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SECONDARY FLOWS AND LOSSES IN

GAS TURBINES

Volume II of II

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A thesis submitted for the degree of Doctor of Philosophy of the University of Durham

March 1985

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LOW SPEED WIND TUNNEL WORKING SECTION AND CASCADE ARRANGEMENT



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POSITION OF BLADE SURFACE PRESSURE TAPPINGS AT MIDSPAN X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



FIGURE 3.2

POSITIONS OF THE EXPERIMENTAL TRAVERSING SLOTS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



FIGURE 3.3

CASCADE SIGN CONVENTION



CASCADE ENDWALL BOUNDARY LAYER DISTURBER



BE 3.5

DATA ACQUISITION UNIT



FISURE 3.6

PRESSURE PROBE ARRANGEMENT



FIGURE 3."



PROBE TRAVERSING GEAR



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DATA ACQUISITION SYSTEM FOR PRESSURE PROBE TRAVERSING



DATA ACQUISITION SYSTEM FOR HOT WIRE PROBE TRAVERSING

• OSCILLOSCOPE CONNECTION POINT FOR SIGNAL VALIDATION

PRESSURE PROBE CALIBRATION MOUNTING



HOT WIRE PROBE CALIBRATION JET



.



FIGURE 3.14



CONDITIONAL SAMPLING OF PRESSURE PROBE DATA



FIGURE 3.16

CONDITIONAL SAMPLING METHOD



NOTE : AT START TOLERANCE (†)=±1%

FIVE-HOLE PROBE DATA ANALYSIS





FIVE-HOLE PROBE \Rightarrow AND ψ AT a=0°

FIGURE 3.19


FIGURE 3.20

A CONTOUR PLOTTING CELL

CELL CO-ORDINATES

a(X(I-1),Y(I-1,J),Z(I-1,J))

b(X(I-1),Y(I-1,J+I),Z(I-1,J+1))

c(X(I),Y(I,J+1),Z(I,J+1))

d(X(I),Y(I,J),Z(I,J))

e (0·5 × (X(I−1) + X(I)),0·25 × (Y(I−1, J) + Y(I−1, J+1) + Y(I, J+1) + Y(I, J)),0·25 × (Z(I−1, J) + Z(I−1, J+1) + Z(I, J+1) + Z(I, J))) NOTE:



THICK LINE PLOTTING ALGORITHM



A VECTOR SCALING CELL



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SLOT 1 EXPERIMENTAL DATA POINTS NATURAL INLET BOUNDARY LAYER





----- 44° YAW ANGLE CONTOUR











CROSS FLOW ANGLE = ϵ (LOCAL) - ϵ (MIDSPAN) = -ve OVERTURNING ANGLE

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SLOT 2 EVPERIMENTAL DATA POINTS



SLOT 2 TOTAL PRESSURE LOSS COEFFICIENT ((POI-POLOCAL) / (POI-PI)) CONTOURS NATURAL INLET BOUNDARY LAYER





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SLOT 3 EXPERIMENTAL DATA POINTS







× PASSAGE VORTEX CENTRE









SLOT 4 EXPERIMENTAL DATA POINTS

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× PASSAGE VORTEX CENTRE







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SLOT 5 EXPERIMENTAL DATA POINTS

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× PASSAGE VORTEX CENTRE









SLOT 6 EXPERIMENTAL DATA POINTS



SLOT 6 TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS





× PASSAGE VORTEX CENTRE







			NATURA K-AXIS Y-AXIS + PROB	L I T E D	NLET TANGEN PANVI DATA	SOUNI SE CI	DARY CO DDR NUAL	LAY DRDI DINA LY 1	FR NATE TE FF NTERF	FRO	M TR PERSI	ATLII PEX E DATA	NG E	DGE ! ALL EXTR	DATUM (MM) APOLATE	(MM)			
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SLOT 7 EXPERIMENTAL DATA POINTS







× PASSAGE VORTEX CENTRE







BLADE PASSAGE LOSS CORE DEVELOPMENT AND LOCI OF PASSAGE VORTEX CENTRE AND LOSS CORE PEAK

X-AXIS TANGENTIAL CO-ORDINATE FROM BLADE SUCTION SURFACE (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)



PASSAGE VORTEX CENTRE SITUATED AT INTERSECTION OF ZERO SPANWISE AND ZERO CROSS FLOW ANGLE CONTOURS ON EACH PROBE TRAVERSE PLANE

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			NATUR	RAL	INLET	BOUN	DARY	LAYE	R										

SLOT 8 EXPERIMENTAL DATA POINTS



SLOT S TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS



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× PASSAGE VORTEX CENTRE + COUNTER VORTEX CENTRE







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			NATUR X-AX1	RAL IN IS TA		BOUN	NDARY I		TC 6	EDOM .									

SLOT 9 EXPERIMENTAL DATA POINTS





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× PASSAGE VORTEX CENTRE







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× PASSAGE VORTEX CENTRE

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LOSS CORE DEVELOPMENT DOWNSTREAM OF THE BLADE PASSAGE

X-AXIS TANGENTIAL CO-ORDINATE FROM BLADE SUCTION SURFACE OR TANGENTIAL CO-ORDINATE FROM WAKE CENTRE-LINE (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)



LOCI OF PASSAGE VORTEX CENTRE AND LOSS CORE PEAK

X-AXIS TANGENTIAL CO-ORDINATE FROM BLADE SUCTION SURFACE OR TANGENTIAL CO-ORDINATE FROM WAKE CENTRE-LINE (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)

ADDITIONAL POINTS KEY

POINT	SLOT NO.	BOUNDARY LAYER								
		AT CASCADE INLET								
۵	8	THICKENED								
Ь	10	INCREMED	LASS CORE POSITION							
۵	8	THINNED								
с	10									
d	8	THICKENED								
е	10	THICKENED	PASSAGE VORTEX CENTRE							
f	8	THINNED	FASSAGE VORTEX CENTRE							
g	10									



PASSAGE VORTEX CENTRE SITUATED AT INTERSECTION OF ZERO SPANWISE AND ZERO CROSS FLOW ANGLE CONTOURS ON EACH PROBE TRAVERSE PLANE





PITCHWISE MASS MEANED OVERTURNING ANGLE WITHIN THE BLADE PASSAGE







DEVELOPMENT OF AREA MASS AVERAGED TOTAL PRESSURE LOSS COEFFICIENT

X-AXIS PERCENTAGE OF AXIAL CHORD FROM BLADE TRAILING EDGE Y-AXIS AREA MASS AVERAGED TOTAL PRESSURE LOSS COEFFICIENT

INLET BOUNDARY LAYER

- × NATURAL
- + THICKENED
- THINNED



DEVELOPMENT OF SECONDARY LOSSES

X-AXIS PERCENTAGE OF AXIAL CHORD FROM BLADE TRAILING EDGE Y-AXIS SECONDARY TOTAL PRESSURE LOSS COEFFICIENT



NORMALIZED CASCADE MASS FLOW RATE

X-AXIS PERCENTAGE OF AXIAL CHORD FROM BLADE TRAILING EDGE Y-AXIS CASCADE MASS FLOW RATE NORMALIZED USING INLET MASS FLOW (DURHAM DATA NORMALISED USING NATURAL INLET BOUNDARY LAYER DATA)





PLOT ON PLANE 1.0 MM FROM PERSPEX ENDWALL (3-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO'-POLOCAL)/(PO!-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 5.0 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL)/(PO1-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 5.0 MM FROM PERSPEX ENDWALL (3-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO -POLOCAL) / (PO1-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 20.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL)/(PO1-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 20.' MM FROM PERSPEX ENDWALL (3-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO'-POLOCAL)/(PO'-P1)) CONTOURS X-A/IS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



FIGURE 4.89

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PLOT ON PLANE 40.0 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 60.0 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 80.0 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO!-POLOCAL)/(PO!-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 100.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL)/(PO1-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 140.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL)/(PO1-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 220.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)

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PLOT ON PLANE 1.0 MM FROM PERSPEX ENDWALL (3-HOLE PROBE DATA) TOTAL VELOCITY MAGNITUDE CONTOURS (CONTOUR UNITS METRES/SEC) X-AXIS TANGENTIAL CO-ONDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 20.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL VELOCITY MAGNITUDE CONTOURS (CONTOUR UNITS METRES/SEC) X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 20.1 MM FROM PERSPEX ENDWALL (3-HOLE PROBE DATA) TOTAL VELOCITY MAGNITUDE CONTOURS (CONTOUR UNITS METRES/SEC) X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 50.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL VELOCITY MAGNITUDE CONTOURS (CONTOUR UNITS METRES/SEC) X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 220.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) TOTAL VELOCITY MAGNITUDE CONTOURS (CONTOUR UNITS METRES/SEC) X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)









PLOT ON PLANE 2.0 MM FROM PERSPEX ENDWALL (3-HOLE PROBE DATA) VECTOR PLOT OF AXIAL AND TANGENTIAL VELOCITIES X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) VECTOR SCALE 40 METRES/SEC




PLOT ON PLANE 4.0 MM FRO: PERSPEX ENDWALL (3-HOLE PROBE DATA) VECTOR PLOT OF A/IAL AND TANGENTIAL VELOCITIES X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) VECTOR SCALE 40 METRES/SEC



PLOT ON PLANE 5.0 MM FROM PERSPEX ENDWALL (3-HOLE PROBE DATA) VECTOR PLOT OF AXIAL AND TANGENTIAL VELOCITIES X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) VECTOR SCALE 40 METRES/SEC





PLOT ON PLANE 15.0 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) VECTOR PLOT OF AXIAL AND TANGENTIAL VELOCITIES X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) VECTOR SCALE 40 METRES/SEC



PLOT ON PLANE 40.0 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) VECTOR PLOT OF AXIAL AND TANGENTIAL VELOCITIES X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) VECTOR SCALE 40 METRES/SEC









PLOT ON PLANE 20.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) SPANWISE ANGLE (PITCH ANGLE) CONTOURS (CONTOUR UNITS DEGREES) X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 20.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) YAW ANGLE CONTOURS (CONTOUR UNITS DEGREES) X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 220.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) SPANWISE ANGLE (PITCH ANGLE) CONTOURS (CONTOUR UNITS DEGREES) X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT GN PLANE 220.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) YAW ANGLE CONTOURS (CONTOUR UNITS DEGREES) X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 1.0 MM FROM PERSPEX ENDWALL (3-HOLE PROBE DATA) STATIC PRESSURE COEFFICIENT ((P1-PLOCAL)/(P01-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



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PLOT ON PLANE 20.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) STATIC PRESSURE COEFFICIENT ((P1-PLOCAL)/(P01-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 20.1 MM FROM PERSPEX ENDWALL (3-HOLE PROBE DATA) STATIC PRESSURE COEFFICIENT ((P1-PLOCAL) / (P01-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 30.0 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) STATIC PRESSURE COEFFICIENT ((P1-PLOCAL)/(P01-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 60.0 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) STATIC PRESSURE COEFFICIENT ((P1-PLOCAL)/(P01-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT ON PLANE 220.1 MM FROM PERSPEX ENDWALL (5-HOLE PROBE DATA) STATIC PRESSURE COEFFICIENT ((P1-PLOCAL)/(P01-P1)) CONTOURS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



TWO DIMENSIONAL STATIC PRESSURE COEFFICIENT DISTRIBUITON PREDICTED VALUES ((P1-PLOCAL)/(P01-P1)) CONTOURS X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX FNDWALL (MM)



PLOT APPROXIMATELY 93.3 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE AVERAGED TANGENTIAL EXPERIMENTAL POINTS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



PLOT APPROXIMATELY 6.7 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE AVERAGED TANGENTIAL EXPERIMENTAL POINTS X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)



			X-A) Y-A) + PP	KIS AX KIS SP ROBE DA	IAL CO-O ANWISE C TA V MA	RDINATE FR D-ORDINATE		LING EDGE ERSPEX END	DATUM (MM) VALL (MM)		•		
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PLOT APPROXIMATELY 93.3 % DF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE EXPERIMENTAL DATA POINTS

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PLOT APPROXIMATELY 6.7 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE EXPERIMENTAL DATA POINTS

FIGURE 4.127

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PLOT APPROXIMATELY 93.3 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)



PLOT APPROXIMATELY 85.4 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDVALL (MM)







PLOT APPROXIMATELY 61.9 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)



PLOT APPROXIMATELY 53.9 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANVISE CO-ORDINATE FROM PERSPEX ENDVALL (MM)



PLOT APPROXIMATELY 46.1 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS



PLOT APPROXIMATELY 38.2 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE



PLOT APPROXIMATELY 30.3 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE TOTAL PRESSURE LOSS COEFFICIENT ((PO!-POLOCAL) / (PO:-P!)) CONTOURS



PLOT APPROXIMATELY 22.5 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE TOTAL PRESSURE LOSS COEFFICIENT ((PO1-POLOCAL) / (PO1-P1)) CONTOURS





SPANWISE MIGRATION OF THE LOSS CORE

X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)

> PERCENTAGE OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE



F15 27 4. 42




FIGURE 4.142

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PLOT APPROXIMATELY 93.3 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANWISE (RADIAL) VELOCITIES X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)

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# PLOT APPROXIMATELY 85.4 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANWISE (RADIAL) VELOCITIES

#### X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANVISE CO-ORDINATE FROM PERSPEX ENDVALL (MM) VECTOR SCALE 40 METRES/SEC

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### PLOT APPROXIMATELY 77.5 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANWISE (RADIAL) VELOCITIES X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)

			VEC	TOR SCA	LE 40 M	ETRES/SEC		PERSPEA	CINDAN	LL (MM)				
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### PLOT APPROXIMATELY 69.7 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANVISE (RADIAL) VELOCITIES X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANVISE CO. OPDINATE FROM DEDGOES FOR MULT (MM)

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### PLOT APPROXIMATELY 61.9 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANWISE (RADIAL) VELOCITIES X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)

FIGURE 4.147

		X-A Y-A VEC	XIS AX XIS SP TOR SCA	IAL CO-ORE ANVISE CO- LE 40 METE	DINATE FRO -ORDINATE RES/SEC	FROM PER	NG EDGE DA SPEX ENDVA	ATUM (MM) ALL (MM)				
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PLOT APPROXIMATELY 53.9 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANWISE (RADIAL) VELOCITIES

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PLOT APPROXIMATELY 46.1 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANWISE (RADIAL) VELOCITIES X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)

			X-A Y-A VEC	XIS AX XIS SP. TOR SCA	IAL CO-O ANVISE C LE 40 ME	RDINATE FRO 0-ORDINATE TRES/SEC —	FROM PER	NG EDGE DA	NTUM (MM) NEL (MM)				
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PLOT APPROXIMATELY 38.2 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANWISE (RADIAL) VELOCITIES



PLOT APPROXIMATELY 30.3 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANVISE (RADIAL) VELOCITIES

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PLOT APPROXIMATELY 22.5 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANWISE (RADIAL) VELOCITIES X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDVALL (MM)

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## PLOT APPROXIMATELY 14.6 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANWISE (RADIAL) VELOCITIES X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)

			X-A) Y-A)	KIS AX	IAL CO-ORI	ONATE FRO	OM TRAIL	ING EDGE DA	TUM (MM)	1)			
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			SF SE		ATIVE SU FION LINE	CTION SU	JRFACE						

PLOT APPROXIMATELY 6.7 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE VECTOR PLOT OF AXIAL AND SPANWISE (RADIAL) VELOCITIES



# ZERO CROSS FLOW ANGLE CONTOURS CLOSE TO THE BLADE SUCTION SURFACE

X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)

> PERCENTAGE OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE

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	6.7





FIGURE 4.157



PLOT APPROXIMATELY 53.9 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE STATIC PRESSURE COEFFICIENT ( (P1-PLOCAL) / (P01-P1) ) CONTOURS X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANVISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)

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# FIGURE 4.158

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PLOT APPROXIMATELY 38.2 % OF BLADE PITCH LESS THICKNESS FROM SUCTION SURFACE STATIC PRESSURE COEFFICIENT ( (P1-PLOCAL) / (P01-P1) ) CONTOURS

FIGURE 4.159



FIGURE 4.160



### SLADE SURFACE STATIC PRESSURE COEFFICIENT DISTRIBUTION (SHOWING DATA FROM ADJACENT PASSAGES) NATURAL BOUNDARY LAYER DATA

X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)

Y-AXIS STATIC PRESSURE COEFFICIENT ( (P1-PLOCAL) / (P01-P1) )



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# BLADE SURFACE STATIC PRESSURE COEFFICIENT DISTRIBUTION

## NATURAL BOUNDARY LAYER DATA

X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)

Y-AXIS STATIC PRESSURE COEFFICIENT ( (P1-PL_CAL)/(P01-P1) )



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PLOT ON BLADE PRESSURE SURFACE LOCATION OF BLADE SURFACE STATIC PRESSURE TAPPINGS X-AXIS AXIAL CO-ORDINATE FROM TRAILING FR

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PLOT ON BLADE SUCTION SURFACE





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SLOT 1 HOT WIRE EXPERIMENTAL DATA POINTS

TRAVERSING SESSIONS

! PROBE TIP CHANGE

X-AXIS Y-AXIS



SLOT 1 TOTAL VELOCITY MAGNITUDE CONTOURS (CONTOUR UNITS METRES/SEC)



SLOT 1 YAW ANGLE CONTOURS (CONTOUR UNITS DEGREES)



FIGURE

ເກ 4



SLOT 1 STREAMWISE SPANWISE ANGLE CONTOURS (CONTOUR UNITS DEGREES)



SLOT 1 STREAMWISE SPANWISE ANGLE CONTOURS (CONTOUR UNITS DEGREES) X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (AM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM) CONTOURS OBTAINED FROM HOT-WIRE MEAN VELOCITY DATA



# SLOT 1 NORMALIZED TURBULENT KINETIC ENERGY CONTOURS



SLOT ! TURBULENCE INTENSITY CONTOURS FOR U DASH

FIGURE 5.8



SLOT 1 TURBULENCE INTENSITY CONTOURS FOR V DASH


SLOT 1 TURBULENCE INTENSITY CONTOURS FOR V DASH

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## X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM) CONTOURS NORMALIZED USING UPSTREAM REFERENCE VELOCITY







SLOT 1 NORMALIZED SHEAR STRESS CONTOURS (FROM UV CORRELATION)

X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM) CONTOURS NORMALIZED USING UPSTREAM REFERENCE DYNAMIC HEAD



SLOT 1 NORMALIZED SHEAR STRESS CONTOURS (FROM UW CORRELATION)

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SLOT 8 HOT WIRE EXPERIMENTAL DATA POINTS

X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILINC EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM) + DATA POINT + IMAGINARY ROOT FOR ONE UBAR OTHER VALUED USED

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SLOT 8 TOTAL VELOCITY MAGNITUDE CONTOURS (CONTOUR UNITS METRES/SEC)



SLOT 8 YAW ANGLE CONFOURS (CONTOUR UNITS DEGREES)







SLOT 8 NORMALIZED TURBULENT KINETIC ENERGY CONTOURS



SLOT S FURBULENCE INTENSITY CONTOURS FOR U DASH



SLOT 8 TURBULENCE INTENSITY CONTOURS FOR V DASH X-AXIS TANGENTIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM) CONTOURS NORMALIZED USING UPSTREAM REFERENCE VELOCITY



SLOT 8 TURBULENCE INTENSITY CONTOURS FOR V DASH







SLOT 8 NORMALIZED SHEAR STRESS CONTOURS (FROM UV CORRELATION)



SLOT 8 NORMALIZED SHEAR STRESS CONTOURS (FROM UV CORRELATION)

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SLOT I EXPERIMENTAL DATA POINTS

FIGURE 6.1

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----- 44° YAW ANGLE CONTOUR

FIGURE 6.4



----- 44° YAW ANGLE CONTOUR







SLOT 8 TOTAL PRESSURE LOSS COEFFICIENT ( (PO1-POLOCAL) / (PO1-P1) ) CONTOURS

FIGURE 6.8



SLOT 8 COMPARISON OF THE THREE INLET BOUNDARY LAYER LOSS CORES

X-AXIS TANGENTIAL CO-ORDINATE FROM WAKE CENTRE-LINE (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)



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X PASSAGE VORTEX CENTRE
+ COUNTER VORTEX CENTRES

X PASSAGE VORTEX CENTRE + COUNTER VORTEX CENTRES







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FIGURE 8.15



## FIGURE 6.16



SLOT 10 COMPARISON OF THE THREE INLET BOUNDARY LAYER LOSS CORES

X-AXIS TANGENTIAL CO-ORDINATE FROM WAKE CENTRE-LINE (MM) Y-AXIS SPANWISE CO-ORDINATE FROM PERSPEX ENDWALL (MM)


#### X PASSAGE VORTEX CENTRE

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X PASSAGE VORTEX CENTRE





SLOT 10 STATIC PRESSURE COEFFICIENT ( (P1-PLOCAL), (P01-P1) ) CONTOURS

FIGURE 6.22









FIGURE 6.26





### BLADE SURFACE STATIC PRESSURE COEFFICIENT DISTRIBUTION THICKENED BOUNDARY LAYER DATA

X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)

Y-AYIS STATIC PRESSURE COEFFICIENT ( (P1-PLOCAL) / (P01-P1) )



#### BLADE SURFACE STATIC PRESSURE COEFFICIENT DISTRIBUTION

THINNED BOUNDARY LAYER DATA

X-AXIS AXIAL CO-ORDINATE FROM TRAILING EDGE DATUM (MM)

Y-AXIS STATIC PRESSURE COEFFICIENT ( (P1-PLOCAL) / (P01-P1) )













a POINT OF MINIMUM PRESSURE (P_{0LOC} =P₁) b OUTER TOTAL PRESSURE LOSS COEFFICIENT CONTOUR















CARRICK'S CASCADE SECONDARY LOSS PREDICTION ZERO INLET SKEW LOW REYNOLDS No.

FIGURE 7.8

CARRICK'S CASCADE SECONDARY LOSS PREDICTION HIGH INLET SKEW LOW REYNOLDS No. X-AXIS PERCENTAGE OF BLADE SPAN FROM ENDWALL Y-AXIS SECONDARY LOSS COEFFICIENT (NORMALIZED USING INLET DYNAMIC HEAD) ^{0·30} A 1 1 1 ٦ 1 1 ł 1 I 1 X EXPERIMENTAL DATA Х PREDICTED SECONDARY LOSS (a+b+c) Х Х LOSS CORE a - --0.25 NEW ENDWALL BOUNDARY LAYER 5 SECONDARY KINETIC ENERGY USING INLET PROFILE - -Х 0.20 X Х Х Х Х Х 0.15 Х Х Х Х Х Х 0.10 Х Х ×× Х 0 05 Х 0 10 30 15 2**5** 35 40 45 50 5 20 0

FIGURE

## SJOLANDER'S CASCADE SECONDARY LOSS PREDICTION

X-AXIS PERCENTAGE OF ANNULUS HEIGHT FROM HUB Y-AXIS SECONDARY LOSS COEFFICIENT (NORMALIZED USING INLET DYNAMIC HEAD)



# TEST TURBINE NOZZLE GUIDE VANE EXIT ANGLE PREDICTION

X-AXIS PERCENTAGE OF ANNULUS HEIGHT FROM HUB Y-AXIS YAW ANGLE (DEGREES)



FIGJAL .11

# TEST TURBINE NOZZLE GUIDE VANE SECONDARY LOSS PREDICTION

X-AXIS PERCENTAGE OF ANNULUS HEIGHT FROM HUB Y-AXIS SECONDARY LOSS COEFFICIENT (NORMALIZED USING EXIT DYNAMIC HEAD)





X-AXIS PERCENTAGE OF ANNULUS HEIGHT FROM HUB Y-AXIS YAW ANGLE (DEGREES ROTOR RELATIVE)



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## TEST TURBINE ROTOR SECONDARY LOSS PREDICTION

X-AXIS PERCENTAGE OF ANNULUS HEIGHT FROM HUB Y-AXIS SECONDARY LOSS COEFFICIENT IN STATIC FRAME OF REFERENCE (NORMALIZED USING ROTOR EXIT DYNAMIC HEAD)







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