span (S), location of moment and torque axes relative to span and chord (defined by U and W). Also required are tunnel boundary correction data (ϵ), (δ), (τ) and (τ_2).

Due to the limitations in output format of Interactive Basic, a limited number of data columns can be printed out. It was therefore decided to output rudder angles α and δ , lift coefficient, force coefficient normal to rudder, drag coefficient, force coefficient normal to skeg (or ship) and centre of pressure (chordwise and spanwise) for Rudder plus Skeg, Rudder Alone and Skeg Alone.

The following notes outline the principal features of the analysis:

Derivation of nominal wind speed for test:

$$V = 140.07 \cdot \sqrt{H} / \sqrt{\rho_A}$$

where H = Betz manometer reading in metres of water

ρ_A = mean density of air at mean test temp. and press. (kg/m^3)

constant 140.07 derived from

$$V = \sqrt{\frac{\rho_w . g . H . 2}{\rho_A}}$$

$$= \sqrt{1000 \times 9.81 \times 2} \times \sqrt{H} / \sqrt{\rho_A}$$

$$= 140.07 \sqrt{H} / \sqrt{\rho_A}$$

Derivation of nominal Reynolds Number for test:

$$Rn = \frac{V \bar{c}}{\nu}$$

Solution of interaction matrix:

The main analysis first requires the solution of the interaction matrix (Ref.1, SECTION 5.10, pg.42), hence deriving forces and moments relative to the dynamometer (skeg) axes, X_β - X_β and Y_β - Y_β :

$$N_\beta = k_1 R_1 + k_2 R_2 + k_3 R_3 + k_4 R_4 + k_5 R_5$$

$$A_\beta = k_6 R_1 + k_7 R_2 + k_8 R_3 + k_9 R_4 + k_{10} R_5$$

$$MZ_\beta = k_{11} R_1 + k_{12} R_2 + k_{13} R_3 + k_{14} R_4 + k_{15} R_5$$

$$MX_\beta = k_{16} R_1 + k_{17} R_2 + k_{18} R_3 + k_{19} R_4 + k_{20} R_5$$

$$MY_\beta = k_{21} R_1 + k_{22} R_2 + k_{23} R_3 + k_{24} R_4 + k_{25} R_5$$

Where R_1 to R_5 are the measured meter readings (μv), **with averaging and zero corrections having been applied as necessary.**

k_1 to k_{25} are the matrix coefficients in terms of meter readings, i.e. according to terminology of Ref.1, page 42

Lc = .9999580 Lu ....

= .9999580 k_L R_L .... where k_L = calibration slope

R_L = meter reading

whence for general case $N_\beta = k_1 R_1$ ....

where k_1 incorporates the interaction coefficient and calibration slope. The coefficients k_1 to k_{25} were converted for the program whereby the forces and moments are derived in N and N.m.

Each equation is required to be multiplied by (7/Vo) where 7 is the lift bridge calibration voltage and Vo is the lift bridge voltage recorded under test conditions: this correction is described in SECTION 6.7 of Ref.1.

Resolution of forces and moments:

The above forces and moments are required to be resolved into wind axes X - X and Y - Y.

$$L = N_\beta \cos\beta - A_\beta \sin\beta$$

$$D = A_\beta \cos\beta + N_\beta \sin\beta$$

$$MZ = MZ_\beta$$

$$MX = MX_\beta \cos\beta - MY_\beta \sin\beta$$

$$MY = MY_\beta \cos\beta + MX_\beta \sin\beta$$

For derivation of centre of pressure, force and moment normal to rudder are required:

$$N = L \cos\alpha + D \sin\alpha$$

$$MN = MX \cos\alpha + MY \sin\alpha$$

where $\alpha = \delta + \beta$

whence $CP\bar{c} = (MZ/N + W) \times 100/\bar{c}$

$CPs = (MN/N - U) \times 100/S$

For definitions of W and U, see Fig.2.

Forces are required in coefficient form:

$$C_L = L/qA = L/(S \times \bar{c} \times 9810 \times H)$$

$$C_D = D/qA = D/(S \times \bar{c} \times 9810 \times H)$$

$$C_Y = N_\beta/qA = N_\beta/(S \times \bar{c} \times 9810 \times H)$$

Wind tunnel boundary corrections are then required to be applied to C_L, C_D, C_Y and α as described in APPENDIX A6. **C_N is derived from $C_N = C_L \cos\alpha + C_D \sin\alpha$, using the corrected values of C_L, C_D and α.**

The foregoing analysis is first applied to the case of Rudder plus Skeg.

The analysis is then repeated for the case of Rudder Alone; in this case, further corrections due to skeg interactions are required as described in APPENDIX A5.

Finally, by analysing the difference between Rudder plus Skeg and Rudder Alone the **forces** on the skeg and location of its centre of pressure are also derived.

General Notes on Analysis:

In the program the tunnel boundary correction to rudder angle is not applied to the skeg angle β . This correction varies typically from zero up to about 0.7° at maximum rudder angle; without cross fairing, therefore, its application would not allow direct comparison between results for different fixed values of β for variation in rudder angle. Further, it is not immediately clear whether the correction could be directly applied to the skeg when at a negative angle of attack. For the purposes of comparison, therefore, the analysed results are presented in terms of skeg angle β as tested, and rudder angle corrected for boundary effects.

The drag coefficient for the case of Rudder Alone is corrected for boundary effects using the corrected lift coefficient for Rudder plus Skeg. Although only lift on Rudder Alone is measured in this case, downwash will be due to lift on Rudder and Skeg.

The total area of Rudder plus Skeg is also used in deriving the force coefficients for Rudder Alone and Skeg Alone; this allows direct comparisons to be made between the absolute forces on the rudder, skeg and rudder plus skeg.

3 EXPLANATION OF PROGRAM CONTENT/OUTPUT

3.1 General:

A general description of the program is given using a flow diagram, and brief explanations of program lines are given as necessary.

The program is written in Interactive Basic and it is assumed that the reader has a knowledge of this language.

3.2 Program Flow Diagram:

The program flow diagram and its relevant notes are given in APPENDIX A1.

Since skeg corrections to experimental condition (B) (Rudder Alone) are based on the difference between experimental conditions (A) (Rudder plus Skeg) and (B), condition (A) must always exist if (B) is required to be analysed. Condition (A) can, however, exist on its own (e.g. poor, or omitted data for condition (B), or the all-movable rudder case); hence in the event of condition (A) alone, a "Dummy Number" (-9998) is inserted in lieu of the data for (B), and the analysis and output for (B) is by-passed.

A "Terminating Number" (-999) is used as a test for end of data, as shown in the flow diagram.

3.3 Comments on Program Listing, Data Input and Worked Example:

The use of the program control devices such as Dummy Number -9998 and Terminating Number -999 were described in SECTION 3.2, hence only those lines specifically relating to the analysis are explained.

A listing of the Program is given in APPENDIX A2 and brief line descriptions are given below; the reader is referred to the end of the Report for definitions of the individual program variables.

Line Number				
430	-	Conversion of skeg angle β° to radians		
440	-	" " rudder angle α° " "		
470 to 710	-	Coefficients of interaction matrix		
720 to 760	-	Interaction Matrix	-	Rudder plus Skeg
770 to 830	-	Resolution of Components	-	" " "
840 to 1000	-	Derivation of Coefficients, CP and angles; corrections for boundary effects and limitation of decimal places	-	" " "
1060 to 1100	-	Interaction Matrix	-	Rudder Alone
1110 to 1170	-	Corrections to Rudder Alone, caused by skeg interaction		
1180 to 1240	-	Resolution of Components	-	Rudder Alone
1250 to 1390	-	Derivation of Coefficients, CP and angles; corrections for boundary effects and limitation of decimal places	-	" "

1400 to 1410	-	Derivation of $CP\bar{c}$	-	Skeg Alone
1420 to 1430	-	Derivation of CPs	-	" "
1440 to 1450	-	Derivation of Lift Coefficient	-	" "
1460 to 1470	-	Derivation of Drag Coefficient	-	" "

Using the Integer function the outputs for velocity, Rn, angles and centre of pressure are expressed to two decimal places, and the force coefficients are expressed to three decimal places. The function is applied in this manner in lines 130, 150, 850, 870, 900, 930, 950, 970, 1000, 1020, 1260, 1280, 1310, 1340, 1360, 1390, 1410, 1430, 1450, 1470.

Boundary corrections are described in APPENDIX A6 and are incorporated in lines 890, 920, 940, 990, 1300, 1330, 1380.

APPENDIX A3 gives the required format of data input; the use of "Dummy Number" -9998 and "Terminating Number" -999 are indicated. The line numbers indicated were chosen for convenience. It is not intended to store the sets of data, although the program will, of course, be stored. Hence with Line 9999 as END, Program can be loaded and data typed in between Line Nos 1560 and 9999.

APPENDIX A4 gives an example of a typical input data listing and program output for that data. The relevant particulars of the rudder under test, and tunnel test conditions, are given in Fig.3. Following the preceding descriptions, the input format and output are self-explanatory. Condition (B), Rudder Alone, was omitted for Rudder Angles (Alpha) of 10° and 15° in order to illustrate the use of the "Dummy Number" -9998.

4 CONCLUDING REMARKS

The program described in this Report provides a convenient and relatively fast means of analysing the raw data derived from the dynamometer described in Ref.1.

The main shortcomings of the program are the limitation in the output format availability of Interactive Basic, and the time spent on typing-in the input data on an interactive facility.

Instrumentation facilities exist for recording the output from the dynamometer in the form of punched tape. If zero corrections and program controls were added to the tape, it could be used as a direct link to the computer. However, as reported in Ref.1, dynamic oscillations of rudder and dynamometer lead to data output fluctuations; the arithmetic mean of five readings for each test case provides a reliable method of averaging the raw data at present. Satisfactory electrical filtering of the readings will be required before direct punched tape data handling can be realistically considered.

NOMENCLATURE
(in accordance with that used in Ref.1)

A	-	Rudder Area
A_β	-	Force axial to dynamometer when at an angle β
$\bar{c}$	-	Rudder mean chord
C	-	Wind tunnel section area
$CP_{\bar{c}}$	-	Centre of pressure chordwise measured from leading edge
CP_s	-	Centre of pressure spanwise measured from root
C_D	-	Drag Coefficient
C_L	-	Lift Coefficient
C_N	-	**Force Coefficient normal to rudder**
C_Y	-	Force Coefficient normal to dynamometer, or skeg, or ship
D	-	Drag = force in direction of X - Axis
H	-	Betz manometer reading
L	-	Lift = force in direction of Y - Axis
MN	-	Spanwise moment normal to rudder
MX	-	Spanwise moment about X axis through dynamometer roll centre
MX_β	-	Spanwise moment about X_β axis through dynamometer roll centre
MX_s	-	Skeg moment about X axis through skeg roll centre
MY	-	Spanwise moment about Y axis through dynamometer roll centre
MY_s	-	Skeg moment about Y axis through skeg roll centre
MY_β	-	Spanwise moment about Y_β axis through dynamometer roll centre
MZ	-	Torque = Moment about Z - Axis
MZ_β	-	Torque = Moment about Z_β (= Z) Axis
N	-	**Force normal to rudder axis**
N_β	-	Force normal to dynamometer axis when at an angle β
q	-	Dynamic pressure $= \frac{1}{2} \cdot \rho_A . V^2$
R_n	-	Reynolds Number
S	-	Rudder span
V	-	Air speed

X - Axis	-	Air flow axis = longitudinal axis of tunnel
Y - Axis	-	Axis normal to air flow
Z - Axis	-	Vertical axis
α	-	Rudder angle relative to flow
β	-	Dynamometer (and skeg) angle relative to flow
δ	-	Rudder angle relative to dynamometer (or ship, or skeg)
(δ	-	also specific use for tunnel boundary correction)
ϵ	-	Tunnel boundary correction
ρ_A	-	Air density
τ_2	-	Tunnel boundary correction
ν	-	Kinematic viscosity
μV	-	Microvolts (Datalogger voltmeter output)

Suffixes: β .... represent the axes, loads and moments when dynamometer is at an angle β

DEFINITION OF PROGRAM VARIABLES

VARIABLE				UNITS
A1	-	A_β	, Force axial to dynamometer when at an angle β , Rudder plus Skeg	N
A3	-	A_β	, Force axial to dynamometer when at an angle β , Rudder Alone	N
A4	-	A_β	, Force axial to dynamometer when at an angle β , Rudder Alone, corrected for skeg interaction	N
B1	-	ϵ	, Wind tunnel boundary correction	
B2	-	δ	, " " " "	
B3	-	C	, " " " "	m^2
B4	-	τ_2	, " " " "	
C	-	$\bar{c}$	, Rudder mean chord	m
C1	-	C_L	, Lift Coefficient (Rudder plus Skeg)	
C2	-	C_D	, Drag Coefficient (Rudder plus Skeg)	
C3	-	C_N	, Normal Force Coefficient (Rudder plus Skeg)	
C4	-	C_Y	, Normal Force Coefficient (Rudder plus Skeg)	
C5	-	C_L	, Lift Coefficient (Rudder Alone)	
C6	-	C_D	, Drag Coefficient (Rudder Alone)	
C7	-	C_N	, Normal Force Coefficient (Rudder Alone)	
C8	-	C_Y	, Normal Force Coefficient (Rudder Alone)	
C9	-	C_L	, Lift Coefficient (Skeg Alone)	
C10	-	C_D	, Drag Coefficient (Skeg Alone)	
D	-	ρ_A	, Density of air, at test temperature and pressure	kg/m^3
D1	-	Drag	= Force in direction of X - Axis, Rudder plus Skeg	N
D2	-	Drag	= Force in direction of X - Axis, Rudder Alone	N

E1, E2, E3, E4, E5 E6, E7, E8, E9, E F1, F2, F3, F4, F5 F6, F7, F8, F9, F G1, G2, G3, G4, G5	}	Interaction Matrix Coefficients	
H	-	Betz manometer reading	m
I1	-	β, Dynamometer (or skeg) angle	rad
I2	-	β°, " " "	deg
I3	-	δ, Rudder angle relative to dynamometer	rad
I4	-	δ°, " " " " "	deg
I5	-	α, Rudder angle relative to tunnel	rad
I6	-	α°, " " " " "	deg
I7	-	α°corr., I6 corrected for boundary effects	deg
I8	-	δ° corr., I4 corrected for boundary effects	deg
K	-	ν, Kinematic viscosity of air	m^2 /s
L1	-	Lift = Force in direction of Y - Axis, Rudder plus Skeg	N
L2	-	Lift = Force in direction of Y - Axis, Rudder Alone	N
M1	-	MX, Spanwise moment about X - Axis, Rudder plus Skeg	N.m
M2	-	MY, " " " Y - Axis, " " "	N.m
M3	-	MN, Spanwise moment normal to rudder, " " "	N.m
M4	-	Rudder Alone skeg interaction correction function in direction of Y_{β} - Axis	
M5	-	Rudder Alone skeg interaction correction function in direction of X_{β} - Axis	
M6	-	MX, Spanwise moment about X - Axis, Rudder Alone	N.m
M7	-	MY, " " " Y - Axis, " "	N.m
M8	-	MN, Spanwise moment normal to rudder, " "	N.m

N	-	Rudder number allocated to rudder under test	
N1	-	N_β , Force normal to dynamometer when at an angle β , Rudder plus Skeg	N
N2	-	Force normal to rudder, Rudder plus Skeg	N
N3	-	N_β , Force normal to dynamometer when at an angle β , Rudder Alone	N
N4	-	N_β , Force normal to dynamometer when at an angle β , Rudder Alone, corrected for skeg interaction	N
N5	-	Force normal to rudder, Rudder Alone	N
P1	-	CP_c , % chord from L.E. (Rudder plus Skeg)	%
P2	-	CP_s , % span from root (Rudder plus Skeg)	%
P3	-	CP_c , % chord from L.E. (Rudder Alone)	%
P4	-	CP_s , % span from root (Rudder Alone)	%
P5	-	CP_c , % chord from L.E. (Skeg Alone)	%
P6	-	CP_s , % span from root (Skeg Alone)	%
Q$	-	String variable of dimension [26] for insertion of date(s) of test(s)	
R	-	Reynolds Number	
R1	-	N_β component, zero-corrected meter reading (Rudder plus Skeg)	μv
R2	-	A_β " " " " (Rudder plus Skeg)	μv
R3	-	MZ_β " " " " (Rudder plus Skeg)	μv
R4	-	MX_β " " " " (Rudder plus Skeg)	μv
R5	-	MY_β " " " " (Rudder plus Skeg)	μv
R6	-	N_β component, zero-corrected meter reading (Rudder Alone)	μv
R7	-	A_β " " " " (Rudder Alone)	μv
R8	-	MZ_β " " " " (Rudder Alone)	μv
R9	-	MX_β " " " " (Rudder Alone)	μv
RØ	-	MY_β " " " " (Rudder Alone)	μv
S	-	S , Rudder span	m

T1	-	MZ_β , Torque about measurement axis, Rudder plus Skeg	N.m
T2	-	= T1	N.m
T3	-	MZ_β , Torque about measurement axis, Rudder Alone	N.m
T4	-	MZ_β , Torque about measurement axis, Rudder Alone corrected for skeg interaction	N.m
T5	-	= T4	N.m
U	-	Rudder root location relative to true roll centre of dynamometer - see Fig.2	m
V	-	Air speed	m/s
VØ	-	Lift Bridge supply voltage	volts
W	-	Rudder stock location, chordwise - see Fig.2	m
X1	-	MX_β , Spanwise moment about X_β - Axis, Rudder plus Skeg	N.m
X3	-	MX_β , " " " " " , Rudder Alone	N.m
X4	-	MX_β , Spanwise moment about X_β - Axis, Rudder Alone corrected for skeg interaction	N.m
Y1	-	MY_β , Spanwise moment about Y_β - Axis, Rudder plus Skeg	N.m
Y3	-	MY_β , " " " " " , Rudder Alone	
Y4	-	MY_β , Spanwise moment about Y_β - Axis, Rudder Alone, corrected for skeg interaction	N.m

REFERENCES

1. Molland A.F. : 'The Design, Construction and Calibration of a Five-Component Strain Gauge Wind Tunnel Dynamometer'. University of Southampton, Ship Science Report No.177, 1976.

2. Pope A. and Harper J.J. : 'Low Speed Wind Tunnel Testing". John Wiley & Sons Inc.

APPENDIX A1

PROGRAM FLOW DIAGRAM

Diagram is drawn on next page

Notes relating to flow diagram :

There are two experimental (derived data) conditions : (A) Rudder + Skeg
(B) Rudder Alone

There are three data output conditions : (A) Rudder + Skeg
(B) Rudder Alone
(C) Skeg Alone

Correction to output (B) is based on the difference of (A) and (B)

Output (C) is derived by the difference of (A) and corrected (B)

Experimental condition (A) Always Exists

" " (B) May or May Not Exist

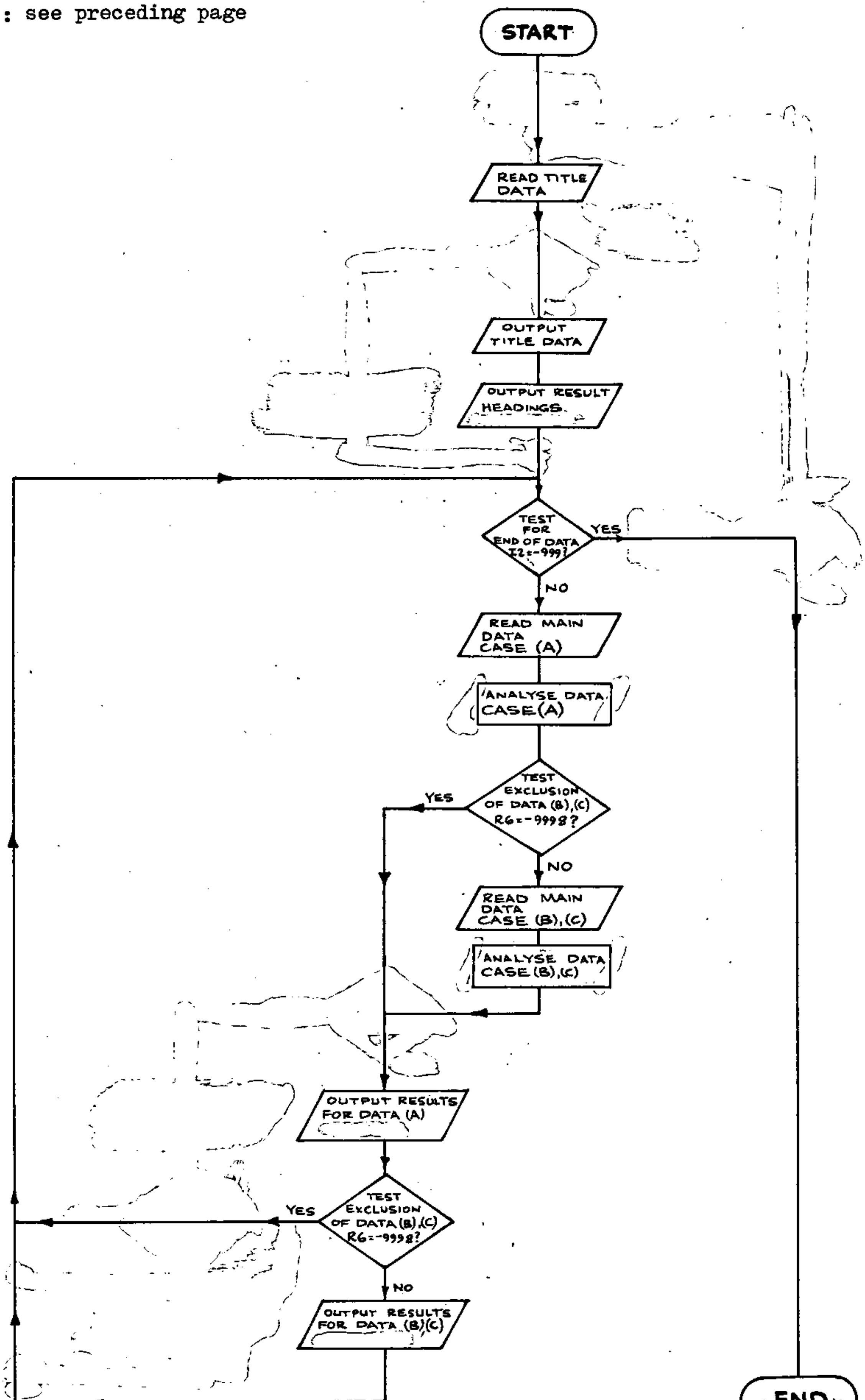
If data for experimental condition (B) not included,
"Dummy Number" R6 = -9998 inserted.

End of data defined by insertion of "Terminating Number" I2 = -999.

APPENDIX A1 (continued)

PROGRAM FLOW DIAGRAM

NOTES : see preceding page



APPENDIX A2

PROGRAM LISTING.

```
LIST

100 DIM Q$[26]
110 READ N, H, C, D, K, Q$, V0, I2
120 LET V = 140.07 * H ^ .5 / D ^ .5
130 LET V = INT((100 * V) + .5) / 100
140 LET R = V * C / K
150 LET R = INT((R / 10000) + .5) * 10000
160 PRINT
170 PRINT
180 PRINT
190 PRINT "WIND TUNNEL RUDDER DATA ANALYSIS"
200 PRINT
210 PRINT "RUDDER NUMBER", TAB(15), "="; TAB(18), N
220 PRINT "DATE OF TEST", TAB(15), "="; TAB(19), Q$
230 PRINT "WIND SPEED", TAB(15), "="; TAB(18), V; "M/S"
240 PRINT
250 PRINT "AA=RUDDER ANGLE,ALPHA(DEG.), AD=RUDDER ANGLE,DELTA(DEG.)"
260 PRINT "CL=LIFT COEFFICIENT, CN=RUDDER NORMAL COEFFICIENT"
270 PRINT "CY=SHIP NORMAL COEFFIENT, CD=DRAG COEFFICIENT"
280 PRINT "CPC=C OF P CHORD(%C), CPS=C OF P SPAN(%S)"
290 PRINT "ALL COEFFICIENTS BASED ON TOTAL AREA OF RUDDER PLUS SKEG"
300 PRINT
310 PRINT "(A)=RUDDER PLUS SKEG, (B)=RUDDER ALONE, (C)=SKEG ALONE"
320 PRINT
330 PRINT "REYNOLDS NO.", TAB(15), "="; TAB(18), R
340 PRINT
350 PRINT "SKEG ANGLE,BETA(DEG.) ="; TAB(24), I2
360 PRINT
370 PRINT TAB(6); "AA"; TAB(15), "AD"; TAB(24), "CL"; TAB(32),
380 PRINT "CN"; TAB(40), "CY"; TAB(48), "CD";TAB(56),"CPC";TAB(65),"CPS"
390 READ S, W, U, B1, B2, B3, B4
400 READ I2
410 IF I2 = -999 THEN 9999
420 READ I4, R1, R2, R3, R4, R5
430 LET I1 = I2 * 3.14159 / 180
440 LET I3 = I4 * 3.14159 / 180
450 LET I5 = I1 + I3
460 LET I6 = I2 + I4
```

(cont'd.)

```
470 LET E1 = .338035
480 LET E2 = -1.1881E-3
490 LET E3 = -3.952E-4
500 LET E4 = -1.4848E-3
510 LET E5 = -3.2605E-3
520 LET E6 = 2.12E-5
530 LET E7 = .252512
540 LET E8 = -6.659E-4
550 LET E9 = 1.6823E-3
560 LET E0 = -9.901E-4
570 LET F1 = -.000182
580 LET F2 = 2.845E-4
590 LET F3 = 3.96366E-2
600 LET F4 = 1.344E-4
610 LET F5 = .00032
620 LET F6 = 7.002E-4
630 LET F7 = -2.37E-5
640 LET F8 = -3.4036E-3
650 LET F9 = 6.34925E-2
660 LET F0 = 2.049E-4
670 LET G1 = -3.3E-6
680 LET G2 = 6.333E-4
690 LET G3 = 1.47E-5
700 LET G4 = -3.008E-4
710 LET G5 = 4.84685E-2
720 LET N1 = 7 / V0 * (E1 * R1 + E2 * R2 + E3 * R3 + E4 * R4 + E5 * R5)
730 LET A1 = 7 / V0 * (E6 * R1 + E7 * R2 + E8 * R3 + E9 * R4 + E0 * R5)
740 LET T1 = 7 / V0 * (F1 * R1 + F2 * R2 + F3 * R3 + F4 * R4 + F5 * R5)
750 LET X1 = 7 / V0 * (F6 * R1 + F7 * R2 + F8 * R3 + F9 * R4 + F0 * R5)
760 LET Y1 = 7 / V0 * (G1 * R1 + G2 * R2 + G3 * R3 + G4 * R4 + G5 * R5)
770 LET L1 = N1 * COS(I1) - A1 * SIN(I1)
780 LET D1 = A1 * COS(I1) + N1 * SIN(I1)
790 LET T2 = T1
800 LET M1 = X1 * COS(I1) - Y1 * SIN(I1)
810 LET M2 = Y1 * COS(I1) + X1 * SIN(I1)
820 LET N2 = L1 * COS(I5) + D1 * SIN(I5)
830 LET M3 = M1 * COS(I5) + M2 * SIN(I5)
840 LET P1 = (T2 / N2 + W) * 100 / C
850 LET P1 = INT((100 * P1) + .5) / 100
860 LET P2 = (M3 / N2 - U) * 100 / S
870 LET P2 = INT((100 * P2) + .5) / 100
880 LET C1 = L1 / (S * C * 9810 * H)
890 LET C1 = C1 * (1 - 2 * B1)
900 LET C1 = INT((1000 * C1) + .5) / 1000
910 LET C2 = D1 / (S * C * 9810 * H)
920 LET C2 = C2 * (1 - 2 * B1) + B2 * 2 * S * C / B3 * C1 * C1
930 LET C2 = INT((1000 * C2) + .5) / 1000
940 LET I7 = I6 + (B2 * 2 * S * C / B3 * 57.3 * C1) * (1 + B4)
950 LET I7 = INT((100 * I7) + .5) / 100
960 LET C3 = C1 * COS(I7 * 3.14159 / 180) + C2 * SIN(I7 * 3.14159 / 180)
970 LET C3 = INT((1000 * C3) + .5) / 1000
980 LET C4 = N1 / (S * C * 9810 * H)
990 LET C4 = C4 * (1 - 2 * B1)
1000 LET C4 = INT((1000 * C4) + .5) / 1000
1010 LET I8 = I7 - I2
1020 LET I8 = INT((100 * I8) + .5) / 100
```

(cont'd.)

```
1030 READ R6
1040 IF R6 = -9998 THEN 1480
1050 READ R7, R8, R9, R0
1060 LET N3 = 7 / V0 * (E1 */R6 + E2 * R7 + E3 * R8 + E4 * R9 + E5 * R0)
1070 LET A3 = 7 / V0 * (E6 * R6 + E7 * R7 + E8 * R8 + E9 * R9 + E0 * R0)
1080 LET T3 = 7 / V0 * (F1 * R6 + F2 * R7 + F3 * R8 + F4 * R9 + F5 * R0)
1090 LET X3 = 7 / V0 * (F6 * R6 + F7 * R7 + F8 * R8 + F9 * R9 + F0 * R0)
1100 LET Y3 = 7 / V0 * (G1 * R6 + G2 * R7 + G3 * R8 + G4 * R9 + G5 * R0)
1110 LET M4 = (X1 - X3) + .1155 * (N1 - N3)
1120 LET M5 = (Y1 - Y3) + .1155 * (A1 - A3)
1130 LET N4 = N3 - 4.40092E-2 * M4
1140 LET A4 = A3 + 5.228E-4 * M4 - 7.67963E-2 * M5
1150 LET T4 = T3 + 3.77794E-2 * M4 - 1.5721E-3 * M5
1160 LET X4 = X3 - 1.08122E-2 * M4
1170 LET Y4 = Y3 + 6.8072E-3 * M4
1180 LET L2 = N4 * COS(I1) - A4 * SIN(I1)
1190 LET D2 = A4 * COS(I1) + N4 * SIN(I1)
1200 LET T5 = T4
1210 LET M6 = X4 * COS(I1) - Y4 * SIN(I1)
1220 LET M7 = Y4 * COS(I1) + X4 * SIN(I1)
1230 LET N5 = L2 * COS(I5) + D2 * SIN(I5)
1240 LET M8 = M6 * COS(I5) + M7 * SIN(I5)
1250 LET P3 = (T5 / N5 + W) * 100 / C
1260 LET P3 = INT((100 * P3) + .5) / 100
1270 LET P4 = (M8 / N5 - U) * 100 / S
1280 LET P4 = INT((100 * P4) + .5) / 100
1290 LET C5 = L2 / (S * C * 9810 * H)
1300 LET C5 = C5 * (1 - 2 * B1)
1310 LET C5 = INT((1000 * C5) + .5) / 1000
1320 LET C6 = D2 / (S * C * 9810 * H)
1330 LET C6 = C6 * (1 - 2 * B1) + B2 * 2 * S * C / B3 * C1 * C1
1340 LET C6 = INT((1000 * C6) + .5) / 1000
1350 LET C7 = C5 * COS(I7 * 3.14159 / 180) + C6 * SIN(I7 * 3.14159 /180)
1360 LET C7 = INT((1000 * C7) + .5) / 1000
1370 LET C8 = N4 / (S * C * 9810 * H)
1380 LET C8 = C8 * (1 - 2 * B1)
1390 LET C8 = INT((1000 * C8) + .5) / 1000
1400 LET P5 = ((T2 - T5) / (N1 - N4) + W) * 100 / C
1410 LET P5 = INT((100 * P5) + .5) / 100
1420 LET P6 = ((X1 - X4) / (N1 - N4) - U) * 100 / S
1430 LET P6 = INT((100 * P6) + .5) / 100
1440 LET C9 = C1 - C5
1450 LET C9 = INT((1000 * C9) + .5) / 1000
1460 LET C0 = C2 - C6
1470 LET C0 = INT((1000 * C0) + .5) / 1000
1480 PRINT
1490 PRINT "(A)"; TAB(4), I7; TAB(13), I8; TAB(22), C1; TAB(30),
1500 PRINT C3; TAB(38), C4; TAB(46), C2; TAB(54), P1; TAB(63), P2
1510 IF R6 = -9998 THEN 400
1520 PRINT "(B)"; TAB(4), I7; TAB(13), I8; TAB(22), C5; TAB(30),
1530 PRINT C7; TAB(38), C8; TAB(46), C6; TAB(54), P3; TAB(63), P4
1540 PRINT "(C)"; TAB(4), I7; TAB(13), I8; TAB(22), C9; TAB(46),
1550 PRINT C0; TAB(54), P5; TAB(63), P6
1560 GOTO  400
9999 END
```

APPENDIX A3

REQUIRED FORMAT OF DATA INPUT

```
2000    DATA    N, H, C, D, K
2010    DATA    Q$, VØ, I2
2020    DATA    S, W, U
2030    DATA    B1, B2, B3, B4

2040    DATA    I2, I4                      ]
2050    DATA    R1, R2, R3, R4, R5          }  DATA SETS
2060    DATA    R6, R7, R8, R9, RØ          ]

2070    DATA    I2, I4                      ]
2080    DATA    R1, R2, R3, R4, R5          }
2090    DATA    R6, R7, R8, R9, RØ          ]
                  |
                  |
                  |
9000    DATA    -999
```

For "Rudder + Skeg" only, or "All-Movable" Rudder:-

```
2040    DATA    I2, I4                      ]
2050    DATA    R1, R2, R3, R4, R5          }  DATA SETS
2060    DATA    -9998                       ]

2070    DATA    I2, I4                      ]
2080    DATA    R1, R2, R3, R4, R5          }
2090    DATA    -9998                       ]
                  |
                  |
                  |
9000    DATA    -999
```

APPENDIX A4

EXAMPLE OF TYPICAL DATA LISTING AND PROGRAM OUTPUT

(Data Listing)

```
LIST-2000


2000 DATA 1, .1194, .457, 1.128, 1.69E-5
2010 DATA "27/7/76,29/7/76", 7, -5.25
2020 DATA .68, .162, .175
2030 DATA .0022, .115, 6.5065, .225
2040 DATA -5.25, -5
2050 DATA -519, 50, 212, -1334, 94
2060 DATA -333, 33, 59, -990, 89
2070 DATA -5.25, -2.5
2080 DATA -398, 30, 214, -999, 51
2090 DATA -236, 16, 87, -723, 36
2100 DATA -5.25, 0
2110 DATA -274, 21, 183, -683, 38
2120 DATA -146, 2, 81, -459, 9
2130 DATA -5.25, 2.5
2140 DATA -172, 23, 134, -412, 45
2150 DATA -63, -6, 55, -222, -3
2160 DATA -5.25, 5
2170 DATA -60, 28, 78, -137, 67
2180 DATA 10, -3, 18, -13, 14
2190 DATA -5.25, 7.5
2200 DATA 46, 39, 22, 131, 108
2210 DATA 80, 9, -16, 189, 50
2220 DATA -5.25, 10
2230 DATA 141, 58, -12, 388, 159
2240 DATA 162, 38, -27, 422, 130
2250 DATA -5.25, 12.5
2260 DATA 246, 87, -11, 663, 245
2270 DATA 255, 78, 11, 659, 232
2280 DATA -5.25, 15
2290 DATA 275, 124, 8, 784, 441
2300 DATA -9998
2310 DATA -5.25, 17.5
2320 DATA 329, 159, -3, 964, 428
2330 DATA 357, 137, 6, 1008, 409
2340 DATA -5.25, 20
2350 DATA 377, 192, -23, 1125, 521
2360 DATA -9998
2370 DATA -5.25, 25
2380 DATA 562, 274, -37, 1565, 758
2390 DATA 500, 253, 15, 1428, 724
9000 DATA -999
9999 END
```

(Program Output)

RUN

WIND TUNNEL RUDDER DATA ANALYSIS

RUDDER NUMBER = 1
DATE OF TEST = 27/7/76,29/7/76
WIND SPEED = 45.57 M/S

AA=RUDDER ANGLE,ALPHA(DEG.), AD=RUDDER ANGLE,DELTA(DEG.)
CL=LIFT COEFFICIENT, CN=RUDDER NORMAL COEFFICIENT
CY=SHIP NORMAL COEFFIENT, CD=DRAG COEFFICIENT
CPC=C OF P CHORD(%C), CPS=C OF P SPAN(%S)
ALL COEFFICIENTS BASED ON TOTAL AREA OF RUDDER PLUS SKEG

(A)=RUDDER PLUS SKEG, (B)=RUDDER ALONE, (C)=SKEG ALONE

REYNOLDS NO. = 1.23000E+06

SKEG ANGLE,BETA(DEG.) = -5.25

	AA	AD	CL	CN	CY	CD	CPC	CPS
(A)	-10.61	-5.36	-.471	-.477	-.476	.074	24.94	46.79
(B)	-10.61	-5.36	-.298	-.302	-.301	.048	33.11	58.4
(C)	-10.61	-5.36	-.173			.026	10.8	26.87
(A)	-8.03	-2.78	-.362	-.365	-.365	.05	21.6	45.32
(B)	-8.03	-2.78	-.211	-.213	-.213	.028	28.45	61.42
(C)	-8.03	-2.78	-.151			.022	11.98	22.8
(A)	-5.44	-.19	-.249	-.251	-.251	.035	18.22	45.01
(B)	-5.44	-.19	-.131	-.131	-.131	.011	24.32	64.29
(C)	-5.44	-.19	-.118			.024	11.58	24
(A)	-2.87	2.38	-.156	-.157	-.158	.028	15.24	42.31
(B)	-2.87	2.38	-.056	-.056	-.055	-.001	19.02	76.64
(C)	-2.87	2.38	-.1			.029	13.38	23.57
(A)	-.29	4.96	-.054	-.054	-.056	.023	.86	38.99
(B)	-.29	4.96	.01	.01	.01	-.004	52.98	-53.55
(C)	-.29	4.96	-.064			.027	9.98	24.32
(A)	2.28	7.53	.043	.044	.041	.023	48.03	55.52
(B)	2.28	7.53	.074	.074	.073	-.001	28.89	41.96
(C)	2.28	7.53	-.031			.024	3.52	22.32
(A)	4.85	10.1	.13	.132	.127	.03	33.72	52.47
(B)	4.85	10.1	.149	.15	.147	.014	31.02	48.74
(C)	4.85	10.1	-.019			.016	13.67	19.59

(cont'd.)

(Program Output, cont'd.)

(A)	7.43	12.68	.227	.231	.222	.042	34.7	50.83
(B)	7.43	12.68	.235	.238	.231	.035	36.89	47.85
(C)	7.43	12.68	-.008			.007	96.3	-41.17
(A)	9.95	15.2	.254	.262	.247	.066	36.71	57.17
(A)	12.49	17.74	.305	.317	.296	.087	35.7	56.76
(B)	12.49	17.74	.33	.337	.322	.069	36.03	54.58
(C)	12.49	17.74	-.025			.018	39.9	17.24
(A)	15.02	20.27	.35	.366	.339	.106	34.45	58.13
(A)	20.15	25.4	.521	.541	.506	.15	34.3	53.2
(B)	20.15	25.4	.462	.482	.448	.14	37.22	55.47
(C)	20.15	25.4	.059			.01	9.97	37.21

DONE

APPENDIX A5

DYNAMOMETER CORRECTION EQUATIONS FOR RUDDER ALONE

Refer to SECTION 5.9.9 (pg.37) Ref.1.

Corrections caused by skeg when attached to base (Rudder Alone Case) are as follows (in S.I. units) :-

Correction to	L	=	-0.0433206	MXs		
	D	=			-0.0761211	MYs
	MZ	=	+0.0371777	MXs	-0.0015583	MYs
	MX	=	-0.0106430	MXs		
	MY	=	+0.0067007	MXs		

and $MXs = [MX_1 - MX_2] + 0.1155 [L_1 - L_2]$

where L_1 and MX_1 = Lift and moment about X - Axis respect. for Rudder + Skeg

L_2 and MX_2 = " " " " " " " " Rudder Alone

0.1155 m = Difference in roll centres of MX or MY and MXs or MYs

Similarly $MYs = [MY_1 - MY_2] + 0.1155 [D_1 - D_2]$

(Note: The above corrections apply only to the case of Rudder Alone; the measured values of L_1, D_1, MZ_1, MX_1 and MY_1 for Rudder plus Skeg are not subject to the above corrections).

Using the additional suffix 'c' to designate the corrected components for Rudder Alone, the complete correction equations read as follows:-

$$L_{2c} = L_2 - 0.0433206 \cdot \left[(MX_1 - MX_{2c}) + 0.1155 \cdot (L_1 - L_{2c}) \right]$$

$$D_{2c} = D_2 - 0.0761211 \cdot \left[(MY_1 - MY_{2c}) + 0.1155 \cdot (D_1 - D_{2c}) \right]$$

$$MZ_{2c} = MZ_2 + 0.0371777 \cdot \left[(MX_1 - MX_{2c}) + 0.1155 \cdot (L_1 - L_{2c}) \right] - 0.0015583 \cdot \left[(MY_1 - MY_{2c}) + 0.1155 \cdot (D_1 - D_{2c}) \right]$$

$$MX_{2c} = MX_2 - 0.0106430 \cdot \left[(MX_1 - MX_{2c}) + 0.1155 \cdot (L_1 - L_{2c}) \right]$$

$$MY_{2c} = MY_2 + 0.0067007 \cdot \left[(MX_1 - MX_{2c}) + 0.1155 \cdot (L_1 - L_{2c}) \right]$$

It had been assumed in Ref.1 that the above corrections would be carried out by iteration since the equations were relatively complex, and contained corrected values L_{2c}, D_{2c}, MZ_{2c}, MX_{2c} and MY_{2c} on both sides of the equations. Iteration would, of course, be handled relatively easily in a computer analysis. However, further investigation showed that by a series of substitutions the equations could be re-arranged so that the corrected terms are defined by the uncorrected (i.e. measured) values of L_2, D_2, MZ_2, MX_2 and MY_2.

The final equations, in terms of measured values are, therefore, as follows:

$$L_{2c} = L_2 - 0.0440092 \left[(MX_1 - MX_2) + 0.1155 (L_1 - L_2)\right]$$

$$D_{2c} = D_2 - 0.0767963 \left[(MY_1 - MY_2) + 0.1155 (D_1 - D_2)\right] + 0.0005228 \left[(MX_1 - MX_2) + 0.1155 (L_1 - L_2)\right]$$

$$MZ_{2c} = MZ_2 + 0.0377794 \left[(MX_1 - MX_2) + 0.1155 (L_1 - L_2)\right] - 0.0015721 \left[(MY_1 - MY_2) + 0.1155 (D_1 - D_2)\right]$$

$$MX_{2c} = MX_2 - 0.0108122 \left[(MX_1 - MX_2) + 0.1155 (L_1 - L_2)\right]$$

$$MY_{2c} = MY_2 + 0.0068072 \left[(MX_1 - MX_2) + 0.1155 (L_1 - L_2)\right]$$

As reported in Ref.1, L, D, MZ, MX and MY refer to the special case when $\beta = 0$; when $\beta \neq 0$ the general case applies and the five components are N_β, A_β, MZ_β, MX_β and MY_β.

The above correction equations and their coefficients are, of course, applicable to the general case and are incorporated in lines 1110 to 1170 of the computer program.

For convenience of analysis, the functions in square brackets :

$$\left[(MX_1 - MX_2) + 0.1155 (L_1 - L_2)\right] \quad \text{and}$$

$$\left[(MY_1 - MY_2) + 0.1155 (D_1 - D_2)\right]$$

are solved first (lines 1110 and 1120) and the corrections then applied using the above coefficients in lines 1130 to 1170.

APPENDIX A6

WIND TUNNEL BOUNDARY CORRECTIONS

Use was made of Ref.2 in which wind tunnel boundary corrections are reviewed and described.

The corrections applicable to reflection plane models in a closed test section which were considered and investigated are as follows: (some of the nomenclature is peculiar to this APPENDIX, being that normally applied to this particular subject)

Solid Blocking :

Lateral constraint to the flow pattern about a body; is the same as an increase in dynamic pressure, increasing all forces and moments at a given angle of attack.

$$\frac{\Delta V}{V} = \epsilon_{sb} = k_1 . \tau_1 . \frac{W}{C^{3/2}}$$

where W = wing volume ≡ 0.7 x t x chord x span

C = tunnel cross-sectional area

k_1 for known $^t/c$, TABLE I

τ_1 for known $^b/B$, $^B/H$, TABLE II

where b = model span

B = tunnel breadth

Wake Blocking :

Lateral constraint to the flow pattern about the wake; effect increases with increase in wake size (drag) and increases drag of model.

$$\epsilon_{wb} = \frac{1}{4} \left(\frac{S}{C}\right) . C_{D_0} \quad \text{.... streamline flow}$$

where S = area of wing

Ref.2 also describes the work of Maskell, which takes account of wake blocking in separated flow as well as streamline flow. Total drag is divided into three parts, a constant amount C_{Do} , C_{Di} proportional to C_L^2 and one due to separated flow C_{Ds}

and total $$\epsilon_{wb} = \frac{1}{4}\left(\frac{S}{C}\right) \cdot C_{Do} + \frac{5}{4}\left(\frac{S}{C}\right) \cdot C_{Ds}$$

For the rudder tests being analysed, separation was observed aft of the skeg at relatively low angles of attack. Preliminary analysis of the results indicated that, due to the discontinuity of the lift curve when separation commences, the derivation of the linear part of the drag ($C_{Di} \propto C_L^2$) would prove very difficult if not impossible. Further, the computer program would require internal solution of C_{Do} and a prediction of $C_{Di} = k.C_L^2$, based on very limited data, prior to application of this correction. Tentative estimates indicated that there would be a decrease in C_L and C_D at large angle of up to 1% for $\beta = 0$, 0.4% for $\beta = +5^\circ$ and 0.2% for $\beta = -5^\circ$. Since the same errors apply to tests with and without skeg for any angle β , and the errors are small compared with the actual differences between results for different values of β , the correction for wake blocking in separated flow was neglected. Wake blocking in streamline flow is a function only of C_{Do} and estimates indicated the largest correction to be less than 0.1%, hence this correction was also neglected.

Streamline Curvature :

Alteration to the normal curvature of flow about a wing so that the wing moment coefficient, wing lift and angle of attack are increased in a closed test section.

$$\Delta\alpha_{sc} = \tau_2 \cdot \delta \cdot \left(\frac{S}{C}\right) \cdot C_L \times 57.3$$

τ_2 for known $\frac{L_T}{B}$, $\lambda = \frac{h}{B}$ from TABLE IV

where L_T = tail length = $\frac{\text{wing chord}}{2}$ - i.e. correction applied entirely to angle (rather than to angle and lift)

B = tunnel breadth

h = " height

δ for known k and λ from TABLE III

where k = $\frac{be}{B}$ and be $\doteqdot$ 0.9b

Downwash :

Alteration to the normal downwash so that the lift is too large and the drag too small at a given geometric angle of attack.

$$\Delta\alpha = \delta.\left(\frac{S}{C}\right).C_{Lc} \times 57.3$$

$$\Delta C_D = \delta.\left(\frac{S}{C}\right).C_{Lc}^2$$

Where C_{Lc} is lift coefficient, corrected for blocking.
" δ, S and C are defined as above.

Summary of Corrections :

(suffixes c and u refer to corrected and uncorrected values respectively)

$$\epsilon = \epsilon_{sb}$$

$$V_c = V_u \,.\, (1 + \epsilon) \qquad (1)$$

$$R_{nc} = R_{nu} \,.\, (1 + \epsilon) \qquad (2)$$

$$q = q_u \,.\, (1 + 2\epsilon) \qquad (3)$$

$$C_{Lc} = C_{Lu} \,.\, (1 - 2\epsilon) \qquad (4)$$

$$\alpha_c = \alpha_u + \left[\delta.\left(\frac{S}{C}\right) \times 57.3 \times C_{Lc}\right].(1 + \tau_2) \qquad (5)$$

$$C_{Dc} = C_{Du} \,.\, (1 - 2\epsilon) + \delta.\left(\frac{S}{C}\right).C_{Lc}^2 \qquad (6)$$

Due to relatively large variations in air temperature when testing, fluctuations occurred in velocity and density. Tests were carried out at constant Betz manometer reading; the velocity and Reynolds Number derived are based on a mean temperature and pressure and are, therefore, nominal values. It was, therefore, considered unnecessary to apply the blocking corrections in equations (1) and (2) above. Blocking correction to q, equation (3) is applied to C_L and C_D as shown in equations (4) and (6) ; hence the corrections applied, and written into the program, were equations (4), (5) and (6) above, namely corrections to C_L, α and C_D .

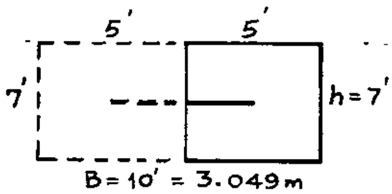
Example of Calculations for Rudder No.1 (Tested) :

Using the rudder particulars shown in Fig.3 the following calculations illustrate the derivation of the boundary correction factors. (The tunnel parameters are assumed to remain constant, whilst allowance is made for future changes in rudder parameters).

$$\overline{W} = \text{wing vol.} \doteqdot 0.7 \times t \times \text{chord} \times \text{span}$$

$$= 0.7 \times 0.09 \times 0.4567 \times (0.68 \times 2)$$

$$= 0.03913\ \text{m}^3$$



TUNNEL SECTION

$$C = 7\text{ft} \times 10\text{ft}$$

$$= 6.5065\ \text{m}^3$$

$$C^{3/2} = 16.5967$$

$$\frac{B}{h} = \frac{10}{7} = 1.43$$

$$\text{model span/tunnel breadth} = \frac{b}{B} = \frac{1.36}{3.049} = 0.446$$

From TABLE I, $k_1 = 1.082$

" TABLE II, $\tau_1 = 0.864$

$$\therefore\ \epsilon_{sb} = k_1 . \tau_1 \frac{W}{C^{3/2}} = 1.082 \times .864 \times \frac{.03913}{16.5967}$$

$$= 0.0022$$

$$\lambda = \frac{h}{B} = \frac{7}{10} = 0.7$$

$$k = \frac{\text{effective span}}{\text{jet width}} = \frac{0.9\ b}{B} = \frac{0.9 \times 1.36}{3.049} = 0.4014$$

From TABLE III, $\delta = 0.115$

$$\text{tail length} \quad L_T = \bar{c}/2 = \frac{.457}{2} = .2285$$

$$L_T / B = .2285/3.049 = .0749$$

From TABLE IV, $\tau_2 = .2247 \doteqdot 0.225$

Summary :

			Assigned Program Variable
ϵ	=	0.0022	B1
δ	=	0.115	B2
C	=	6.5065	B3
τ_2	=	0.225	B4

S = rudder area ⟶ defined in program as 2 × S x C

The wind tunnel boundary corrections are incorporated in lines 890, 920, 940, 990 of the program for the case of Rudder plus Skeg and in lines 1300, 1330, 1380 for the case of Rudder Alone.

BOUNDARY CORRECTION DATA TABLES

(Derived from Figs. 6.15, 6.16, 6.32 and 6.56 respectively of Ref.2).

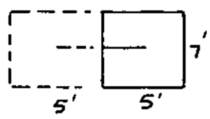
t/c	k_1
.12	1.006
.16	1.047
.20	1.082

TABLE I

Values of k_1 for Four Digit Airfoil Series

b/B	τ_1
.2	.860
.4	.862
.6	.870
.8	.887

key :



$\frac{B}{h} = \frac{10}{7} = 1.43$

TABLE II

Values of τ_1 for $B/h = 1.43$

k	δ
.2	.118
.4	.115
.6	.115
.8	.129

$k \doteqdot \frac{0.9b}{B}$

TABLE III

Values of δ (for $\lambda = \frac{h}{B} = 0.7$) for wing with uniform loading

L_T/B	τ_2
0	0
0.05	.150
0.10	.300

TABLE IV

Values of τ_2 (for $\lambda = \frac{h}{B} \simeq 0.7$)

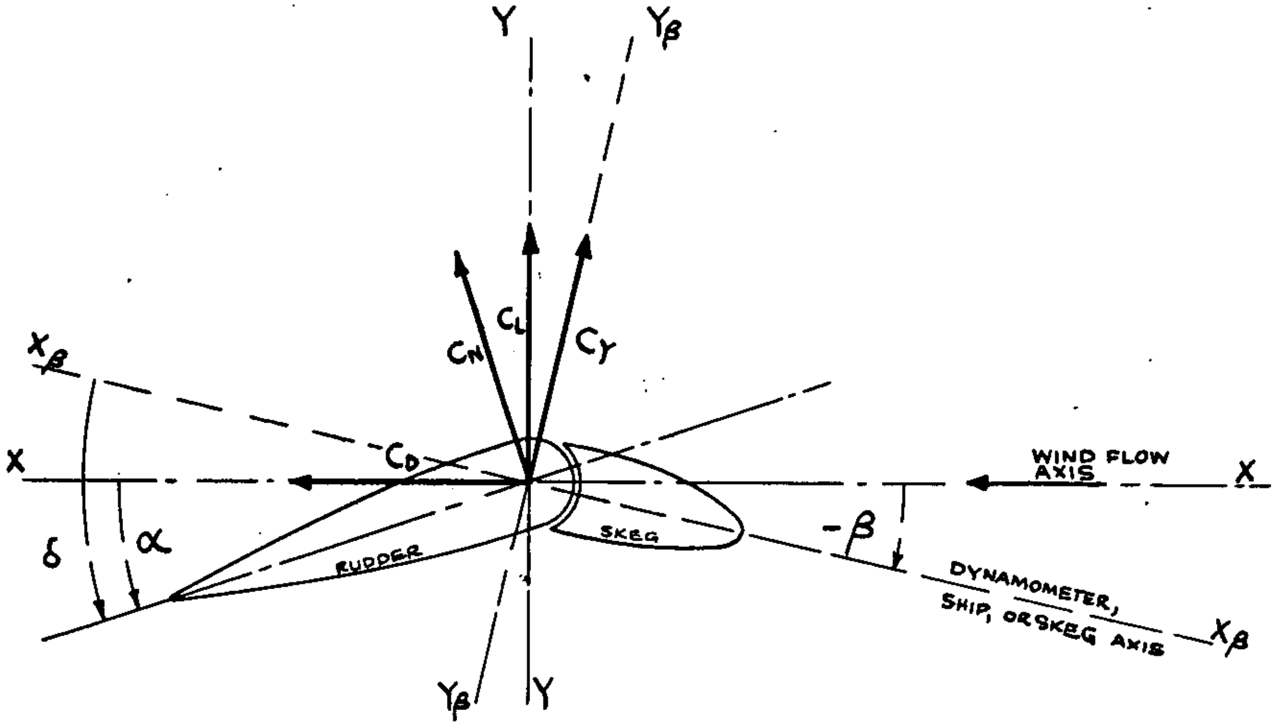


Fig. 1 NOTATION OF ANGLES AND COEFFICIENTS

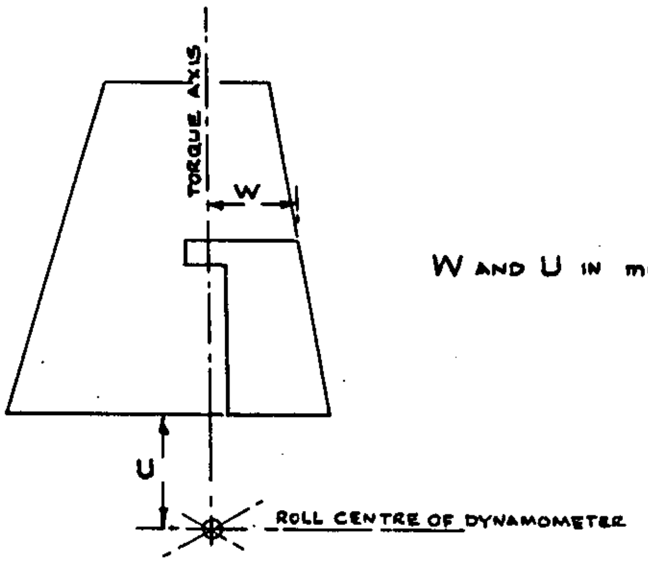
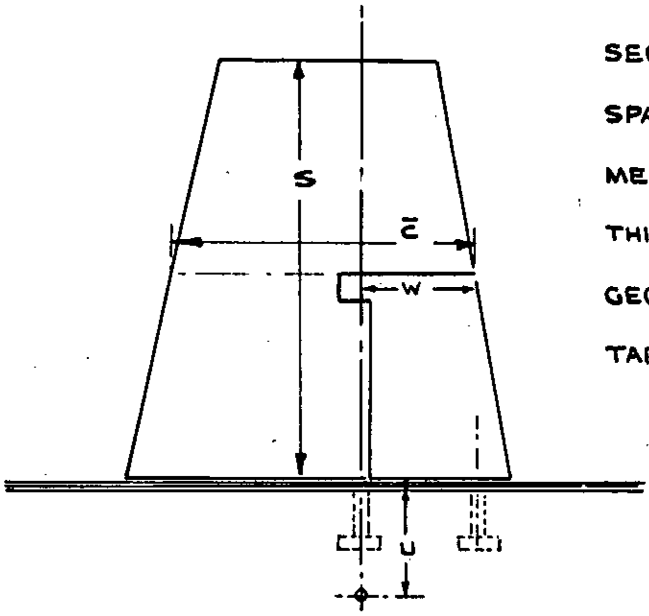


Fig. 2 DEFINITION OF PROGRAM VARIABLES U AND W



SECTION : NACA 0020

SPAN	S	= 0·680 m
MEAN CHORD	$\bar{c}$	= 0.457 m
THICKNESS RATIO	t/c	= 20%
GEOMETRIC ASPECT RATIO	AR_G	= 1.49
TAPER RATIO	C_T/C_R	= 0.59
	W	= 0·162 m
	U	= 0·175 m

BETZ MANOMETER READING = 0·1194 m OR 0.0584 m of water.

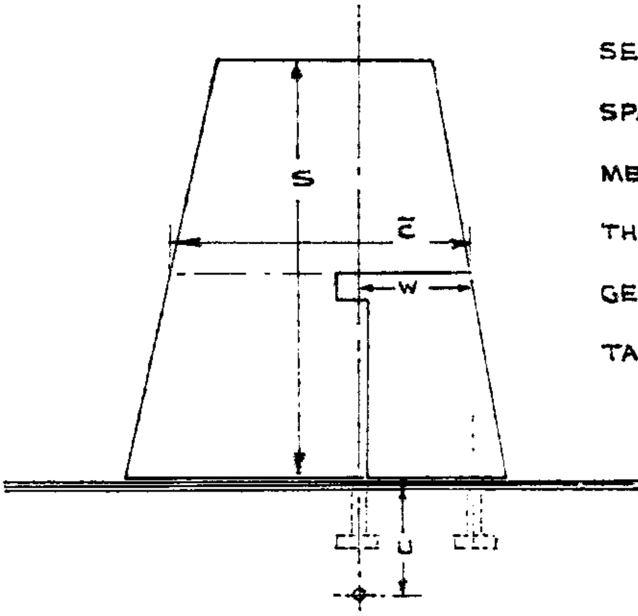
MEAN ATMOSPHERIC (TEST AIR) PRESSURE = 102×10^3 N/m^2

" TEMPERATURE (TEST AIR) = 38°C

" AIR DENSITY ρ_A = 1.128 kg./m^3

" AIR KINEMATIC VISCOSITY ν = 1.69×10^{-5} m^2/s

Fig. 3 GENERAL PARTICULARS OF RUDDER No. 1 AND TEST CONDITIONS



SECTION : NACA 0020		
SPAN	S	= 0.680m
MEAN CHORD	$\bar{c}$	= 0.457m
THICKNESS RATIO	t/c	= 20%
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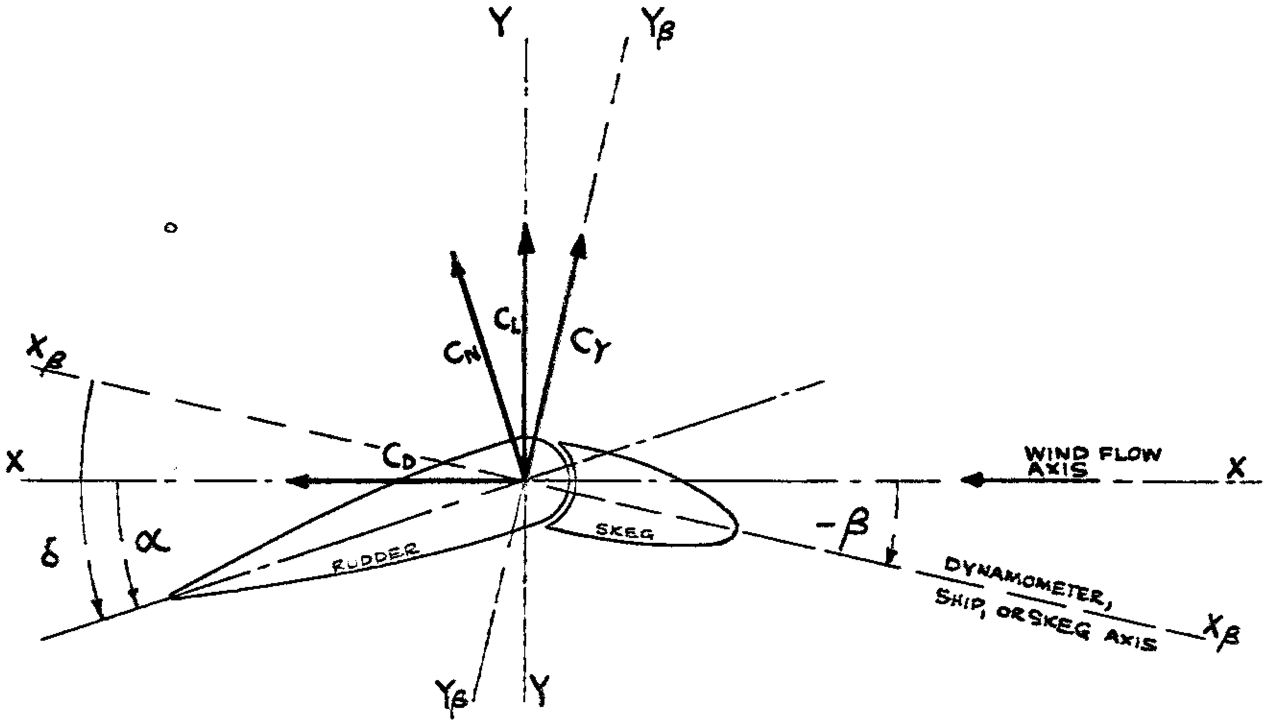

Fig. 1 NOTATION OF ANGLES AND COEFFICIENTS

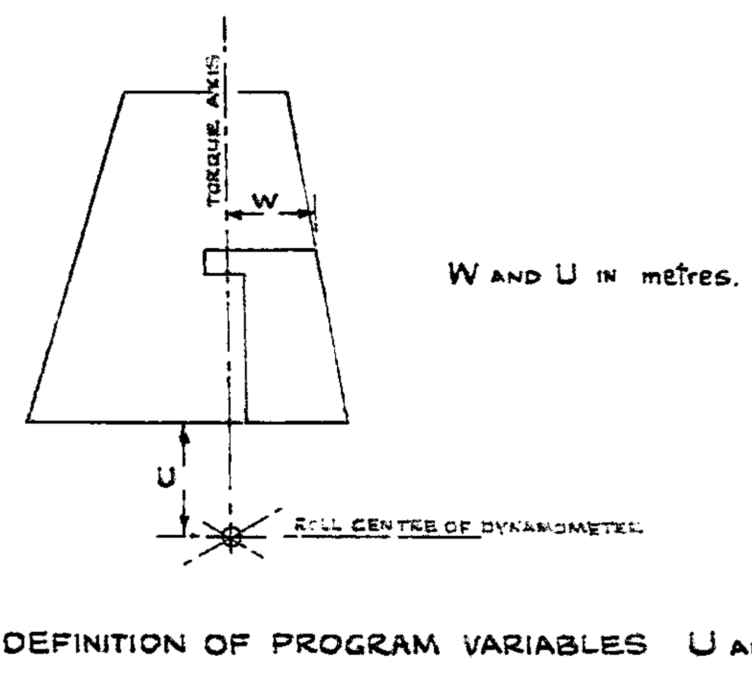

Fig. 2 DEFINITION OF PROGRAM VARIABLES U AND W