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Tornado-Borne Missile Speeds

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Tornado - Borne Missile Speeds

Emil Simiu and Martin Cordes

At the request of the United States Nuclear Regulatory Commission (NRC) the National Bureau of Standards (NBS) has carried out an independent investigation into the question of tornado-borne missile speeds, with a view to assisting NRC in identifying pertinent areas of uncertainty and in estimating credible tornado-borne missile speeds - within the limitations inherent in the present state of the art. The investigation consists of two parts: (1) a study, covered in this report, in which a rational model for the missile motion is proposed, and numerical experiments are carried out corresponding to various assumptions on the initial conditions of the missile motion, the structure of the tornado flow, and the aerodynamic properties of the missile; (2) a theoretical and experimental study of tornado-borne missile aerodynamics, conducted by Colorado State University (CSU) under contract with NBS, to be covered in a separate report by CSU. In the present report, the factors affecting missile motion, and their influence upon such motion, are examined. Information is provided on a computer program developed for calculating missile speeds. Maximum speeds for a number of specified potential tornado-borne missiles are presented, corresponding to a set of assumptions believed by the writers to be reasonable for design purposes. It is pointed out that higher speeds are conceivable if it is assumed that certain circumstances, examined in the body of the report, will obtain. is the judgment of the writers that the probabilities of occurrence of such higher specus for any given tornado strike are low. More than qualitative estimates of such probabilitie are, however, beyond the scope of this investigation.

KEY WORDS: Missiles; nuclear engineering; structural engineering; tornadoes; wind.

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LIST OF SYMBOLS

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٨	⇒ effective area
A1, A2, A3	= projected areas
c	= coefficient in Eq. 25
C	= coefficient in Eq. 12
c ^D	- effective drag coefficient
c _{D1} , c _{D2} , c _{D3}	\sim drag coefficients corresponding to areas $\lambda_1, \lambda_2, \lambda_3$, respectively
с _г	= lift coefficient
d	- characteristic dimension of body
D	m drag force .
g	- acceleration of gravity
ħ	- vertical displacement
ī, j, k	- unit vectors
k ₁ , k ₂ , k ₃	- parameters of the tornado flow
n .	= mass of missile
r	 radius (distance from vortex center)
R	 value of r at which the horizontal velocity in the vortex flow maximum
R*(z)	= radius beyond which radial and vertical velocity components vanish
Re	- Reynolds number
t	- time
υ	- velocity
V	- fluid velocity relative to the body
v mex H	- maximum horizontal missile speed
v _m	- maximum horizontal wind velocity in vortex flow
^v м	- missile velocity, with components vH_vH_vH_
v _{rot}	- horizontal wind velocity in vortex flow
v _R	- radial wind velocity in vortex flow
vtorn	$v_{n} + v_{T}$
Ϋ́T	- translation velocity of tornado
v	- wind velocity

•

v ₂	vertical wind velocity
ν _θ .	- tangential wind velocity in vortex flow
۷ ₀	- maximum tangential velocity
น พ	- weight of missile
x	- coordinate axis
У	= coordinate axis
Z	- coordinate axis
۵	m angular displacement
ν	kinematic viscosity
q	- air density

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1. INTRODUCTION

To ensure the safety of nuclear power plants in the event of a tornado strike it is required that, in addition to the direct action of the wind and of the moving ambient pressure field, the designer consider the impact of tornado-borne missiles, i.e., of objects moving under the action of aerodynamic forces induced by the tornado wind. It is, therefore, necessary that estimates be made of the speeds attained by potential missiles under tornado wind conditions specified for the design of nuclear power plants.

Several such estimates have been reported so far [1, 2, 3, 4, 5, 6, 7]. In certain instances the differences between various estimates are very large; for example, the predicted speeds of a utility pole [13-in (0.33 m) diameter and a 35-ft (10.7 m) length] predicted by Refs. 5, 6, 1, 2, 4 and 3 are 16.5 m/s, 30.5 m/s, 41.2 m/s, 42.7 m/s, 52.2 m/s and 54.9 m/s, respectively. For any given missile, the kinetic energy associated with translational motion is proportional to the square of the speed; in the case of the utility pole, therefore, the ratio of the largest to the smallest of the kinetic energy estimates of Ref. 1 through Ref. 6 is greater than 10. For other missiles, the ratio varies from almost 2 in the case of a 1-in (2.54 cm) diameter steel rod to over 5 in the case of a 4000 lb (18,000N) standard automobile.

In most cases, such large discrepancies are the consequence of differences between basic assumptions used in the various estimation procedures. These assumptions include:

- the initial conditions of the problem, i.e., the initial position of the object with respect to the ground and to the tornado center, and the initial velocity of the object.
- the detailed features of the wind flow field.
- the aerodynamic characteristics of the object (which, in most cases of practical interest, is a bluff body).

Differences between the various sets of basic assumptions used in estimating tornadoborne missile velocities may be ascribed, in part, to the probabilistic nature of the problem. Indeed, for any given tornado wind field, the initial conditions constitute a set or random variables with a very large number of possible values, the choice of which is not unique. More importantly, however, such differences are a consequence of serious uncertainties regarding both the structure of the tornado flow and the aerodynamic behavior of the potential missile.

At the request of the United States Nuclear Regulatory Commission (NRC), the National Bureau of Standards has carried out an independent investigation into the question of tornado-borne missile speeds, with a view to assisting NRC in identifying pertinent areas of uncertainty and in estimating credible tornado-borne missile speeds-within the limitations inherent in the current state of the art.

The objectives of the investigation were defined as follows:

- 1. To select a rational model for the tornado-borne missile motion.
- To develop a computer program based on this model, capable of computing missile trajectories and velocities for any specified initial conditions, tornado wind speed model, and assumptions regarding the drag force acting on the missile.
- To calculate, for a specified set of initial conditions and for a specified wind speed model, the trajectories and velocities corresponding to a number of specified potential missiles.
- 4. To determine, in a number of representative cases, the sensitivity of the calculated results to changes in the assumed initial conditions or in the assumed tornado wind speed model.
- 5. To obtain and interpret information, based on wind tunnel tests, regarding the aerodynamic behavior of various potential missiles, i.e., drag coefficients for various missile motions, including motion in the tumbling mode.
- 6. From the results of items 3, 4 and 5, suggest credible speeds of selected potential tornado-borne missiles, compatible with the current state of the art in nuclear power plant design.

2. MODEL FOR THE TORNADO-BORNE MISSILE MOTION

The motion of an object may be described in general by solving a system consisting of three equations of balance of momenta and three equations of balance of moments of momenta. In the case of a bluff body, one major difficulty in writing these six equations is that the aerodynamic forcing functions are not known.

It is possible to measure in the wind tunnel aerodynamic forces and moments acting on a bluff body under static conditions for a sufficient number of positions of the body with respect to the mean direction of the flow. On the basis of such measurements, the dependence of the forces and moments on position, and corresponding aerodynamic derivatives, can be obtained. Aerodynamic forces and moments can then be calculated following the well-known pattern used in airfoil theory; for example, if an airfoil has a time-dependent vertical motion h(t) in a uniform flow with velocity U, and if the angle of attack is $\alpha = \text{const}$, the lift coefficient is

$$C_{L} = \frac{dC_{L}}{d\alpha} \left(\alpha + \frac{1}{U} \frac{dh}{dt} \right)$$
(1)

This procedure for calculating aerodynamic forces and moments is valid if the quasisteady assumption [Ref. 8, p. 192] is acceptable and if the body concerned behaves aerodynamically like an airfoil - i.e., if the body is streamlined and if no flow separation occurs. However, in the case of unconstrained bluff bodies moving in a wind flow the validity of such a procedure remains to be demonstrated.

In the absence of a satisfactory model for the aerodynamic description of the missile as a rigid (six-degress-of-freedom) body, it is customary to resort to the alternative of describing the missile as a material point acted upon by a drag force

$$\overline{D} = 1/2 \rho C_{D} A | \overline{v}_{W} - \overline{v}_{H} | (\overline{v}_{W} - \overline{v}_{H})$$
(2)

where p = air density, $\overline{v_{u}} = wind velocity$, $\overline{v_{M}} = missile velocity$, A is a suitably chosen area and C_{n} is the corresponding drag coefficient.

This model is reasonable if, during its motion, the missile either (a) maintains a constant or almost constant attitude with respect to the relative velocity vector $\overline{v_{u}}$ - $\overline{v_{M}}$, or (b) has a tumbling motion such that, with no significant errors, some mean value of the quantity $C_{D}A$ can be used in the expression for the drag \overline{D} . The assumption of a constant body attitude with respect to the flow would be credible if the aerodynamic force were applied at all times exactly at the center of mass of the body--which is highly unlikely in the case of a bluff body in a tornado flow--, or if the body rotation induced by a non-zero aerodynamic moment with respect to the center of mass were inhibited by aerodynamic damping forces intrinsic in the body-fluid system. The question thus arisen as to whether such stabilizing forces may be expected to be present.

It is of interest at this point to mention certain experimental results--obtained in studies of bridge deck aerodynamic stability--which provide useful insights into the question at hand. Consider a body restrained by four springs of equal stiffness, immersed in a horizontal flow (Fig. 1), and subjected to an impulse which produces angular oscillations $\theta(t)$ about the position of equilibrium [9]. In the case of an airfoil with a sufficiently small angle of attack so that flow separation does not occur, the aerodynamic damping, which is proportional to the quantity denoted by H_2^* in Ref. 9, is positive. This implies that the flow will contribute, along with the viscous damping inherent in the springs, to the damping out of the oscillations. On the other hand, for bluff bodies, at high velocities of the flow and for vanishing values of the spring stiffness, the aerodynamic damping is negative in the large majority of the cases tested [9].

These results suggest that, in general, no stabilizing effect by the flow can be expected to inhibit the tumbling of bluff bodies. The assumption that potential tornadoborne missiles will tumble during their motion appears therefore to be reasonable. It will be this assumption that will be used in this work.



Figure 1 Bluff Bridge Deck Section



Figure 2 Notations

Assuming that Eq. 2 is valid and that the average lift force vanishes under tumbling conditions, the motion of the missile viewed as a one-degree-of-freedom system is governed by the relation:

$$\frac{d\overline{v}_{H}}{dt} = -1/2 p \frac{C_{D}A}{m} | \overline{v}_{H} - \overline{v}_{u} | (\overline{v}_{H} - \overline{v}_{u}) - s\overline{k}$$
(3)

where g = acceleration of gravity, $\overline{k} = unit$ vector along the vertical axis and m = mass of missile.

It follows from Eq. 3 that for a given flow field and initial conditions, the motion depends only upon the value of the parameter C_D^A/m . Throughout this work, the area, A, will be expressed in m^2 and the mass, m, in kg. To transform the parameter C_D^A/w , where A is expressed in ft² and the weight in 1b, into the parameter C_D^A/m , where A is expressed in m^2 and the mass, m, in kg, the following relations are used:

$$\frac{C_D A}{v} = 1 \frac{ft^2}{1b} \rightarrow \frac{C_D A}{m} = .205 \frac{m^2}{kg}$$
(4a)

 $\frac{C_D^A}{m} = 1 \frac{m^2}{kg} \rightarrow \frac{C_D^A}{w} = 4.902 \frac{ft^2}{1b}$ (4b)

3. COMPUTER PROGRAM FOR CALCULATING TORNADO-EORNE MISSILE TRAJECTORIES AND VELOCITIES

To calculate and plot trajectories and velocities of tornado-borne missiles, a computer program was developed in which the assumed models for the tornado wind field and the drag coefficients are specified by specialized subroutines (details of such models are given in subsequent sections).

In Eq. 3 the components of the missile velocity \overline{v}_{M} and of the wind velocity \overline{v}_{W} must be referred to an absolute frame. The wind velocity \overline{v}_{W} is usually specified as a sum of two parts. The first part represents the wind velocity of a stationary tornado vortex and is referred to a cylindrical system of coordinates. The second part represents the translation velocity of the tornado vortex--or, equivalently, of the cylindrical system of coordinates--with respect to an absolute frame of reference. The transformations required to represent \overline{v}_{W} in an absolute frame are derived in Appendix A and are incorporated in the computer program. Documentation on the computer program and a sample input and output are given in Appendix C. The program, which is written in ANSI Fortran language, may be obtained on tape from the National Technical Information Service, Springfield, Virginia 22151.

For the particular case of a parallel flow, an analytical solution to the problem of the missile trajectory can be easily obtained. This solution, which can be found in Appendix B, has been used to test the program, in which the subroutine describing the wind field was modified to represent a parallel flow.

4. NUMERICAL COMPUTATIONS

It was previously noted that, for a given flow field and for given initial conditions, the missile motion depends only upon the value of the parameter $C_{\rm p}A/m$. In this section, numerical results will be presented which show the effect of this parameter on the maximum horizontal missile speed. The calculations are based on the following assumptions:

1. The parameter $C_n A/m$ is constant during the missile flight.

2. The tornado wind field may be represented by a vortex translating with a uniform velocity v_T along an axis denoted by Ox (Fig. 2). Let v_R , v_θ , v_z and $v_{rot} = (v_R^2 + v_\theta^2)^{1/2}$ denote the radial, tangential, vertical and horizontal velocity in the vortex flow, respectively. It is assumed that

$$\mathbf{v}_{rot} = \frac{\mathbf{r}}{\mathbf{R}_{m}} \mathbf{v}_{m} \qquad \qquad \mathbf{0} \leq \mathbf{r} \leq \mathbf{R}_{m} \qquad \qquad (5)$$
$$\mathbf{v}_{rot} = \frac{\mathbf{R}_{m}}{\mathbf{r}} \mathbf{v}_{m} \qquad \qquad \mathbf{R}_{m} \leq \mathbf{r} \leq \infty \qquad \qquad (6)$$

where v_m is the maximum horizontal velocity in the vortex flow, r is the radius (distance from the vortex center) and R_m is the value of r at which this velocity is attained. Eqs. 5 and 6 are similar to descriptions of the flow proposed in Ref. 10 (p. 135).. Furthermore, it is assumed that $v_R = 1/2 v_8$ and $v_z = 0.67 v_8$, i.e., (see Fig. 2).

$$v_{\rm R} = -\frac{1}{\sqrt{5}} v_{\rm rot} \tag{7}$$

$$v_{\theta} = \frac{2}{\sqrt{5}} v_{rot}$$
(8)

$$v_z = \frac{4}{3\sqrt{5}} v_{rot}$$
 (9)

The type of model just described is referred to as the Rankine vortex and appears to be a reasonable representation of tornado flows. Estimates based on field observations suggest that it is reasonable to assume--as is done in this model--that R is independent of height [Ref. 10, p. 131]. The following values for the tornado wind field parameters were used in the calculations:

·····			·		J		1	
Ť		T	v m		v _{torn} -	R		
Tornado Type	m/s*	mph	m/a *	mph	m/s*	mph	m *	ft
1	31 .	70	130	290	161	360	46	150
2	27	60	107	240	134	300	46	150
3	22	50	85	190	107	240	4.	150
4	31	70	146	325	177	395	46	150
5	27	60	120	288	147	348	46	150
6	22	50	95	213	117	263	46	150

Table 1 - Values of v_r, v_r and R_r Used in Numerical Calculations

* Approximately

The values given in Table 1 for tornado types 1, 2, 3 are suggested in Ref. 11 as providing an acceptably low level of failure if used in the design of nuclear power plants. The values for tornado type 4, 5 and 6 were included for the purpose of studying the effect upon missile velocity of relatively small increments in the value of v_{m} .

3. The assumed initial conditions are: $x(0) = R_m$, y(0) = 0, z(0) = 40m, $v_{Hx}(0) = 0$, $v_{Hy}(0) = 0$, $v_{Hz}(0) = 0$ at time t = 0, where x, y, z are the coordinates of the missile (i.e., of its center of mass) and v_{Hx} , v_{Hy} , v_{Hz} are the missile velocity components along the x, y, z axes (Fig. 2). Also, at time t = 0 the center of the tornado vortex coincides with the origin 0 of the coordinate axes. The effect of assuming initial conditions different from those indicated is examined in the next section of this report.

The dependence upon the parameter $C_D^{A/m}$ of the maximum horizontal missile speed calculated in accordance with assumptions 1 through 3 is represented in Fig. 3 for tornado types 1 through 6 as defined in Table 1. In Fig. 3 $v_{torn} = v_T + v_m$ (Table 1).

> 5. SENSITIVITY OF CALCULATED RESULTS TO CHANGES IN THE ASSUMED INITIAL CONDITIONS OR IN THE ASSUMED TORNADO WIND SPEED MODEL

5.1 Changes in the Assumed Initial Position of the Missile.

For flows with $v_m = 146 \text{ m/s}$, $R_m = 46 \text{ m}$, and $v_T = 31 \text{ m/s}$, the maximum horizontal speeds of missiles with $C_D^{A/m} = 0.001$ and $C_D^{A/m} = 0.01$ were calculated using the initial positions shown in Table 2. Except for the initial positions, the results of Table 2 are based on the assumptions described in the preceding section. It is seen from Table 2 that

Table 2 - Maximum Horizontal Missile Speeds, v , <u>(m/s)</u> Corresponding to Various Initial Positions

	Initial	Positi	on	C _D A/E	······································
(1)	(2)	(3)	(4)	(5)	(6)
	I	x(0)	y(0)	0.001	0.01
L		(mei	ters)		1
(a)	0+	46	0	10	65
(Ъ)	0+	23	D	18	93
(c)	0++	69	0	9	48
(d)	0+	-46	0	18	82
(e)	0+	D	46	16	68
(£)	.0+	0	23	20	84
(8)	Q+	0	-23	35	50
(h)	Q+	0	-46	54	70

1. Arrows in column (2) represent direction of translation velocity $v_{T_{r}}$

2. Assumed elevation of missile at time t = 0: z(0) = 40m in all cases.

Table 3 - Maximum Horizontal Missile Speeds, v_{II}, (m/s) Corresponding to Initial Elevations z(0) = 10m, z(0) = 20m and $z(0) = 40m (C_0A/m = 0.001)$

						
1	initisl P	Positi	on .		z (0)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
		×(0)	y(0)	10m	20m	40m
		(me	ters)			
	1	{				1
(a)	0 +	46	0	6	7	10
(b)	0+	23	O	. 2	8	18
(c)	0	69	0	9	9	9
(6)	0 +	-46	0	14	16	18
(e)	0 +	0	46	3	9	16
(£)		0	23	12	16	20
(g)	Q +	0	-23	19	29	35
(h)	Q +	σ	-46	33	42	54



the initial position used in the calculations of the preceding section, (position (a) of Table 2) does not result in the largest possible maximum horizontal missile speeds. It is also noted that the initial positions to which there correspond the largest possible missile speeds depend upon the value of C_DA/m . For example, for $C_DA/m = 0.01$, that initial position is (b); for $C_DA/m = 0.001$, it is (h) [see Table 2].

As indicated in Note 2 of Table 2, the initial elevation assumed in the calculations was z(0) = 40m. If the weight of the missile is smaller than the upward drag induced by the vertical wind velocity component, then the calculated missile velocities at time t are independent of z(0). (This is the case because, in the assumed tornado model, the flow field is invariant with z). However, if the missile weight exceeds the upward drag, i.e., if the missile moves downward,--as in the case of column (5) of Table 2-- the interval between time t = 0 and the time at which the missile hits the ground decreases as z(0) decreases. Therefore, the maximum missile speed may decrease if lower values of the initial elevation z(0) are assumed. Table 3 lists speeds calculated using the assumptions z(0) = 10m and z(0) = 20m, all other values of the various parameters being the same as for column (5) of Table 2. For comparison the calculated speeds in column (5) of Table 2 were also included in Table 3.

Missile speeds were also calculated corresponding to various initial elevations 0 < z (0) < 10m. It is of interest to note that the maximum horizontal speed of a missile with $c_p A/m = 0.001$ starting the motion from position (h) is relatively high even for low values of the initial elevation z(0). For example, for z(0) = 3m and z(0) = 5m, the maximum missile speeds are 23 m/s and 27 m/s, respectively.

Calculations were also carried out for the horizontal distances traveled by the missiles. For example, for $C_DA/M = 0.001$ and the initial position (h), the horizontal distances corresponding to z(0) = 3m, 5m, 10m, 20m, and 40m are, approximately, 20m, 30m, 50m, 90m and 160m, respectively.

5.2 Changes in the Assumed Initial Velocity of the Missile.

The results given in the preceding sections are based on the assumption that the initial velocity of the missiles is zero. If the missile is injected in the flow, for example by an explosion, this assumption is no longer valid. However, all other conditions being equal, a non-zero initial velocity does not necessarily result in a maximum missile velocity higher than that corresponding to zero initial velocity. This is illustrated in Table 4, in which type 1 tornado (see Table 1), and the conditions $v_{Hx}(0) \neq 0$, $v_{Hy}(0) = 0$, $v_{Hy}(0) = 0$ were assumed.

Table 4 - Maximum Horizontal Missile Speeds	vu ,	(m/s)	Corresponding	to	Various	Initial	Velocities
---	------	-------	---------------	----	---------	---------	------------

				$C_{D}^{A/m} = 0.001$			$C_{\rm p}^{\rm A/m} = 0.01$		
ω	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		x(0)	y(0)		$v_{Mx}(0)$	(met	ers/seco	nđ)	
		(meters)		0	10	20	0	10	20
(A) (2)	0+ ;;+	46 0	0 -23	8 35	9 45	20 35	62 63	58 59	53 59

5.3 Changes in the Assumed Tornado Wind Speed Model. 5.3.1 Tornado Described by Eqs. 5 through 9 with $v_{\tau} = 0$.

Table 5 lists maximum horizontal missile speeds for the same parameter values and initial conditions as those used in Table 2, except that the translation velocity of the tornado vortex is zero, rather than 31 m/s. It is seen by comparing Tables 2 and 5 that the calculated speeds are, on the average, higher in the case $v_T = 31 m/s$, although for some initial positions the reverse is true.

Table 5 - Maximum Horizontal Missile Speeds, v_{H}^{max} Corresponding to Various Initial Positions ($v_{T} = 0$)

	Initia	C _D A/m			
(1)	(2)	x(0) (met	y(0) ers)	(2) 0.001	(3) 0.01
(a) (b) (c) (d) (e) (f) (g) (h)	000000000000000000000000000000000000000	46 23 69 -46 0 0 0 0	0 0 46 23 -23 -46	30 7 19 30 30 8 8 30	65 61 65 65 61 61 65

5.3.2 Tornado Vortex Hodels Based on Data Obtained During the Dallas Tornado of April 2, 1957 [13].

In this family of models, the velocities in the tornado vortex depend upon the quantities $R_m = radius$ of maximum tangential velocity at elevation z = 0, $v_{0m} = maximum$ tangential velocity and $R^*(z) = radius$ beyond which the radial and vertical velocity components vanish. In addition, the flow depends on three parameters k_1 , k_2 , k_3 , as will be shown subsequently. The radius of maximum tangential velocity at elevation z is denoted by R_m (z) and is assumed to be

$$R_{m}(z) = R_{m} + k_{j} z$$
 ' $0 < z < 60m$ (10)

$$R_{m}(z) = R_{m} + 60 k_{1}$$
 $z \ge 60m$ (11)

It is seen that the parameter k_1 is a measure of the extent to which the tornado vortex deviates from a cylindrical shape. If $k_1 = 0$ the radius of maximum tangential velocity is invariant with height, as in the model described by Eqs. 5 through 9. An assumption commonly employed in tornado-borna missile speed investigations is $k_1 = 0.45$ [see, for example, Refs. 3 and 12]. It is further assumed [3, 12]:

$$R^{*}(z) = CR_{m}(z)$$
 (12)

where C is a coefficient which depends upon $V_{\Theta m}$. In this work, it was assumed C = 2.35 for $v_{\Theta m}$ = 130 m/s, C = 2.10 for $v_{\Theta m}$ = 107 m/s and C = 1.80 for $v_{\Theta m}$ = 85 m/s. These values are similar to those used in Ref. 3.

Let r denote the distance to the center of the tornsdo vortex. The components of the velocity in the tornsdo vortex are assumed to be

$$V_{R} = -k_{2} \frac{R^{*}(z) - r}{R^{*}(z) - R_{12}(z)} r r \leq R^{*}(z)$$
 (13)

$$v_{R} = 0$$
 $r > R^{*}(z)$ (14)

$$v_{\theta} = \frac{r}{R_{m}(z)} v_{\theta m}$$
 $r \leq R_{m}(z)$ (15)

$$v_{\theta} = \frac{R_{m}(z)}{r} v_{\theta m} \qquad r > R_{m}(z) \qquad (16)$$

$$v_z = k_3 \frac{R^{*}(z) - r}{R^{*}(z) - R_{m}(z)} z + \frac{v_{\theta}}{3} r < R^{*}(z)$$
 (17)

$$v_z = 0 \qquad r \ge R^{+}(z) \qquad (18)$$

<u>60 m < z < 240m</u>

$$v_{\rm R} = -k_2 \frac{R^{\star}(z) - r}{R^{\star}(z) - R_{\rm m}(z)} r \frac{240 - z}{180} r \le R^{\star}(z)$$
 (19)

$$v_{\rm R} = 0$$
 $r > R^* (z)$ (20)

$$v_{\theta} = \frac{r}{R_{m}(z)} v_{\theta m} \qquad r \leq R_{m}(z) \qquad (21)$$

$$v_{\theta} = \frac{R_{m}(z)}{r} v_{\theta m} \qquad r > R_{m}(z) \qquad (22)$$

$$v_z = (1.33 - \frac{z}{180}) (k_3 \frac{R^{*}(z) - r}{R^{*}(z) - R(z)} 60 + \frac{v_B}{3}) r < R^{*}(z)$$
 (23)

$$v_z = 0$$
 $z \ge R^{+}(z)$ (24)

Table 6 - Maximum Horizontal Missile Speeds v Max, (m/s) Corresponding to Various

Case	v _{êm}	v _T	k ₁	k ₂	k ₃	C _D A/m	v ^{max} H
	(m/s)	(m/s)				m ² /kg	(m/s)
1	85	22	.45	1	1	0.025	90*
2	85	22	.45	1	0	0.025	83*
3	85	22	0	1	0	0.025	77
4	85	22	0	1	1	0.025	79
5	130	31	.45	1 .	1	0.025	90*
6	130	31	•45.	1	0	0.025	126*
7	130	31	.0 .	1	о	0.025	80*
8	130	31	0	1	1	0.025	75*
9	130	31	.45	1	1	0.01	91*
10	130	31	.45	1	0	0.01	, 87
11	130	31	.25	1	0	0.01	73
12	130	31	0	·1	1	0.01	60
13	130	31	0	1	0	0.01	60
14	130	31	.45	0	1	0.025	60
15	130	31 -	45.	0	1	0.01	36

Parameter Values

* Calculated speeds are higher at z > 60m.

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The most commonly used value of the parameter k_2 is unity (see, for example, Ref. 3 and 12). However, it is by no means certain that Eqs. 13 and 19 with $k_2 = 1$ are a satisfactory model of the radial valority v_R . Indeed, according to Ref. 10 (p. 135), v_R is negligible throughout the tornado flow except in the vicinity of $r = R_m$ (z). It is, therefore, of interest to examine the influence upon the calculated missile speeds of the assumption $v_p = 0$. This can be done by assuming $k_2 = 0$ in Eqs. 13 and 19.

Similarly, while it is commonly assumed $k_3 = 1$, it is of interest to examine the case in which the value of the vertical velocity component v_2 is smaller than that given by Eqs. 17 and 23 with $k_3 = 1$. This can be done, for example, by assuming $k_3 = 0$.

Calculations of missile trajectories and speeds based on the assumption that the tornado vortex is described by Eqs. 13 through 24 were carried out for the 15 cases listed in Table 6. In all cases of Table 6 it was assumed $x(0) = R_{m} = 46m$, y(0) = 0, z(0) = 0. Table 6 only includes the maximum calculated horizontal missile speeds v_{H}^{max} at elevations $z \leq 60$ m.

A discussion will now be presented of the results of Table 6. The cases corresponding to the set of parameters $k_1 = 0.45$, $k_2 = 1$, $k_3 = 1$ which, as previously indicated, are most commonly assumed in missile speed calculations, will be examined first. It is noted that the missile speeds for cases 1, 5 and 9 of Table 6 are higher than the corresponding speeds of Fig. 3, as shown in Table 7.

	Table	5	Figure 3		
	Case	v ^{max} H (m/s)	Tornado Type	v _H ^{max} (m/s)	
0.025	1	90	3*	57	
0.025	5	90	1* •	81	
0.01	9	91	1*	63	

Table 7 - Comparison between Calculated Speeds Based on Eqs. 13 through 24 and on Eqs. 5 through 9

* See Table 1

This can be explained as follows. Assume that $v_R = v_T = 0$ and that the missile starts from an initial position $x(0) = R_m$. As the missile gains momentum, it tends to fly in a straight line along the direction of the tangential velocity, i.e., at larger distances from the center of the vortex. In the case of a tornado with a radius of maximum tangential speed that is constant with height, as the missile moves away from the initial position, it will be subjected to winds of lower intensity and its speed will increase more slowly. On the other hand, if the radius of maximum tangential speed increases with height, and if the elevation of the missile increases under the action of vertical wind speed components larger than the missile weight, then as the missile moves away from the center and up it continues to fly in zones of maximum winds and thus continues to gain momentum at a fast

rate. This mechanism is modified only slightly in most, although not in all cases, if non-zero radial and translation velocities are present. The explanation just advanced is confirmed by comparing cases 4 to 1, 8 to 5, and 12 to 9. In cases 4, 8 and 12, $k_1 =$ 0, i.e., the radius of maximum tangential velocity is constant, and the missile speeds are lower than in cases 1, 5, 9, in which that radius increases with height. A similar conclusion is reached by comparing cases 3 to 2, 7 to 6, 11 and 13 to 10.

The parameter k_3 , which controls the magnitude of the vertical wind velocity component, does not appear to affect the missile speeds in a uniform fashion, i.e., to the value k_3 = 0 there correspond in certain cases lower values of the missile speed than to the value $k_3 = 1$ (e.g., case 2 vs. case 1); in other cases, the reverse is true (e.g., case 6 vs. case 5).

Some meteorologists have expressed the view that the radial velocity component v_R is smaller over most of the tornado field than that described by either Eq. 7 or Eqs. 13 and 19 with $k_2 = 1[10]$. It is therefore of interest to examine the case $k_2 = 0$. It is seen, by comparing in Table 6 cases 14 and 15 with cases 5 and 9, respectively, that the assumption $k_2 = 0$ results in considerably lower missile speeds than the assumption $k_2 =$ 1. This is the case because, if $k_2 = 0$, (i.e., if $v_R = 0$), the missile is ejected (i.e., it flies at larger distances from the center of the vortex and therefore, in a region of lower speeds) sooner than if $k_2 = 1$, (i.e., than if a radial velocity is present that resists the tendency of the missile to fly away from the center). This reasoning is valid for the assumed initial condition $x(0) = R_m$, y(0) = 0. It is conceivable however, that initial conditions exist which might result in higher missile speeds for $k_2 = 0$ than for $k_2 = 1$.

6. AERODYNAMIC FORCES

In this work it was assumed that the aerodynamic force acting upon a missile is

$$\overline{D} = 1/2 \rho C_{D} A | \overline{v}_{u} - \overline{v}_{H} | (\overline{v}_{u} - \overline{v}_{H})$$
(24)

where p = air density, $\overline{v}_{w} = wind velocity$, $\overline{v}_{M} = missile velocity and <math>C_{D}A$ is a suitably chosen quantity with the dimensions of an area. As indicated in Section 2, Eq. 2 may be assumed to be valid under random tumbling conditions, i.e., if the motion is such that the body "presents all possible aspects to the flow, . . the orientation of the surface elements with respect to the flow sweeps through all the possible angles" (Ref. 14) and, moreover, the angular speed of the tumbling body is sufficiently large. In this connection it may be argued that, instantaneously, lift forces do exist, and that the momentum they impart to the missile may not be negligible if the rotational motion of the missile is relatively slow. The acceleration of the missile would then no longer be parallel, at every instant, to the vector $\overline{v}_{w} - \overline{v}_{M}$ and the missile trajectory would deviate from that predicted by using the aerodynamic model implicit in Eq. 2. It is believed, however, that the effect of such deviations on the maximum appeed of the tornado-borne missile is comparable to the effect of changes in the initial conditions of the problem such as were studied in Section 5. For the purposes of this report, the existence of lift forces which are not taken into account in the calculations is believed not to invalidate the serodynamic model used herein.

The value C_DA that corresponds to tumbling conditions can, in principle, be determined experimentally. Unfortunately, little information on this topic appears to be presently available. Ref. 14 examines tumbling motions for supersonic wind conditions, while Ref. 15 contains information on tumbling under flow conditions corresponding to Mach numbers 0.5 to 3.5. Hoerner extrapolated the data of Ref. 15 to lower subsonic speeds (Ref. 16, p. 14-16, Fig. 7); according to this extrapolation, for a randomly tumbling cube the quantity C_DA equals, approximately, the average of the products of the projected areas corresponding to "all positions statistically possible" by the respective static drag coefficients (Ref. 16, p. 14-16 and P. 13-17). An investigation into this question is currently carried out, within the framework of this project, by Colorado State University (CSU). The theoretical and experimental results of this investigation will be reported in a separate document by CSU.

In the absence of more experimental information, it appears reasonable to assume that the effective product C_nA is given by the expression

$$C_{D}^{A} = c (C_{D_{1}}^{A} + C_{D_{2}}^{A} + C_{D_{3}}^{A})$$
 (25)

in which $C_D A_i$ (i = 1, 2, 3) are products of the projected areas corresponding to the cases in which the principal axes of the body are parallel to the vector $\overline{v}_{u} - \overline{v}_{M}$, by the respective static drag coefficients. In Eq. 25, c is a coefficient assumed to be $\cdot 0.50$ for planks, rods, pipe and poles and 0.33 for the automobile.

An upper bound for the quantity $C_n A$ is believed to be

$$(C_{D}A)_{u.b.} = C_{D_{1}}A_{1}$$
 (26)

in which $C_{D_1}A_1$ is the largest of the quantities $C_{D_1}A_1$ (i = 1, 2, 3). The Reynolds number is defined as

$$Re = \frac{Vd}{V}$$

where V = fluid velocity relative to the body, d = characteristic dimension of the body (in the case of a cylinder, d = diameter) and v = kinematic viscosity (v = 1.5×10^{-5} m/s for air). For a circular cylinder Re = $.67 \times 10^{5}$ Vd, where V and d are expressed in m/s and m, respectively. For Re > 4×10^{5} , i.e., the Reynolds number is in the supercritical range and it may therefore be assumed, conservatively, C_D = 0.7 (see Ref. 8, p. 67). In the case of the 1 inch (2.54 cm) rod, it may be assumed that Re is in the subcritical range even for velocities V of the order of 100 m/s and, therefore, that C_D = 1.2 (Ref. 8).

7. SPEEDS OF SELECTED POTENTIAL TORNADO-BORNE MISSILES

In this section calculated speeds of selected potential tornado-borne missiles will be given, based on the following assumptions:

(1) The model of the tornado vortex consisting of Eqs. 5 through 9 is valid, with the parameter values corresponding to cases 1, 2 and 3 of Table 1.

(2) The initial conditions are $x(0) = R_m$, y(0) = 0, z(0) = 40m (for comments on the initial condition z(0) = 40m, see p. 10 of this report); $v_{Hx}(0) = v_{Hy}(0) = v_{Hz}(0) = 0$. Assumptions (1) and (2) just described were used in calculating the values on curves 1, 2 and 3 of Fig. 3.

(3) The effective product C_D^A is given by Eq. 25. The results of the calculations based on these assumptions are shown in Table 8.

The missile speeds of Table 8 are based on a set of assumptions which, while reasonable, might in certain cases not correctly reflect the actual physical phenomenon. It follows from Sections 5 and 6 that the order of magnitude of uncertainties in the estimates of maximum missile speeds can in certain cases be as high as 50% or even more. Whether or not actual missile speeds will be higher than those listed in Table 8 depends in large measure on the extent to which the tornado flow model consisting of Eqs. 5 through 9 (the so-called Rankine vortex) is realistic. In particular, if, as suggested in Ref. 10, the radial and vertical velocity components in a tornado are actually lower than those given by this model, it could be expected--all other conditions being equal-that the predictions of Table 8 are conservative. If, on the other hand, the actual tornado flow is more closely represented by Eqs. 13 through 24 with certain unfavorable values of the parameters included in these equations, then higher missile speeds than those of Table 8 may occur, as shown in Tables 6 and 7.

The speeds of Table 8 may also be exceeded if unfavorable initial conditions obtain. The uncertainties pertaining to the tornado flow modeling are due to the lack of reliable information; on the other hand, those pertaining to the initial conditions are a consequence of the probabilistic nature of the problem. Probabilities of occurrence may be assigned to each set of initial conditions. The probability that (a) the wind speed will reach the intensity levels of Table 1, (b) that a missile starts from a highly unfavorable set of initial conditions and (c) that it will hit a certain installation with a speed V_H^{max} can be expected to be negligibly low. Such probabilities can in principle be evaluated using, for example, procedures similar to those outlined in Ref. 18. Attempts to calculate such probabilities are beyond the scope of this work.

			·		1						H	
		Dimensions	Weight (1b/ft)	Hass (kg/m)	c _{p1}	c _{p2}	с _р ј	C _D A/4 (ft ² /1b)	C _D A/m (m ² /kg	Tornado Type 1	fornado Type 2	Tornado Type 3
1	Wooden Plank	3 5/8" x 11 3/8" x 12'	8.2 to 11 ^d	12.2 to 16.3	2.0	2.0	z.0	0.132	0.0270	272fps	230fps	190fpø
		(0.092m x 0.289m x 3.66m)	(say, 9.6)	(say 14.3)						(83 ¤/s)	(70 m/s)	(58 m/s)
2	6" Sch. 40	6.625" (diam) x	18.97	28.18	0.7	2.0		0,0212	0.0043	171fp s	138fps	33fps
	ripe	(0.168m x 4.58m)								(52 m/s)	(42 m/s)	(10 m/s)
3	Automobile	16.4' x 6.6' x	4,000 1b	1.810 kg	2.0	z.0	2.0	0.0343	0.0070	193Ep#	170fp s	134£ps
ł		(5m x 2m x 1.3m)	(cocat wergur)	(LOLAI MABB)						(59 =/ 5)	(52 m/s)	(41 œ/s)
4	1" Solid Steel Rod	1" (diam) x 3'	9.67	4.0	1 7	7.0	1.7	0.0190	0.0040	167fps	131fps	326fps
	-	(0.0254= x 0.915m)	07، ن	1 4.0						(51 ¤/s)	(40 m/s)	(8 m/s)
5	13.5" Utility Pole	13.5" (diam) x	27.5 to 36.5	40.8 to 54.2	0.7	2.0	0.7	0.0254	0.0052	180fps	157fps	85fps
		(0.343 cm x 10.68m)	(B4y, 52)		}					(55 m/c)	(48 m/s)	(26 m/s)
6	12" Sch 40	12.75" (diam) x	49.56 .	73.6	0.7	2.0	0.7	0.016	0.00330	LS4Eps	92fps	2Jfps
		$(0.32m \times 4.58m)$		1				1		(47 =/ 5)	(28 m/s)	(7 m/s)
				}	}		1]]		

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Table 5 - Characteristics and Maximum Norizontal Speeds of Selected Hissiles

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The uncertainties regarding the actual aerodynamic drag coefficients constitute another source of error. It is noted that the curves in Fig. 3 are S-shaped. Large errors in the assumed value of the quantity C_D^A may therefore in certain cases result in considerable changes of the estimated value of V_H^{max} . For example, if, for a 12 in Sch. 40 pipe (entry 6 in Table 8) it was assumed $C_D^{A/m} = 0.0066 \text{ kg/m}^2$ instead of $C_D^{A/m} = 0.0033 \text{ kg/m}^2$, it follows from Fig. 3 that $V_H^{max} = 40 \text{ m/s}$, rather than $V_H^{max} = 7 \text{ m/s}$, as in Table 8. It is interesting to note, on the other hand, that as long as a change in the assumed value of $C_D^{A/m}$ does not displace the point from the upper or from the lower branch of an S-shaped curve, the sensitivity of V_H^{max} to even considerable changes in the value of $C_D^{A/m}$ is fairly small. For example, if for the 6 in Sch. 40 pipe (entry 2 in Table 8) it is assumed that $C_D^{A/m} = 0.0086$, then, for a ternado type 1, $V_H^{max} = 61 \text{ m/s}$ (see Fig. 3), whereas to the assumption $C_D^{A/m} = 0.0043$ there corresponds $V_H^{max} = 52 \text{ m/s}$, i.e., to an error of 100% in the value of $C_D^{A/m}$ there corresponds an error of only 17% in the estimated value of V_R^{max} .

Finally, it must be noted that the actual missiles may have properties that are more unfavorable than those listed in Table 8; for example, the case is mentioned in Ref. 19 of a beam attached, during its flight, to a portion of a carport roof which considerably increased the surface area of the missile and, therefore, the parameter $C_{\rm p}A/m$.

8. CONCLUSIONS

In the preceding section calculated maximum speeds of tornado-borne missiles are given in Table 8, based on a set of assumptions believed to be reasonable. However, in assessing these speeds, it must be recognized that:

1. The problem of determining tornado-borne missile speeds has a probabilistic character. As shown in the body of the report, unfavorable initial conditions may obtain--to which there correspond relatively low probabilities of occurrence--for which the maximum missile speeds would be higher than in Table 8. The estimation of such probabilities is beyond the scope of the investigation covered by this report.

2. Estimates of tornado-borne missile speeds are also affected by significant uncertainties with regard to: (a) the detailed structure of the tornado flow and (b) to the acordynamic behavior of the missile. Under certain assumptions regarding one or both of these factors, calculated missile speeds can be higher than those of Table 8. However, it is believed that the assumption used to derive the values

of Table 8 are conservative. In particular, it is believed that the actual vertical wind speeds are lower than indicated by Eq. 9, so that the relatively heavy missiles would tend to hit the ground sooner than calculated on the basis of this equation, with a consequent reduction in the calculated maximum missile speed.

In spite of the many uncertainties involved, the writers believe that the assumptions used to estimate the speeds of Table 8 are sufficiently conservative for purposes of nuclear power plant design. It is the writers' judgement that, although higher values of tornado-borne missile speeds are conceivable, their probabilities of occurrence, for any given tornado strike, are low.

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APPENDIX A - EQUATIONS OF HOTION

A1.1 Absolute and Translating Frames of Reference

Consider the absolute frame of reference 0_1 xyz (Fig. Al.1) and a frame 0_2 x'y'z such that $0_2 z$ is parallel to $0_1 z$. It is assumed that the frame 0_2 x'y'z translates with respect to 0_1 xyz with a constant velocity, the components of which (in the 0_1 xyz frame) are $(v_{Tx}, v_{Ty}, 0)$. The angle between $0_2 x'$ and $0_1 x$ being denoted by θ_c .

$$\cos \theta_{c} = \frac{v_{Tx}}{(v_{Tx}^{2} + v_{Ty}^{2})^{1/2}}$$
(A1.1)

$$\sin \theta_{c} = \frac{v_{Ty}}{(v_{Tx}^{2} + v_{Ty}^{2})^{1/2}}$$
(A1.2)

Al.2 Vectors of Position

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Using the notations of Fig. Al.1, the vectors of position of the particle P in the absolute and in the translating frame of reference may be written as follows:

<u>Absolute frame</u> (with origin 0_1)

$$\overline{R} = x \overline{i} + y \overline{j} + z \overline{k} = r \cos \theta \overline{i} + r \sin \theta \overline{j} + z \overline{k}$$
(A1.3)

where $\overline{1}$, \overline{j} , \overline{k} are unit vectors along the axes $0_1 x$, $0_1 y$, $0_1 z$ respectively.

Translating frame (with origin 0_2)

 $\bar{R}' = x'\bar{1}' + y'\bar{j}' + z\bar{k} = r'\cos\theta'\bar{1}' + r'\sin\theta'\bar{j}' + z\bar{k}$ (A1.4)

where $\vec{1}, \vec{j}', \vec{k}$ are unit vectors along the axes $0_2 x', 0_2 y', 0_2 z$, respectively

Al.3 Transformations of Unit Vectors

The unit vectors T, B, k of the revolving frame of reference (see Fig. Al.1) may



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Figure Al Notations

be written in terms of the unit vectors of the translating frame $0_2 x'y'z$ and the angle between the lines $0_3 P$ and $0_3 x''$, where $0_3 x''$ is parallel to $0_2 x'$, as follows:

$$\overline{r} = \cos \theta' \overline{1}' + \sin \theta' \overline{1}'$$

$$\overline{\theta} = -\sin \theta' \overline{1}' + \cos \theta' \overline{1}' \qquad (&1.5)$$

$$\overline{k} = \overline{k}$$

The unit vectors $\vec{1}', \vec{j}', \vec{k}$, of the translating frame $0_2 \times y^2$ may be written in terms of the unit vectors of the absolute frame of reference and of the angle θ_c as follows:

$$\vec{1}' = \cos \theta_c \quad \vec{1} + \sin \theta_c \vec{j}$$

$$\vec{j}' = -\sin \theta_c \quad \vec{1} + \cos \theta_c \quad \vec{j} \qquad (A1.6)$$

$$\vec{k} = \qquad \vec{k}$$

Al.4 Expression of Wind Velocity in an Absolute Frame of Reference

Let the vortex wind velocity with respect to the translating frame of reference be denoted \overline{v}_{ω} , and let its components along the vectors \overline{r} , $\overline{\theta}$ and \overline{k} be denoted by $v_{\omega r}$, $v_{\omega \theta}$ and $v_{\omega k}$, respectively, i.e.,

$$\overline{v}_{\omega} = v_{\omega r} \overline{r} + v_{\omega \theta} \overline{\theta} + v_{\omega k} \overline{k}$$
 (A1.7a)

With respect to the absolute frame of reference, $\overline{v}_{_{AI}}$ may be written as

$$\overline{v}_{\omega} = v_{\omega x} \overline{1} + v_{\omega y} \overline{j} + v_{\omega z} \overline{k}$$
 (A1.7b)

The components $v_{\omega x}$, $v_{\omega y}$ and $v_{\omega z}$ are obtained by substituting Eqs. Al.5 and Al.6 into Eq. Al.7s, i.e., in matrix form,

$$\begin{bmatrix} \mathbf{v}_{\omega \mathbf{x}} \\ \mathbf{v}_{\omega \mathbf{y}} \\ \mathbf{v}_{\omega \mathbf{y}} \\ \mathbf{v}_{\omega \mathbf{z}} \end{bmatrix} \begin{bmatrix} \cos \theta_{\mathbf{c}} - \sin \theta_{\mathbf{c}} & 0 \\ \sin \theta_{\mathbf{c}} & \cos \theta_{\mathbf{c}} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos \theta_{\mathbf{c}} - \sin \theta_{\mathbf{c}} & 0 \\ \sin \theta_{\mathbf{c}} & \cos \theta_{\mathbf{c}} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathbf{v}_{\omega \mathbf{r}} \\ \mathbf{v}_{\omega \mathbf{b}} \\ \mathbf{v}_{\omega \mathbf{b}} \\ \mathbf{v}_{\omega \mathbf{k}} \end{bmatrix}$$
(A1.8)

The total wind velocity $\overline{v_{w}}$ consists of the sum of the vortex wind velocity and the translating velocity of the vortex, i.s.,

$$\overline{v}_{w} \approx v_{wx} \overline{1} + v_{wy} \overline{j} + v_{wk} \overline{k}$$
 (A1.9)

where

$$\begin{array}{c} v_{wx} = v_{wx} + v_{Tx} \\ v_{wy} = v_{wy} + v_{Ty} \\ \vdots \\ v_{vz} = v_{wz} \end{array}$$
 (A1.10)

and v_{wx} , v_{wy} , v_{wz} are given by Eqs. Al.8. In Eqs. Al.10 and Al.8, the quantities v_{Tx} , v_{Ty} , v_{wr} , $v_{w\theta}$, v_{wk} and θ_c are specified. The quantity θ' is a function of time and is obtained from the relations

$$\begin{array}{c} \cos \theta^{1} = \frac{x^{1}}{r^{1}} \\ \sin \theta^{1} = \frac{y^{1}}{r^{1}} \\ r^{1} = (x^{1^{2}} + y^{1^{2}})^{1/2} \end{array}$$
(A1.11)

in which x' and y' are determined as explained in the following.

Let the initial conditions of the problem be

t_o = initial time
(x_o, y_o, x_o) = coordinates of particle at time t_o in the absolute frame
(v_{Pxo}, v_{Pyo}, v_{Pyo}) = velocity components of particle at time t_o in the
absolute frame

 $(x0_{20}, y0_{20}, 0) \equiv \text{position of } 0_2$ (origin of the translating frame) at time t_p , in the absolute frame.

At time t, the position vector of the origin O_2 is

$$\overline{RO}_{2} = [xO_{20} + v_{Tx} (t - t_{0})] \overline{1} + [yO_{20} + v_{Ty}'(t - t_{0})] \overline{1}$$
(A1.12)

so that for any time $t \ge t_0$ we have

$$\bar{R}' = \bar{R} - \bar{R}O_2$$
 (A1.13)
 $\bar{R} = x \bar{1} + y \bar{j} + z\bar{k}, \ 1.e.,$

where

$$\begin{bmatrix} x_{R} \\ y_{R} \\ z_{R} \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x 0_{20} + v_{Tx} (t - t_{0}) \\ y 0_{20} + v_{Ty} (t - t_{0}) \\ 0 \end{bmatrix}$$
(A1.14)

Since

$$x_{R'} \overline{i} + y_{R'} \overline{j} + z_{R'} \overline{k} = x' \overline{i}' + y' \overline{j}' + z' \overline{k}$$
 (A1.15)

it follows, using the inverse of the transformation A1.6,

$$\begin{bmatrix} \mathbf{x}' \\ \mathbf{y}' \\ \mathbf{z}' \end{bmatrix} = \begin{bmatrix} \cos \theta_{c} & \sin \theta_{c} & 0 \\ -\sin \theta_{c} & \cos \theta_{c} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathbf{z}_{R'} \\ \mathbf{y}_{R'} \\ \mathbf{z}_{R'} \end{bmatrix}$$
(A1.16)

where $x_{R^{1}}$, $y_{R^{1}}$, $z_{R^{1}}$, are given by Eq. A1.14. The quantities x^{1} , y^{1} , z^{1} , in Eq. A1.11, and thus the quantity θ^{2} in Eqs A1.10, A1.8 are expressed in terms of the coordinates of point P with respect to the absolute frame, and of the quantities $x0_{x0}$, $y0_{20}$, v_{Tx} , v_{Ty} , t_{0} and t. The problem of expressing the components in the absolute frame of the wind velocity at point P (x, y, z) in terms of the vortex wind velocity components v_{wT} , $v_{w\theta}$, v_{bk} , of the translation velocity components v_{Tx} , v_{Ty} , of the initial conditions and of the coordinates x, y, z of the point P is thus solved.

A1.5 Equations of Motion _

The equations of motion may be written as

$$\mathbf{E} \begin{bmatrix} \ddot{\mathbf{x}} \\ \ddot{\mathbf{y}} \\ \ddot{\mathbf{z}} \end{bmatrix} = \frac{1/2 \ p \ C_{D} A |\mathbf{v}_{Rel}| \ \overline{\mathbf{v}}_{Rel} - g \overline{\mathbf{x}}$$
(A1.17)

where m = mass of particle, p = air density, C_D = drag coefficient, A = area of the particle, $\overline{v}_{Re1} = (v_{UX} - x)\overline{1} + (v_{Uy} - y)\overline{1} + (v_{UX} - z)\overline{k}$, and g = acceleration of gravity.

APPENDIX B - ANALYTIC SOLUTION TO THE EQUATIONS OF HOTION FOR A UNIFORM WIND FIELD.

In the case of a uniform wind field an analytic solution of the equations of motion of a particle may be obtained as shown herein. This solution was used to test the computer program, in which the wind field subroutine was suitably modified. The following assumptions were used:

- 1) The initial velocity of the particle is zero
- 2) The motion occurs in the x x plane only

3) The wind velocity vector is at all points parallel to the horizontal axis 0_x and has the constant magnitude v_y .

The equation of motion in the horizontal direction is

$$\frac{dx^2}{dt^2} = \alpha \left(v_{ij} - \frac{dx}{dt}\right)^2 \qquad (A2.1)$$

where

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$$\alpha = 1/2 \quad \frac{\rho}{m} c_{D}^{A}, \text{ or}$$

$$\int \frac{d(\frac{dx}{dt})}{(v_{w} - \frac{dx}{dt})^{2}} = \int \alpha dt + c_{1} \qquad (A2.2)$$

With the change of variables $u = \frac{dx}{dt} - v_y$, $du = d \frac{dx}{dt}$, Eq A22 becomes

$$\int \frac{du}{u^2} = \alpha t + c_1 \tag{A2.3}$$

$$-\frac{1}{\frac{dx}{dt} - v_w} = \alpha t + C_1$$
 (A2.4)

$$\frac{dx}{dt} = v_w - \frac{1}{\alpha t + C_1}$$
(A2.5)

Integrating Eq. A2.5, there follows

$$x = v_{v}t - \int \frac{dt}{\alpha t + c_1} + c_2 \qquad (A2.6)$$

With the change of variables $a + c_1 = u$, a dt = du, $dt = \frac{du}{a}$, Eq. A2.6 becomes

$$x = v_{w}t - \frac{1}{\alpha}\int \frac{du}{u} + C_{2} \qquad (A2.7)$$

$$x = v_{yt} - \frac{1}{\alpha} \ln (\alpha t + C_1) + C_2$$
 (A2.8)

The constants of integration are determined as follows: At t = 0, x = x₀ and $\frac{dx}{dt}$ = 0, i.e.,

$$x_0 = -\frac{1}{n} \ln c_1 + c_2$$
 (from Eq. A2.8) (A2.9)

 $0 = v_{w} - \frac{1}{c_{1}}$

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Thus

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$$C_1 = \frac{1}{v_w}$$
 (A2.11)

$$C_2 = x_0 - \frac{1}{\alpha} \ln v_y$$
 (A2.12)

and

$$x = x_{a} + v_{y}t - \frac{1}{a} \ln (a v_{y}t + 1)$$
 (A2.13)

APPENDIX C

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DOCUMENTATION,

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SAMPLE INPUT AND OUTPUT

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XPO, YPO, ZPO, VXPO, VYPO, VZPO 6F12.0 232 С 1 233 С XOTE, YOTE, VXTE, VYTE, TU 5E12.0 ¢ 2 234 C 235 SUBGHOUP 3.2. FINAL CONDITION CARD. C 236 C 237 E12.0 C 3 TIMEIT 238 С 239 C C SUBGROUP 3.3. ODE SULVER PARAMETER CARD. 240 241 HI. FXTHIT. EPSI 3E12.0 242 С ۸ c 243 SUBGROUP 3.4. PLOT AND VALIDATION PRAMETER CARD. 244 С 245 C WTPTZY. WTPTYX, WTPTZX, WTPTXT. 712 C 5 246 WIPISX, WIPIHT, WIVALD C 247 C 248 VARIABLE DEFINITION TABLE (GROUP 3). C 249 250 C XPO ARE THE INITIAL X. Y. Z COORDINATES OF THE С 251 С YPO PARTICLE. 252 ZPO С 253 254 С APE THE INITIAL X .. Y. Z VELOCITY COMPONENTS OF С VXPO 255 c VYPO THE PARTICLE. 256 C VZPO 257 C 258 ARE THE INITIAL X, Y COOPDINATES OF THE ORIGIN 259 C XOTE OF THE TRANSLATING FRAME WHICH THE TORNADD IS С YOTF 260 STATICNARY IN. С 261 C 262 ς VXTE ARE THE CONSTANT X. Y VELOCITY COMPUNENTS OF THE 263 С VYTE TRANSLATING FRAME. 264 265 C IS THE INITIAL TIME. TO С 266 С 267 IS THE INTERVAL OF INTEGNATION. С TIMEIT 268 c 269 IS THE INITIAL TIME STEP. A GOOD VALUE TO USE 270 C H1 IS 1.0E-4 С 271 272 С С FXTHIT CONSTRAINS THE ODE SOLVER TO PRODUCE RESULTS FOR 273 С PRINTING AT EQUALLY SPACED TIME INTERVALS OF 274 С THIS SIZE. 275 276 С IS THE LOCAL ERROR TOLERANCE USED BY THE ODE С FPS1 277 SOLVER. A GOOD VALUE TO USE IS 1.0E-4. С 278 279 С 280 С THE NEXT & VARIABLES ARE FLAGS FOR PRODUCING PLOTS. IF A FLAG IS SET TO I THE CORRESPONDING PLUT IS PRODUCED. С 281 С OTHERWISE, THE PLOT IS NOT PRODUCED. 282 С 283 c WTPTZY IS THE FLAG FOR A PLOT OF Z VERSES Y. 284 С 285 С **NTPTYX** IS THE FLAG FOR A PLOT OF Y VERSES X. 286 С 287 288 С WTPTZX IS THE FLAG FOR A PLOT OF Z VERSES X. 289 С

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290	с	WIE	PTXT	15 THE	FLAG FOR	A PLOT	DF	X VER	5ES TI	ME .
91	С									
-92	С	WTF	PTSX	IS THE I	FLAG FOR	A PLOT	OF	SPEED	VERSE	S X.
293	С							•		
294	с	W T F	РТНТ	IS THE	FLAG FUR	A FLCT	OF	HCRIZO	ONTAL	SPFED
295	č	•		VERSES	TIME.					
256	č				•					
297	С	***	VALD	IS A FL	AG WHICH	IF SET	τn	I CAU	SES VA	LIDATICN
298	c		_	INFURMA	TION TO D	SE HRIN	TED	IN ADD	DITION	1 TO THE
299	¢			LSUAL D	UTPUT AT	FACH P	RINT	STEP	 DT HE 	ERWISE.
300	c			NO EXTR	A DUTPUT	IS GEN	ERAT	ED.		
301	C									
202	С	DECK STRUCT	URE'+							
303	c	•								
304	C	COMMENT	WHAT P	CLLOWS	FACH INDE	EX NUNB	EK B	ELOW I	HUST S	TART A NEW
305	с		CARD.							•
306	c							•		
207	с	INDEX .		CARDS.				•	3	ORMAT.
308	C									
209	Ċ	1	GROUP	1.					5	EE ABOVE.
310	c	•		-						-
311	C	2	GRCUP	2.	•				S	EE ABOVE.
312	с									
313	С	3	GROUP	3.				•	· s	EE ABDVE.
314	С				٠					
315	c	A	SENTIN	IEL a					1	2
31¢	C									
317	С		STL	.00P (F1	RST USE)	•				
318	С									
319	C			STLOUP	'IS AN D	INTEGER	VAR	LAHLE	SPT T	Ω A
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34 R	C	
345	C	GROUP (CARD(S) .
350	С	GROUP 2 CARD.
351	с	GROUP 3 CARDS.
352	c	1
367	č	GROUP 3 CARDS.
454	č	
365	č	1
356	č	GROUP 2 CARD.
357	c	GROUP 3 CARDS.
358	C	٥
359	C	0
360	c	1
361	C	GROUP 1 CARD(S).
36 2	C	GROUP 2 CARD.
363	С	GROUP 3 CARDS.
364	c	
76.5	č	
366	č	
365	c c	
368	c	
369	ē	0
370	č	-
371	c	STRUCTURE OF USER SUPPLIED SUBPROGRAMS.
272	c	
37 3	С	THE DEFINITION OF THE CALLING PARAMETERS USED IN USEP SUPPLIED
374	С	SUBREUTINES TORWER AND DHAG CAN BE OBTAINED FROM THE CURRENTLY
375	с	SUPPLIED VERSIONS OF THESE ROUTINES.
376	С	•
	C	
377	Ç-22.	
377 378	C	
377 378 379	C C	SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VANTF,
377 378 379 380	C C C C	SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, * VZWTF, WHICHG)
377 378 379 380 381	C C C C	SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, * VZWTF, WHICHG)
377 378 379 380 381 382	C C C C C C C	SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, * VZWTF, WHICHG) DECLARATIONS.
377 378 379 380 361 382 383		SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, VZWTF, WHICHG) DECLARATIONS,
377 378 379 380 381 382 383 384		SUBROUTINE TORWOF(RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, * VZWTF, WHICHG) Declarations. GD TD (100, 500, 1000), WHICHG
377 378 379 380 381 382 383 384 385		SUBROUTINE TORWOF(RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, * VZWTF, WHICHG) Declarations. GD TD (100, 500, 1000), WHICHG
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377 378 379 380 381 382 383 384 385 386 387		SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, * VZWTF, WHICHG) DECLARATIONS. GD TD (100, 500, 1000), WHICHG 100 SECTION FOR READING IN PARAMETERS TO BE USED IN THIS SUBROUTINE.
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377 378 379 380 381 382 383 385 386 386 386 386 386 385 385 385 391 292		SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, * VZWTF, WHICHG) DECLARATIONS. GD TD (100, 500, 1000), WHICHG 100 SECTION FOR HEADING IN PARAMETERS TO BE USED IN THIS SUBROUTINE. KFTURN 500 SECTION FOR COMPUTING THE VELOCITY COMPONENTS OF THE TORNADD WIND FIELD.
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377 378 379 381 382 383 384 388 388 388 388 388 388 388 388		SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, VZWTF, WHICHG) DECLARATIONS. GD TD (100, 500, 1000), WHICHG 100 SECTION FOR READING IN PARAMETERS TO BE USED IN THIS SUBROUTINE. KFTURN ' 500 SECTION FOR COMPUTING THE VELOCITY COMPONENTS OF THE TORNADD WIND FIELD. RETURN
377 378 380 381 382 383 384 388 388 388 388 388 388 388 388		SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, VZWTF, WHICHG) DECLARATIONS. GD TO (100, 500, 1000), WHICHG 100 SECTION FOR READING IN PARAMETERS TO BE USED IN THIS SUBROUTINE. KETURN 500 SECTION FOR COMPUTING THE VELOCITY COMPONENTS OF THE TORNADO WIND FIELD. RETURN
377 378 381 381 381 383 384 388 388 388 388 391 293 394 591 294 591 294 591 294 591 294 591 294		SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, VZWTF, WHICHG) DECLARATIONS. GD TD (100, 500, 1000), WHICHG 100 SECTION FOR READING IN PARAMETERS TO BE USED IN THIS SUBROUTINE. KFTURN 500 SECTION FOR COMPUTING THE VELOCITY COMPONENTS OF THE TORNADD WIND FIELD. RETURN 1000 SECTION FOR PRINTING ANY RELEVANT PARAMETERS USED IN THE
377 378 381 381 382 383 384 388 388 388 399 299 299 299 299 299 299 299 299 299		SUBROUTINE TORWOF (RPTF, COSPTF, 5INPTF, ZPTF, VRWTF, VAWTF, VZWTF, WHICHG) DECLARATIONS. GD TD (100, 500, 1000), WHICHG 100 SECTION FOR READING IN PARAMETERS TO BE USED IN THIS SUBROUTINE. KFTURN 500 SECTION FOR COMPUTING THE VELOCITY COMPONENTS OF THE TORNADO WIND FIELD. RETURN 1000 SECTION FOR PRINTING ANY RELEVANT PARAMETERS USED IN THE
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37789012345678901234567890012		SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, VZWTF, WHICHG) DECLARATIONS. GD TD (100, 500, 1000), WHICHG 100 SECTION FOR HEADING IN PARAMETERS TO BE USED IN THIS SUBROUTINE. KFTURN 500 SECTION FOR COMPUTING THE VELOCITY COMPONENTS OF THE TORNADD WIND FIELD. RETURN 1000 SECTION FOR PRINTING ANY RELEVANT PARAMETERS USED IN THE COMPUTATION. RETURN END
377890123456789012345678900123 38888789012345678900123		SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, VZWTF, WHICHG) DECLARATIONS. GD TD (100, 500, 1000), WHICHG 100 SECTION FOR HEADING IN PARAMETERS TO BE USED IN THIS SUBROUTINE. NETURN 500 SECTION FOR COMPUTING THE VELOCITY COMPONENTS OF THE TORNADD WIND FIELD. RETURN 1000 SECTION FOR PRINTING ANY RELEVANT PARAMETERS USED IN THE COMPUTATION. RETURN END
3778901234567890123456789001234		SUBPOUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, VZWTF, WHICHG) DECLARATIGNS. GD TD (100, 500, 1000), WHICHG 100 SECTION FOR READING IN PARAMETERS TO BE USED IN THIS SUBROUTINE. KFTURN 500 SECTION FOR COMPUTING THE VELOCITY COMPONENTS OF THE TORNADD WIND FIELD. RETURN 1000 SECTION FOR PRINTING ANY RELEVANT PARAMETERS USED IN THE COMPUTATION. RETURN END SUBROUTINE DRAG(PARMIS, DRAGCE, WHICHG)
3778901234567890123456789001224		SUBROUTINE TORWOF (RPTF, COSPTF, SINPTF, ZPTF, VRWTF, VAWTF, VZWTF, WHICHG) DECLARATIONS. GD TD (100, 500, 1000), WHICHG 100 SECTION FOR HEADING IN PARAMETERS TO BE USED IN THIS SUBROUTINE. KFTURN 500 SECTION FOR COMPUTING THE VELOCITY COMPONENTS OF THE TORNADD WIND FIELD. RETURN 1000 SECTION FOR PRINTING ANY RELEVANT PARAMETERS USED IN THE COMPUTATION. RETURN END SUBROUTINE DRAG(PAPMTS, DRAGCE, WHICHG)

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41.0	С	100 SECTION FOR HEADING IN PARAMETERS TO BE USED IN THIS
411	C	SUBRCUTINE.
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426	c	
427	c c	FREGRAM USAGE (DUTPUT).
429	c	LAYCUT OF OUTPUT.
430	c	
431	С	THE PROGRAM OUTPUT IS DROKEN INTO 4 SECTIONS.
432	C	
433	C	SECTION 1. FROBLEM DESCRIPTION.
434	C	
435		THE PELLOWING DESCRIPTIVE INFIRMATION IS PRINTED.
437	Ċ	WIND VELOCITY PARAMETERS.
438	č	
439	C	ALL THE PARAMETERS WHICH ARE INPUTED FOR COMPUTED THE
440	C	TORNADO WIND FIELD ARE PRINTED. THE NUMBER, NAMES, AND
441	c	MEANING OF THE PARAMETERS ARE DETERMINED BY THE USER.
442	C C	
14J	c c	DRAG UNEFFICIENT PARAMETERS.
445	č	ALL THE PARAMETERS WHICH ARE INPUTED FOR COMPUTING THE
446	С	DRAG COEFFICIENT ARE PRINTED. THE NUMBER, NAMES, AND
447	С	MEANING OF THE PARAMETERS ARE DETERMINED BY THE USER.
448	С	
449	C	PARTICLE PARAMETERS.
450	C C	
452	د د	SELF-FXPLANAIORY. FROM INPUT.
453	č	INITIAL CONDITIONS (TORNADD WIND FIELD).
454	С	
455	C	SELF-EXPLANATORY. FROM INPUT.
456	c	
458	ر د	INITIAL LUNUITIONS (MARTICLE).
459	c	SELF-EXPLANATORY, FROM INDUT.
460	č	ware anternation to the SHEATS
461	Č	· SECTION 2. TABULAR RESULTS.
462	с	
463	С	FIRST. THE INITIAL TIME AND THE TIME INTERVAL FOR OUTPUT ARE

464	~	PRINTED, NEXT, 13 COLUMNS OF BUTPUT ARE GENERATED. EACH LINE
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	·,	COLUMN IS AS EFTIONS.
460	C C	CULOMA 12 43 CCLO#31
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478	Ċ	R(XY) 15 SORT(XP ## 2 + YP ## 2).
A70	č	
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486	c	SPEED 15 SORT(VXP ** 2 + VYP ** 2 + VZP ** 2)
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439	C C	THE PARTICLE IN THE AUSOLUTE FRAME.
490		DIE (YY) IS THE HOUSTONIAL DISTANCE OF THE DADITICLE SDON
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492	C C	THE URIGIN OF THE TRANSLATING FRAME.
443	د م	15 WIVALD - I THEN JODITIONAL OUTDUT TO CENEDATED AT EACH
494		THE STRED - I THEN ADDITIONAL OUTPUT IS GENERATED AT EACH
496	с с	THIS ADDITIONAL CUITOUT.
497	č	
49 E	č	SECTION 3. PROBLEM TERMINATION.
499	С	
500	c	FIRST. THE REASON FOR TERMINATION IS PRINTED. IT CAN BE FOR
501	c	ONE OF THREE REASONS.
502	C	
203	C	IJ THE FINAL TIME HAS DEFN HEACHED.
504	C C	2) THE DISTICLE WIT THE EDGIND
505		21 THE PARTICLE FIT THE GROUND.
500	c c	3) THE ODE SOLVER FAILED DECNATURELY
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510	c	CURRENTLY TAKEN TO BE THE HAX IMUH IN ABSOLUTE VALUE OVER
511	c	VALUES GENERATED AT THE PRINT STEPS. THEY HAVE THE FOLLOWING
512	C	ME ANING.
513	c	
514	C	MAXVXP ARE THE MAXIMUM X. Y. Z COMPONENTS IN ABSOLUTE
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519	č	ABSOLUTE FRAME.
520	č	
521	c	SECTION 4. PLOTS.
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564CSTEP ADAMS CODE DESIGNED AND IMPLEMENTATED BY C. W. GEAR IN565CREFERENCE 1). SINCE THE SYSTEM OF ODES TO BE SOLVED IS NON-STIFF566CALL PARAMETERS AND CALLS TO SUBROUTINES REDUIRED FOR SOLVING567CSTIFF SYSTEMS HAVE REEN DELETED.568C569CCN EACH CALL TO VOADAM THE DDE SOLVER IS ASKED TO INTEGRATE THE570CSYSTEM OF DDES OVER A STEP OF LENGTH H. THE VALUE OF H ARISES FROM571CGNE OF TWO SDURCES.572C573C11 THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.574C575C2) THE VALUE OF H SPECIFIED BY CALLER INTERACTION.576C577CSOURCE 2) IS USED ONLY FOR THE INITIAL STEP AND WHEN THE STEP576CINTERVAL USED FOR PRINTING. OTHERWISE, SOURCE 1) IS USED SO AS TO	563	C	THE ODE SOLVER, VOADAN, IS BASED ON THE VARIABLE ORDER, VARIABLE
565CREFERENCE 1). SINCE THE SYSTEM OF DDES TO BE SOLVED IS NCN-STIFF566CALL PARAMETERS AND CALLS TO SUBROUTINES REQUIRED FOR SOLVING567CSTIFF SYSTEMS HAVE REEN DELETED.568C569CCN EACH CALL TO VOADAM THE DDE SOLVER IS ASKED TO INTEGRATE THE570CSYSTEM OF DDES OVER A STEP OF LENGTH H. THE VALUE OF H ARISES FROM571CGNE OF THO SOURCES.572C573C1) THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.574C575C2) THE VALUE CF H SPECIFIED BY CALLER INTERACTION.576C577C578C579C570C571C572C574C575C576C577C578C579C579C579C579C579C570C571C572C	56 A	C	STEP ADAMS CODE DESIGNED AND IMPLEMENTATED BY C. W. GEAR IN
566CALL PARAMETERS AND CALLS TO SUBROUTINES REQUIRED FOR SOLVING567CSTIFF SYSTEMS HAVE REEN DELETED.568C569CCN EACH CALL TO VOADAN THE DDE SOLVER IS ASKED TO INTEGRATE THE570CSYSTEM OF ODES OVER A STEP OF LENGTH H. THE VALUE OF H ARISES FROM571CGNE OF TWO SDURCES.572C573C1) THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.574C575C576C577C578C578C579C1NTFRVAL USED FCR PRINTING. OTHERWISE, SDURCE 1) IS USED SD AS TO	565	C	REFERENCE 1) . SINCE THE SYSTEM OF DDES TO BE SOLVED IS NON-STIFF
567CSTIFF SYSTEMS HAVE REEN DELETED.568C569C569CCEACH CALL TO VOADAN THE DDE SOLVER IS ASKED TO INTEGRATE THE570C571C571C572C573C574C575C21THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.576C577C578C579C579C579C579CINTERVAL USED FOR PRINTING. OTHERWISE, SOURCE 1) IS USED SD AS TO	566	Ç	ALL PARAMETERS AND CALLS TO SUBROUTINES REQUIRED FOR SOLVING
568C569CCN EACH CALL TO VOADAN THE DDE SOLVER IS ASKED TO INTEGRATE THE570CSYSTEM OF DDES OVER A STEP OF LENGTH H. THE VALUE OF H ARISES FROM571CGNE OF TWO SDURCES.572C573C1) THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.574C575C2) THE VALUE OF H SPECIFIED BY CALLER INTERACTION.576C577C578C579C1NTERVAL USED FOR PRINTING. OTHERWISE, SOURCE 1) IS USED SD AS TO	567	C	STIFF SYSTEMS HAVE REEN DELETED.
569CCN EACH CALL TO VOADAN THE DDE SOLVER IS ASKED TO INTEGRATE THE570CSYSTEM OF DDES OVER A STEP OF LENGTH H. THE VALUE OF H ARISES FROM571CGNE OF TWO SDURCES.572C573C1) THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.574C575C2) THE VALUE OF H SPECIFIED BY CALLER INTERACTION.576C577C578C579C10SUSED ONLY FOR THE INITIAL STEP AND WHEN THE STEP579C10INTERVAL USED FCR PRINTING. OTHERWISE, SOURCE 1) IS USED SD AS TO	568	C	
570CSYSTEM OF ODES OVER A STEP OF LENGTH H. THE VALUE OF H ARISES FROM571CGNE OF TWO SDURCES.572C573C1) THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.574C575C2) THE VALUE OF H SPECIFIED BY CALLER INTERACTION.576C577C578C579C11STAR C579C579C11STAR C579C11STAR C11STAR C12STAR C13STAR C14STAR C15STAR C16STAR C17STAR C17STAR C18STAR C19STAR C10STAR C10STAR C10STAR C10STAR C10STAR C10STAR C10STAR C10STAR C10STAR C11STAR C12STAR C13STAR C14STAR C15STAR C16STAR C17STAR C18STAR C19STAR C10STAR C10STAR C10STAR C10STAR C10STAR C10STAR C10STAR C10STAR C10STAR	569	. C	CN EACH CALL TO VOADAN THE DDE SOLVER IS ASKED TO INTEGRATE THE
571CGNE OF TWO SDURCES.572C573C1) THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.574C575C2) THE VALUE OF H SPECIFIED BY CALLER INTERACTION.576C577C578C15MODIFIED SC THAT IT FALLS ON A MULTIPLE OF THE FIXED TIME579C10INTERVAL USED FCR PRINTING. OTHERWISE, SOURCE 1) IS USED SD AS TO	570	C	SYSTEM OF DDES OVER A STEP OF LENGTH H. THE VALUE OF H ARISES FROM
E72CE73C1) THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.574C575C2) THE VALUE OF H SPECIFIED BY CALLER INTERACTION.576C577C577C578C15MODIFIED SC THAT IT FALLS ON A MULTIPLE OF THE FIXED TIME579C10INTERVAL USED FOR PRINTING. OTHERWISE, SOURCE 1) IS USED SD AS TO	571	С	GNE OF THO SDURCES.
1) THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.574C575C576C577C578C578C578C579C570C570C570C570C570C570C571C572C573C574C575C575C576C577C578C579C570C570C570C570C570C5	572	C	
574C575C2) THE VALUE OF H SPECIFIED BY CALLER INTERACTION.576C577C577C578C15MDDIFIED SD THAT IT FALLS ON A MULTIPLE OF THE FIXED TIME579C1INTERVAL USED FOR PRINTING. OTHERWISE, SOURCE 1) IS USED SD AS TO	573	C	1) THE VALUE OF H RETURNED BY THE PREVIOUS CALL OF VOADAM.
575C2) THE VALUE OF H SPECIFIED BY CALLER INTERACTION.576C577C577C578C15MDDIFIED SC THAT IT FALLS ON A MULTIPLE OF THE FIXED TIME579C1INTERVAL USED FOR PRINTING. OTHERWISE, SOURCE 1) IS USED SD AS TO	574	ç	
577 C SOURCE 2) IS USED ONLY FOR THE INITIAL STEP AND WHEN THE STEP 578 C IS MODIFIED SO THAT IT FALLS ON A MULTIPLE OF THE FIXED TIME 579 C INTERVAL USED FOR PRINTING. OTHERWISE, SOURCE 1) IS USED SO AS TO	575	c	2) THE VALUE OF H SPECIFIED BY GALLER INTERACTION.
STRCSOURCE 21 IS USED UNLY FOR THE INITIAL STEP AND WHEN THE STEPSTRCIS MODIFIED SO THAT IT FALLS ON A MULTIPLE OF THE FIXED TIMESTSCINTERVAL USED FOR PRINTING. OTHERWISE, SOURCE 11 IS USED SO AS TO	2/6	C	
579 C INTERVAL USED FOR PRINTING. OTHERWISE, SOURCE 1) IS USED SO AS TO	577	C A	SUURCE 21 IS USED UNLY FOR THE INITIAL STEP AND WHEN THE STEP
DIT C INTERVAL USED FOR PRINTING. OTHERWISE, SOURCE IT IS USED SO AS TO	2/13	C	IS MUDIFIED SU THAT IT FALLS ON A HULTIPLE OF THE FIXED TIME
	5/4	C.	, INTERVAL USED FLH PHINTING. UTHERWISE, SOURCE IT IS USED SO AS TO

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580	С	ACHIEVE AN	ECCNCHICAL INTEGRATION.
581	с		
582	с	THE INPUT V	ALUE OF H IS USED UNLESS THE FRPCR CRITERIA CANNOT RF
E # 3	č	META IN THE	S CASE THE STEP AND/CR ORDER ARE MODIFIED TO TRY TO
ENA	ċ	NEET THE ER	ROR CRITERIA. IF AN ATTEMPT IS MADE TO REDUCE THE STEP
505			ED SUDD TED VALUE, WIN, THE DDE SOLVED DUITS AND
500		052(17 5 CAL)	ADDUDDIATE NONTEDD FUURU CONDITION CODE.
270		RETURNS THE	VERGENTALE ADDIEND CHELK CLANTIION CODE
SC /	č	INCE A SUCC	ESSEUL STEP HAS HEEN TAKEN. VOADAN ESTIMATES AND
589	č	RETURNS A G	COD VALUE OF H TO HE USED FOR THE NEXT STEP. THIS
590	C	ESTIMATED S	TEP CANNUT BE GREATER THAN A CALLER SUPPLIED VALUE.
591	C	HHAX -	
295	С		
593	C	FOR MORE DE	TAILS ON VOADAM CONSULT THE MACHINE READABLE
594	C	DOCUMENTATI	IN AT THE REGINNING OF THE SUBROUTINE.
595	С		
596	C	VALIDATICA.	
597	С		•
598	C	THE PROGRAM	FREVIDES THE USER BY WAY OF THE WIVALD INPUT VARIABLE
599	C	THE CAPABIL	ITY OF PRINTING IMPORTANT INTERMEDIATE QUANTITIES.
600	C	THESE OUANT	ITIES ARE PRINTED AS ADDITIONAL OUTPUT AT THE NORMAL
601	С	PRINTING ST	EPS. THE AMOUNT OF OUTPUT PER PRINT STEP INCREASES FROM
602	C,	ONF LINE TO	SEVEN LINES. TO INTERPRET THE MEANING OF THE VARIABLES
603	ç	PRINTED CON	SULT THE TABLE BELOW ACCOMPANIED BY APPENDIX A OF
604	C C	REFIRENCE 2	1.
EUD 404	<u> </u>	1) 7 E	TE THE CHINNELCH BADINE OF THE OPICIN OF THE
6407		RIF	TOING ATING SUMME FROM THE ODICIN OF THE ABOUNTS
608	ب م		FRANKLAND FRANK FRUM INC. UNIGIN UP INC ANSULUIG
600	č		
610	с г	CUSTE	AVE THE COCINE, SINE WE THE INCLE THAT THE DIDECTION
411		CU31F	ARE THE CUSTACE STAL OF THE ANDLE THAT THE DIRECTION
611		51616	LE TRANSLATION MARCO WITH THE A AXIS OF THE AUSULUTE
417	ر م	•	r 64 65 • •
414	с г	DDTE	TE THE CHI INDUICH DADING OF THE DADILE FROM THE
615	c		DRIGIN OF THE TRANSLATING FRAME.
616	č		Putato de los construitos nemet
617	c	FCUSTF	ARE THE CUSINE, SINE OF THE ANGLE THAT THE CYLINDRICAL
618	С	PSINTF	RADIUS TO THE PARTICLE PAKES WITH THE X AXIS OF THE
619	C		TRANSLATING FRAME.
620	С		
621	С	WRTF	ARE THE RADIAL, ANGULAR, AND Z COMPONENTS OF THE WIND
622	С	WAN GT F	VFLOCITY AT THE PARTICLE USING THE REVOLVING FRAME.
E23	С	N2TF	
624	С		
625	c	*XTF	ARE THE X. Y COMPONENTS OF THE KIND VELOCITY AT THE
626	С	WYTF	PARTICLE USING THE TRANSLATING FRAME.
627	ç		
628	c		ARE THE X, Y, Z COMPONENTS OF THE WIND VELOCITY AT THE
629		W TAP	PARTICLE USING THE AUSCLUTE FRAME.
431		4 6 AT	
632	r r	N VYPAF	ARE THE X. Y. 7 CONDONENTS OF THE DELATIVE VELOCITY OF
633	r	RVYDAF	THE PARTICLE WITH RESPECT TO THE WIND HEADE THE
634	c	RV7PAF	ABSOLUTE FRAME.
635	c c	** * 6. * * 1	
636	Ċ		
637	Ċ	PORTARIILTY.	•
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638	C.	
635	C	LANGUAGE •
640	r	
C41	L	BELL VENIFIER FURIMAN.
642	C	
643	С	PRECISION.
644	С	•
645	c	SINGLE.
646	С	· · ·
ć4 7	С	RESTHICT IONS .
648	C	
649	c	THIS PROGRAM WAS DESIGNED TO RUN CORRECTLY WITH A NINIPUP LP
650	С	RODIFICATION ON MACHINES WHICH HAVE A SINGLE PRECISION
651	С	FLOATING POINT WORD WITH A MANTISSA IN THE RANGE OF 24 THROUGH
652	c	AB EITS.
653	С	
KEA	č	ALL INDIT IS FORM FORTHAN FORMATTED CARD INAGES AND IS PEAD
10.4		CONTRACTOR CONTRACTOR CONTRACTOR CONTRACTOR CONTRACTOR CONTRACTOR CONTRACTOR
623	Ľ	FRUM EUGICAE UNIT 5.
656	Ç	
657	C	ALL OUTPUT IS FORTRAN FORMAT GENERATED AND IS WRITTEN TO
658	С	LOGICAL UNIT 8. THE INTENDED DEVICE IS A LINE PRINTER SET TO
659	C	AT LEAST A 132 CHARACTERS PER LINE AND AT LEAST GO LINES PER
660	c	· PAGE •
661	C	THE CHERNER DEFAILS FOR THE CERTICAL MACUNE (EVENETING DESCRIPTION)
503	C	FOR FURITIES DETAILS SEE INE SECTION, MACHINESSIEM UPPENDENT
663		PEALORES, AT THE REGISTION OF THE EXECUTABLE LUDG IN STREAM
564	C	PROGRAM AND ALL SUBPROGRAMS LISTED IN THE SUBPROGRAM DIRECTORY.
665	С	
666	С	CEDE RESPENSIBILITY.
667	С	· · · · · · · · · · · · · · · · · · ·
668	с	HARTIN CURDES
669	С	APPLIED MATHEMATICS DIVISION
670	ē	NATIONAL BUREAU OF STANDARDS
671	c	WA 5H INGTON , D. C. 20234
672	c	
673	č	(301) 921-2631
674	č	
675	ċ	HISTORY.
676	Ċ	
A77	Ċ	OPICINAL VERSION.
678	č	
470		MAN 1076
619		C141 10
401		
001	L A	VEATSEN AEMSTRUISIO
CHZ	C	
083	C	AUG 1575
684	C	APR 1976
685	C	
080	C	REFERENCES •
687	C	
688	· C	IJ C. W. GEAR, NUMERICAL INITIAL VALUE PROBLEMS IN ORDINARY
689	C	DIFFERENTIAL EQUATIONS, PRENTICE-HALL, 1971, 253P.
690	с	
691	С	2) E. STHIU AND N. CORDES, TORNADO - BORNE MISSILE SPEEDS,
692	С	NBS INTERAGENCY REPORT
693	С	
694	C	
	C	

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TORNADE+WI	ND()	J.TCHWOFSFX(0)
1		SUBROUTINE TORWOFIEPTE, COSPTE, SINPTE, LPTE, VRWTE, VAWTE, VZWTE,
5		★ \\HICHG\
3	C	
4	С	THIS SUBROUTINE COMPUTES THE TORNADO WIND VELOCITY COMPONENTS
E	C	
6	С	DEFINITION OF PARAMETERS.
7	C	RPTF.COSPTF.SINPTF.ZPTF = RADIAL CCCRDINATE. COSINE AND SINE OF
8	C	THE ANGLE, AND Z CCCRDINATE OF THE
а 10	2	CODUDINATE SYSTEM DEFINED AS THE
11	č	TRANSLATING FRAME
12	č	VRNTF, VAWTF, VZWTF = RADIAL, ANGULAR, AND Z COMPONENTS OF THE
13	С	WIND AT THE PARTICLE AS MEASURED IN THE
14	C	THANSLATING FRAME
15	С	WHICHG = 1 - READ IN WIND VELOCITY PARAMETERS
16	с	2 - COMPUTE WIND VELOCITY COMPONENTS
17	c	3 - PHINT WIND VELOCITY PARAMETERS
1.6	č	
19	č	PARANETER DECLARATIONS.
20	c	
21		REAL RPIF, COSPTF, SINPIF, ZPTF, VRWTF, VAWTF, VZW7F
55		INTEGER WHICHG
52	c	
24	C C	CTHEH COMMON VARIABLES.
20	C	DFAI DHTV70-HTV-K1-K3-K3-K5
23	c	
28		COMMON /IWDEDR/RHIV/0.MIV.K1.K2.K3.K4.K5
. 20	r	
30	č	LOCAL VARIABLE DECLARATIONS.
21	c	
32	•	REAL RATV2.R332.RATIO
33		INTEGER ID, DD
34	c	
35	C-	,
36	C	
37	c	MACHINE/SYSTEM DEPENDENT FEATURES.
38	Ċ	DEGINITION OF LOO UNITE HEED IN THE CURRENTLY
35	د م	VERTITION OF IND UNITS USED IN INTS SUBROUTINES
41	ř	ID IS THE UNIT USED FOR INPUTING DATA.
42	c	1. In the out, onto the fundation being
43	ċ	CD IS THE UNIT USED FOR OUTPUTING RESULTS.
4.4	č	
45	c	
46		DATA ID, DD/5+ 6/
47	С	
48	C	
45	C-	
50	C	
51	~	an ter finntanntinnnitkuicua
52 57	c	READ IN NIND VELOCITY PARAMETERS
54	č	
55	-	100 REAC(10,250) RNTVZ0.HTV.K1.K2.K3.K4.K5
56		250 FORMAT(1CEC.0)
57		RETURN

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50	¢		
59	C COM	PUTE WIND VELUCITY CO	NPONENTS .
60	с		•
61	500	IF(ZPTF.GE.60.0) GD	TO 525
52		RHTVZ#RHTVZ0+K1+	ZPTF
63		GC TO 550	
64	525	RMTVZ=RMTV20+K1#60.	0
65	550	R332= (MTV/33.0) ++.6	25+RHTVZ
66	C		
67	-	IF(RPTF.GE.RMTVZ) G	O TO 575
69		HATIO=RPTF/RHTVZ	
69		GO TO 600	
70	575	HAT ICERNTV7/RPTF	
71		1F(84)F.GF.8337) GD	TD 650
70	c		
73		15(7015.65.60.0) CO	TC 625
72	000	VP & TF = - Y 5 4 (P 3 7 -	DDTE)/(417-DMTV7)#DDTE
75		VANTENDATIONNTV	
75		V/STEEKIS(0337-9	9751/(8337-8MTV71+7075+K4/3-0+V4WTF
77		DETHON	
78	625	IFLITELGE-240.0) G	D TD 650
79		VPhTF==K5#/8332=	RPTE)/(R337-RMTV7) +RPTE + (240.0-2PTE)/180.0
80		VANTERATICANTV	
81		VZWTF=(1.33-ZPTF	/180+0)+(K3+(R432-HPTF)/(H332-RMTVZ)*60+0+
82	•	K4/3.0+VAW	TF)
83		RETURN	
84	650	VRNTF=0.0	•
85		VANTE=PAT 10+HTV	
86		VZ WTF = Q, D	
87		RETURN	
e e	с.		
89	C PRI	NT WIND VELOCITY PARA	METERS
90	c		1.
91	1000	WRITE (00+1100) HMTV	ZÓ+HTV+K1+K2+K3+K4+K5
92	1100	FORMAT(26HOWIND VEL	UCITY PARANETERS./
93		5X:15H RMTV20	= 11PE12.4/
94		EX+15H MTV	= +1PE12+4/
95		5X +15H K1	= •1PE12.4/
96	*	5X +15H K2	= ,1PE12.4/
97	•	1 EX+15H K3	= +1PE12+4/
98	*	5X+15H KA	= .1PE12.4/
99	*	5X,15H K5	= +1PE12+4)
100	RI	ETURN	
101	c		
102	E1	ND .	
END PRT			

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DPRT.S F1.DRAGSEX

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TOPNADO+NINU(1).DRAG SEX(0) SUBROUTINE DRAG(PARMTS, DRAGCE, WHICHG) 1 2 С THIS SUBPOUTINE COMPUTES THE DRAG COEFFICIENT FOR THE PARTICLE 3 C . С 5 c. DEFINITION OF PARAMETERS. £ С PARMIS(1) # ARRAY OF TIME DEPENDENT PARAMETERS THAT 7 С AFFECT THE COMPUTATION OF THE DRAG 8 C COFFFICIENT . DRAGCE Q С . BPAG COEFFICIENT COMPUTED BY THIS 10 C SUBROUTINE 11 C WHICH 1 - READ IN DEAG COEFFICIENT PARAMETERS C 2 - COMPUTE DRAG COLFFICIENT 12 Ċ 13 3 - PRINT DRAG COEFFICIENT PARAMETERS 14 С 15 С PARAMETER DECLARATIONS. 16 С 17 REAL PARMIS(1) 18 REAL DRAGCE 10 INTEGER WHICHG 20 С 21 С OTHER COMMON VAHIABLES. 22 С 23 REAL CORAG 24 ٢ 25 CCPHEN /CGCOPR/CORAG С 2ć 27 С LCCAL VARIABLE CECLARATIONS. 28 С 29 INTEGER ID.DD С 30 31 C~ 32 С 22 С MACHINE/SYSTEM DEPENDENT FEATURES. 34 C DEFINITION OF I/C UNITS USED IN THIS SUBROUTINE. 35 C 36 C 37 c 10 IS THE UNIT USED FOR INPUTING DATA. 38 С 39 C CD IS THE UNIT USED FOR DUTPUTING RESULTS. 4 C С 41 С 42 DATA 10, 00/5, 6/ С 43 44 С 45 c-46 С 47 GO TO (100,500,1000), WHICHG 48 С 49 С READ IN DRAG COEFFICIENT PAHAHETERS 50 C 51 100 READ(ID,250) CDRAG FORMAT(6E12.0) 52 250 53 RETURN 54 С 55 C CUMPUTE DRAG COEFFICIENT 56 C 57 500 DRA GCF=CDRAG

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57	REICRN .
EJ	C
60	C PRINT DRAG COEFFICIENT PARAMETERS
e 1	C
67	1000 #RITE(OC.LIOO) CORAG
· 63	1100 FORMAT(29HODRAG CUEFFICIENT PARAFETERS./
6▲	
6 2	PETURN
66	C
67	END

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END PRT

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SPRT.S FI.CATAGEX

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I CHKADUWRII	NU(I)+DATASEY())					
1	46.0 130.0	0.0	0.0 1.0	1.0	1.0	
2	1.0					
3	1.0	10.0				
4	46.0	0.0	A0 - 0	0.0	0.0	~ ~
5	0.0	0.0	35.0	0.0	0.0	0.0
6	10.0		5	0.0	0.0	
7	1-0E-4	1 - 0E - 1				
R.	1 1 1 1 1 1 0					
S	o					
10	C					
11	0					
END PRT						

DXOT FL.ABSSEX

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PROBLEM DESCRIPTION

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MEZD	VELCCITY P	ARAPET	ERS.			_							
	RHTVZO	25	4 . 60(00+01									
	MTV	-	1.300	00402			•			•			
	K 1	#	0.000	00									
	K2	11	0.000	00									
	K3		1.00	00+00									
	1C 🔺		1.00	CC+00									
	K5	-	1.00	00+00									
DRAG	COEFFICIEN	T PARA	>ETE=	5.									
	CCRAG		1.00	CO+00									
PARTI	CLE PARAME	TERS.				•							
	AREA	=	1.00	00+00									
	MASS	-	1.00	10+01									
INITI	AL CONDITI	0N5. (TORNA	ON VIND FI	Fint								
	PGSITION.	X 7	0.	0000	Y =	0-0000							
	VELOCITY.	VX w	3.	5000+01	VY =	0.0000							
INITI	AL CONDITI	ONS. L	PAHTI	CLEI									
	POSITION	<u>х</u> =	4.	6000+01	y a	0.000	2 =	A + 0000+0	•				
	VELCCITY.	VX Z	C.	0000.	VY =	0.0009	VZ =	0.0000	• •				
					TABUL	A RESULTS							
T 171 T 176	AL TIME. Interval P	00,0 110 RO	00 PUT+	1.0000-	01	•	•			·	_	•	
		¥			70	3(**)	VXP	VYP	vzp	HSPFFD	SPEED	HUSPEED	RTF (XY)
	0-00	4.6	0+01	0-00	A - 00+11	4160401	0-00	0.00	0.00	0.00	0.00	1.30+02	4-60+01
21		A.5	6+01	3-73+00	4.24+01	4-56+01	-6-17+00	5.94+01	3-95+01	5.98+01	7.17+01	1.17+02	4.23401
	2-00-01		A+ 01	1.06401	4.71+01	4-58401	-1-37+01	7-33+01	5-31+01	7.45+01	9+15+01	1.01+02	3-91+01
4.F	1 3.00-01	4.2	9401	1-00+01	5,294.01	4+65+01	~2.1:1+01	7+56+01	6+20+01	7.86+01	1.00+02	8.86+01	3.71+01
50	4.00-01	4.0	3+01	2-54401	5. 96+ 01	4.76+01	-1-15+01	7.07+01	7.12+01	7.75+01	1-05+02	e.08+01	3+66+01
66	5-00-01	3.6	5401	7.19+01	6-71+01	4-85+01	- 4 - 36+01	5.92+01	7.90+01	7.35+0t	1.05+02	7.84+01	3.72+01
72		3.1	6+01	3.71401	7.52+01	4-87401	-5-42+01	4.20+01	5+35+01	6-90+01	1-08+02	8.11+01	3+86+01
60	7.00-01	2-5	7+01	4-04+01	5-37+01	4.79+01	-6.25+01	2.26+01	8.52+01	6.64+01	1.08+02	5,75+01	4.04+01
	5 6.00-01	1.9	2+01	4-15+01	9.22+01	4-58+01	-6.73101	7.00-02	A++9+01	6+73+01	1.08+02	9.64+01	4.24401
90	9.00-01	1.2	4+01	4-04+01	1-01+02	4.22+01	-5.80+91	-2-38+01	8.32401	7.20+01	1.10+02	1.07+02	4.46+01
1 02	1-00+00	5.7	0+00	3-68+01	1.09107	3.72+01	-6-27+01	-4+76+01	8-03+01	7.96+01	1.13+02	1.14+02	4.70+01
111	1.10400	-8-5	5-02	3.10+01	1.17+02	3.16+01	-5.27+01	-6.76+01	7.61+01	8,57+01	1.15+02	1+15+02	4+95+01
114	1.20.00	-4-5	9+00	2.24+01	1.24+02	2+39+01	-3.67+01	-A-27+01	7.10+01	9.04+01	1-15+02	1.17+02	5.21+01
122	1.30+00	-7-3	6+00	1.46+01	1.31+02	1.64+01	-1.25+01	-9-24+01	6.56+01	9.43+01	1+15+02	1.14+02	5+48+01
122	t_40+00	-8-2	8+00	5.00+00	1.37+02	9.72+00	-1.15-01	-9.74+01	6.01+01	9,74+01	1.14+02	1.18+02	5.75+01
1.75	1 1.40+00	-7.4	2+00	-4.75+00	1.43+02	8.01+00	1.72+01	-9.86+61	5.50+01	1+00+02	1+14+02	1+19+02	6-01+01
1 71	1.60+00	-4_9	0+00	-1+45+01	1.48+02	1+53+01	3.28+01	-9-68+01	5.02+01	1.02+02	1.14+02	1.19+02	6.26+01
143	2 1.70+00) -942	6-01	-2.40+01	1.53+02	2.41+01	4,64+01	-9+30+01	4.58+01	1-04+02	1+14+02	1.18+02	6.50-01
14/	5 1,40+00		11+00	-3+31+01	1-57+02	3.34+01	5.90+01	-8.78+01	4.17+01	1.05+02	1.13+02	1.18+02	6.74+01
1.44 1.44	1.90+00	1.0	6+01	-4-16+01	1-61+02	4.29+01	6.78+01	-8-17+01	3.81+01	1,06+02	1.13+02	1.17+02	6.97+01
14	1 2.00+00	1 1-7	B+0)	-8-98+01	1.65+02	5.25+01	7.59+01	-7.51+01	3.97+01	1.07+02	1.12+02	1.16+02	7+19+01
143	7 2,10100		1048	-5+66+01	1.68+02	6.22+01	8.25+01	-6.83+01	3,17+01	1+07+02	1 +12+02	1.14+02	7.49401
16:	2,70+00	3.4	3+01	-6-31+91	1+71+02	7.18+01	8.79+01	-6.14+01	2.89+01	1.07+02	1+11+02	1+13+02	7+62+01
164	1 2,30+00) 4=3	13+01	-5+89+01	1.74+02	8-13+91	9.21+01	-5+46+01	2.64+01	1.07+02	1.10+02	1.11+02	7.03+01
161	3 2.40+00) 5.2	7+01	-7+40+01	1.77+02	9.08+01	9.53+01	-4.80+01	2.40+01	1+07+02	1-09+02	1-10+02	8+04+01

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170 2.63 400 6.22140 -7.2401	NSTP	т	XP	ΥP	ZP	R(XY)	VXP	VYP	y zp	HSPEED	SPEED	HWSPEED	RTF(XY)
174 2.40400 7.2200 1.09002 1.09002 1.09001 1.09001 1.09002 1.09002 0.09002 0.09001 1.09001 1.09001 1.09002 0.09002 0.09001 0.09001 1.09001 1.09002 0.09002 0.09001	170	2.50 +00	6.23+01	-7-85+01	1.79+02	1.00+02	9.77+01	-4-15+01	7-19+01	1.04+02	1.08+02	1.05+02	8+24+01
179 2.70000 0.22001 -0.5001 1.09002 1.09002 1.09002 1.09002 1.09002 0.09001 0.09001 0.09002 0.09001	174	2.60+00	7-22+01	-8.23+01	1-81+02	1-09+02	9.94+01	-3-55+01	1.99601	1.06+02	1 - 07+02	1.07+02	8-4401
100 2.00000	178	2-70+00	8-22+01	-8-56+01	1.01407	1.19407	1.00+02	-7-98+01	1-80+01	1+05+02	1.06+02	1.05+02	8.65+01
103 2.400.00 1.200.02 -0.500.01 1.300.02 1.0000.02 1.000.02 1.	180	2-60+00	9-73401	-8-83401	1.84407	1.784.07	1.01402	-7.44401	1-63401	1.04+02	1.05+02	1.03+02	8+85+01
117 3.100000 1.2102 -0.22001 1.47002 1.47002 1.31001 1.02002 1.02002 0.40001 0.42001	183	2-90400	1-02402	-0.05401	1 84402	1.37403	1.01+02	=1.04401	1.48+01	1-03+02	1+04+02	1.01+02	9.05+01
	187	3-00+00	1.17602	~0.77401	1.876.02	1.45402	1.01402	-1 47 401	1.73401	1-02+02	1+01+02	9.96+01	9.25+01
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	107	3.10400	1 77402		1267402	1.5.02	1.01+02	-1.04401	1 104.01	1.01+02	1.02402	9.77+01	9.45+01
199 3.2000 1.2000 -0.2000 1.0000 -0.2000 0.2000	170	3 30.00	1 23502	-9.34401	1.89702	1-34-02	0.00.02		1. 04.403	1-00+02	1.01402	9-62+01	9.65+01
201 2.4400 1.4200 -4.400 1.4200 -4.200	174	3.20,00	1033402	-9.43+01	1.90402	1.03+02	9.90101	-7 63400	0.37400	100000	0.93401	9-45+01	9.85+01
201 3.5000 1.5200 -0.6500 1.07000 0.67000 0.6700 0.6700	201	3,30+00	1.43+02	-9.47+01	1.91+02	1 471+02	9.89701	-2.02+00	9,37,000	0.78401	0.51401	9-29+01	1.01+02
200 3.40000 1.72000 -0.80001 1.03000 1.03000 3.57001	201	3.50100	1+32+02		1.92-02	1.74+02	9.70.01	7.02-01	3 4 7 4 0 0	9 67.01	d. 69401	9-13+01	1+03+02
210 3.7.9000 1.4.8402 -4.82001 1.0.9002 5.0000 5.4.401 5.4.401 5.4.401 5.4.401 5.4.401 1.0.9002 213 3.60000 2.40002 -4.2201 1.9.902 2.11902 7.1101 1.1.901 7.3101 7.1101 1.1.901 7.3101 7.1101 1.1.902 224 4.0000 2.0002 -8.9401 1.0902 2.3502 6.7001 1.1101 1.1401 5.9001 6.9401 8.2001 1.1502 224 4.0000 2.3402 -6.3501 1.0902 2.3502 6.7001 1.1101 1.1401 5.9001 6.9401 8.2001 1.11702 224 4.2000 2.3502 -8.4501 2.0100 -6.4201 8.6001 7.0001 1.1702 224 4.2000 2.3502 -8.4501 2.3402 8.4501 2.3400 8.7301 7.0001 1.17402 237 4.35000 2.3102 -7.6001 1.9402 2.4402 7.4701 2.4000 4.4001 1.22001 1.24002 236 4.00000 2.75002	204	3430400	1.02702		1.93+02	1.00+02	9.00+UI	3.9000	6 - 0 - 0 0	0.55401	a. 47401	3.97+01	1.05+02
210 3.0000 1.0000	202	3.80400	1.72+02	-9.40+01	1.93+02	1.00+02	4.53.01	0 74 400	R.09+00	903001	0.44401	8-82401	1 - 07+92
212 3.00000 1.00002 -0.22401 1.00002 -0.2401 1.01002 -0.2401 1.01002 212 3.00000 2.00002 -0.00001 1.00002 2.01002 0.11001 1.01001 0.00001 0.20001 0.10001 0.10001 0.20001 1.01002 1.01002 212 4.0000 2.00002 -0.5001 1.09002 2.01002 0.0001 -0.0001 0.0501 0.0501 0.0501 1.17402 224 4.0000 2.3502 -0.57001 1.09002 2.4202 0.42001 2.10401 -1.4400 0.75001 0.0501 1.17402 234 4.0000 2.3502 -0.57001 1.09402 2.4400 0.2001 0.04001 0.4001 1.24002 237 4.0000 2.3502 -7.4001 1.09402 2.47002 2.4000 0.3501 0.04001 1.2402 24 4.0000 2.47002 -7.4001 1.09402 2.7702 7.7501 2.70001 -0.0000 0.35010 0.3601 7.3001 1.2402 255 4.00000 2.47002 -7.4	210	3. 0000	1-81+02	-9.32+01	1-94+02	2.04+02	9.40+01	9,32+00	5,10+00	9.44+01	9140701	8 68401	1-09+02
218 3.40000 2.0042 00400 1.00402 2.21022 2.2102 2.2102	215	3+80+00	1.90+02	-9-22+01	1.74+02	Z+12+02	9+26+01	1-17+01	4,07+00	4-23+01	9	51401	1-11+02
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	218	3.90.00	2+00+02	~9+09+01	1.95+02	2=19+02	9-11+01	1.39+01	2.64+00	9+22+01	9+22+01		1 1 1 1 1 2 2
224 4.16400 2.18402 -6.77401 1.05402 2.33402 2.34001 2.18401 3.14-01 0.98401 8.48401 8.42001 1.17402 225 4.20400 2.35402 -6.37401 1.40402 2.44402 8.43401 2.14401 -1.47400 8.73401 8.73401 1.47402 237 4.50400 2.31402 -7.40401 1.04402 2.51401 2.31401 2.24400 8.60401 7.64401 1.64401 7.64201 1.25402 237 4.50400 2.51402 -7.40401 1.04402 2.77401 2.77401 2.47401 4.60400 7.64401 1.25402 245 4.70102 2.77401 1.04402 2.77402 7.77401 2.77401 -2.04400 8.27401 1.25402 245 4.60402 2.77402 -7.77401 2.77401 -2.04400 8.27401 1.25402 1.25402 245 4.60402 2.67402 -7.37401 1.04402 2.77401 2.77401 -7.77401 7.75401 7.75401 7.75401 7.75401 7.75401 7.75401 7.75401 7.75401 <td>222</td> <td>4.00100</td> <td>2.09+02</td> <td>~8,94+01</td> <td>1.95+02</td> <td>2+27+02</td> <td>8=95+01</td> <td>1+61+01</td> <td>1.40+00</td> <td>9.10+01</td> <td>9-10-01</td> <td>0.36+01</td> <td>1.15102</td>	222	4.00100	2.09+02	~8,94+01	1.95+02	2+27+02	8=95+01	1+61+01	1.40+00	9.10+01	9-10-01	0.36+01	1.15102
228 4.20400 2.224012 -6.50401 1.02402 2.42402 8.62501 2.00401 -6.44-01 8.62501 1.02402 234 4.40400 2.43402 -6.14401 1.05502 2.56402 R.250401 2.34401 -2.24400 R.60401 7.76401 1.74402 234 4.60400 2.25902 -7.64401 1.04402 2.77402 7.64401 2.65701 2.4460 8.35701 6.25701 7.44101 1.26402 245 4.60400 2.25902 -7.64401 1.04402 2.77401 2.64801 -3.56400 6.25401 7.34401 1.26402 253 4.60400 2.6702 -7.6401 1.09402 2.774701 2.64801 -3.5540 6.2401 7.34401 1.26402 253 4.60400 2.6702 -6.60401 1.09402 2.70402 7.6701 3.00401 -5.97401 6.60401 1.32402 262 5.10400 2.67020 -6.6101 1.92402 3.03402 7.67401 3.10401 -3.75401 7.67401 4.64401 1.32402 264 5.20403 <	224	4-10+00	2.18+02	-8.77+01	1.95+02	2.35+02	8.79+01	1_81+01	3-14-01	0-98+01	6+95+01	8.20+01	1 171A7
232 4.30400 2.33402 -6.37401 1.95402 2.43402 2.43401 2.13401 -2.14400 6.47341 6.73401 7.70401 1.11402 237 4.50400 2.51402 -7.6001 1.94402 2.51402 7.32401 6.60401 7.60401 1.24402 242 4.60400 2.50402 -7.73401 1.94402 2.77402 7.77401 -4.6400 0.54401 7.64401 1.24402 245 4.77400 2.47602 -7.77401 1.94422 2.77402 7.77401 -4.04400 0.23401 6.2401 7.3401 1.24402 250 4.60400 2.47602 -7.37401 1.94422 2.47402 7.57401 2.40401 7.97401 6.4041 1.32402 253 4.60400 2.4702 -6.6040 1.92402 2.47002 7.27401 3.0040 4.74401 4.94401 1.32402 254 5.1040 2.47040 1.92402 2.47401 7.2401 3.0040 7.47411 1.24402 254 5.1040 2.47040 1.92402 2.47401 2.47401 2.47401<	228	4 . 20 +0 0	2.24+02	-8,58+01	1 = 95+ 02	Z=42+02	5.62+01	2.00+01	-6.44-01	5.85+01	8+85+01	5.05+01	1.1702
234 4.40000 2.43402 -0.14001 1.05512 2.55002 2.55001 2.53001 2.53001 2.53001 2.53001 2.53001 2.53001 1.2402 242 4.66000 2.55002 -7.64001 1.94022 2.77001 2.64001 -5.20100 5.35001 6.34001 7.46001 1.22402 245 4.7000 2.67002 -7.77011 2.04001 2.27001 2.04001 5.23001 6.34001 7.40001 1.22402 250 4.60000 2.77002 -7.67001 2.07002 2.07001 2.07001 4.60000 7.02701 1.04011 5.2002 257 5.00400 2.70402 -6.4001 1.9202 2.07002 7.07001 3.1001 -5.3500 7.07001 1.04001 5.2002 258 5.20400 2.40402 -5.45001 1.92402 2.07002 2.07001 3.1001 -5.3500 7.07001 1.04001 3.2702 258 5.20400 3.40402 -5.45001 1.92402 3.0002 4.0001 3.2702 7.47001 1.04001 1.32402 260 </td <td>232</td> <td>4-32+00</td> <td>2.35+02</td> <td>-8.37+01</td> <td>1=95+02</td> <td>2.49+02</td> <td>8+45+01</td> <td>2+18+01</td> <td>-1.49+00</td> <td>8.73+01</td> <td>. 8+73+01</td> <td>7.90+01</td> <td>1.14402</td>	232	4-32+00	2.35+02	-8.37+01	1=95+02	2.49+02	8+45+01	2+18+01	-1.49+00	8.73+01	. 8+73+01	7.90+01	1.14402
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	234	4.40+00	2.43+02	-8-14+01	1.95+02	2+56+02	8.25+01	2.34+01	-2,24+00	8.60+01	n+60+01	7.76+01	1.71+02
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	237	4-50+00	2.51+02	-7,90+01	1.94+02	2+53+02	8+10+01	2 - 50 + 01	-2.91+00	8.48+01	5.45+01	7.62+01	1.23+02
2454.70+002.47+001.04+022.77+007.75+012.77+01-4.04+00 B_{-2}	242	4.60+00	2+59+02	-7.54+01	1.94+02	2.70+02	7.92+01	2.64+01	-3,50+00	8-35+01	8+36+01	7.48+01	1.25+02
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	245	4.79+00	2.67+02	-7,37+01	1.94+02	2.77+02	7.75+01	2.77+01	-4.04+00	8.23+01	8.24+01	7,34+01	1.28+02
253 4.00400 2.02402 -0.00401 1.03402 7.40401 3.00401 -4.06400 7.09401 6.00401 7.09401 1.30402 257 5.00400 2.07402 -0.0901 1.02402 7.2041 3.10401 -5.71401 7.47401 6.64401 1.32402 264 5.20400 3.04402 -5.52401 1.09402 3.00402 -6.0011 3.25401 -6.63400 7.45401 7.64401 1.76401 6.73011 1.35402 270 5.00400 3.1402 -5.52401 1.40402 3.21402 6.43401 3.45401 -6.63400 7.45401 6.61401 1.34602 270 5.00400 3.24002 -4.49401 1.80402 3.21402 6.43401 7.40401 7.24041 7.4401 6.29401 1.40402 276 5.60400 3.24002 -1.37401 6.32401 3.40202 5.47401 3.60401 7.24041 7.24041 7.4401 6.49401 1.44402 276 5.60400 3.24202 -1.77401 1.87402 5.47401 3.60401 7.240401 1.44402 1.44402	250	4.80+00	2.75+02	-7-09+01	1-934-02	2=84+02	7=57+01	2.89+01	-4-52+00	8-11+01	8+12+01	7.21+01	1+26+02
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	253	4.90+00	2.62+02	-0.80+01	1 .93+02	2.90+02	7.40+01	3.00+01	-4.96+00	7.99+01	8.00+01	7,09+01	1.30+02
262 5.10+00 2.07402 -6.18+01 1.92+02 3.03402 7.07+01 3.19+01 -5.71+00 7.07+01 6.84+01 1.23+02 264 5.20+00 3.01+02 -5.52+01 1.90+02 3.12+02 6.74+01 3.325+01 -6.63+00 7.53+01 6.73+01 1.37+02 270 5.10+00 3.17+02 -5.21+02 6.73+01 3.325+01 -6.63+00 7.42+01 6.53+01 1.40+02 274 5.50+00 3.24+02 -4.84+01 1.80+02 3.27+02 6.43+01 3.43+01 7.42+01 6.39+01 1.40+02 276 5.60+00 3.24+02 -4.84+01 1.80+02 3.23+02 6.28+01 3.43+01 7.31+01 7.34+01 6.39+01 1.44+02 276 5.60+00 3.24+02 -4.84+01 1.80+02 3.53+02 5.78+01 3.65+01 7.31+01 7.34+01 6.39+01 1.44+02 285 5.00+00 3.42+02 -4.31+01 1.80+02 3.55+01 7.40+01 6.39+01 5.30+01 1.44+02 285 5.00+00 3.42+02 -2.5+0+01	257	5-00400	2.90+02	-6,49+01	1.92+02	2 •97+0Z	7 . 23 +0 1	3,10+01	-5.35+00	7-87+01	7+89+01	6.96+01	1.32+02
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	262	5.10+00	2.97+02	-6-18+01	1.92+02	3.03+02	7+ C7+01	3.19+01	-5.71+00	7.75+01	7.77401	6.84+01	1-32+02
268 5,00400 3,11402 -5,22401 1,09402 3,12402 6,74401 3,35401 -6,35400 7,52401 7,52401 1,04102 1,0402 270 5,00400 3,24402 -4,86401 1,04002 3,22402 6,88401 3,42401 -6,63400 7,42401 7,43401 6,39401 1,40402 274 3,50400 3,24402 -4,86401 1,89402 3,23402 6,22401 7,31401 7,31401 6,24401 1,41402 276 3,60400 3,34602 -4,13401 1,88402 3,35402 6,22401 -7,58400 7,0101 7,12401 6,24401 1,41402 276 3,60400 3,24402 -4,13401 1,88402 3,35402 5,0100 3,62401 -7,58400 6,09401 7,03401 6,42401 1,44402 285 5,00400 3,44402 -3,04401 1,25402 3,55402 5,7401 3,06401 -7,95401 6,49401 1,47402 286 6,00400 3,54402 -3,04402 3,6402 5,57401 3,71402 -4,1400 6,59401 6,74401 5,64001	264	5.20+00	3.04+02	-5.85+01	1.91+02	3.09+02	6.90+01	3.28+01	-6.05+00	7=64+01	7.66401	6.73÷01	1.35+02
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	268	5.30+00	3+11+02	-5.52+01	1-90+02	3+15+0Z	5.74+01	3-35+01	-6.35+00	7.53+01	7.55+01	6.61+01	1 - 37+02
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	270	5.10+00	3-17+02	-5-18+01	1.90+02	3+21+02	6-56+01	3+42+01	-6.63+00	7.42+01	7.45+01	6.50+01	1.30+02
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	274	3,50+00	3+24+02	-4.84+01	1.89+02	3-27+02	5.43+01	3.40+01	-6.89+00	7-31+01	7.34+01	6.39+01	1-40+02
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	276	5.60+00	3.30+02	-4-49+01	1.85402	3.33.02	6 . 25+01	3.53+01	-7.14+00	7,20+01	7.24+01	6.29+01	1.41+02
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	279	5.70400	3.36+02	-4.13+01	1.85+02	3+30+02	6+13+01	3.56+01	-7.36+00	7+10+01	7+13+01	6-18+01	1.43+02
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	283	5.80+00	3-+2+92	-1.77+01	1.87+02	3+44+02	5.90+01	3.62+01	-7.58+00	6.99+01	7.03+01	5.08+01	1.44+02
$ \begin{array}{c} 289 & 6,00+00 & 3,54+02 & -3,04+01 & 1,25+02 & 3,55+02 & 5,70+01 & 3,69+01 & -7,96+00 & 6,79+01 & 6,84+01 & 5,88+01 & 1,47+02 \\ 292 & 6,10+00 & 3,60+02 & -2,57+01 & 1,85+02 & 3,61+02 & 5,57+01 & 3,71+01 & -8,11+00 & 4,669+01 & 6,74+01 & 5,79+01 & 1,49+02 \\ 296 & 6,20+00 & 3,65+02 & -2,30+01 & 1,69+02 & 1,69+02 & 1,53+00 & 5,71+01 & -8,31+00 & 6,50+01 & 6,659+01 & 1,50+02 \\ 300 & 6,30+00 & 3,71+02 & -1,92+01 & 1,63+02 & 3,71+02 & 5,31+01 & 3,77+01 & -8,61+00 & 6,50+01 & 6,559+01 & 1,51+02 \\ 304 & 6,40+00 & 3,76+02 & -1,55+01 & 1,63+02 & 3,71+02 & 5,31+01 & 3,77+01 & -8,61+00 & 6,50+01 & 6,559+01 & 1,53+02 \\ 309 & 6,50+01 & 3,81+02 & -1,17+01 & 1,81+02 & 3,41+02 & 5,06+01 & 3,77+01 & -8,61+00 & 6,31+01 & 6,46+01 & 5,51+01 & 1,53+02 \\ 312 & 6,60+01 & 3,81+02 & -1,17+01 & 1,81+02 & 3,41+02 & 5,06+01 & 3,79+01 & -8,670+00 & 6,31+01 & 6,370+01 & 5,42+01 & 1,53+02 \\ 312 & 6,60+01 & 3,81+02 & -1,37+00 & 1,39+02 & 3,40+02 & 3,40+01 & 3,79+01 & -8,670+00 & 6,31+01 & 6,20+01 & 5,25+01 & 1,56+02 \\ 314 & 6,70+00 & 3,91+02 & -4,33+00 & 1,77+02 & 3,90+02 & 4,22+01 & 3,79+01 & -9,02+00 & 6,13+01 & 6,20+01 & 5,25+01 & 1,56+02 \\ 323 & 6,70+00 & 3,91+02 & -4,33+00 & 1,77+02 & 3,90+02 & 4,22+01 & 3,79+01 & -9,02+00 & 5,96+01 & 6,03+01 & 5,09+01 & 1,56+02 \\ 323 & 6,70+00 & 3,90+02 & -3,38-01 & 1,78+02 & 3,90+02 & 4,59+01 & 3,79+01 & -9,02+00 & 5,96+01 & 6,03+01 & 5,09+01 & 1,58+02 \\ 323 & 6,70+00 & 4,09+02 & 1,10+01 & 1,78+02 & 4,00+02 & 4,59+01 & 3,79+01 & -9,39+00 & 5,96+01 & 6,03+01 & 5,09+01 & 1,58+02 \\ 324 & 7,20+00 & 4,09+02 & 1,10+01 & 1,76+02 & 4,09+02 & 4,39+01 & 3,79+01 & -9,39+00 & 5,70+01 & 5,86+01 & 4,92+01 & 1,61+02 \\ 334 & 7,20+00 & 4,09+02 & 1,10+01 & 1,76+02 & 4,09+02 & 4,39+01 & 3,79+01 & -9,39+00 & 5,70+01 & 5,86+01 & 4,69+01 & 1,61+02 \\ 334 & 7,20+00 & 4,14+02 & 1,48+01 & 1,75+02 & 4,128+02 & 3,77+01 & -9,39+00 & 5,70+01 & 5,86+01 & 4,69+01 & 1,61+02 \\ 343 & 7,40+00 & 4,22+02 & 2,23+01 & 1,73+02 & 4,22+02 & 4,08+01 & 3,75+01 & -9,77+00 & 5,53+01 & 5,62+01 & 4,69+01 & 1,64+02 \\ 343 & 7,40+00 & 4,22+02 & 2$	255	5-90+00	3.48+02	-3.41+01	1.86402	3+50+02	5-64+01	3-65+01	-7.78+00	6.89+01	6+93+01	5.98+01	1. A6+0Z
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	289	6.00+00	3-54+02	-3-04+01	1 . P5+ 0Z	3.55+02	5.70+01	3-69+01	-7.96+00	6.79+01	6.84+01	5.88+01	1.47+02
$\begin{array}{c} 296 \\ 6.20400 \\ 3.62402 \\ -2.30401 \\ 1.64402 \\ -2.30401 \\ 1.63402 \\ -2.30401 \\ 1.63402 \\ -2.30400 \\ 3.71402 \\ -1.55401 \\ 1.63402 \\ -1.55401 \\ 1.63402 \\ 3.76402 \\ -1.55401 \\ 1.62402 \\ 3.76402 \\ -1.55401 \\ 1.62402 \\ 3.76402 \\ -1.55401 \\ 1.62402 \\ 3.76402 \\ -1.55401 \\ 1.62402 \\ 3.76402 \\ -1.55401 \\ 1.62402 \\ 3.76402 \\ -1.55401 \\ 1.62402 \\ 3.76402 \\ -1.55401 \\ 1.62402 \\ 3.76402 \\ -1.55401 \\ 1.62402 \\ 3.76402 \\ -1.55401 \\ 1.62402 \\ 3.76402 \\ -1.55401 \\ 1.63402 \\ 3.76402 \\ -1.55401 \\ 1.63402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.76402 \\ -1.55402 \\ 3.77401 \\ -1.62400 \\ 6.31401 \\ 6.22401 \\ 6.31401 \\ 6.22401 \\ 5.25401 \\ 5.25401 \\ 1.55402 \\ 3.25401 \\ 1.55402 \\ 3.76402 \\ -2.52801 \\ 3.77401 \\ -3.27400 \\ -3.28400 \\ 5.96401 \\ 5.95401 \\$	292	6.10+00	3.60+02	-2-57+01	1-85+02	3+61+07	5-57+01	3.71+01	-8-14+00	6+69+01	6.74+01	5.79+01	1.49+02
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	296	6-20+00	3+65+02	-2-30+01	1-44+02	7+66+07	5-44+01	3-78+01	-8-31400	6-59+01	6.65+01	5-69+01	1-50+02
304 6.40400 3.76402 -1.55401 1.42402 3.76402 5.06401 3.77401 -4,61400 6.41401 6.46401 5.1401 1.53402 309 6.50400 3.61402 -1.17401 1.81402 3.41402 5.06401 3.78401 -8.76400 6.31401 6.46401 5.42401 1.54402 312 6.60400 3.86402 -7.92400 1.80402 3.66402 4.94401 3.79401 -8.69400 6.22401 5.23401 5.34401 1.45402 316 6.70400 3.91402 -4.13400 1.79402 3.91402 4.62401 3.79401 -9.02400 6.13401 6.41401 5.42401 1.55402 316 6.70400 3.91402 -4.13400 1.79402 3.90402 4.62401 3.79401 -9.02400 6.13401 6.41401 5.425401 1.55402 323 6.90400 4.00402 3.95402 4.59401 3.79401 -9.26400 5.96401 6.03401 5.09401 1.55402 327 7.00400 4.05402 1.640402 4.69401 1.77402 4.05402 4.49401<	300	6-30+00	3.71402	-1.97401	1.07402	3.71+02	5-31401	3.781.01	-8.45+00	6-50+01	6+55+01	5.60+01	1.51+02
309 6.50400 3.61402 -1.17401 3.60402 3.78401 3.78401 -6.76400 6.31401 5.42401 1.54402 319 6.60400 3.60402 -1.17401 3.81402 3.80402 3.78401 3.78401 -6.37400 6.31401 5.42401 1.54402 316 6.70400 3.91402 -4.13400 1.79402 3.91402 4.22401 3.79401 -9.02400 6.13401 6.20401 5.25401 1.56402 314 6.80400 3.96402 -3.38-01 1.79402 3.96402 4.71401 3.79401 -9.14400 6.1401 5.17401 1.56402 323 6.90400 4.00402 3.496402 4.71401 3.79401 -9.26400 5.96401 6.03401 5.09401 1.579402 323 6.90400 4.00402 3.496402 4.39401 3.79401 -9.26400 5.96401 6.03401 5.09401 1.579402 327 7.00400 4.009402 1.10401 1.77402 4.05402 4.39401 3.79401 -9.37400 5.87401 5.09401 1.60402 330	304	6-40400	1.76543		1.37407	30.1402	5. 19.01	3-77401		6-41401	6.46401	5-51+01	1.53+02
212 6+60+0.0 3+60+0.0 1+01+0.0 1+01+0.0 3+70+0.1 3+70+0.0 6+20+0.0 6+20+0.1 5+70		4.8040A	T.01107		1 - 81444	3.8140~	50 104 UL	3.78401		6.31401	6. 17401	5-42+01	1.34+02
316 6.70+00 3.91+02 -4.13+00 1.79+02 3.91+02 4.92+01 3.79+01 -9.02+00 6.13+01 6.25+01 1.56+02 316 6.70+00 3.91+02 -4.13+00 1.79+02 3.91+02 4.82+01 3.79+01 -9.02+00 6.13+01 6.20+01 5.25+01 1.56+02 318 6.400+00 3.90+02 -3.38-01 1.78+02 3.90+02 4.00+02 3.79+01 -9.25+00 5.96+01 6.03+01 5.09+01 1.56+02 323 6.90+00 4.00+02 3.4500 1.78+02 4.00+02 4.59+01 3.79+01 -9.25+00 5.96+01 6.03+01 5.09+01 1.56+02 327 7.000+00 4.05+02 7.24+00 1.77+02 4.05+02 4.99+01 3.79+01 -9.25+00 5.96+01 5.09+01 1.60+02 330 7.10+00 4.09+02 1.10+01 1.76+02 4.38+01 3.76+01 -9.37+01 5.86+01 5.00+01 1.61+02 334 7.20+00 4.14+02 1.48+02 4.14+02 4.18+02 4.18+01 3.76+01 -9.58+00 5.62+01 </td <td>307</td> <td>4.40404</td> <td>3.06403</td> <td>-1.1/701</td> <td>1-30407</td> <td>3-86403</td> <td></td> <td>7.70.01</td> <td></td> <td>6.33601</td> <td>6470401</td> <td>5.34+01</td> <td>1.45+02</td>	307	4.40404	3.06403	-1.1/701	1-30407	3-86403		7.70.01		6.33601	6470401	5.34+01	1.45+02
314 6+R0+00 3+96+02 -3+38+01 1+78+02 3+96+02 4+71+01 3+79+01 -9+12+00 6+12+01 5+17+01 1+58+02 323 6+90+00 4+00+02 3+35+00 1+78+02 3+96+02 4+59+01 3+79+01 -9+14+00 6+04+01 6+11+01 5+17+01 1+58+02 323 6+90+00 4+00+02 3+59+01 3+79+01 -9+14+00 5+96+01 6+03+01 5+09+01 1+58+02 323 6+90+00 4+05+02 3+39+01 3+79+01 -9+26+00 5+96+01 6+03+01 1+59+02 327 7+00+00 4+05+02 7+20+02 4+05+02 4+99+01 3+79+01 -9+37+00 5+87+01 5+09+01 1+59+02 330 7+10+00 4+09+02 1+10+01 1+76+02 4+38+01 3+76+01 -9+38+00 5+79+01 5+86+01 4+92+01 1+61+02 334 7+20+00 4+14+02 1+14+02 4+14+02 4+18+02 3+76+01 -9+38+00 5+62+01 5+70+01 1+62+02 339 7+30+00 4+18+02 1+84+02 4+18+02 <	212	6-70400	JOEUVUZ		1.70107	3+00+02		2017701	-0.07744	A. 13461	17427-VI	5.25401	1-56+07
323 6.90+00 4.00+02 3.43+00 1.78+02 4.00+02 4.59+01 3.79+01 -9.26+00 5.96+01 6.03+01 5.09+01 1.59+02 327 7.00+00 4.05+02 7.24+00 1.77+02 4.05+02 4.49+01 3.79+01 -9.26+00 5.96+01 6.03+01 5.09+01 1.60+02 330 7.10+00 4.09+02 1.10+01 1.76+02 4.05+02 4.38+01 3.78+01 -4.48+00 5.79+01 5.86+01 4.92+01 1.61+02 334 7.20+00 4.14+02 1.48+01 1.75+02 4.14+02 4.18+01 3.77+01 -9.58+00 5.70+01 5.74+01 4.45+01 1.62+02 339 7.30+00 4.18+02 1.48+01 1.74+02 4.18+02 4.18+01 3.76+01 -9.58+00 5.62+01 5.70+01 4.77+01 1.63+02 343 7.40+00 4.22+02 2.23+01 1.73+02 4.22+02 4.08+01 3.75+01 -9.77+00 5.54+01 5.62+01 4.69+01 1.64+02	310	4.80400	J-071702		1.74402	3-91-02	4+22701	J. / YVUL	-9.02900	6-04401	4.11441	5-17+01	1.56+02
327 7.00+00 4.05+02 7.24+00 1.77+02 4.05+02 4.49+01 3.79+01 -4.25+00 5.59+01 5.95+01 5.00+01 1.60+02 330 7.10+00 4.09+02 1.10+01 1.76+02 4.05+02 4.38+01 3.78+01 -4.88+00 5.79+01 5.86+01 4.92+01 1.661+02 334 7.20+00 4.14+02 1.48+01 1.75+02 4.14+02 4.28+01 3.77+01 -9.58+00 5.70+01 5.78+21 4.85+01 1.62+02 339 7.30+00 4.18+02 1.86+01 1.75+02 4.18+02 4.18+01 3.76+01 -9.58+00 5.62+01 5.70+01 4.77+01 1.63+02 343 7.40+00 4.22+02 2.23+01 1.73+02 4.22+02 4.08+01 3.75+01 -9.77+00 5.54+01 5.62+01 4.69+01 1.64+02	314	6.00.00	A.00402	-3,30-91	1 . 734 C-	J 470702	44/1TUL	3.70401	-9318400	5.06401	A.01401	5-09+01	1-59+02
317 7.00000 4.09402 1.10401 1.76402 4.09402 4.38401 3.76401 4.48400 5.79401 5.86401 4.92401 1.61402 330 7.10400 4.14402 1.48401 1.75402 4.14402 4.28401 3.77401 4.88400 5.79401 5.86401 4.92401 1.61402 334 7.20400 4.14402 1.48401 1.75402 4.14402 4.28401 3.77401 -9.58400 5.70401 5.7841 4.85401 1.62402 339 7.30400 4.18402 1.48401 1.74402 4.18402 4.18401 3.76401 -9.58400 5.62401 5.70401 4.77401 1.63402 343 7.40400 4.22402 2.23401 1.73402 4.22402 4.08401 3.75401 -9.77400 5.54401 5.62401 4.69401 1.64402	343 797	7.04400		7.34400	10702			3 70474	-7420700	2.90701	* K. GAAAI	5.00401	1-69+02
334 7+20400 4+14+02 1+48+01 1+75+02 4+14+62 4+28+01 3+77+01 -9+38+60 5+70+01 5+78+01 4+45+01 1+62+02 339 7+30+00 4+18+02 1+86+01 1+74+02 4+18+02 4+18+01 3+76+01 -9+58+00 5+62+01 5+70+01 4+77+01 1+63+02 343 7+40+00 4+22+02 2+23+01 1+73+02 4+22+02 4+08+01 3+75+01 -9+77+00 5+34+01 5+62+01 4+69+01 1+64+02	347	7.10400	4.00402	1.106.51	1.74bc7	4 AU 34UZ	4,78401	30/9401	-9+3/+00	3-87-01	S. 64+51	4.03401	1.61402
]]= /***********************************	770	7410400		1+10+01	1. 75-02		44 JUTUI	30/8701		347940[7400701		1.42602
]]Y /#JUTUU ##[27UZ]#86+01 1.74+02 ##16402 ##16401 J.74+01 =4.68400 D.62+01 Sef000 ##77401 1.63402]43 7.40400 ##22402 2.23401 1.73402 ##22402 ##08401 J.75401 =9.77400 S.54401 5.62401 4.69401 1.64402				1.48401	1.73402	4.14+62	4+20+01	3-77-01	-9.38.00	3.70-01	Delet	4473701	1-43403
343 /44U7WU 4422FUZ 2623FU[[673FUZ 46224UZ 46UA4UL 3673FU] ~9677FUD 3434401 36024U] 46044UI 1504442	339	7.30400	4+10+0Z	1+86+01	1.74+02	4+10+0Z	4 + 15 +0 1	3.75.01	-7465+00	3.62+01	2010-01	4077701	1.64403
•	343	7.40.0400	9+2Z+02	2.23401	1.73+02	4 +ZZ+02	4.05+01	3.75.01	-9677800	2424401	202001	=\$0¥4A1	* * II A A II C
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hSTP	T	۲P	YP	ZP	R(XY)	VXP	VYP	VZP	HSPEED	SPEED	HUSPEED	RTF (XY)
345	7-50+00	4+26+02	2.61+01	1 - 72+ 02	4.27+07	3-98+01	3.74+01	-9.86+00	5.46+01	5.55+01	4.62+01	1+65+02
310	7.60+00	4-30+02	2.78+01	1 - 71+02	4-31+02	3+69+01	3.72+01	-9.94+00	5-38+01	5.47+01	4.54+01	1.67+02
352	7.70+00	4.34+02	3+35+01	1.70+02	4.35402	3.79401	3.70+01	-1.00+01	5+30+01	5+40+01	4+47+01	1=68+02
356	7.80+00	4+37+02	3.72+01	1-69+02	4-39+02	3.71+01	3+68+01	-1+01+01	5.22+01	5.32+01	4.40+01	1.69+02
360	7.90+00	4-41+02	4.09+01	1.68+02	4-43+02	3.62+01	3.66+01	-1.02+01	5-15+01	5.25+01	4.33+01	1.70+07
364	8-00+00	4.45+02	4+45+01	1 + 57+ 02	4.47+02	3+23+01	3+64+01	-1.03+01	5-07+01	5.15+01	4,26+01	1.71+02
366	8-10400	4.48+02	4.82+01	1-66+0Z	4.51+02	3, 45+01	3.62+01	-1.03+01	5.00+01	5.10+01	4.19+01	1.72+02
370	8,20+00	4+52+02	5-14+01	1.65+02	4.55+02	3 . 37 +0 1	3-59+01	-1.04+01	4.92+01	5.03+01	4+12+01	1 . 73+02
374	8.30+00	4-55+02	5-53+01	1.64+02	4.58+02	3.29+01	3+57+01	-1.05+01	4,85+01	4.96+01	4.05+01	1.73+02
376	C+40+00	4-56+02	5.89+01	1.€3+0Z	4-62+02	3+21+01	3.54+01	-1.05+01	4.75+01	4-79+01	3.59+01	1.74+02
380	8.50+00	4.61+02	6.24+01	1.62+02	4+66+02	3-14+01	3.51+01	-1.05+01	4.71+01	4.53+01	3.92+01	1-75+02
283	E+6C+00	4.64+02	6.59+01	1-60+02	4.69+02	3-06+01	3+48+01	-1.06+01	4-64+01	4.76+01	3-56+01	1.76+02
387	B =70 +0 0	4.67+02	6.94+0t	L+59+02	4.73+02	2+99+01	3-45+01	-1.07+01	4-57+01	4.69+01	3.79+01	1.77+02
391	8=50+00	4+70+02	7.28+01	1.58+02	4.76+02	2.92+01	3.42+01	-1.07+01	4+50+01	4+63+01	3.73+01	1.78+02
, 395 ,	8.90+00	4.73+02	7=62+01	1 + 57+ 0z	A.79+02	2+85+01	3-37+01	-1-08+01	4.43+01	4.56+01	3.67+01	1.79+02
397	9+00+00	4.76+02	7.96+01	1.56+02	4+83+02	2.79+01	3+36+01	-1-08+01	4-37+01	4.50+01	3-51+01	1.80+02
+01	9.10+90	4.79+02	8-30+01	1.55+02	4.86+02	2.72+01	3-33+01	-1.09+01	4.30+01	4,43+01	3+54+01	1-#1+02
404	9 • 20 •00	4.82+02	8+63+01	1.54+02	4.87+02	2+66+01	3+29+1	-1.09+01	10+23+01	4.37+01	3-48+01	1.01+02
408	9-30+00	4. 24+ 02	8.95+01	1 - 53+02	4.92+02	2-60+01	3.26'	-1.10+01	4-17+01	4+31+01	3.42+01	1-82+02
411 *	9-40+00	4 .B7+02	9-28+01	1.52+02	4.96+02	2+54+01	3.2	-1-10+01	4-10+01	4.25+01	3.37+01	1.83+02
415	5.50+00	4=89+02	9+60+01	1.51+02	4.99+02	2+48+01	3.19	-1+11+01	4.04+01	4-19+01	3+31+01	1.84+02
418	9.60+00	4-92+02	9.92+01	1+50+0Z	5+02+02	2.42+01	3+15+01	-1+11+01	3-98+01	4.13+01	3.25+01	1. 95+02
422	5.70+00	4 . 94 + 02	1.92+02	1.4R+02	5.05+02	2.37+01	3.12+01	-1+11+01	3.91+01	4.07+01	3.19+01	1.85+02
424 1	· 9.00+00	4.96+02	1-05+02	1+47+02	5+08+02	2+31+01	3.08+01	-1+12+0 t	3+85+01	4.01+01	3.14+01	1=86+02
427	9-90+00	4.99+02	1.08+02	1-46+02	5.10+02	2,26+01	3-04+01	-1+12+01	3.79+01	3-95+01	3.08+01	1-87+02
429	1.00+01	5.01+02	1 • 11 * 02	1.45+02	5+13+02	2.21+01	3-01+01	-1-12+01	3.73+01	3.90+01	3+03+01	1+88+02

PROBLEM TERMINATION

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REASON. FINAL TIME HAS BEEN REACHED

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RESULTS RELEVANT TO WHOLE RUN. MAXVXP = 1.0121+02 MAXVYP = -5.8577+01

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MAXVZP	-	8+2524+01
NAXNVP	a .	1-1499+02

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CPDINATE. 2 Abscissa. y

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CRDINATE. Y Auscissa. >

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2-4634+02

3.7365+02

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5+0094+02

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51

1.1903+02

-0-2546+00



OPDINATE: X APSCISSA: TIME

ORDINATE. SPERD Adscissa. x







BBEKPT PRINTS