STEAM TURBINE INFORMATION

TURBINE MISSILE REPORT

(HP296-LP281-LP281)

CT-24821
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AUGUST, 1980

VIRGINIA ELECTRIC & POWER COMPANY

NORTH ANNA STATION, UNIT NO. 1

SERIAL NUMBERS 13A3591-1, 23A3592-1, 23A3593-1

WESTINGHOUSE ELECTRIC CORPORATION

STEAM TURBINE GENERATOR DIVISION

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1 INTRODUCTION

This report summarizes Westinghouse's evaluation of potential turbine missiles above the turbine deck from the high pressure (HP) rotor and the low pressure (LP) rotor discs of the HP 296 and LP 281 turbine elements for Unit 1, North Anna Station, Virginia Electric & Power Company, Serial Numbers 13A3591-1, 23A3592-1, and 23A3593-1. The contents of this report supersede any previously issued information for this unit on turbine missile energies.

2 DESCRIPTION OF TURBINE ELEMENTS

2.1 High Pressure Turbine

The HP element is a double flow design similar to the HP double flow design shown in Figure 1, and consists of a forged single-piece double flow rotor, a cast steel outer cylinder, and four cast steel blade rings supported inside the outer cylinder. Steam from four control valves enters nozzle chambers at the center of the turbine element through four inlet pipes (two in the cylinder base and two in the cylinder cover). In these chambers, the steam is distributed equally to both halves of the rotor and flows axially through the blading to the exhaust chambers at each end of the HP cylinder. The HP cylinder cover and base are held together at the horizontal joint by studs and stud-bolts have lengths ranging from 23 to 59

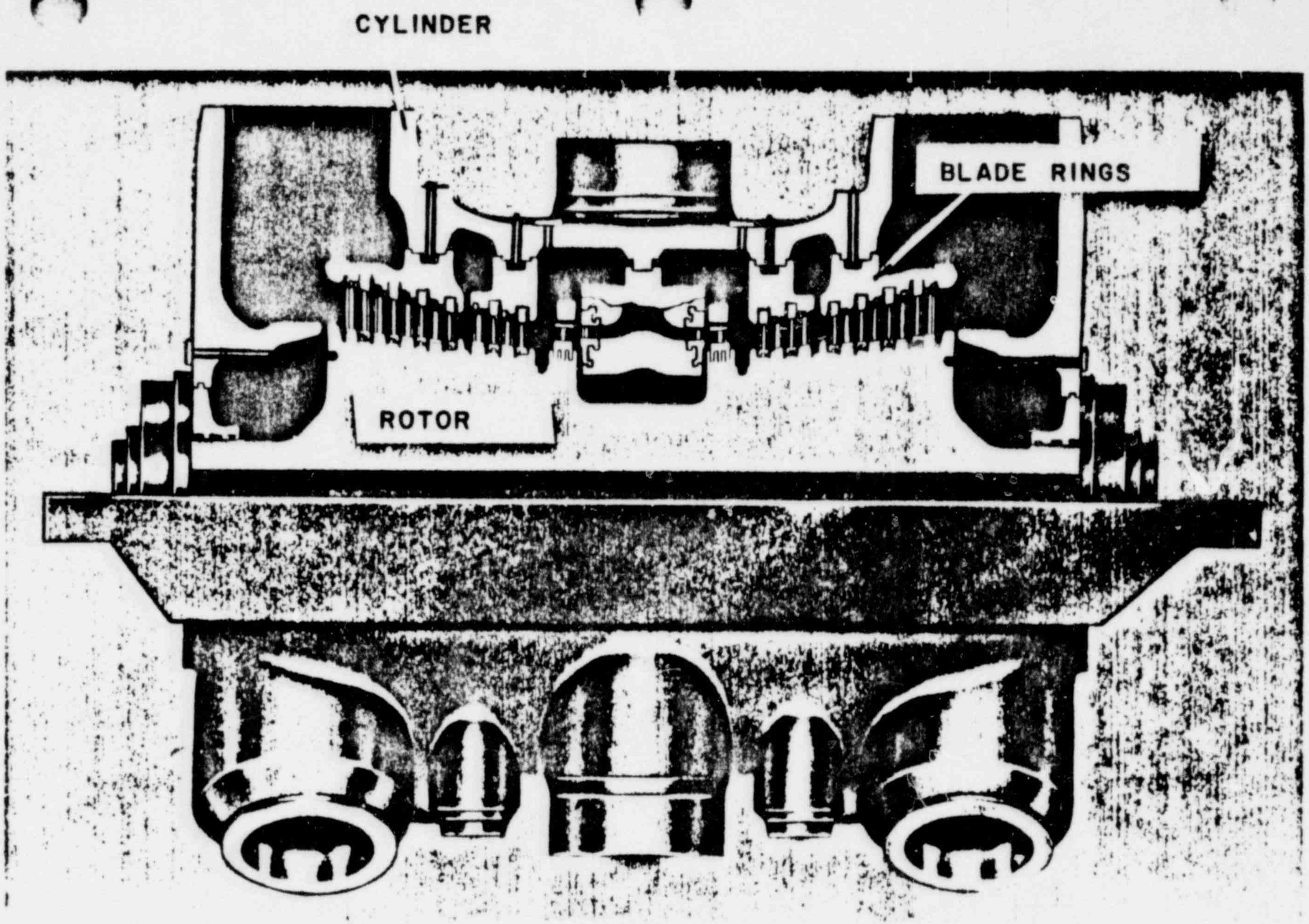

FIGURE 1
HP DOUBLE-FLOW TURBINE

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inches and diameters ranging from 2.50 to 3.50 inches. The total cross-sectional area of the studs and bolts is approximately 620 square inches and the total free-length volume is approximately 31,500 cubic inches.

2.2 Low Pressure Turbine

The LP turbines are of a double flow design similar to the double flow design shown in Figure 2. Each element consists of a double flow rotor assembly, an outer cylinder, two inner cylinders, and blade rings. The rotor assembly consists of a shaft with 10 shrunk-on discs made of low alloy steel and two shrunk-on couplings. Steam enters at the top of each outer cylinder where it flows to the inlet chamber of the inner cylinders. In the inlet chamber, the steam is distributed equally to both halves of the rotor and flows through the blading to the condenser. LP turbines are numbered from the HP element to the generator. The LP-1 element is next to the HP element, the highest numbered LP element is next to the generator.

3 COMMENTS AND ASSUMPTIONS

3.1 High Pressure/Low Pressure Turbines

3.1.1

When a disc or rotor fails in quarters, the failure occurs in steps with the result that two fragments gain velocity and two lose velocity. The velocities and energies given are for the higher velocity fragments.

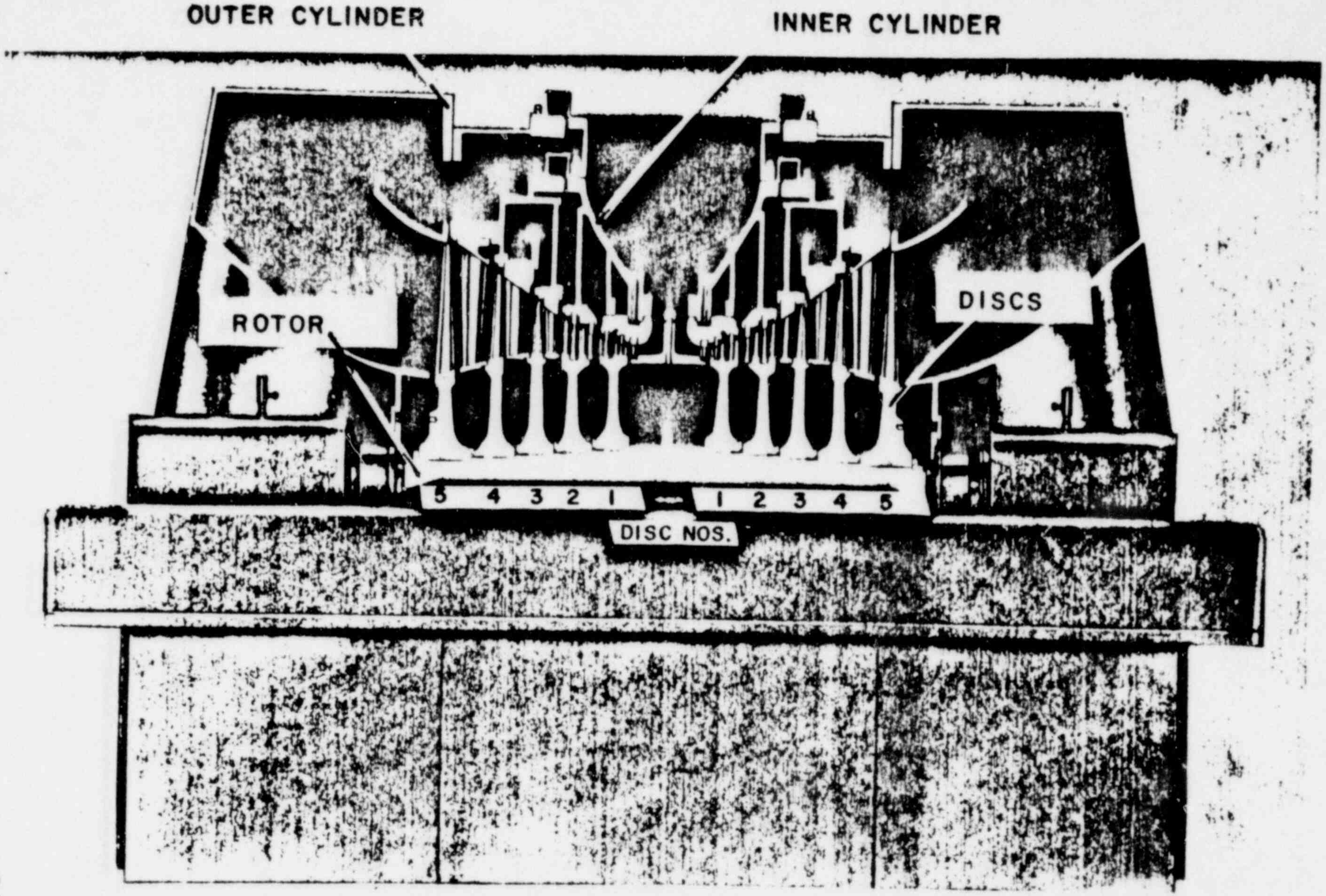

FIGURE 2
LP DOUBLE-FLOW TURBINE

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3.1.2

In predicting the ability of the fragment to penetrate the turbine casing, test results and analytical considerations indicate that the translational kinetic energy of a fragment is of much greater importance than the rotational kinetic energy. Rotational kinetic energy tends to be dissipated as a result of friction forces developed between the surface of the disc or rotor fragment and the stationary part; therefore, rotational kinetic energy was not considered in the penetration calculations.

3.1.3

The analysis considers the energy absorbed by the inner and outer cylinders, blade rings, and cylinder rings where appropriate. The results of R&D tests, including the 1979 non-symmetrical tests, are incorporated into the analysis.

3.1.4

When missile energies exiting the turbine are less than 100,000 ft-lb, they are not reported in the Analysis Results section of this report.

3.1.5

Blade ring and cylinder exiting fragments vary significantly in shape. Fragments of equivalent area are reported rather than furnishing separate tables and sketches for the numerous possible configurations (refer to Figure 3). HP/LP turbine cylinder and blade ring fragment equivalent areas are tabulated in TABLES 1 and 2.

3.1.6

Minimum ultimate strength was used to establish the dynamic strength of the cylinders and blade rings for the missile penetration calculations.

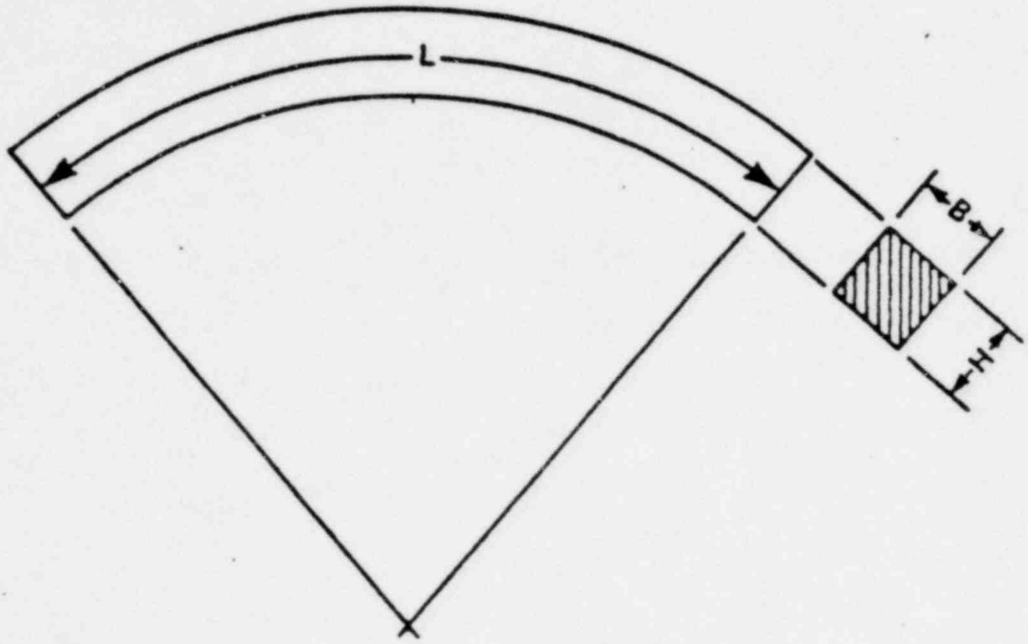

FIGURE 3
HP & LP CYLINDER & BLADE RING FRAGMENTS

TABLE 1

HP CYLINDER AND BLADE RING FRAGMENT DIMENSIONS

(REFER TO FIGURE 3)

	L (in)	B (in)	H (in)
Blade Ring 1	52.1	25.8	4.9
Blade Ring 2	55.2	24.6	6.8
Cylinder	67.6	27.9	7.4

TABLE 2

LP CYLINDER AND BLADE RING FRAGMENT DIMENSIONS

(REFER TO FIGURE 3)

FRAGMENT NUMBER	L (in) 90° SEGMENT	L (in) 120° SEGMENT	B (in)	H (in)	NOTES
1.1 *	87.9	—	18.1	7.7	(c)
1.2	103.7	—	8.5	9.1	(c)
1.3	117.1	—	3.0	19.3	(c)
2.1	95.8	129.5	12.0	8.9	
2.2	36.7	—	9.5	5.5	(a,b)
2.2	—	48.9	9.5	5.5	
2.2	36.7	—	1.9	6.6	(c)
3.1	86.7	115.6	9.4	5.5	(a)
3.1	85.3	—	6.1	5.2	(b,c)
3.1	—	115.6	9.4	5.5	(b)
3.1	—	113.7	6.1	5.2	(c)
3.2	87.6	116.8	4.0	9.8	
4.1	81.8	108.9	4.5	4.6	
4.2	91.0	121.3	18.5	5.0	
5.1	73.2	97.9	2.5	6.6	
5.2	74.0	98.7	14.0	4.4	

*Except as indicated by the following notes, dimensions apply to 100% and 120% speed and destructive overspeed.

NOTES: (a) 100% speed

(b) 120% speed

(c) Destructive overspeed

3.2 High Pressure Turbine

3.2.1

For this report, it is assumed that the HP rotor fails as shown in Figure 4. Failure such as that illustrated will generate eight fragments that may become missiles; note that the two end sections of the rotor are assumed not to become missiles. HP turbine missile impact areas and dimensions are given in Figure 5 and tabulated in TABLE 3.

3.2.2

It is not necessary to calculate missiles at the ductile bursting speed of the HP rotor since this bursting speed is higher than the theoretical terminal speed of the unit.

3.2.3

The ejection angle of the HP rotor fragments is assumed to be ± 5 degrees measured from the vertical radial plane perpendicular to the rotor's longitudinal axis.

3.3 Low Pressure Turbine

3.3.1

In evaluating the capability of LP turbine structures to contain fragments, it is assumed that a single disc fails and fractures into several parts. Segments of 90, 120 and 180 degrees have been considered but only 90 and 120 degree segment properties are reported. Because of kinematic considerations, a 180 degree disc segment will have a lower initial translational energy and more of the energy is absorbed by the internal structures. As a result, the likelihood of generating

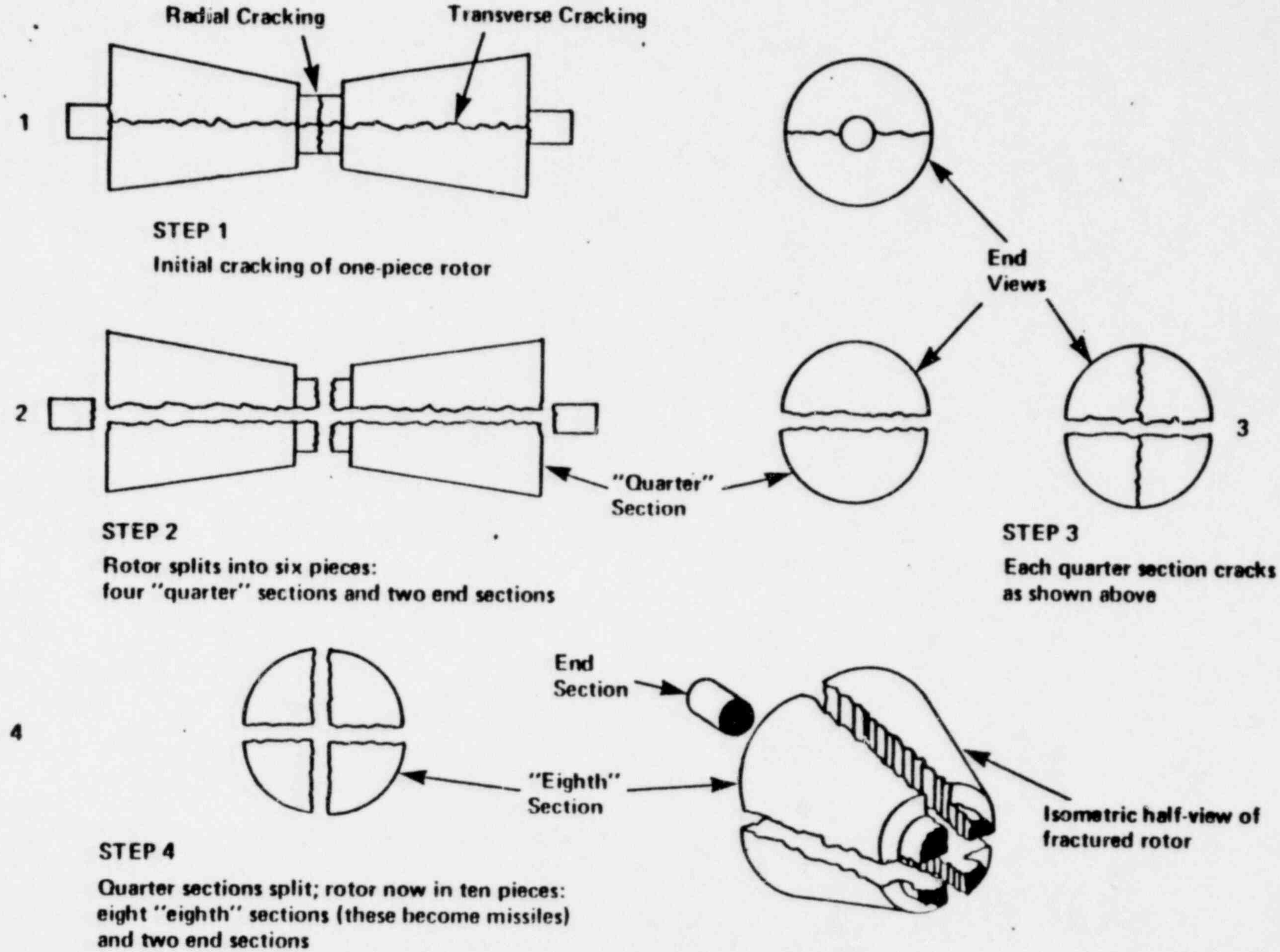

FIGURE 4
HP ROTOR FRACTURE SEQUENCE

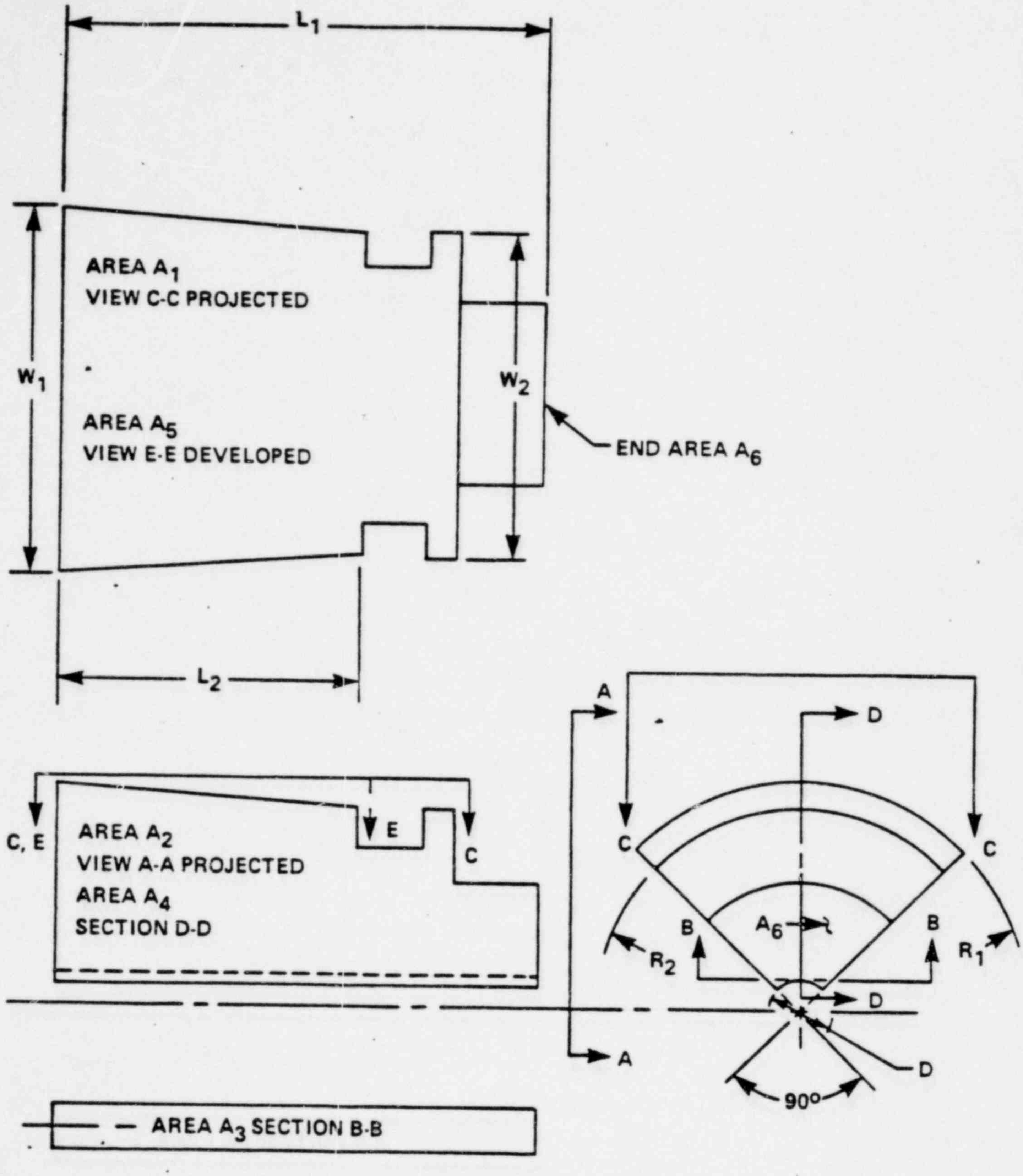

FIGURE 5
HP MISSILE AREAS AND DIMENSIONS

TABLE 3

HP TURBINE ROTOR MISSILES — DIMENSIONS AND IMPACT AREAS

(REFER TO FIGURE 5)

DIMENSIONS (ft)		IMPACT AREAS (ft^2)	
L_1	5.44	A_1	16.83
L_2	3.34	A_2	11.48
W_1	3.96	A_3	4.08
W_2	3.65	A_4	10.88
D	0.75	A_5	14.00
R_1	2.80	A_6	1.66

missiles is less than for the other segments, and exit energies will be lower. LP turbine missile impact areas and dimensions are given in Figure 6 and tabulated in TABLES 4 and 5.

The potential for distributed bore cracks and field experience indicate that an LP disc burst may result in major segments (hub to rim fractures) varying in size from approximately 30 to 200 degrees. Although missile data for only 90 and 120 degree segments are presented in this report, an assessment was made to determine if smaller, larger, or intermediate size disc segments could exit with higher energies. The results of this assessment indicate that 90 and 120 degree segments are reasonable approximations for the highest exiting energy disc segment.

3.3.2

The bursting speed of each shrunk-on disc is calculated. The criterion used is that the disc will fail when the average tangential stress equals the maximum temperature corrected tensile strength of the disc material. The maximum value was taken as the minimum specification value plus 20 KSI. Upon failure of the initial disc, further acceleration is assumed to halt because of damage to the turbine. For purposes of calculating and reporting the energies of missiles, all other discs are assumed to fail at the same speed as the initial disc.

3.3.3

The calculated value of destructive overspeed for this unit is 191% of rated speed. This is the speed at which the initial LP disc fails. The No. 2 disc is the initial disc to fail on this unit.

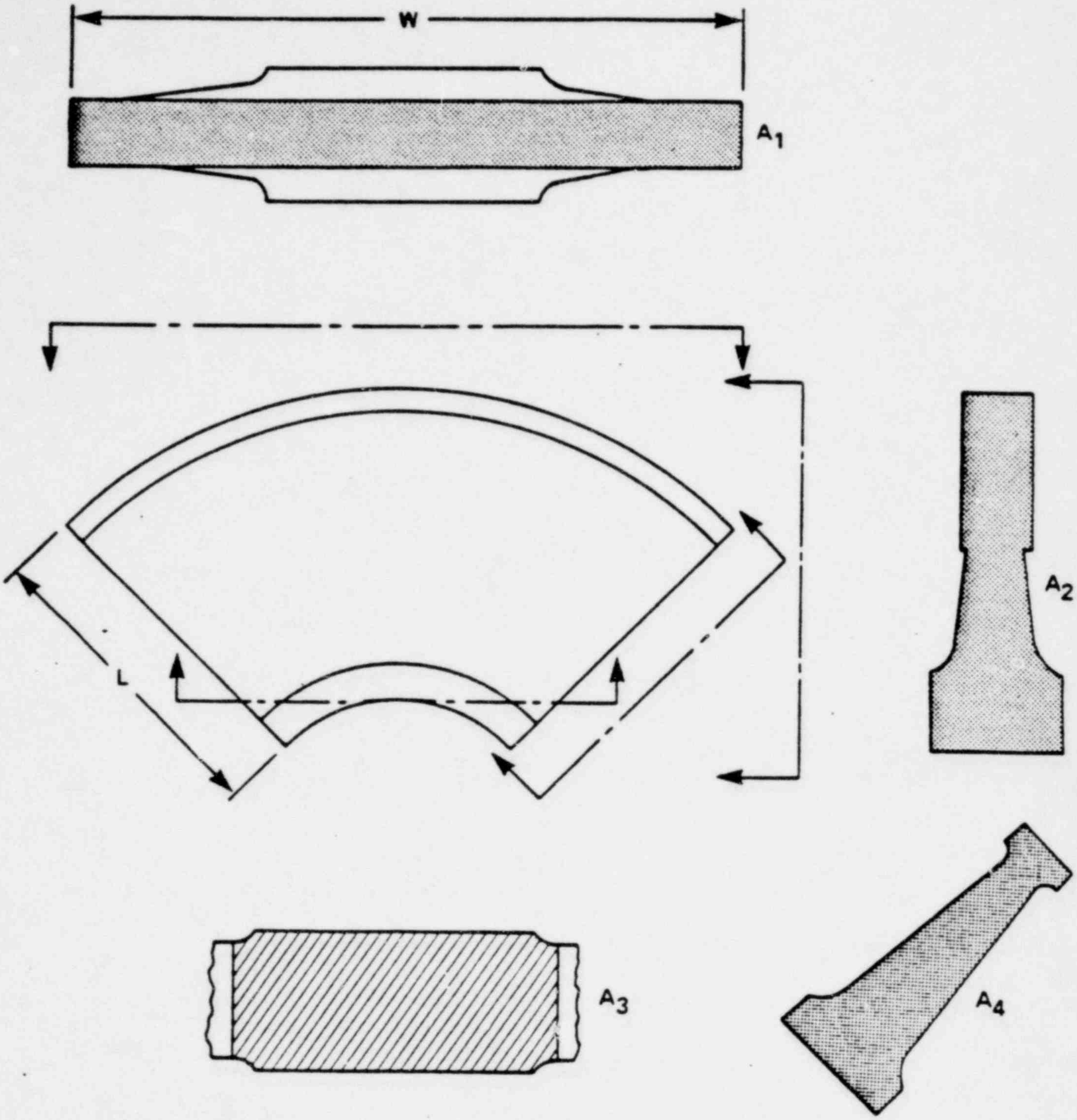

FIGURE 6
LP DISC MISSILES (See tables 4 & 5)

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TABLE 4
DIMENSIONS AND IMPACT AREAS FOR 90° LP DISC FRAGMENTS

(REFER TO FIGURE 6)

DISC NO.	A_1 (ft^2)	A_2 (ft^2)	A_3 (ft^2)	A_4 (ft^2)	W (ft)	L (ft)
1	4.94	2.40	3.33	1.27	6.08	2.64
2	4.28	2.23	3.09	1.26	6.08	2.72
3	2.03	1.77	3.09	1.28	6.08	2.80
4	2.45	2.03	3.33	1.46	5.88	2.74
5	3.10	2.60	4.00	1.89	5.32	2.43

TABLE 5
DIMENSIONS AND IMPACT AREAS FOR 120° LP DISC FRAGMENTS

(REFER TO FIGURE 6)

DISC NO.	A_1 (ft^2)	A_2 (ft^2)	A_3 (ft^2)	A_4 (ft^2)	W (ft)	L (ft)
1	6.05	3.12	4.61	1.27	7.45	2.64
2	5.24	2.84	4.34	1.26	7.45	2.72
3	2.48	2.11	4.35	1.28	7.44	2.80
4	3.00	2.40	4.74	1.46	7.20	2.74
5	3.80	3.03	5.92	1.89	6.51	2.43

3.3.4

The ejection angles of the disc missiles are given by the following guidelines (refer to Figure 7):

- o Discs 1, 2, 3, and 4: $\pm$ 5 degrees measured from the vertical radial plane passing through the disc.
- o Disc 5: 5 degrees to 25 degrees measured from the vertical radial plane passing through the disc. Fragments from this disc will eject only towards the cylinder end wall.

ANALYSIS RESULTS

This section gives the weights, velocities, and translational kinetic energy for the potential HP and LP missiles described in this report. The data for this section is presented in tabular form; the following is a breakdown of these tables:

- o HP Element Initial Rotor Fragment Properties are given in TABLE 6,
- o HP Element Exit Missile Properties are given in TABLE 7,
- o LP Element Initial Disc Segment Properties are given in TABLE 8,
- o LP Element Exit Missile Properties are given in TABLES 9 through 13, and
- o LP Disc Indentification Information is given in TABLE 14.

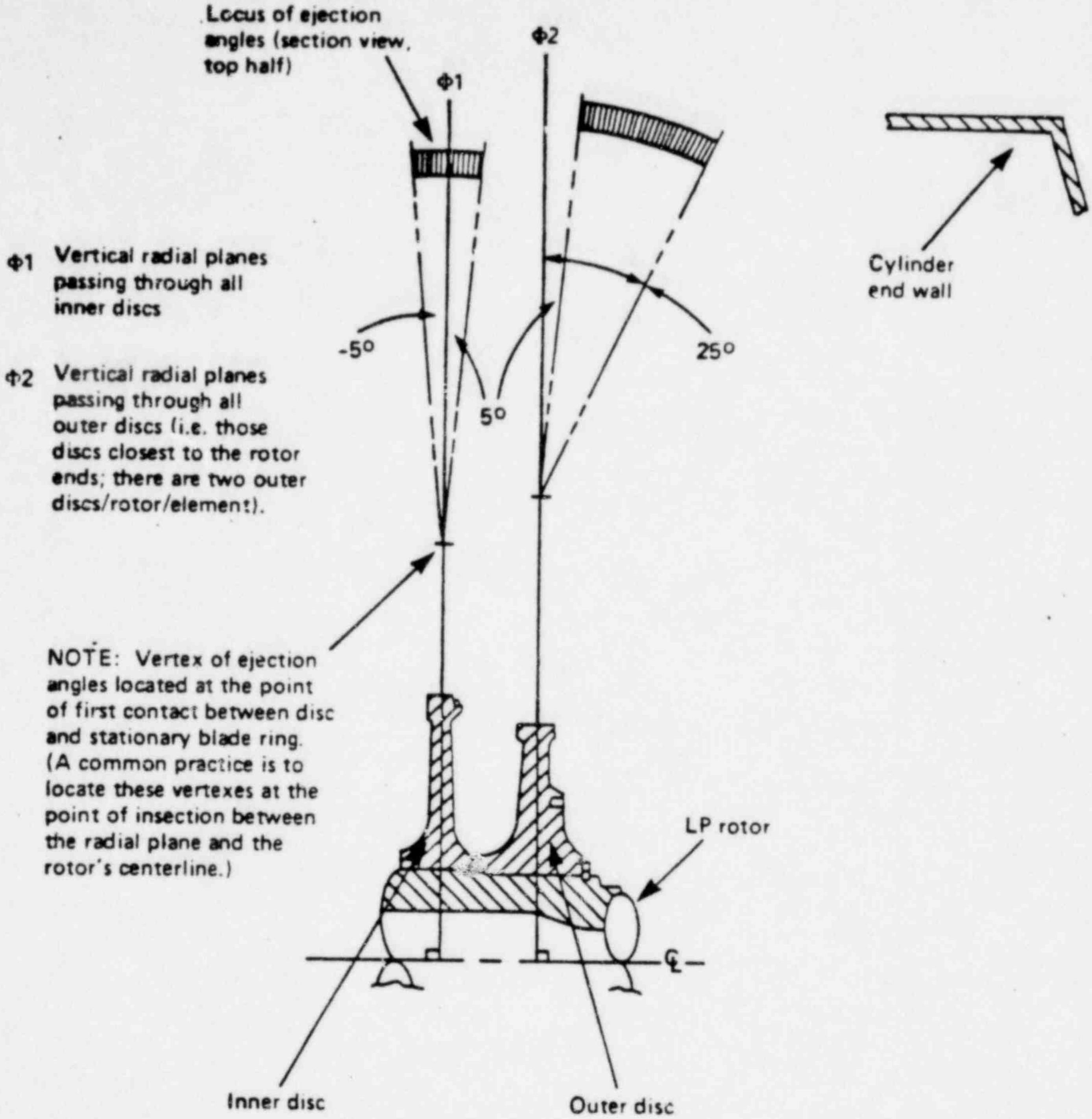

FIGURE 7
EJECTION ANGLES FOR LP MISSILES

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TABLE 6

INITIAL ROTOR FRAGMENT PROPERTIES — HIGH PRESSURE TURBINE (90° ROTOR FRAGMENT)

	100% SPEED			120% SPEED	
FRAGMENT	WEIGHT (lb)	VELOCITY (ft/sec)	ENERGY (10^6 ft-lb)	VELOCITY (ft/sec)	ENERGY (10^6 ft-lb)
Initial 90° Section	11830	307	17.30	371	25.27

TABLE 7

EXIT MISSILE PROPERTIES — HIGH PRESSURE TURBINE (90° ROTOR FRAGMENT)

	100% SPEED			120% SPEED	
FRAGMENT	WEIGHT (lb)	VELOCITY (ft/sec)	ENERGY (10^6 Ft-lb)	VELOCITY (ft/sec)	ENERGY (10^6 ft-lb)
Initial 90° Section	11830	Contained	—	95	1.67
BLADE RING NO. 1	1870	Contained	—	95	0.26
BLADE RING NO. 2	2625	Contained	—	95	0.37
CYLINDER	3960	Contained	—	95	0.56

TABLE 8
INITIAL DISC SEGMENT PROPERTIES FOR LP DISCS NOS. 1 THROUGH 5 (LP 1, 2)

	WEIGHT (lb)	100% SPEED VELOCITY (ft/sec)	100% SPEED ENERGY 10^6 ft-lb)	120% SPEED VELOCITY (ft/sec)	120% SPEED ENERGY (10^6 ft-lb)	DESTRUCTIVE OVERSPEED VELOCITY (ft/sec)	DESTRUCTIVE OVERSPEED ENERGY (10^6 ft-lb)
90^o DISC SEGMENT							
DISC No. 1	2700	558	13.04	674	19.03	1101	50.89
DISC No. 2	2965	581	15.52	702	22.72	1149	60.80
DISC No. 3	2775	543	12.70	657	18.59	1076	49.84
DISC No. 4	3210	544	14.76	658	21.61	1077	57.85
DISC No. 5	3980	522	16.83	631	24.57	—	—
DISC No. 5*	3710	—	—	—	—	931	49.92
120^o DISC SEGMENT							
DISC No. 1	3600	491	13.46	589	19.38	937	49.11
DISC No. 2	3955	511	16.04	613	23.08	976	58.48
DISC No. 3	3695	477	13.08	573	18.84	912	47.74
DISC No. 4	4285	479	15.24	575	21.95	914	55.60
DISC No. 5	5305	462	17.58	554	25.32	—	—
DISC No. 5*	4945	—	—	—	—	799	48.98

*Weight change due to loss of blades prior to reaching destructive overspeed.

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TABLE 9
EXIT MISSILE PROPERTIES FOR NO. 1 LP DISC AND FRAGMENTS (LP 1, 2)

	WEIGHT (lb)	100% SPEED VELOCITY (ft/sec)	100% SPEED ENERGY (10^6 ft-lb)	120% SPEED VELOCITY (ft/sec)	120% SPEED ENERGY (10^6 ft-lb)	DESTRUCTIVE OVERSPEED VELOCITY (ft/sec)	DESTRUCTIVE OVERSPEED ENERGY (10^6 ft-lb)
90^o DISC BURST							
DISC No. 1	2700	Contained		Contained		113	0.54
FRAGMENT No. 1.1	3470	Contained		Contained		113	0.69
FRAGMENT No. 1.2	2270	Contained		Contained		113	0.45
FRAGMENT No. 1.3	1920	Contained		Contained		113	0.38
120^o DISC BURST							
DISC No. 1		Contained		Contained		Contained	
FRAGMENT No. 1.1		Contained		Contained		Contained	
FRAGMENT No. 1.2		Contained		Contained		Contained	
FRAGMENT No. 1.3		Contained		Contained		Contained	

TABLE 10
EXIT MISSILE PROPERTIES FOR NO. 2 LP DISC AND FRAGMENTS (LP 1, 2)

		100% SPEED		120% SPEED		DESTRUCTIVE OVERSPEED	
	WEIGHT (lb)	VELOCITY (ft/sec)	ENERGY (10^6 ft-lb)	VELOCITY (ft/sec)	ENERGY (10^6 ft-lb)	VELOCITY (ft/sec)	ENERGY (10^6 ft-lb)
90^o DISC BURST							
DISC No. 2	2965	184	1.56	239	2.64	441	8.94
FRAGMENT No. 2.1	2895	184	1.52	239	2.57	441	8.73
FRAGMENT NO. 2.2	545	123	0.13	157	0.21	—	—
FRAGMENT NO. 2.2	130	—	—	—	—	484	0.47
120^o DISC BURST							
DISC No. 2	3955	148	1.34	197	2.39	352	7.61
FRAGMENT No. 2.1	3915	148	1.33	197	2.36	352	7.53
FRAGMENT No. 2.2	725	108	0.13	138	0.22	239	0.64

TABLE 11
EXIT MISSILE PROPERTIES FOR NO. 3 LP DISC AND FRAGMENTS (LP 1, 2)

	WEIGHT (lb)	100% SPEED VELOCITY (ft/sec)	100% SPEED ENERGY (10^6 ft-lb)	120% SPEED VELOCITY (ft/sec)	120% SPEED ENERGY (10^6 ft-lb)	DESTRUCTIVE OVERSPEED VELOCITY (ft/sec)	DESTRUCTIVE OVERSPEED ENERGY (10^6 ft-lb)
90° DISC BURST							
DISC No. 3	2775	166	1.19	292	3.67	600	15.54
FRAGMENT No. 3.1	1270	219	0.95	—	—	—	—
FRAGMENT No. 3.1	765	—	—	377	1.69	710	6.00
FRAGMENT No. 3.2	970	177	0.47	310	1.46	639	6.17
120° DISC BURST							
DISC No. 3	3695	82	0.39	148	1.26	471	12.75
FRAGMENT No. 3.1	1690	188	0.93	244	1.57	—	—
FRAGMENT No. 3.1	1020	—	—	—	—	594	5.60
FRAGMENT No. 3.2	1295	89	0.16	159	0.51	507	5.17

TABLE 12
EXIT MISSILE PROPERTIES FOR NO. 4 LP DISC AND FRAGMENTS (LP 1, 2)

	WEIGHT (lb)	100% SPEED VELOCITY (ft/sec)	100% SPEED ENERGY (10^6 ft-lb)	120% SPEED VELOCITY (ft/sec)	120% SPEED ENERGY (10^6 ft-lb)	DESTRUCTIVE OVERSPEED VELOCITY (ft/sec	DESTRUCTIVE OVERSPEED ENERGY (10^6 ft-lb)
90° DISC BURST							
DISC No. 4	3210	369	6.78	460	10.54	781	30.44
FRAGMENT No. 4.1	480	369	1.01	460	1.58	781	4.55
FRAGMENT No. 4.2	2380	186	1.28	232	2.00	395	5.76
120° DISC BURST							
DISC No. 4	4285	315	6.62	391	10.20	650	28.14
FRAGMENT No. 4.1	640	315	0.99	391	1.52	650	4.21
FRAGMENT No. 4.2	3175	196	1.89	243	2.91	404	9.03

TABLE 13
EXIT MISSILE PROPERTIES FOR NO. 5 LP DISC AND FRAGMENTS (LP 1, 2)

	WEIGHT (lb)	100% SPEED VELOCITY (ft/sec)	100% SPEED ENERGY (10^6 ft-lb)	120% SPEED VELOCITY (ft/sec)	120% SPEED ENERGY (10^6 ft-lb)	DESTRUCTIVE OVERSPEED VELOCITY (ft/sec)	DESTRUCTIVE OVERSPEED ENERGY (10^6 ft-lb)
90° DISC BURST							
DISC No. 5	3980	408	10.29	498	15.35	—	—
DISC No. 5*	3710	—	—	—	—	756	32.90
FRAGMENT No. 5.1	340	408	0.88	498	1.32	756	3.04
FRAGMENT No. 5.2	1290	193	0.74	235	1.11	358	2.56
120° DISC BURST							
DISC No. 5	5305	352	10.22	428	15.12	—	—
DISC No. 5*	4945	—	—	—	—	635	30.95
FRAGMENT No. 5.1	455	352	0.88	428	1.30	635	2.86
FRAGMENT No. 5.2	1720	198	1.04	240	1.54	357	3.41

*Weight change due to loss of blades prior to reaching destructive overspeed.

TABLE 14

LP TURBINE DISC IDENTIFICATION INFORMATION

LP-1 (23A3592-1) DISC TEST NUMBERS

DISC NO.	GOVERNOR END	GENERATOR END
1	TN 1302	TN 1301
2	TN 1362	TN 1361
3	TN 1364	TN 1363
4	TN 1240	TN 1241
5	TN 1303	TN 1304

LP-2 (23A3593-1) DISC TEST NUMBERS

DISC NO.	GOVERNOR END	GENERATOR END
1	TN 1306	TN 1659
2	TN 1366	TN 1629
3	TN 1368	TN 1367
4	TN 1231	TN 1233
5	TN 1307	TN 1308