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COMMISSION OF THE EUROPEAN COMMUNITIES

EURCYL
A COMPUTER PROGRAM TO GENERATE FINITE ELEMENT MESHES FOR CYLINDER-CYLINDER INTERSECTIONS

by

P. DE WINDT and J. REYNEN

1973

Joint Nuclear Research Centre
Ispra Establishment - Italy
Technology Division

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ABSTRACT

EURCYL is a computer program dealing with the automatic mesh generation of cylinder-cylinder intersections, with special attention to the thick-walled vessel-nozzle junctions with curved transitions. Linear, parabolic and cubic isoparametric elements can be applied. The output consists of punched cards for topology and geometry.

KEYWORDS

E-CODES
FINITE ELEMENT METHOD
NOZZLES
PRESSURE VESSELS
JOINTS
GEOMETRY

CONTENTS

1. INTRODUCTION

The finite element method for structural and thermal analysis requires the subdivision of the structure into a large number of regions, called the mesh. This report deals with the automatic generation of three-dimensional meshes for general perpendicular cylinder-cylinder intersections. A computer program (EURCYL) has been written which, as output, produces punched cards for finite element programs. The program is particularly suited to generate a mesh for thick-walled vessel-nozzle junctions, including local reinforcement and transition radii at the intersection.

EURCYL is similar to the program described in [1], the difference lies in the more general geometry and the use of various types of isoparametric elements with a view to using the programs BERSAFE[2] and FLHE[3].

2. TOPOLOGY

The general geometry of 1/4 of the cylinder-cylinder intersection as dealt with by EURCYL is represented in fig. 1 and 2, including the necessary dimensions, a cartesian (x,y,z) and a cylindrical (r, θ, z) coordinate system.

Three regions are recognized:

— nozzle zone	A – D
— transition zone	D – B – C – E
— vessel zone	E – F

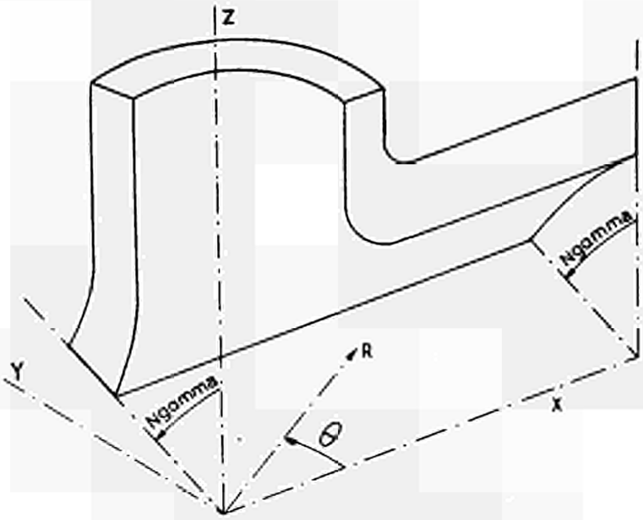


Fig. 1 : General view of nozzle geometry

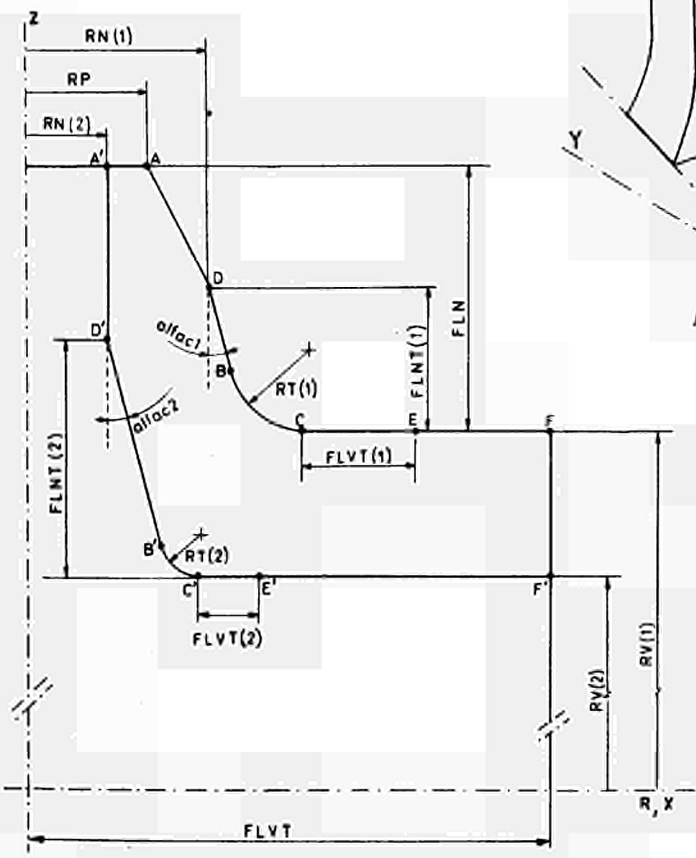


Fig. 2 : Two dimensional view of nozzle geometry

The topology of the elements corresponds to the topology of a wall (fig. 3) with the three directions and corresponding number of elements as indicated in Table 1 and fig. 4.

Table 1

Direction	Number of elements
Length Angular Thickness	NELL NELA NELTH

The number of elements in angular direction corresponds to 1/4 of the structure i.e. $0 \leqslant \theta \leqslant 90°$ (first quadrant). The number of elements in length direction is subdivided into the three zones mentioned before, as indicated in Table 2.

Table 2

Zone	Number of elements
Nozzle Transition Vessel	NELN NELT NELV
Total lenth	NELL = NELN + NELT + NELV

The numbering of elements is as indicated in fig. 3, in thickness, angular and length direction respectively. Since for most applications NELTH < NELA < NELL, this numbering gives the smallest bandwidth for a front solution [4].

The option NELEM is introduced in order to be able to continue a mesh with NELEM-1 elements already generated.

Three types of elements can be used corresponding to the isoparametric elements used in BERSAFE [2] and FLHE [3]. They are given in Table 3 and fig. 5.

Table 3

EURCYL el.type	BERSAFE el.type	Number of nodes	description
1	EZ24	8	linear
2	EZ60	20	parabolic
3	EZ96	32	cubic

The node numbering is straightforward and proceeds in the angular, thickness and length direction respectively (fig. 6). The option NPOIN is introduced in order to be able to continue a mesh with NPOIN-1 nodes already generated.

EURCYL defines the bandwidth of the generated topology and the job is abandoned if the bandwidth exceeds a preset value defined by input (NBTOT).

EURCYL has options to generate 1/4, 1/2 or the complete intersection to be specified by input data NTHETA (Table 4). The node numbering starts at the angular plane θ-start. For option NTHETA = 4 the nodes of the first angular plane (θ-start) coincide with those of the last angular plane (θ-end). In the topology definition the former are retained. A similar situation occurs for NGAMMA = 180° (fig. 1) and NTHETA = 2 or 4, and also here the lower node numbers are retained.

Table 4

NTHETA	quadrants	θ-start	θ-end
1	1	0°	90°
2	1,4	90°	90°
3	1,2	0°	180°
4	1,2,3,4	−180°	180°

The output of the topology consists of the list of elements defined by nodes, in a right hand screw sequence (fig. 5).

Punched cards compatible with BERSAFE and FLHE are produced.

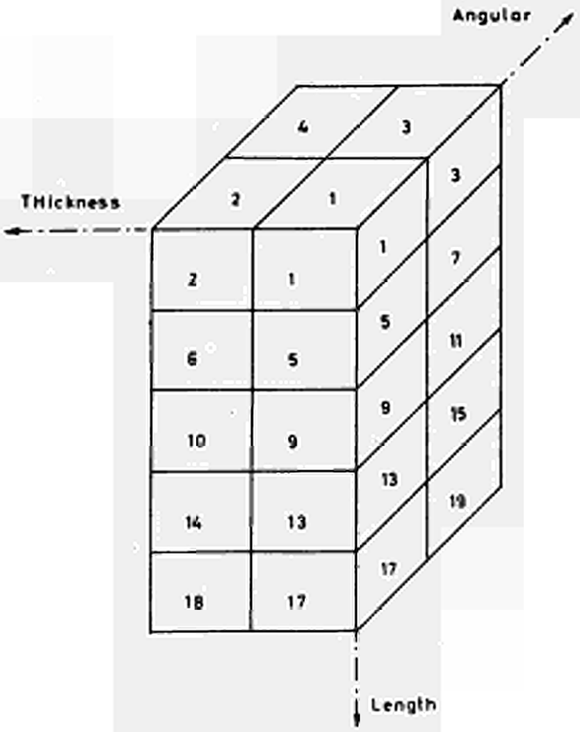


Fig. 3 : Element indexation

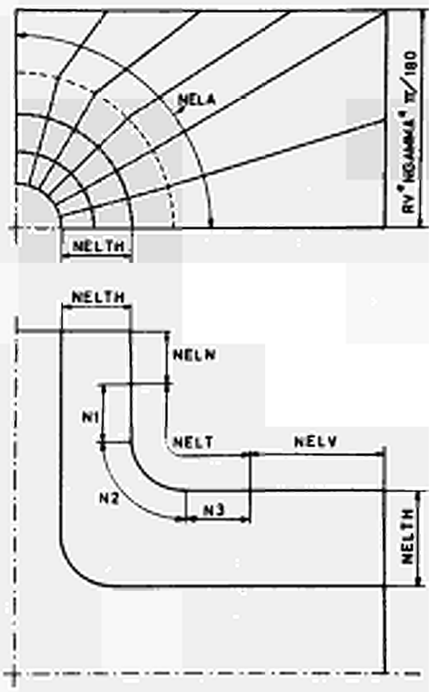


Fig. 4 : Element distribution

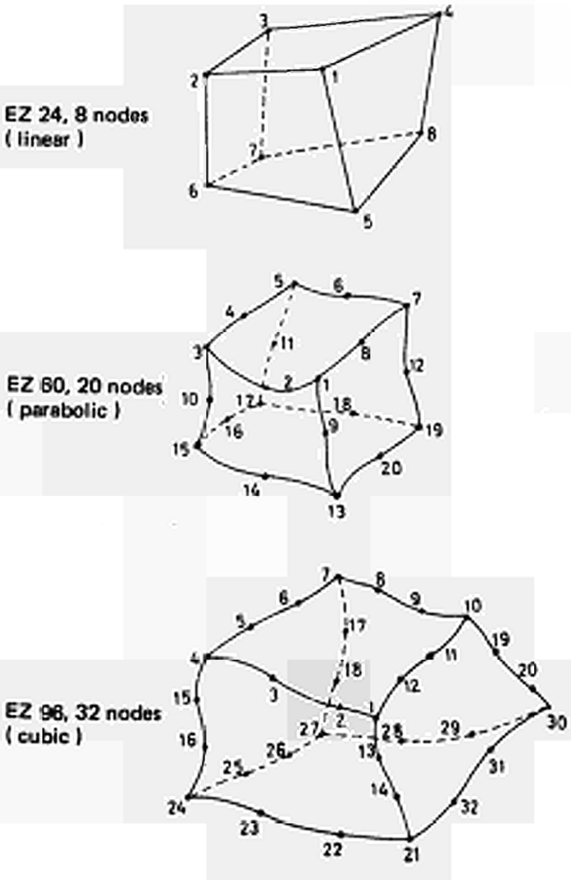


Fig. 5 : Element types

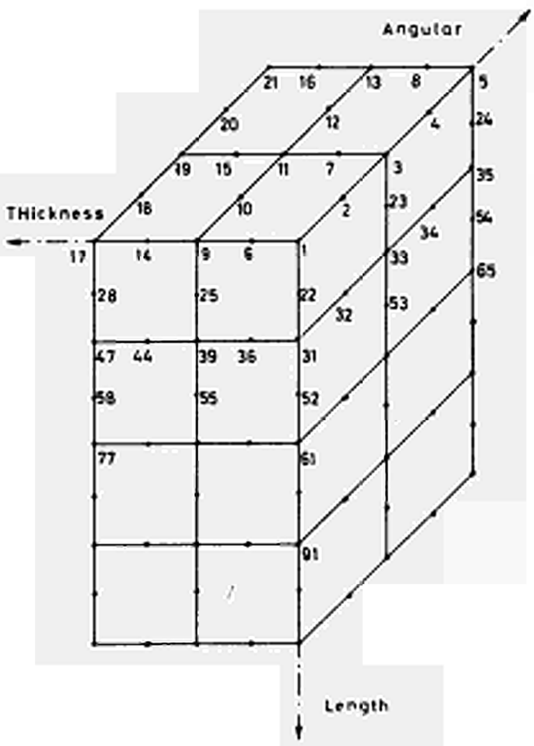


Fig. 6 : Nodes indexation

3. GEOMETRY

The coordinates of the nodal points depend on the distribution and on the type of the elements. The distribution and the type of elements depend on their turn on the structure and the expected stress distribution. For the nozzle structure the type of element should preferably be the parabolic or cubic isoparametric ones, in order to represent accurately the geometry of the curved surfaces (the linear element EZ24 with straight edges has only been included for completeness). The distribution of elements should be fine in regions of steep stress gradients and can be coarser elsewhere.

In EURCYL the distribution of elements is controlled by input. As far as the angular direction is concerned, the distribution is homogeneous for the nozzle zone (A – D) and transition zone (D–B–C–E) and nearly homogeneous for the vessel zone (E – F), see fig. 4.

In the thickness direction the distribution is governed by a crowding factor CROWTH, according to a geometrical series with the smaller elements at the inside for CROWTH > 1 (see appendix 1).

In the length direction the distribution is defined by NELN, NELT, NELV (see chapter 1) with corresponding crowding factors CROWN, CROWTR, CROWV according to geometrical series with increasing elements in the direction away from the intersection.

For the determination of the coordinates of the nodal points, first the coordinates of the points A,D,B,C,E and F (fig. 2) for inside and outside surfaces and for the various angular planes have to be defined. For A and D the procedure is straight forward because they are on a cylindrical surface with axis z. The coordinates of B and C follow from a transcendental equation, which is solved by iteration (appendix 3). Points C,E and F lie on a cylindrical surface with axis x. This surface is developped in a z-x plane in which the coordinates are defined. Once the points A,D,B,C,E and F are defined, the summit nodes are found by geometrical interpolation using the crowding factors. Next the midside nodes are defined.

For the structural options NTHETA ≠ 1 the additional coordinates are found by symmetry.

The output of the geometry consists of a list of cartesian (x-y-z) or cylindrical (r,θ,z) coordinates depending on the option NCOORD. Punched cards are produced to be used in subsequent runs with finite element programs.

4. HOW TO USE

Card No. 1: job title card

ccs 1- 4	AJOB	A4	job name for BERSAFE program
ccs 5-80	TITLE	19A4	title of the job

Card No. 2: dimension card (see fig. 1 and 2)

ccs 1- 6	RV(1)	F6.2	external vessel radius
ccs 7-12	RV(2)	F6.2	internal vessel radius
ccs 13-18	FLV	F6.2	vessel length
ccs 19-24	RN(1)	F6.2	external nozzle radius
ccs 25-30	RN(2)	F6.2	internal nozzle radius
ccs 31-36	FLN	F6.2	nozzle length
ccs 37-42	RT(1)	F6.2	outside transition radius = 0 if transition not curved
ccs 43-48	RT(2)	F6.2	inside transition radius = if transition not curved
ccs 49-54	FLVT(1)	F6.2	length of transition zone, outside vessel
ccs 55-60	FLVT(2)	F6.2	length of transition zone, inside vessel
ccs 61-66	FLNT(1)	F6.2	length of transition zone, outside nozzle
ccs 67-72	FLNT(2)	F6.2	length of transition zone, inside nozzle
ccs 73-78	RP	F6.2	external radius of nozzle entry, in case of conical form if = 0,RP=RN(1) (cylindrical form)

Card No. 3

ccs 1- 6	ALFAC1	F6.2	angle in degrees of transition nozzle part, if conical = 0 cylindrical
ccs 7-12	ALFAC2	F6.2	angle in degrees of transition nozzle part, if conical = 0 if cylindrical

Card No. 4: element and structure option card

ccs 1- 6	NELN	I6	number of elements in nozzle length
ccs 7-12	NELT	I6	number of elements in transition length
ccs 13-18	NELV	I6	number of elements in vessel length
ccs 19-24	NELA	I6	number of elements in angular direction
ccs 25-30	NELTH	I6	number of elements in the thickness
ccs 31-36	NELTYP	I6	element option: = 1 type EZ24 = 2 type EZ60 = 3 type EZ96
ccs 37-42	NTHETA	I6	structure option: = 1 quadrant 1 = 2 quadrant 1 + 4 = 3 quadrant 1 + 2 = 4 quadrant 1 + 2 + 3 + 4
ccs 43-48	NGAMMA	I6	angle in degrees of vessel sector (up to maximum 180°)
ccs 49-54	NCOORD	I6	coordinates option = 0 x-y-z = 1 r-θ-z

Card No. 5: crowding factor card

ccs 1- 6	CROWN	F6.2	crowding factor along the nozzle if > 1 elements increasing away from the transition
ccs 7-12	CROWV	F6.2	crowding factor along the vessel if > 1 elements increasing away from the transition
ccs 13-18	CROWTH	F6.2	crowding factor along the thickness if > 1 elements increasing away from the inside surface
ccs 19-24	CROWTR	F6.2	crowding factor along the transition nozzle and vessel zones if > 1 elements increasing away from the junction

Card No. 6

ccs 1- 6	NPOIN	I6	index of first nodal point
ccs 7-12	NELEM	I6	index of first element
ccs 13-18	NBTOT	I6	maximum number of nodes allowed in the bandwidth if = 0, NBTOT=99

5. RESULTS

The following results are printed:

- the input data
- the total number of nodes (1)
- the total number of elements (1)
- the maximum bandwidth (1)
- the topology
- the geometry

(1) the job is immediately abandoned if these parameters do not agree with the BERSAFE and FLHE limitations.

The topology and the geometry are punched on cards with the required formats for BERSAFE [2] or FLHE [3] use:

Topology cards

ccs 1- 4	AJOB	A4	job name
ccs 5- 6	11	I2	card type number (BERSAFE)
ccs 7-12			blank
ccs 13-16	NOEL	I4	element number
ccs 17-18	NNODES	I2	number of nodes
ccs 19-22			
	NODES	15I4	nodes series
ccs 75-78			

N.B. if NNODES > 15,a continuation card is used with I4 formats (ccs 19-22, etc.) and NNODES = NNODES + 1

Geometry cards

ccs 1- 4	AJOB	A4	job name
ccs 5- 6	21	I2	card type number (BERSAFE)
ccs 7-10	NODE	I4	node number
ccs 11-18	GNODE	F8.3	X or R coordinate
ccs 19-26	GNODE	F8.3	Y or θ coordinate (θ in degrees)
ccs 27-34	GNODE	F8.3	Z coordinate

Appendix 4 gives an example of the printed results of a structure represented by the Calcomp plot of fig. 7. In fig. 8 another example of a Calcomp plot is given.

6. CONCLUSION

A computer program has been presented dealing with the automatic mesh generation for finite element analysis of cylinder-cylinder intersections. EURCYL is in particular suited for BWR pressure vessel nozzles.

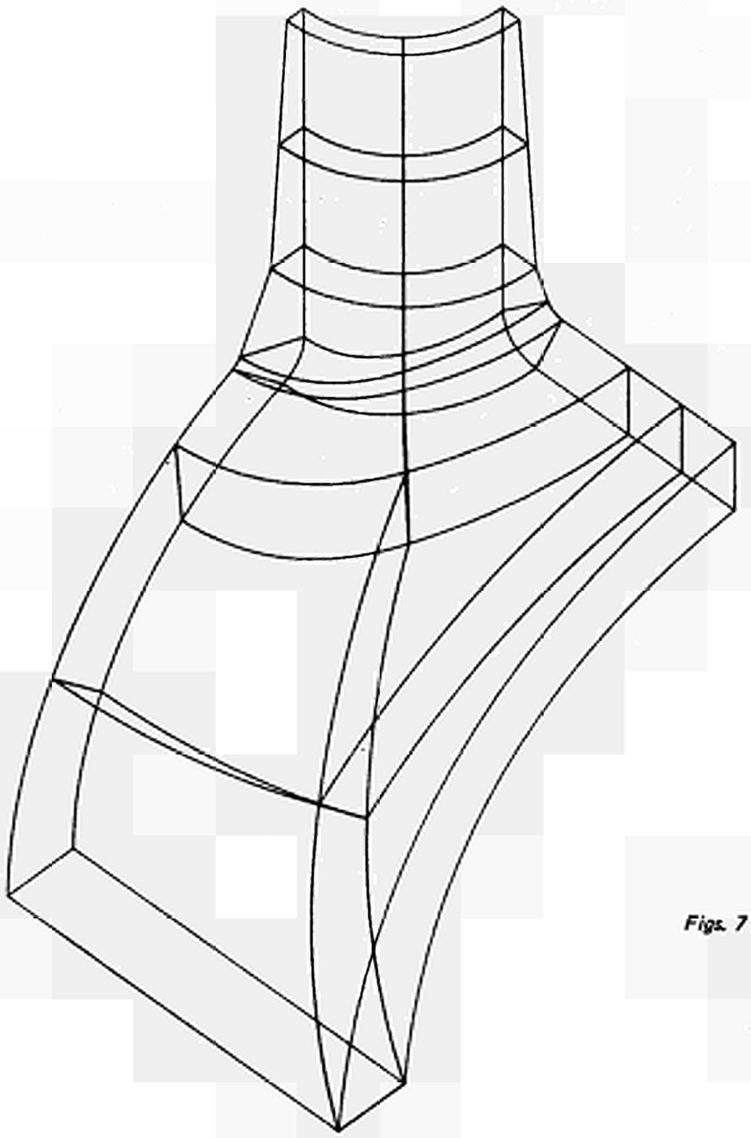
REFERENCES

1) Krishnamurthy N. "Three-dimensional finite element analysis of thick walled vessel-nozzle junctions with curved transitions" – ORNL-TM-3315.

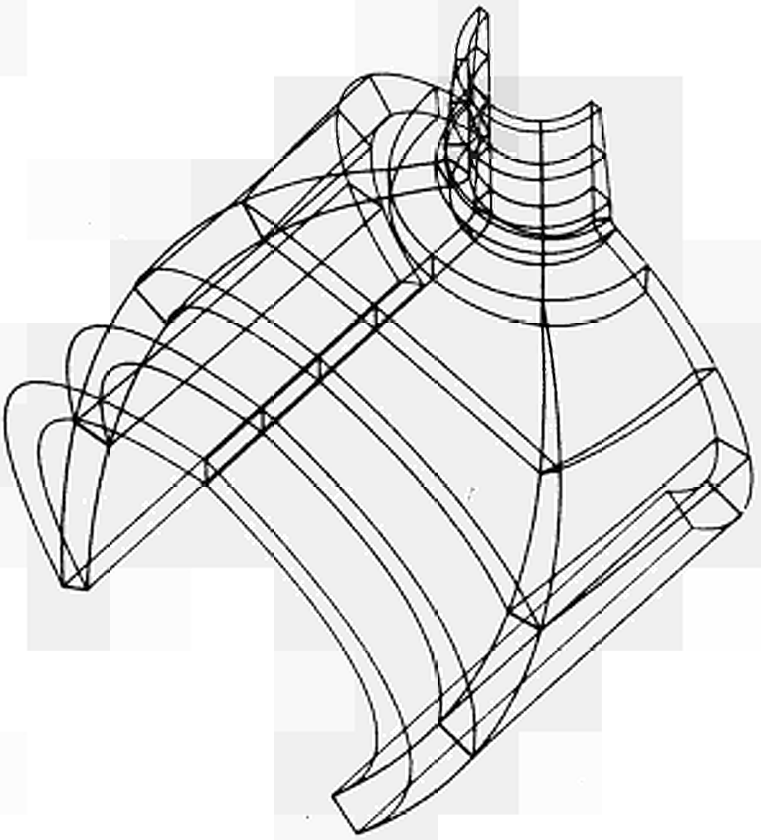
2) Hellen T.K. "BERSAFE (Phase 1) a computer system for stress analysis – Part 1: user's guide" – October 1970, CEGB Report RD/B/N1761.

3) Fullard K. "FLHE, a finite element program for the calculation of temperatures in arbitrary structures. Part 1: user's guide" – CEGB Report RD/B/N1849.

4) Hellen T.K. "A front solution for finite element techniques" CEGB Report RD/B/N1459 – October 1969.



Figs. 7 and 8 : Calcomp example



APPENDIX 1

Crowding Factors

If N is the number of nodes to be generated on a straight or curved line defined by the parameters x_1 and x_N with crowding factor R, the coordinates of the intermediate nodes are defined from:

$$x_j = x_1 + (x_N - x_1)\,CN$$

$$CN = (R^{j-1} - 1) / (R^{N-1} - 1)$$

$$CN = (j - 1) / (N - 1) \qquad \text{for } R = 1.$$

These formulae are used to define the coordinates of the summit nodes in the thickness direction, and for the nozzle zone A – D and the vessel zone E – F in length direction (fig. 1).

APPENDIX 2

The distribution of the elements in the transition zone is defined by the number of elements NELT and the crowding factor R.

The program has to define the number of elements to be attributed to the distances DB,BC and CE, respectively N1, N2 and N3 (fig. 4). An iterative procedure is applied.

As initial guess for the length of the elements in distance BC is taken.

$$A = (DB + BC + CE) / NELT \qquad (1)$$

The number of elements in DB, BC and CE become respectively

$$N1 = \log(1+(R-1)\ DB/A) / \log R \qquad (2)$$

$$N2 = BC / A \qquad (3)$$

$$N3 = \log(1+(R-1)\ CE/A) / \log R \qquad (4)$$

These equations express that for BC the distribution is homogeneous (3) and for DB and CE the distribution is according to a geometrical series with first term A and ratio R.

The sum of the calculated elements is compared to the prescribed number NELT.

$$N1 + N2 + N3 = SUM \stackrel{?}{=} NELT \qquad (5)$$

A correction is applied to A according to

$$A = A\ (SUM/NELT)^{1/2} \qquad (6)$$

and the iteration loop returns to eq. (1) until (5) is satisfied.

Equations (2) and (4) follow from the sum S of a geometrical series with N terms:

$$S = A\ (R^N - 1) / (R - 1) \qquad (7)$$

Once N1, N2 and N3 are known, the summit nodes in BC are distributed homogeneously, and the summit nodes in DB and CE according to a geometrical series with ratio R (Appendix 1).

APPENDIX 3

The coordinates of points B and C in an angular plane θ are defined by transcendental equations which are solved by iteration.

The intersection of an angular plane θ with the vessel (radius RV) is an ellipse with half axis.

$$RV/\sin\theta \quad \text{and} \quad RV \quad \text{(fig. 9)}$$

The iteration starts with a first guess for the radius RC of point C in the plane of intersection. The vertical position of C is then defined by:

$$ZC = (RV^2 - RC^2 \sin^2\theta)^{1/2} \tag{1}$$

The angle β is defined by:

$$\beta = \text{arctg}\,(RC^2 \sin^2\theta/ZC) \tag{2}$$

The angle α and the coordinates of points B become:

$$\alpha = \pi/2 - \alpha_1 - \beta \tag{3}$$

$$RB = RC + RT \sin\beta - RT \cos\alpha_1 \tag{4}$$

$$ZB = ZC + RT \cos\beta - RT \sin\alpha_1 \tag{5}$$

The radius of point D becomes:

$$RD = RB - (ZD\text{-}ZB)\,\text{tg}\alpha_1 \tag{6}$$

The value of RD is compared to the nozzle radius RN. The difference is subtracted from RC and the iteration continues with equation (1).

Equation (3) gives the value of α and the intermediate nodes between BC are defined by linear interpolation of the variable α.

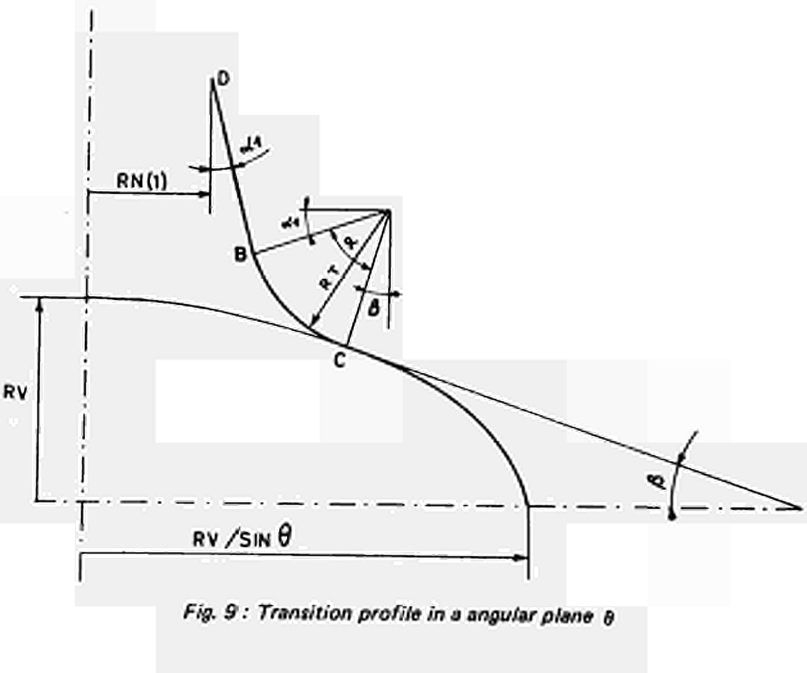


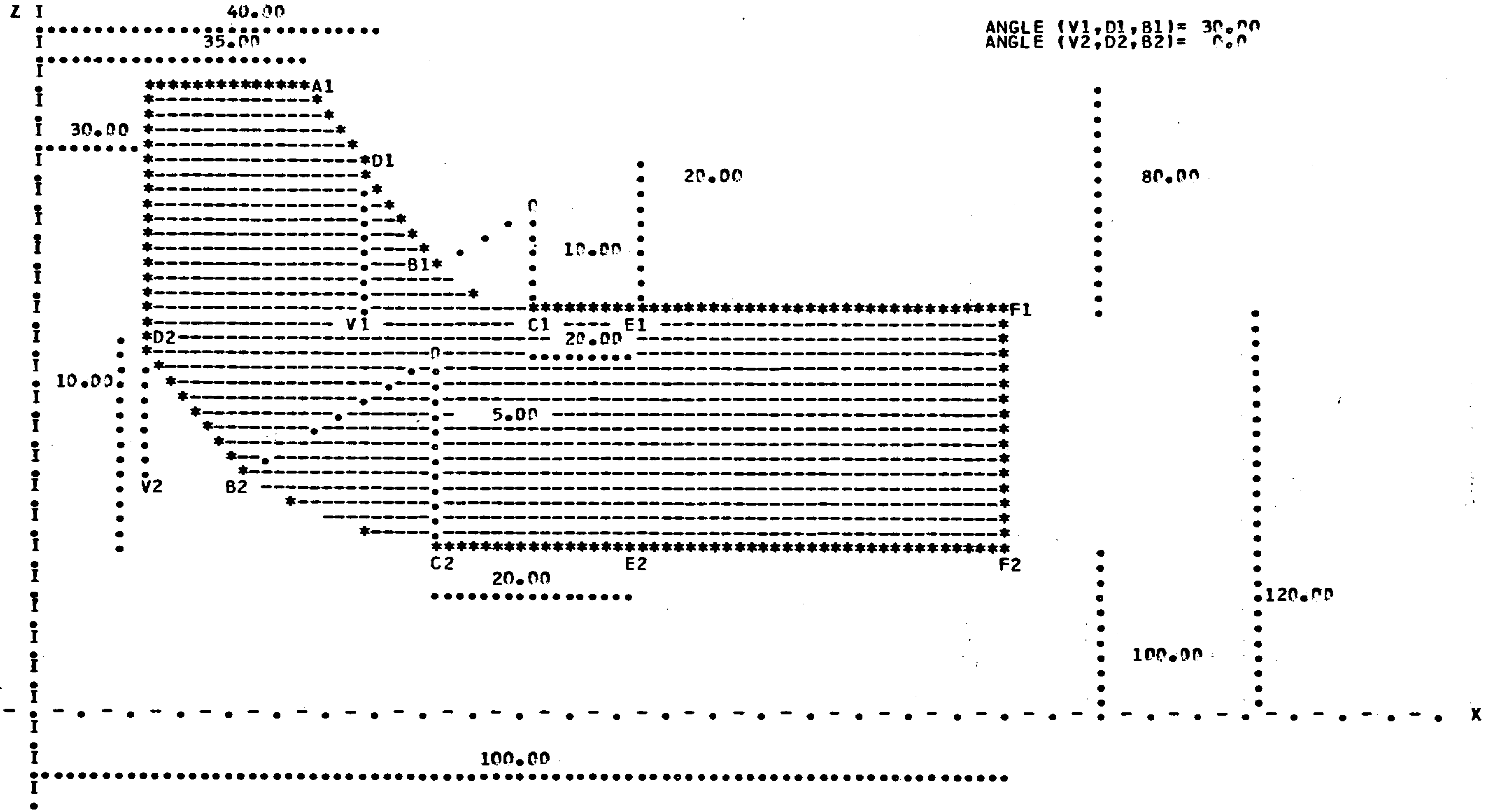
Fig. 9 : Transition profile in a angular plane θ

APPENDIX 4

PROGRAM EURCYL
THREE DIMENSIONAL MESH GENERATION

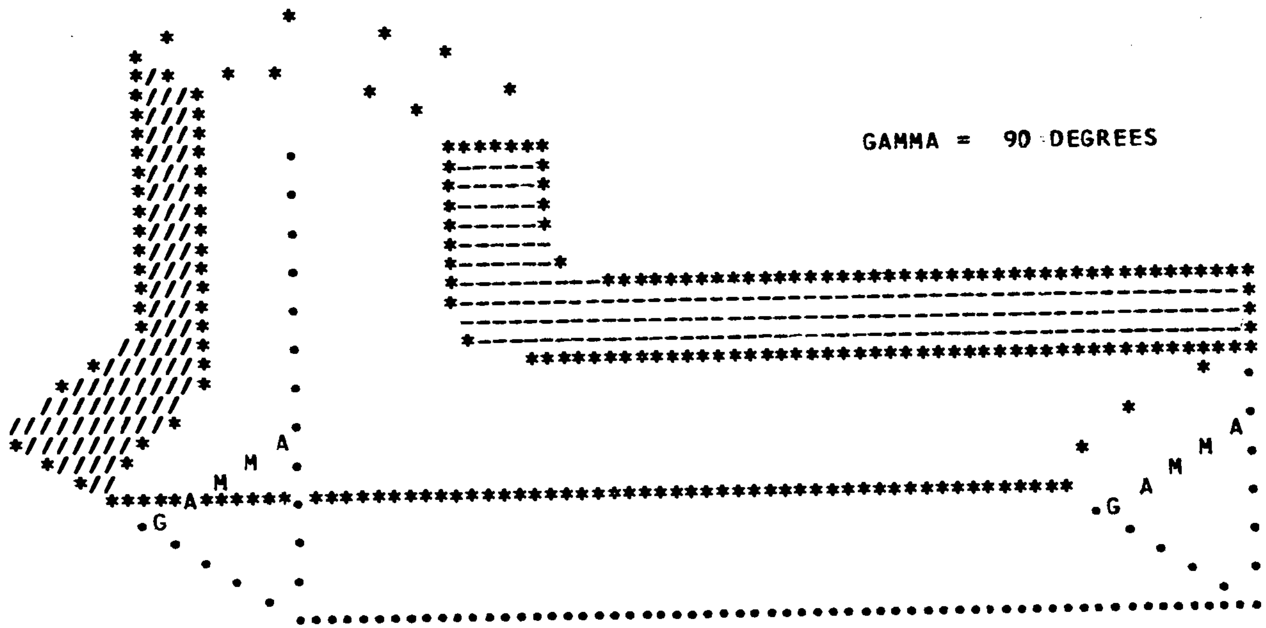
TEST STRUCTURE

GENERAL 2-DIMENSIONAL VUE WITH DIMENSIONS



GENERAL 3-DIMENSIONAL VIEW WITH ELEMENT INFORMATION

STRUCTURE TAKEN INTO CONSIDERATION



THE STRUCTURE IS DEFINED AROUND THE X-AXIS BY A SECTOR OF 90 DEGREES
QUARTER A STRUCTURE IS CONSIDERED AROUND THE Z-AXIS WITH POSITIVE X- AND Y-COORDINATES

```
EZ60 IS THE ELEMENT TYPE
************************
THERE ARE   2  ELEMENTS ALONG THE NOZZLE (FROM A TO D)
THERE ARE   3  ELEMENTS ALONG THE TRANSITION (FROM D TO E)
THERE ARE   2  ELEMENTS IN THE 90 DEGREES NOZZLE SECTOR (BEWARE THE STRUCTURE CHOICE)
THERE ARE   2  ELEMENTS ALONG THE VESSEL(FROM E TO F)
THERE ARE   1  ELEMENTS ALONG THE THICKNESS

THE OUTER PART OF THE NOZZLE IS CONICAL OR CYLINDRICAL,ANGLE =  30.000  DEGREES

THE INNER PART OF THE NOZZLE IS CONICAL OR CYLINDRICAL,ANGLE =   0.0    DEGREES

THERE ARE     0  POINTS AND     0  ELEMENTS BEFORE THIS MESH

FOR THIS PROBLEM    14 ELEMENTS AND   146 NODES ARE EXPECTED
NUMBER OF ELEMENTS ALONG THE TRANSITION     FROM NOZZLE TO VESSEL
         EXTERNAL PART      1 FROM D TO B
                            1 FROM B TO C
                            1 FROM C TO E
         INTERNAL PART      1 FROM D TO B
                            1 FROM B TO C
                            1 FROM C TO E

CROWDING FACTOR ALONG      THE NOZZLE(CROWN)        1.00
                           THE VESSEL(CROWV)        1.20
                           THE SECTOR(CROWTH)       1.00
                           THE TRANSITION(CROWTR)   1.10
```

LIST OF EL. WITH THEIR N.P.(CARDS PUNCHED ALSO FOR BERSAFE)

1	1	6	9	10	11	7	3	2	14	17	18	15	20	25	28	29	30	26	22	21
2	3	7	11	12	13	8	5	4	15	18	19	16	22	26	30	31	32	27	24	23
3	20	25	28	29	30	26	22	21	33	36	37	34	39	44	47	48	49	45	41	40
4	22	26	30	31	32	27	24	23	34	37	38	35	41	45	49	50	51	46	43	42
5	39	44	47	48	49	45	41	40	52	55	56	53	58	63	66	67	68	64	60	59
6	41	45	49	50	51	46	43	42	53	56	57	54	60	64	68	69	70	65	62	61
7	58	63	66	67	68	64	60	59	71	74	75	72	77	82	85	86	87	83	79	78
8	60	64	68	69	70	65	62	61	72	75	76	73	79	83	87	88	89	84	81	80
9	77	82	85	86	87	83	79	78	90	93	94	91	96	101	104	105	106	102	98	97
10	79	83	87	88	89	84	81	80	91	94	95	92	98	102	106	107	108	103	100	99
11	96	101	104	105	106	102	98	97	109	112	113	110	115	120	123	124	125	121	117	116
12	98	102	106	107	108	103	100	99	110	113	114	111	117	121	125	126	127	122	119	118
13	115	120	123	124	125	121	117	116	128	131	132	129	134	139	142	143	144	140	136	135
14	117	121	125	126	127	122	119	118	129	132	133	130	136	140	144	145	146	141	138	137

MAX. BANDWIDTH 25 NODES
****

COORD. SYSTEM X - Y - Z
****

LIST OF N.P. WITH COORD. (PUNCH ON CARDS WITH BERSAFE FORMAT)

1	35.000	0.0	200.000
2	32.336	13.394	200.000
3	24.749	24.749	200.000
4	13.394	32.336	200.000
5	0.000	35.000	200.000
6	32.500	0.0	200.000
7	22.981	22.981	200.000
8	0.000	32.500	200.000
9	30.000	0.0	200.000
10	27.716	11.480	200.000
11	21.213	21.213	200.000
12	11.481	27.716	200.000
13	0.000	30.000	200.000
14	36.250	0.0	185.000
15	25.633	25.633	185.000
16	0.000	36.250	185.000
17	30.000	0.0	185.000
18	21.213	21.213	185.000
19	0.000	30.000	185.000
20	37.500	0.0	170.000
21	34.645	14.351	170.000
22	26.516	26.516	170.000
23	14.351	34.645	170.000
24	0.000	37.500	170.000
25	33.750	0.0	170.000
26	23.865	23.865	170.000
27	0.000	33.750	170.000
28	30.000	0.0	170.000
29	27.716	11.480	170.000
30	21.213	21.213	170.000
31	11.481	27.716	170.000
32	0.000	30.000	170.000
33	38.750	0.0	155.000
34	27.400	27.400	155.000
35	0.000	38.750	155.000
36	30.000	0.0	155.000
37	21.213	21.213	155.000
38	0.000	30.000	155.000
39	40.000	0.0	140.000
40	36.955	15.307	140.000
41	28.284	28.284	140.000
42	15.307	36.955	140.000
43	0.000	40.000	140.000
44	35.000	0.0	140.000
45	24.749	24.749	140.000
46	0.000	35.000	140.000
47	30.000	0.0	140.000
48	27.716	11.480	140.000
49	21.213	21.213	140.000
50	11.481	27.716	140.000
51	0.000	30.000	140.000
52	43.618	0.0	132.500
53	32.088	32.088	128.866
54	0.000	47.698	124.062
55	30.000	0.0	122.500
56	21.205	21.205	120.986
57	0.000	30.002	119.497
58	47.235	0.0	125.000
59	44.516	18.439	123.036
60	35.891	35.891	117.732
61	20.619	49.779	111.289
62	0.000	55.395	108.123
63	38.618	0.0	115.000
64	28.544	28.544	109.852
65	0.000	42.700	103.558
66	30.000	0.0	105.000
67	27.715	11.480	104.106
68	21.197	21.197	101.972
69	11.482	27.719	99.859
70	0.000	30.004	98.993
71	50.895	0.0	121.340
72	37.752	37.752	114.753
73	0.000	57.014	106.023
74	31.464	0.0	101.464
75	22.025	22.025	98.757
76	0.000	30.922	96.107
77	55.895	0.0	120.000
78	51.875	21.487	118.061
79	40.287	40.287	113.035
80	22.322	53.889	107.219
81	0.000	59.128	104.422
82	45.448	0.0	110.000
83	32.204	32.204	105.041
84	0.000	46.233	99.351
85	35.000	0.0	100.000
86	32.097	13.295	99.112
87	24.120	24.120	97.047
88	12.843	31.006	95.072
89	0.000	33.337	94.279
90	65.895	0.0	120.000
91	47.358	46.874	110.466
92	0.000	67.615	99.138
93	55.448	0.0	100.000
94	39.275	38.752	92.186
95	0.000	54.725	83.697
96	75.895	0.0	120.000
97	70.353	28.969	116.451
98	54.429	53.298	107.514
99	29.975	69.696	97.686
100	0.000	75.632	93.166
101	75.895	0.0	110.000
102	54.429	52.880	96.324
103	0.000	74.314	80.757
104	75.895	0.0	100.000
105	70.353	28.842	95.750
106	54.429	52.462	85.133
107	29.975	67.698	73.600
108	0.000	72.997	68.348
109	81.922	0.0	120.000
110	65.822	80.725	88.788
111	0.000	94.306	74.205
112	81.922	0.0	100.000
113	65.822	72.215	69.174
114	0.000	84.491	53.490
115	87.948	0.0	120.000
116	85.176	59.063	104.458
117	77.215	101.970	63.262
118	39.988	106.685	54.939
119	0.000	108.342	51.596
120	87.948	0.0	110.000
121	77.215	94.640	56.008
122	0.000	100.673	44.170
123	87.948	0.0	100.000
124	85.176	51.327	85.823
125	77.215	87.310	48.753
126	39.988	91.569	40.188
127	0.000	93.004	36.745
128	93.974	0.0	120.000
129	88.607	115.404	32.891
130	0.000	117.049	26.448
131	93.974	0.0	100.000
132	88.607	96.776	25.189
133	0.000	98.236	18.702
134	100.000	0.0	120.000
135	100.000	84.853	84.853
136	100.000	120.000	0.000
137	50.000	120.000	0.000
138	0.0	120.000	0.000
139	100.000	0.0	110.000
140	100.000	110.000	0.000
141	0.0	110.000	0.000
142	100.000	0.0	100.000
143	100.000	70.711	70.711
144	100.000	100.000	0.000
145	50.000	100.000	0.000
146	0.0	100.000	0.000

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Alfred Nobel

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