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SUMMARY

The exit energy and velocity of hypothetical turbine wheel missiles from the LP section of nuclear turbines have been calculated. All low pressure turbine wheels are assumed candidates for burst in both "low speed" and "high speed" burst modes. Sixteen fragments are postulated to be generated per wheel burst; missiles weighing up to 8000 pounds may be ejected. A new penetration model is employed to determine the energy absorption capability of the stationary structures. The exit energy and velocity ranges for the entire spectrum of postulated missiles are discussed with reference to the 43 inch last stage bucket nuclear unit.

KEY WORDS

turbine missiles, wheel fragments, energy, velocity, penetration

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I. INTRODUCTION

The licensing procedures of the Atomic Energy Commission require the consideration of hypothetical turbine missiles as part of the review of plant safety. The Turbine Department has assisted the utilities in the preparation of their Safety Analysis Reports by providing a description of these hypothetical turbine missiles. This description includes the probability of occurrence as well as the resulting energy and velocity of the missile, should a burst occur.

Earlier work in connection with missile description includes that of Downs [1]* and Zwicky [2]. Zwicky concludes that the most energetic turbine wheel missile is a 120° fragment of a last stage wheel. Downs finds that the probability of generation of such a missile is extremely small.

The Turbine Department has recently reconsidered the missile problem and has issued a series of Memo Reports [3-6] summarizing its findings. This new body of work considers all the wheels of the low pressure turbine and takes into account a spectrum of fragment sizes per wheel burst. The purpose of this report is to describe the technique employed in the evaluation of these fragments.

Prior to obtaining the information contained in References [3] through [6], missile energies were calculated using Zwicky's method of analysis. Many assumptions were made in

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*Numbers in brackets refer to the references.

that analysis, including the manner in which energy is absorbed by the stationary parts. Zwicky assumed that the stationary material surrounding the last stage wheel would be stretched to its ultimate strength. Simple containment tests recently conducted by the Turbine Department have indicated that energy is lost to the containment primarily by local plastic deformation rather than by gross stretching. In light of these findings, a new technique for the calculation of missile energies has been developed.

II. RESULTS

II. A. Missile Sizes and Energy

Turbine missiles are assumed to be generated as a result of a hypothetical burst of a low pressure turbine wheel. Two burst situations are considered: (1) a "low speed" burst near running speed due to material deficiency and (2) a "high speed" burst at 80% overspeed in a runaway condition following a control system failure. These two postulated burst situations are identified in the studies of the probability of wheel burst by Downs [1] and [3].

All wheels of the low pressure turbine are considered as candidates for bursting. The probability of burst of a given wheel is a function of the speed as well as the particular turbine type under consideration.

To simplify calculations, wheels with similar characteristics (e.g., weight, size, energy) are grouped together and the properties of one wheel of the group are used to calculate missile properties. For example, the seven wheels of the 43 inch last stage bucket low pressure turbine are divided into three Groups. Group I consists of the first three stages; Group II - the fourth through sixth stages; and Group III - the last stage wheel. Assumming that a burst occurs, it has been found that all wheels are capable of producing missiles external to the turbine in both th. low speed and high speed burst situations. However, the analysis contained in Ref.[4] points out that the probability of burst of stages in Groups I and II at low speed is not statistically significant.

For each wheel fragment and assumed burst speed a range of energy is specified. This range results from uncertainties associated with the orientation of the missile fragment as it penetrates the turbine casing as well as the energy absorbing capability of the stationary components. A small fragment, for example, may exit through a hole created in the turbine by a larger missile, or it may be completely contained by the stationary components. In this case, its escape energy can vary between its initial energy (no collision) to zero (containment).

Table 2 is a summary of the exit energy and velocity ranges that have been calculated for the entire spectrum of postulated fragments. Notice that the fragments of the last stage wheel are significantly more energetic than those of all the other wheels. The velocity ranges given in the table are intended for use in trajectory related calculations.

The entire spectrum of fragment sizes, energies, and velocities given in Tables 1 and 2 is required to perform a detailed analysis of the overall probability of unacceptable consequences due to hypothetical turbine missiles. The need for this information has been prompted by consideration of trajectory related calculations.

II. B. Model for Energy Calculations

A small fragment (chosen less than 45°) could escape the turbine through a hole made by a larger fragment. In this case, its escape energy is equal to its initial energy. On the other hand, a small fragment could be completely contained within the turbine, in which case its exit energy is zero. Then the range of exit energies for small fragments is taken to be between their initial energies and zero.

The larger fragments (45° or larger) cannot escape the turbine casing without loss of energy due to impact with and penetration of various stationary components. The model used in estimating the energy absorption capability of these stationary parts is shown in Figure 1.

The complex nature of the geometry and uncertainties such as the effect of rotation has led to an idealization of the overall problem. Components included in the analysis are the wheel fragment, the web and ring of the diaphragm, the inner casing wrapper, and the exhaust hood.

The behavior of the hypothetical missile is postulated as follows: (1) the wheel bursts into various fragments with no loss of total energy, (2) each major fragment impacts the diaphragm web and creates at least two web fragments, (3) the web fragments are accelerated out of the path of the missile, (4) diaphragm ring fragments are also created and accelerated, (5) the inner casing is penetrated, and finally (6) penetration of the exhaust hood occurs.

Figure 2 shows the calculated energy and velocity ranges as a function of fragment size. Data for the 43 inch last stage wheel are used for illustration. Note that a wide variation in velocity exists for the smaller fragments.

III. TECHNICAL DISCUSSION

III. A. Wheel Fragments

Missile studies in the past have been concerned with only one size fragment; the fragment that possessed the highest energy external to the turbine. This simplification was justified since it was further assumed that, given a wheel burst, the fragment would strike a critical target. The missile with the highest energy would, therefore, have the highest overall probability of damaging the critical target.

The introduction of trajectory-related calculations requires consideration of both the energy and the velocity of hypothetical missiles. The velocity is required to determine the strike probability. Downs [6] shows that a missile with low velocity is important since it has a relatively higher probability of striking a given target. Furthermore, various fragment sizes must be considered since the fragment mass influences the relationship between energy and velocity.

Two sources of information have been utilized in estimating the number and associated sizes of wheel fragments assumed in this report. One source is the Hinkley Point failure of September 1969 [7]; the other source is an extensive experimental disc-bursting study conducted by the Steam Turbine Department of the General Electric Company.

A review of General Electric burst tests clearly indicates a trend of fewer fragments with increasing excess temperature* (increasing toughness). All tests produced three or four large fragments. In addition, those tests conducted at negative excess temperatures produced many small fragments.

The failure of the Hinkley Point wheels is attributed to their low material toughness, which made them incapable of accommodating small cracks produced by stress corrosion. These wheels, which burst at negative excess temperature, generated between about 5 and 40 fragments.

The following number of fragments and associated sizes have been selected for use in this report after a careful review of many burst tests:

Fragment Group (See Table I)	Number of Fragments
Type a	2
Type b	1
Type c	3
Type d	10

*The excess temperature is defined as the operating temperature minus the fracture appearance transition temperature.

Because of the high material toughness of wheels used in nuclear turbines built by the author's company, a relatively low number of smaller fragments (Type d) is expected. A number of ten is assumed to admit other potential missiles, such as buckets, to the distribution.

III. B. Assumed Burst Speeds

Two situations are postulated which result in a hypothetical wheel burst. One case is termed a "low speed" burst which is assumed to occur at or near running speed. The specific turbine speed for this situation is taken to be 120% of normal running speed, since it is the maximum rotor speed reached without a complete control system failure. The second case is termed a "high speed" burst during runaway following a complete control system failure.

The "high speed" burst is assumed to occur at the vane shedding speed which is 180% of running speed. It is postulated that the rotational unbalance developed during the loss of the vanes will cause gross mechanical failure, particularly of the bearings, so that higher rotor speed is unlikely.

Thus, the high speed wheel failure is postulated to occur at an upper limit of maximum turbine speed. Even at this speed, it is unlikely that the wheel will fail since the unloading of the wheel caused by the loss of the vanes results in a higher overspeed capability of the wheel.

III. C. Initial Fragment Energy

C.1. Translational and Rotational Energy

The wheel is assumed to fracture into various fragments with the fracture surfaces occurring in an axial-radial plane. The assumption of conservation of linear and angular momentum leads to the following expressions for the translational and angular velocities of the center of gravity of each fragment.

$$V_{cg} = \omega R_{cg} \tag{1}$$

$$\psi_{cg} = \omega \tag{2}$$

where

V_{cg} = linear velocity at center of gravity of fragment,

ω = angular velocity of shaft at burst,

R_{cg} = radius to center of gravity of fragment measured from shaft centerline, and

ψ_{cg} = angular velocity of fragment.

The translational and rotational energy of the fragment are simply:

$$KE_{tr} = \frac{1}{2} M_f V_{cg}^2 \tag{3}$$

$$KE_{ro} = \frac{1}{2} J_f \psi_{cg}^2 \tag{4}$$

where

KE_{tr} = translational kinetic energy of fragment,

KE_{ro} = rotational kinetic energy of fragment,

M_f = total mass of fragment, and

J_f = polar moment of inertia about c.g. of fragment.

These formulations of initial fragment motion and energies conservatively assume that there is no loss of energy during the generation of fragments and that there is no transfer of energy between fragments due to collisions subsequent to the burst.

III. C.2. Effective Translational Energy

The rotational energy comprises a significant fraction of the initial total energy of a fragment, and can contribute to the penetrating capability of the fragment. Hence the rotational energy cannot be neglected in estimating the escape energy of the missile fragment. The rotational energy of a 120° fragment, for example, represents approximately 35% of the total energy.

An "Effective Translational Energy" is defined which accounts for the additional penetrating capability of a fragment possessing rotational as well as translational energy. The fragment is visualized as a system of particles, each with a different velocity. A particle having a velocity normal to a stationary component, has greater penetrating capability than another particle with the same velocity magnitude, but impacting the plate at an oblique angle. A particle with a velocity in a direction parallel to the stationary component has no penetrating capability. This model leads to the following definition of the quantity, "Effective Translational Energy":

$$KE_{eff} \triangleq \frac{1}{2} \int_V V_\alpha^2 \rho \, dv \qquad (5)$$

where

KE_{eff} = effective translational energy,

V_α = component of absolute velocity normal to the stationary component,

ρ = mass density of fragment, and

dv = incremental volume of fragment.

Figure 3 describes the model and the nomenclature which is used to develop Equation 5. The wheel fragment is treated as a sector of a disc and the stationary component as a flat surface. The fragment has both rotational and translational motion.

The integration of Equation 5 leads to the following expression for the Effective Translational Energy of the disc fragment:

$$KE_{eff} = KE_{tr}\left\{1 + \frac{9}{16}\left[\left(\frac{\phi/2}{\sin\phi/2}\right)^2 + \cos\frac{\phi}{2}\left(2\cos^2\alpha - 1\right)\left(\frac{\phi/2}{\sin\frac{\phi}{2}}\right)\right] - \cos^2\alpha\right\} \tag{6}$$

The important feature of this relationship is that the Effective Translational Energy is a function of the missile size, ϕ, and the orientation of the missile at impact, α. Equation 6 can also be expressed in terms of the translational and rotational energies of the disc sector:

$$KE_{eff} = KE_{tr} + C\ KE_{ro} \tag{7}$$

The value of "C" in Equation 7 is a function of the missile size and the orientation at impact. For example, the value of "C" for a 120° segment striking a stationary component in the direction of minimum projected area ($\alpha = 0°$) is 0.25, and in the direction of maximum projected area ($\alpha = 90°$), "C" is 0.75.

A study dealing with the effect of "C" has shown that the hypothetical missile energy external to the turbine is largest when the motion of the fragment is in the direction of minimum projected area ($\alpha = 0$). Although other orientations result in higher initial energies of the missile fragments, the energies external to the turbine are lower because of larger impact areas and greater energy absorption by the stationary components.

Equation 7 is applied to the wheel fragment. The uncertainty concerning the angle of orientation leads to an uncertainty in exit energies and is included in the ranges of hypothetical missile energies.

A number of fragment properties are necessary to compute the initial missile energy. These include the fragment mass, location of center of gravity, and the polar moment of inertia. Because of the irregular shape of the wheel fragment, a numerical technique similar to that described by Zwicky [2] is used to calculate the properties.

III. D. Diaphragm Web and Ring Collisions

The diaphragm is in the path of the wheel fragment and must be accelerated out of the way to permit the escape of the missile. It is assumed that the impact causes the diaphragm web to fracture in a brittle manner with no loss of energy, so that the only energy absorbed is that required to accelerate the diaphragm web fragments out of the missile path. The energy absorption capability of the diaphragm partitions is assumed to be zero--they are neglected.

The wheel fragment is assumed to accelerate the fragments of the diaphragm web that are directly in its path and transfer energy to them during the collision. A similar collision and energy transfer is assumed to occur between the wheel fragment and the diaphragm ring.

Figure 4 illustrates the model that is used to estimate the energy loss by the missile as a result of the web and ring collisions. Recall from the discussion of the Effective Translational Energy that the wheel fragment is assumed to be oriented in the direction of minimum projected area at the instant of impact (to minimize energy loss in penetration, and thus maximize the escape energy).

The wheel fragment is assumed to accelerate two web fragments in directions approximately 45° from the missile path. The assumed number and directions of the web fragments chosen were based primarily on the shape of the impacting wheel fragment missile. The same model is used for the ring impact.

Conservation of both momentum and energy is assumed in calculating the energy of the wheel fragment after collision:

Momentum: $$M_f V_{f_i} = M_f V_{f_f} + 2\left(\frac{M_w}{2}\right) V_{w_f} \cos 45° \qquad (8)$$

Energy: $$M_f V_{f_i}^2 = M_f V_{f_f}^2 + 2\left(\frac{M_w}{2}\right) V_{w_f}^2 \qquad (9)$$

where

M_f = mass of wheel fragment

M_w = mass of web fragments,

V_{fi} = wheel fragment velocity before collision,

V_{ff} = wheel fragment velocity after collision, and

V_{wf} = web fragment velocity after collision.

The resulting expression for the energy retained by the wheel fragment is:

$$KE_f = KE_i \left[\frac{2\frac{M_f}{M_w} - 1}{2\frac{M_f}{M_w} + 1} \right]^2 \qquad (10)$$

where

KE_f = wheel fragment energy after collision and

KE_i = wheel fragment energy before collision.

The mass of the web and ring fragments is calculated using the volume of web and ring material which is in the path of the exiting wheel fragment. One web and ring are considered per wheel.

III. E. Wrapper and Exhaust Hood Penetration

The energy lost by the missile during penetration of the inner casing wrapper and the exhaust hood is calculated by use of the emperical relation described by Moore [8] as the "Stanford formula." The Stanford formula applies to missiles having a right circular solid shape which impact a flat plate with the axis of the cylinder normal to the plate.

An "equivalent circular diameter" concept is used to account for the irregular shape of the wheel fragment missile. Since the penetration is produced primarily by a shear mode, the perimeter of the projected impact area is used to define the equivalent circular diameter:

$$D_{eq} = \frac{P}{\pi} \qquad (11)$$

where

D_{eq} = equivalent circular diameter, and

P = perimeter of projected impact area.

The "window width," which defines the unsupported area of the plate, is conservatively approximated by the equivalent diameter. The modified Stanford formula is thus:

$$E_{loss} = U \; D_{eq} \, t \left(0.344 \, t + 0.008 \, D_{eq}\right) \qquad (12)$$

where

E_{loss} = energy loss during penetration (ft.lbs.),

U = ultimate tensile strength of stationary component (psi),

D_{eq} = equivalent circular diameter (in.), and

t = thickness of stationary component (in.).

Defining the thickness and the perimeter to use in connection with the inner casing wrapper penetration calculations requires judgment. Fig. 5 is a cross section of a typical low pressure turbine illustrating the wheels, diaphragm web and ring sections, and the inner casing wrapper. All structures illustrated extend the full 360° about the machine axis. The flange, axial ribs, and struts are conservatively neglected in penetration calculations.

Note that the wrapper does not extend axially over the entire last stage wheel. In this situation the perimeter is taken to be one half of the value calculated by the minimum projected area of the fragment (Eq. 11). The thickness is taken to be the minimum value.

The second stage has a large radial section which is directly over the wheel. The wheel fragment is assumed to be deflected slightly by this section with no loss of energy. When two wrapper regions cover a wheel, separate energy absorption calculations are made for each thickness, and the total absorbed energy is taken to be the sum of the two individual energy values. Since the exhaust hood completely encloses all wheels, the energy loss to the hood is found using the full projected perimeter and a thickness of 1-1/4".

Many assumptions and approximations are necessary in evaluating the energy absorbed by the inner casing wrapper and exhaust hood. Consideration is given to these uncertainties in defining the reported range of external energies.

III. F. Exit Energy and Velocity

Figure 2 is a typical plot of exit energy and velocity as a function of missile size. Note that ranges of energy are given. These ranges result from the many uncertainties involved.

The energy range shown for the larger fragments (greater than 45° in size) is basically due to the uncertainty connected with the absorption capability of the stationary components. The energy range for the smaller fragments (less than 45°) results from the assumption that the small fragments may be ejected through a hole created by a larger fragment or may be slowed down or stopped by the stationary components.

The velocity is calculated by assuming that the energy is all translational energy. This assumption is consistent with the definition of Effective Translational Energy.

$$V = \frac{2E}{M_f} = \frac{64.4\ E}{W_f} \qquad (13)$$

where

V = velocity of c.g., ft. per sec.;

E = exit energy, ft.lbs.;

M_f = fragment mass, slugs; and

W_f = fragment weight, lbs.

The fragment sizes and associated energy and velocity ranges given in Table 2 assume that the spectrum of fragments described in Section III.A. is generated for each wheel burst.

IV. CONCLUSIONS

A new method for the calculation of the energy of hypothetical turbine missiles has been developed. The principle difference between this new method and the method of Zwicky [3] is the mode by which energy is absorbed by the stationary turbine components. Simple containment tests recently conducted by the General Electric Company indicate that local shear deformation rather than the gross deformation assumed by Zwicky is the principle mode of energy absorption. The local deformation mode of energy absorption is utilized by the new method. This results in considerably higher exit energies than those predicted by Zwicky.

The introduction of trajectory related calculations has led to the consideration of both large and small wheel fragment missiles. The number and sizes of these fragments is taken from disc bursting tests by the author's company and from Ref. [7].

The larger wheel fragments impact with and transfer energy to the stationary components of the turbine casing. An "Effective Translational Energy" is utilized to account for the rotational energy of the postulated missile fragments. The "Stanford formula" is employed in calculation of energy absorbed by the turbine casing. A range of exit energy is reported which accounts for the uncertainties involved in these calculations.

The smaller fragments are visualized as either escaping through a hole in the turbine casing created by a larger fragment or being slowed down (or stopped) by the stationary turbine components. The reported energy ranges for the smaller fragments thus lie between their initial energy and zero.

V. ACKNOWLEDGEMENT

The development of the approach presented in this report involved the combined efforts of many people. Many of the assumptions and approximations evolved as a result of numerous meetings and discussions. The author would like to express his appreciation to the individuals intimately involved in this project.

Many assumptions and approximations are used in connection with the initial size and number of fragments, the initial burst speeds, the path of the missile, and the energy absorption capability of the stationary components. These assumptions result in conservative limits of the reported energy and velocity ranges.

VI. REFERENCES

1. J.E. Downs, "Probability of Turbine-Generator Failure Leading to the Ejection of External Missiles," General Electric Company Memo Report, February 22, 1971.

2. E.E. Zwicky, "An Analysis of Turbine Missiles Resulting from Last-Stage Wheel Failure," TR67SL211, October 3, 1967.

3. J.E. Downs, "Hypothetical Turbine Missiles--Probability of Occurrence," General Electric Company Memo Report, March 14, 1973.

4. J.E. Downs, "Hypothetical Turbine Missile Data - 43-Inch Last Stage Bucket Units," General Electric Company Memo Report, March 15, 1973.

5. J.E. Downs, "Hypothetical Turbine Missile Data - 38-Inch Last Stage Bucket Units," General Electric Company Memo Report, March 16, 1973.

6. J.E. Downs, "Hypothetical Turbine Missiles - Sample Calculation," General Electric Memo Report, March 17, 1973.

7. D. Kalderon, "Steam Turbine Failure at Hinkley Point 'A'," Proc. Instn. Mech. Engrs., Vol. 186, 31, 1972.

8. C.V. Moore, "The Design of Barricades for Hazardous Pressure Systems," Nuclear Eng. and Design, Vol. 5, No. 1, 1967.

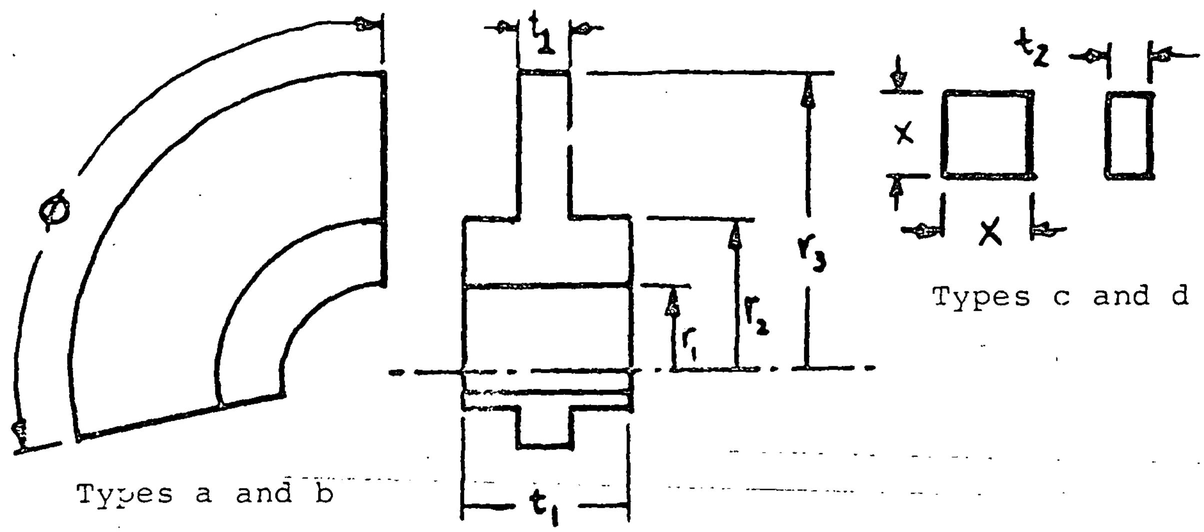
VII. LIST OF TABLES

1. Description of Postulated Wheel Fragments.

2. Energy and Velocity of Hypothetical Wheel Fragment Missiles External to the Turbine.

TABLE 1

Simplified Geometry of Hypothetical Wheel Missiles



Type a: wheel shape, ϕ = 120°

Type b: wheel shape, ϕ = 60°

Type c: x_1, square, t_2 thick

Type d: x_2, square, t_2 thick

Wheel	r_1	r_2	r_3	t_1	t_2	x_1	x_2
43" LSW	17	28	45	27	12	20	8
L-2	18	27	47	12	5	20	10
L-5	20	27	48	9	3	19	11

Note: All dimensions in inches

TABLE 2

Hypothetical Missile Energy and Velocities

For All Wheel Groups and Fragment Types

Of a 43" Last-Stage Bucket Unit

Number of Fragments	Quantity in Table	1st to 3rd Wheel Group	4th to 6th Wheel Group	Last Stage Wheel
2 (Type a)	Weight	2000 (1)	4000	8200
	Energy	0-8 (2) 0-3	0-17 0-7	26-53 10-22
	Velocity	0-510 0-320	0-520 0-340	450-650 280-420
1 (Type b)	Weight	1000	2000	4100
	Energy	0-8 0-3	0-16 0-6	0-38 0-18
	Velocity	0-720 0-440	0-720 0-440	0-770 0-530
3 (Type c)	Weight	300	600	1400
	Energy	0-5 0-2	0-8 0-4	0-16 0-8
	Velocity	0-1000 0-660	0-930 0-660	0-860 0-610
10 (Type d)	Weight	100	150	200
	Energy	0-2 0-1	0-2 0-1	0-3 0-2
	Velocity	0-1100 0-800	0-930 0-660	0-980 0-800

Note: (1) weight is given in lbs ; energy in 10^6 ft lbs ; velocity in ft /sec.

(2) the upper range of values of energy and velocity are calculated for a high speed burst at 180% running speed; lower values - low speed burst at 120% running speed.

VIII. LIST OF FIGURES

1. Sketch of Wheel Region Illustrating Components Included in Penetration Model.

2. Distribution of Hypothetical Missile Energy and Velocity as a Function of Missile Size.

3. Model Employed to Evaluate the Effective Translational Energy

4. Collision Model for Web and Ring Impacts.

5. Cross Section of Typical Low Pressure Turbine.

FIGURE 1

Sketch of Wheel Region Illustrating Components

Included in Penetration Model

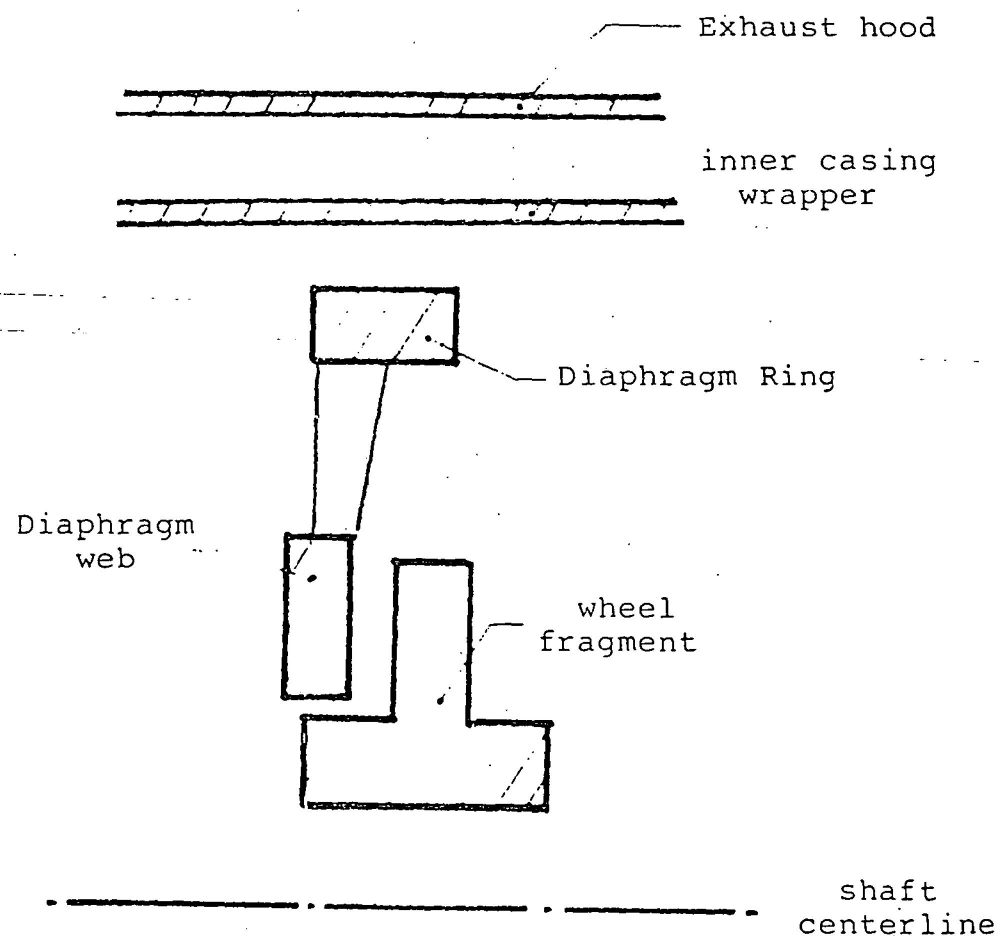


Figure 2

Distribution of Hypothetical Missile Energy

And Velocity as a Function of Missile Size

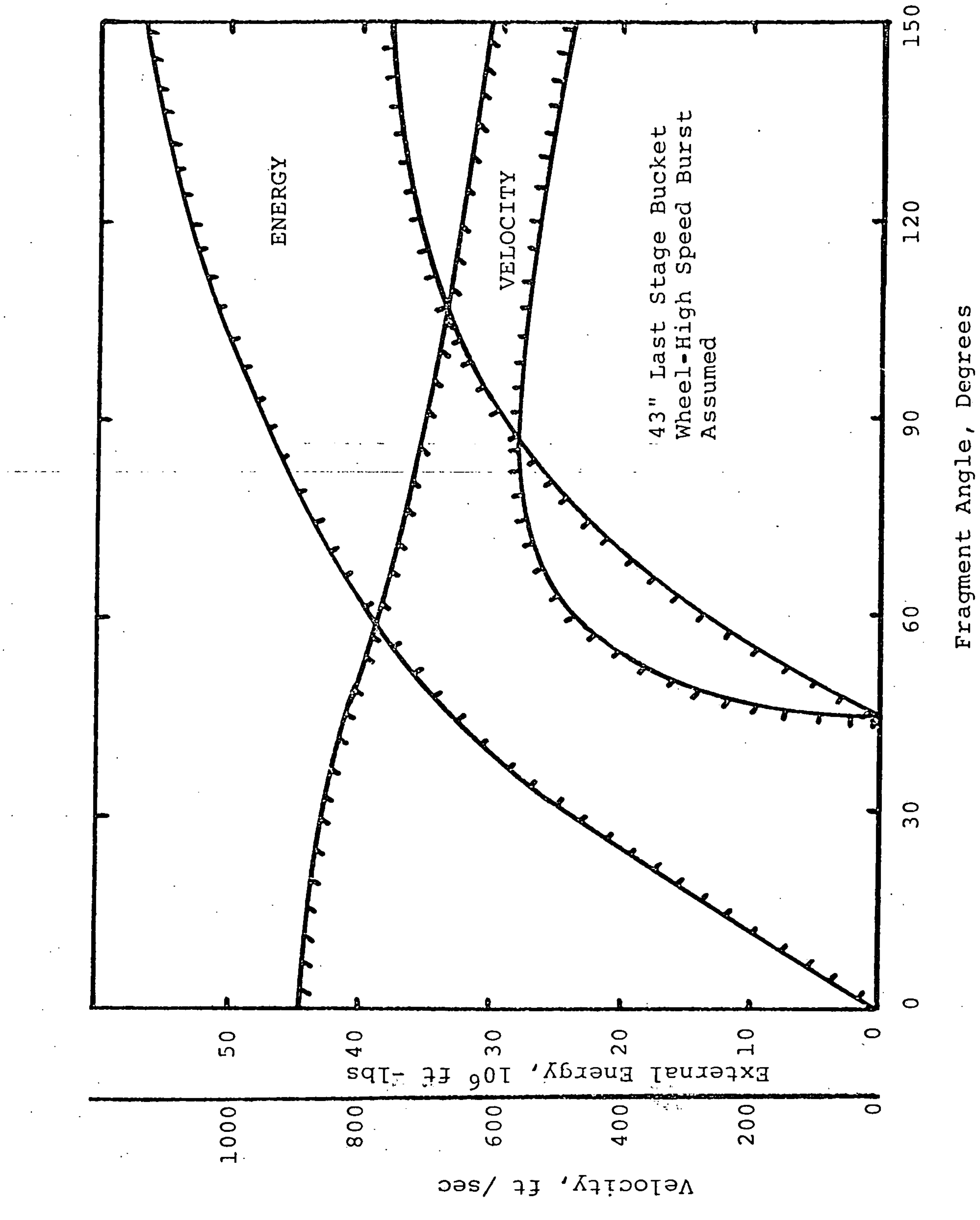


FIGURE 3

Model Employed to Evaluate the

Effective Translational Energy

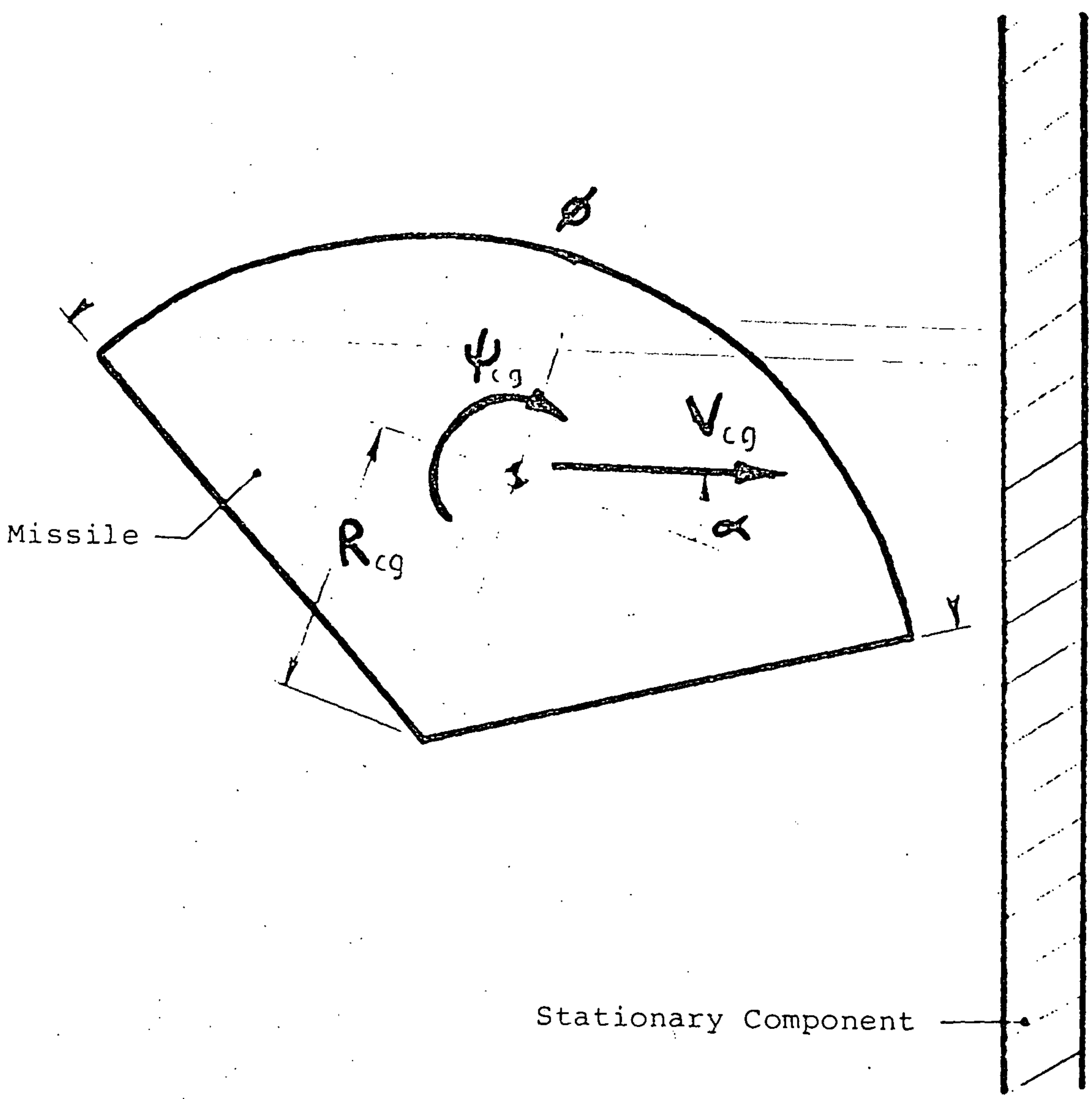


FIGURE 4

Collision Model for Web and Ring Impacts

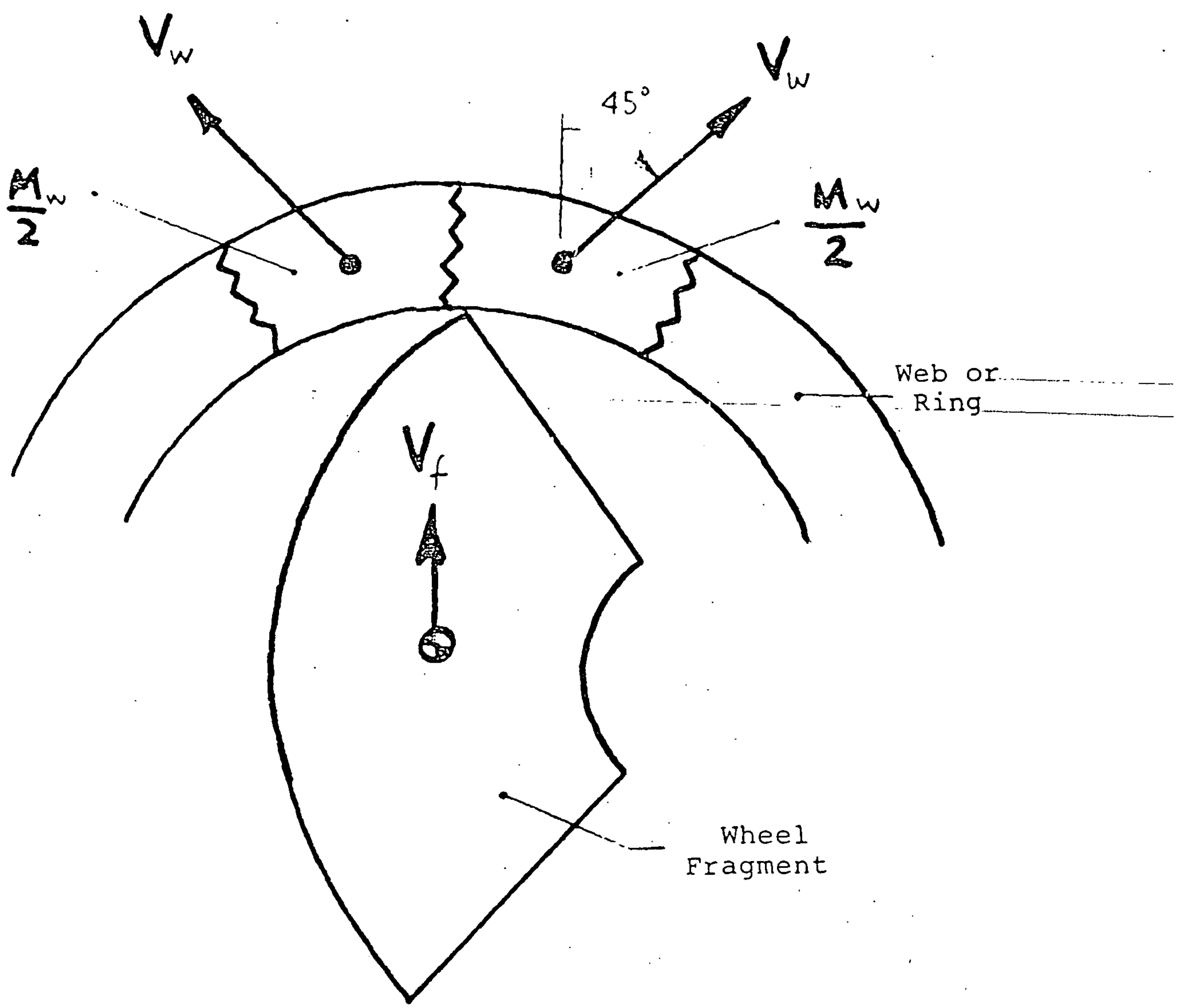


FIGURE 5

Cross-section of Typical Low Pressure Turbine

Illustrating Major Structural Components