U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

NUREG/CR-7004

Technical Basis for Regulatory Guidance on Design-Basis Hurricane-Borne Missile Speeds for Nuclear Power Plants

Office of Nuclear Regulatory Research

AVAILABILITY OF REFERENCE MATERIALS IN NRC PUBLICATIONS

NRC Reference Material

As of November 1999, you may electronically access NUREG-series publications and other NRC records at NRC's Public Electronic Reading Room at http://www.nrc.gov/reading-rm.html. Publicly released records include, to name a few, NUREG-series publications; *Federal Register* notices; applicant, licensee, and vendor documents and correspondence; NRC correspondence and internal memoranda; bulletins and information notices; inspection and investigative reports; licensee event reports; and Commission papers and their attachments.

NRC publications in the NUREG series, NRC regulations, and *Title 10, Energy*, in the Code of *Federal Regulations* may also be purchased from one of these two sources.

1. The Superintendent of Documents
   U.S. Government Printing Office
   Mail Stop SSOP
   Washington, DC 20402–0001
   Internet: bookstore.gpo.gov
   Telephone: 202-512-1800
   Fax: 202-512-2250
2. The National Technical Information Service
   Springfield, VA 22161–0002
   www.ntis.gov
   1–800–553–6847 or, locally, 703–605–6000

A single copy of each NRC draft report for comment is available free, to the extent of supply, upon written request as follows:

Address: U.S. Nuclear Regulatory Commission
Office of Administration
Publications Branch
Washington, DC 20555-0001
E-mail: DISTRIBUTION.RESOURCE@NRC.GOV
Facsimile: 301–415–2289

Some publications in the NUREG series that are posted at NRC's Web site address http://www.nrc.gov/reading-rm/doc-collections/nuregs are updated periodically and may differ from the last printed version. Although references to material found on a Web site bear the date the material was accessed, the material available on the date cited may subsequently be removed from the site.

Non-NRC Reference Material

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, and transactions, *Federal Register* notices, Federal and State legislation, and congressional reports. Such documents as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings may be purchased from their sponsoring organization.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at—

The NRC Technical Library
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852–2738

These standards are available in the library for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from—

American National Standards Institute
11 West 42nd Street
New York, NY 10036–8002
www.ansi.org
212–642–4900

Legally binding regulatory requirements are stated only in laws; NRC regulations; licenses, including technical specifications; or orders, not in NUREG-series publications. The views expressed in contractor-prepared publications in this series are not necessarily those of the NRC.

The NUREG series comprises (1) technical and administrative reports and books prepared by the staff (NUREG–XXXX) or agency contractors (NUREG/CR–XXXX), (2) proceedings of conferences (NUREG/CP–XXXX), (3) reports resulting from international agreements (NUREG/IA–XXXX), (4) brochures (NUREG/BR–XXXX), and (5) compilations of legal decisions and orders of the Commission and Atomic and Safety Licensing Boards and of Directors' decisions under Section 2.206 of NRC's regulations (NUREG–0750).

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

NUREG/CR-7004

Technical Basis for Regulatory Guidance on Design-Basis Hurricane-Borne Missile Speeds for Nuclear Power Plants

Manuscript Completed: February 2011
Date Published: November 2011

Prepared by
Emil Simiu
Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8611

and

Florian A. Potra
Information Technology Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-9811

Selim Sancaktar, NRC Project Manager

NRC Job Code N6726

Office of Nuclear Regulatory Research

ABSTRACT

This report is intended to provide the technical basis for a potential new regulatory guide that would provide licensees and applicants with guidance that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for use in selecting the design-basis hurricane-borne missile speeds for the design of nuclear power plants. The design must prevent undue risk to the health and safety of the public in accordance with General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena," and General Design Criterion 4, "Environmental and Dynamic Effects Design Bases," of Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10, Part 50, of the *Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities."

This report documents the approach to and results of the calculation of hurricane-borne missile speeds that may be considered in the design of nuclear power plants. The missile spectrum, the assumptions on which the analyses are based -- which are similar to assumptions used for the development of Revision 1 to Regulatory Guide 1.76, "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants,"-- and the range of wind speeds being considered, were based on consultations between the authors and NRC staff. In addition, calculated missile speeds based on assumptions on the initial missile height above ground that differ from the assumption used in Revision 1 to Regulatory Guide 1.76 are included in Appendixes. The staff initiated this study because Revision 1 to Regulatory Guide 1.76 was based on the new Enhanced Fujita scale, in which tornado design-basis wind speeds are lower than in the earlier Fujita scale. This reduction in design basis tornado wind speed resulted in a potential for design basis hurricane winds to exceed the wind speeds in Regulatory Guide 1.76, Revision 1. Furthermore, the nature of hurricane winds can result in faster missile speeds than are possible for comparable tornado design basis winds. This report covers missile speeds that, under several hypotheses, could occur in hurricane winds with an exceedance probability of 10^{-7} per year. This is consistent with the 10^{-7} per year exceedance probability used for tornado winds in Regulatory Guide 1.76, Revision 1.

FOREWORD

The Nuclear Regulatory Commission (NRC) has determined that a regulatory guide providing design-basis hurricane-borne missiles for nuclear reactors may be needed for future reactor licensing efforts. This report provides the technical basis for this potential new regulatory guide that would provide licensees and applicants with guidance that the Commission staff considers acceptable for use in determining design-basis hurricane missiles that a nuclear power plant design should withstand to prevent undue risk to the health and safety of the public.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES
(Continued)

Section **Page**

LIST OF TABLES

Table **Page**

LIST OF TABLES
(Continued)

EXECUTIVE SUMMARY

This report is intended to provide the technical basis for a potential new regulatory guide that would provide licensees and applicants with guidance that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for use in selecting the design-basis hurricane-borne missile speeds for the design of nuclear power plants. The design must prevent undue risk to the health and safety of the public in accordance with General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena," and General Design Criterion 4, "Environmental and Dynamic Effects Design Bases," of Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10, Part 50, of the *Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities." The staff initiated this study because Revision 1 to Regulatory Guide 1.76, which was based on the new Enhanced Fujita scale, lowered design basis tornado wind speeds from those wind speeds based on the earlier Fujita scale. The lower design-basis tornado wind speeds in Revision 1 to Regulatory Guide 1.76 do not bound hurricane wind speeds in certain areas of the country. Therefore, additional research was needed to determine design basis hurricane winds for these locations." The design-basis tornado wind speeds presented in Regulatory Guide 1.76 correspond to an exceedance probability of 10^{-7} per year. This report covers missile speeds that could occur in hurricane winds with an exceedance probability of 10^{-7} per year.

The report documents the approach to and results of the calculation of hurricane-borne missile speeds for the design of nuclear power plants. The missile spectrum, the assumptions on which the calculations are based, and the range of wind speeds being considered, were based on discussions between the authors and NRC staff. Four types of missiles were considered in Regulatory Guide 1.76 (RG 1.76), Revision 1, entitled "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants" (see Section 4 of the report). In order to provide an adequate coverage, three more types of missiles (one plate-like missile and two plank-like missiles) were included in the missile spectrum. Such missiles arise from dislodged metallic siding attached to Non-Seismic Category buildings during a tornado event. It is a safety concern that those wind-borne siding missiles may compromise structural integrity of the neighboring nuclear island Seismic Category I structures. This addition was required because the characteristics of those missiles differ significantly from those of the four types tabulated in RG 1.76, Rev. 1.

The analyses were based on the same aerodynamic assumptions, as well as the same assumptions concerning the initial conditions for the missiles, that were used for the analyses of tornado-borne missile speeds adopted for the development of Revision 1 of Regulatory Guide 1.76. In addition to the 40 m initial elevation of the missiles, 30 m, 20 m, and 10 m initial elevations were also considered. No dependence of missile drag coefficient on missile position or relative missile speed with respect to the wind flow was considered. However, unlike for the tornado wind field, for the hurricane wind field it is assumed that the wind velocity is horizontal and varies with height above ground.

For the seven types of missile of interest, tables are provided which list missile speeds at the time the missile reaches the ground level, for hurricane wind speeds at 10 m above ground in open terrain of 40 m/s to 150 m/s in increments of 5 m/s, and for flow over (a) open terrain and (b) suburban terrain. Both horizontal missile speeds and total missile speeds (resultants of horizontal and vertical speeds) are listed. Plots showing those missile speeds as function of a parameter characterizing the missile properties are also provided. Similar tables and plots list maximum (as opposed to terminal) missile speeds.

The analyses just described were solved numerically. In addition, closed form equations were obtained for the case of wind speeds independent of height above ground. The closed form equations can provide useful insights into the dynamic behavior of the missiles as a function of the various parameters of the motion (initial conditions, hurricane wind speed, parameter defining missile properties). The results of this phase of the work are included in Appendix A.

The calculations included in the body of the report and in Appendix A are based on the assumption that, as for Revision 1 of Regulatory Guide 1.76, the initial elevation of the missiles is 40 m. Appendix B, Appendix C, and Appendix D contain results of numerical calculations of missile speeds based on the assumption that the missiles' initial elevations are 30 m, 20 m, and 10 m, respectively.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Selim Sancaktar, Project Manager of the U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, and Brad Harvey, Senior Physical Scientist, of the U.S. Nuclear Regulatory Commission Office of New Reactors, for their help in initiating, planning, and implementing this research effort.

ACRONYMS

ASCE: American Society of Civil Engineers

RG: Regulatory Guide

UNIT CONVERSION

1 m = 0.3048 ft

1 km = 0.621 mile

1 m/s = 2.237 mph

1 kg = 2.205 lb

NOTATIONS

a = missile characteristic given by Eq. 1c

A = effective area of the missile

C_D = missile drag coefficient

D_v = vertical drag force

g = acceleration of gravity

H = initial missile elevation

m = missile mass

r = distance between missile and hurricane center

t = time

$t' = (ga)^{1/2}t$

$t_{\max}$ = time required for missile to reach the ground from its initial elevation

v_h = horizontal wind speed at time t

v_h^{open} = 3-s peak gust wind speed in open terrain

v_h^{sub} = 3-s peak gust wind speed in suburban terrain

v_{mh} = horizontal missile speed at time t

v_{mv} = vertical missile speed at time t

x = horizontal distance traveled by missile

$y = v_h - v_{mh}$

z = height above ground

θ = angle of incidence of the missile velocity with respect to the horizontal

ρ = air density

ς = downward vertical distance from elevation H

τ = variable defined by Eq. 13

1. INTRODUCTION

To ensure the safety of nuclear power plants in the event of a hurricane strike, it is required that, in addition to the direct action of the wind, the designer consider the impact of hurricane-borne missiles, i.e., of objects moving under the action of aerodynamic forces induced by hurricane winds. It is therefore necessary to estimate speeds attained by potential hurricane-borne missiles specified for nuclear power plant design.

Design-basis tornado-borne missile speeds for a specified spectrum of missiles are incorporated in Regulatory Guide 1.76 (2007). The model governing the estimation of those speeds had no explicit probabilistic components. The missile speeds specified in Regulatory Guide 1.76 were based on the aerodynamic assumptions and initial conditions for the missiles reported in Simiu and Scanlan (1996). For consistency the same basic assumptions and initial conditions are used in this report as were used for Regulatory Guide 1.76. The only difference between the tornado- and hurricane-borne missile estimates lies in the nature of the respective flow fields. Details on the hurricane flow field model used to estimate hurricane-borne missile speeds are provided subsequently in this report.

The general equations of motion of the missiles are presented in Section 2. Section 3 describes the assumptions used in this work. Section 4 describes the missile spectrum being considered. Section 5 includes the results of the numerical calculations, based on the assumption that the initial elevation of the missiles is $H = 40$ m, as in Regulatory Guide 1.76 (2007). Appendix A includes the derivation of and results from closed form equations yielding the maximum horizontal missile speeds obtained for two simplified cases: (1) wind speeds independent of height above ground, and vanishingly small vertical drag force experienced by the falling missile, and (2) wind speeds independent of height above ground, and vertical drag force proportional to the square of the vertical missile velocity. The closed form equations can help to provide insight into the dynamic behavior of the missiles as a function of the various parameters of the motion (initial conditions, hurricane wind speed, parameter defining missile properties). Appendixes B, C, and D include results of calculations based on initial missile conditions that differ from those of Revision I to Regulatory Guide 1.76 and can be used to make informed decisions on design basis hurricane-borne missile speeds.

2. EQUATION OF MOTION OF HURRICANE-BORNE MISSILES

The motion of a body may be described in general by solving a system of three equations of balance of momenta and three equations of balance of moments of momenta. The model used in this report assumes that the bodies may be viewed as material points, for which the equations of balance of moments of momenta are not relevant. This assumption was used for the estimates incorporated in Regulatory Guide 1.76, and for the sake of consistency it is also used in this report. (A material point is an ideal representation of a physical body, whose spatial extent is vanishingly small, and whose mass is the same as the mass of the body.)

The equations of horizontal and vertical motion of a missile in a flow with constant velocity v_h are

$$\frac{dv_{mh}}{dt} = (v_h - v_{mh})\{a[(v_h - v_{mh})^2 + v_{mv}^2]^{1/2}\} \tag{1a}$$

$$\frac{dv_{mv}}{dt} = g + \frac{-amv_{mv}[(v_h - v_{mh})^2 + v_{mv}^2]^{1/2}}{m} \tag{1b}$$

where v_h is the horizontal wind speed at the variable elevation of the missile at time *t*, v_{mh} and v_{mv} are the horizontal and vertical missile speed at time *t*, respectively, *g* is standard acceleration of gravity ($\approx$9.8 m/s^2),

$$a = \tfrac{1}{2}\rho C_D A/m, \tag{1c}$$

ρ is the air density ($\approx$1.2 kg/m^3), C_D is the drag coefficient characterizing the average aerodynamic pressure acting on the missile, *A* is the effective area of the missile, that is, the area by which pressures must be multiplied to yield the aerodynamic force, and *m* is the mass of the missile. For high missile velocities, near the ground, where due to friction at the ground surface the horizontal wind speed is relatively low, the direction of the drag force is opposite to the direction of the horizontal component $v_{mh} - v_h$. This has the effect of *reducing* the missile speed, as will be seen in plots included in Section 5. Equation 1 is Newton's second law applied to the missile embedded in the wind flow.

As will be seen subsequently, under the assumption concerning the initial elevation of the missile with respect to the ground level, the time interval during which the missile is wind-borne is typically of the order of 3 s, which is sufficiently short for the change in the hurricane wind field to be small within the distance covered by the missile during its flight. The validity of this assumption will be discussed in the next section.

3. BASIC ASSUMPTIONS

This section lists the assumptions on which the solution of Eqs. 1 will be based.

1. Unlike for tornadoes, for hurricanes winds updraft speeds may be neglected. It follows that forces tending to increase the elevation of the missile with respect to the ground level may be assumed to be negligible as well. In particular, no updraft forces are available to lift automobiles.[1]

2. The missiles start their motion with zero initial velocity from an elevation h above ground. As was done for the tornado missile analyses performed for Regulatory Guide 1.76 (see Simiu and Scanlan, 1996), it is assumed H=40m.

   This assumption implies that the change in the hurricane wind field through which the missile travels during its flight time is small. The flight time t_{max} is the time it takes the missile to reach the ground from the 40 m initial elevation. It may be assumed $t_{max} \approx 3$ s (see Appendix A). Let the hurricane speed be 100 m/s and the radius of maximum wind speed be 1.5 km. Assume, conservatively, that the horizontal distance traveled by the missile is approximately 100 m/s × 3s = 300 m (in reality the missile speed is less than the hurricane wind speed over at least part of its trajectory), and that the missile's horizontal trajectory is tangent to the circle with radius 1.5 km, assumed very conservatively to represent the hurricane's radius of maximum wind speeds (the vast majority of hurricanes have radii of maximum wind speeds one order of magnitude larger than those of tornadoes). At the end of the trajectory the distance of the missile from the center of the circle will then be

   $$r = (1{,}500 \text{ m})/\cos[\tan^{-1}(300/1{,}500)] = 1{,}530 \text{ m}. \qquad (2)$$

   For practical purposes the wind flows at 1,500 m and 1,530 m from the center can be assumed to be approximately the same. The differences between wind fields at the

---

[1] In a personal communication to the authors (Dec. 2008), Dr. Kishor C. Mehta of Texas Tech University stated: "We have not found evidence of automobile becoming airborne. In Omaha tornado of 1975 there was a story that an automobile had gone over a two story building; it was parked on one side and was found on the other side of the building. Lynn Beason (now at Texas A & M) and Joe Minor had done on-site investigation and felt that it had tumbled around the building. Its battery was found on the side of the building where the automobile would have tumbled. Jim McDonald had gone to Nebraska in 1970s where allegedly a railroad car had flown 200 yards. On-site inspection showed that it had tumbled over. In early 2000 there was a video which, according to C. Doswell of the National Severe Storms Laboratory (NSSL), suggested that an automobile was airborne. The tornado had occurred in the Texas Panhandle. We saw the video and it was possible that an automobile was airborne, with a caveat that the tornado had gone over a junk yard where crushed automobiles were stored." (Authors' note: Drs. Beason, Minor, and McDonald are experienced and well-respected experts in their own right.)

In a personal communication to the authors (Dec. 2008), Dr. John D. Holmes, author of *Wind Loading on Structures*, Spon Press (2005) stated: "I would be skeptical about reported cases of windborne automobiles. .. Cars in general would not have significant positive (upwards) lift forces. Those that have aerodynamic design would incorporate small downward negative vertical force coefficients. ...In tornadoes it might be possible to sustain vehicles in the air flow due to the vertical velocities in the tornado. However I don't believe this is possible in horizontal winds from gales or hurricanes. They may of course be rolled around at ground level."

The authors share these experts' opinions.

beginning and end of the missile trajectory (i.e., over a time interval of the order of 3 s) may similarly be assumed to be small if the translational motion of the hurricane is also taken into account.

3. In this report, suburban terrain exposure and open terrain exposure represent, respectively, Exposure B and C as defined in the ASCE 7-05 Standard, Sections 6.5.6.2 and 6.5.6.3. For open terrain exposure the wind speed v_h considered in the calculations represents the peak 3-s gust speed, and varies with height above ground z in accordance with the power law

$$\frac{v_h^{open}(z)}{v_h^{open}(10)} = \left(\frac{z}{10}\right)^{1/9.5} \tag{3a}$$

where $v_h^{open}(10)$ is the peak 3-s gust speed at 10 m above ground in open terrain. A simplified model of the wind field adopted in the ASCE 7-05 Standard (2006) is based on the assumption that the retardation of the wind flow by friction at the ground surface becomes negligible at an elevation, referred to conventionally as the gradient height, z= 274 m. At the gradient height the wind speed is, in accordance with Eq. 3a, $v_h^{open}(274) = 1.42 v_h^{open}(10)$.

In that simplified model it is further assumed that for suburban terrain exposure the retardation of the wind flow by friction at the ground surface becomes negligible at a gradient height z=366 m. (The retardation of the wind flow by surface friction is effective up to higher elevations than over open exposure because the friction is stronger over suburban than over open terrain.)

For suburban terrain exposure the wind speed v_h^{sub} considered in the calculations represents the peak 3-s gust speed, and varies with height above ground z in accordance with the power law

$$\frac{v_h^{sub}(z)}{v_h^{sub}(366)} = \left(\frac{z}{366}\right)^{1/7} \tag{3b}$$

Since $v_h^{sub}(366) = 1.42 v_h^{open}(10)$, Eq. 3b can be written as

$$\frac{v_h^{sub}(z)}{v_h^{open}(10)} = 1.42\left(\frac{z}{366}\right)^{1/7}. \tag{3c}$$

For example, if v_h^{open} (10 m)=40 m/s and 150 m/s (α=1/9.5), then v_h^{sub} (10 m)=34 m/s and 127.5 m/s (α=1/7), respectively. The equations of motion of the missiles used in conjunction with Eqs. 3a and 3c can only be solved numerically. Results of numerical calculations are presented in Section 5. For simplified representations of the hurricane flow field it is possible to solve the equations of motion in closed form. Such closed form solutions are presented in Appendix A.

4. MISSILE SPECTRUM

The missile spectrum contains all the missiles considered in Regulatory Guide 1.76. The assumptions concerning the aerodynamic drag forces acting on these missiles are identical to those assumed for the tornado-borne missile analyses which underlie the specifications of Regulatory Guide 1.76, i.e.,

$a = \frac{1}{2} \times 1.2 \text{ kg m}^{-3} \times 0.0043 \text{ m}^2/\text{kg} = 0.0026 \text{ m}^{-1}$ (Sch. 40 pipe)

$a = \frac{1}{2} \times 1.2 \text{ kg m}^{-3} \times 0.0070 \text{ m}^2/\text{kg} = 0.0042 \text{ m}^{-1}$ (5 m x 2 m x 1.3 m automobile)

$a = \frac{1}{2} \times 1.2 \text{ kg m}^{-3} \times 0.0095 \text{ m}^2/\text{kg} = 0.0057 \text{ m}^{-1}$ (4.5 m x 1.7 m x 1.5 m automobile)

$a = \frac{1}{2} \times 1.2 \text{ kg m}^{-3} \times 0.0034 \text{ m}^2/\text{kg} = 0.0021 \text{ m}^{-1}$ (Solid steel sphere with drag coefficient C_D=0.41)

(see Simiu and Scanlan, 1996).

Note. The 5 m x 2 m x 1.3 m automobile and the 4.5 m x 1.7 m x 1.5 m automobile are associated in Regulatory Guide 1.76 with tornado regions I, II and tornado region III, respectively. For brevity they are identified in this report as the 5 m automobile and the 4.5 m automobile, respectively.

In order to provide an adequate coverage, three additional types of missiles (one plate-like and two plank-like) were included in the missile spectrum. This addition was prompted by the fact that the geometry of those missiles differs significantly from the four types tabulated in Regulatory Guide 1.76, Rev.1 and they often come from dislodged metallic siding attached to Non-Seismic Category buildings during a strong wind event. It is a safety concern that those wind-borne siding missiles may compromise structural integrity of the neighboring nuclear island Seismic Category I structures. As requested by the Nuclear Regulatory Commission (NRC), the three additional missiles being considered are: (1) plank with length and width 3.05 m × 0.305 m, A=0.93 m^2, mass m= 3.8 kg (steel board batten siding coated in PVC), (2) slab with length and width 3.05 m × 1.53 m, A=4.67 m^2, mass m=38 kg, and (3) plank with area A = 1 m^2 and mass m = 9.06 kg.

The assumptions concerning the area A are conservative and conform to NRC's request. For these three missiles it is assumed C_D=1.2. Therefore,

a=0.176 m^{-1}

a=0.0885 m^{-1},

a=0.079 m^{-1},

respectively.

5. NUMERICAL SOLUTIONS

For missiles with parameters given in Section 4, borne by winds over *open* terrain, and for wind speeds $v_h^{open}(10\ \text{m})$ from 40 m/s to 150 m/s in increments of 5 m/s, Table 1 lists terminal horizontal missile speeds, and Table 2 lists terminal total missile speeds (i.e., resultants of the horizontal and vertical missile wind speeds), as well as angles between the maximum wind speeds and the horizontal, if the missiles reach the ground level. Similar listings are provided in Tables 3 and 4 for missiles borne by winds over *suburban* terrain corresponding to $v_h^{open}(10\ \text{m})$ from 40 m/s to 150 m/s in increments of 5 m/s. In all the tables $v_h^{open}(10\ \text{m})$ designates the 3-s peak wind speed at 10 m above ground over open terrain.

For wind speeds over open terrain $v_h^{open}(10\ \text{m})$ from 40 m/s to 150 m/s in increments of 10 m/s, and for all parameters $0.001\ \text{m}^{-1} < a < 0.2\ \text{m}^{-1}$, those horizontal missile speeds and total missile speeds are shown in Figs. 1 and 2, respectively, for missiles borne by winds over open terrain, and in Figs. 3 and 4, respectively, for missiles borne by winds over suburban terrain. Note, however, that the terminal missile speeds at the time the missile reaches the ground level are not necessarily the maximum speeds experienced by the missiles throughout their trajectory. It was found that for values of the parameter $a < 0.006\ \text{m}^{-1}$ (in particular, for the four missiles covered by Regulatory Guide 1.76) the differences between the maximum missile speeds and the speeds at the time the missiles reach the ground level are not significant. However, for larger values of the parameter a, those differences can be large. Maximum (as opposed to terminal) missile speeds are shown in Tables 5, 6, 7, and 8.

The explanation for the decrease of the missile speeds from their maximum values is the following. After reaching those maximum speeds, the difference $v_h - v_{mh}$ between the hurricane wind speed and the horizontal missile speed can become negative as the missile moves at elevations where, due to friction at the ground level, hurricane speeds are small (see Eqs. 3). The missile motion is then decelerated. The speeds listed in Tables 1, 2, 3, 4 for the missiles with a=0.079 m^{-1}, a=0.0885 m^{-1}, and a=0.176 m^{-1} are therefore lower than the maximum speeds reached by those missiles during their flight time.

Table 1 - Terminal horizontal missile speeds - 40 m, open terrain

v_{10}	Missile Characteristic, a (m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	9.9	11.7	16.6	20.1	37.9	37.5	34.8
45	12.1	14.2	19.9	24.0	42.5	42.1	38.9
50	14.4	17.0	23.4	28.0	47.1	46.6	42.9
55	17.0	19.8	27.1	32.1	51.7	51.1	46.9
60	19.6	22.9	30.9	36.4	56.2	55.5	50.8
65	22.4	26.0	34.9	40.8	60.7	59.9	54.7
70	25.4	29.3	39.0	45.3	65.1	64.2	58.5
75	28.4	32.8	43.1	49.8	69.4	68.5	62.3
80	31.6	36.3	47.4	54.4	73.8	72.7	66.0
85	34.9	39.9	51.8	59.1	78.0	76.9	69.7
90	38.3	43.7	56.2	63.9	82.3	81.0	73.3
95	41.8	47.5	60.7	68.7	86.5	85.1	76.9
100	45.3	51.4	65.2	73.6	90.6	89.2	80.4
105	49.0	55.4	69.9	78.5	94.7	93.2	83.9
110	52.7	59.4	74.5	83.4	98.8	97.1	87.3
115	56.5	63.6	79.2	88.4	102.8	101.0	90.8
120	60.4	67.7	84.0	93.4	106.7	104.9	94.2
125	64.3	72.0	88.8	98.4	110.7	108.8	97.5
130	68.3	76.3	93.6	103.5	114.6	112.6	100.8
135	72.3	80.6	98.5	108.6	118.5	116.3	104.1
140	76.4	85.0	103.4	113.7	122.3	120.1	107.4
145	80.6	89.5	108.3	118.8	126.1	123.8	110.6
150	84.8	94.0	113.2	123.9	129.9	127.5	113.9

Terminal horizontal missile speeds (in m/s) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table 2 - Terminal total missile speeds - 40 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	27.7 (69)	28.1 (65)	29.5 (56)	31.0 (49)	39.3 (16)	38.8 (15)	35.4 (11)
45	28.4 (65)	29.1 (61)	31.4 (51)	33.5 (44)	43.8 (14)	43.2 (13)	39.4 (9)
50	29.4 (61)	30.4 (56)	33.6 (46)	36.4 (40)	48.2 (12)	47.6 (12)	43.4 (8)
55	30.6 (56)	31.9 (52)	36.2 (41)	39.6 (36)	52.7 (11)	51.9 (10)	47.3 (7)
60	32.0 (52)	33.8 (47)	39.0 (38)	43.1 (32)	57.1 (10)	56.3 (9)	51.2 (7)
65	33.8 (48)	35.9 (44)	42.2 (34)	46.8 (29)	61.4 (9)	60.6 (9)	55.0 (6)
70	35.7 (45)	38.3 (40)	45.5 (31)	50.7 (27)	65.8 (8)	64.8 (8)	58.8 (5)
75	37.9 (41)	40.9 (37)	49.1 (29)	54.8 (25)	70.1 (8)	69.0 (7)	62.5 (5)
80	40.2 (38)	43.7 (34)	52.9 (26)	59.0 (23)	74.3 (7)	73.2 (7)	66.2 (5)
85	42.8 (35)	46.8 (31)	56.8 (24)	63.3 (21)	78.5 (7)	77.3 (6)	69.9 (4)
90	45.5 (33)	49.9 (29)	60.8 (22)	67.8 (19)	82.7 (6)	81.4 (6)	73.5 (4)
95	48.5 (30)	53.3 (27)	64.9 (21)	72.3 (18)	86.9 (6)	85.5 (5)	77.0 (4)
100	51.5 (28)	56.7 (25)	69.2 (19)	76.9 (17)	91.0 (5)	89.5 (5)	80.5 (3)
105	54.7 (26)	60.3 (23)	73.5 (18)	81.6 (16)	95.0 (5)	93.5 (5)	84.0 (3)
110	58.0 (25)	64.1 (22)	78.0 (17)	86.4 (15)	99.1 (5)	97.4 (4)	87.5 (3)
115	61.5 (23)	67.9 (21)	82.5 (16)	91.2 (14)	103.1 (4)	101.3 (4)	90.9 (3)
120	65.0 (22)	71.8 (19)	87.0 (15)	96.0 (13)	107.0 (4)	105.2 (4)	94.2 (3)
125	68.7 (21)	75.8 (18)	91.7 (14)	100.9 (13)	110.9 (4)	109.0 (4)	97.6 (2)
130	72.4 (19)	79.9 (17)	96.3 (14)	105.8 (12)	114.8 (4)	112.8 (3)	100.9 (2)
135	76.2 (18)	84.0 (16)	101.1 (13)	110.8 (12)	118.7 (3)	116.5 (3)	104.2 (2)
140	80.1 (17)	88.2 (15)	105.8 (12)	115.8 (11)	122.5 (3)	120.3 (3)	107.5 (2)
145	84.0 (16)	92.5 (15)	110.6 (12)	120.8 (11)	126.3 (3)	124.0 (3)	110.7 (2)
150	88.1 (16)	96.8 (14)	115.5 (11)	125.9 (10)	130.0 (3)	127.6 (3)	113.9 (2)

Terminal total missile speeds (in m/s) and angles θ of incidence of the speeds with respect to the horizontal (in parentheses, in degrees) as functions of parameter a (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\text{ m})$ (in m/s). Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table 3 - Terminal horizontal missile speeds - 40 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	7.9	9.4	13.5	16.5	31.6	31.2	28.1
45	9.7	11.5	16.2	19.7	35.5	34.9	31.3
50	11.6	13.6	19.1	23.0	39.2	38.6	34.5
55	13.6	16.0	22.2	26.5	42.9	42.2	37.6
60	15.8	18.4	25.3	30.1	46.6	45.8	40.6
65	18.0	21.0	28.6	33.8	50.2	49.3	43.6
70	20.4	23.7	32.0	37.5	53.7	52.7	46.5
75	22.9	26.5	35.5	41.4	57.2	56.1	49.3
80	25.5	29.4	39.1	45.3	60.6	59.4	52.1
85	28.2	32.4	42.7	49.3	64.0	62.7	54.9
90	30.9	35.5	46.4	53.4	67.3	65.9	57.6
95	33.8	38.7	50.2	57.5	70.6	69.1	60.3
100	36.7	41.9	54.1	61.6	73.8	72.2	62.9
105	39.7	45.2	58.0	65.8	77.0	75.3	65.5
110	42.8	48.6	62.0	70.1	80.1	78.3	68.0
115	45.9	52.0	66.0	74.3	83.2	81.3	70.5
120	49.1	55.5	70.0	78.6	86.2	84.2	73.0
125	52.4	59.1	74.1	82.9	89.2	87.2	75.5
130	55.7	62.7	78.2	87.3	92.2	90.0	77.9
135	59.1	66.3	82.4	91.7	95.1	92.9	80.3
140	62.5	70.0	86.6	96.1	98.0	95.7	82.7
145	66.0	73.8	90.8	100.5	100.9	98.5	85.0
150	69.5	77.6	95.0	104.9	103.7	101.2	87.4

Terminal horizontal missile speeds (in m/s) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 40 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table 4 - Terminal total missile speeds - 40 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	27.2 (73)	27.4 (70)	28.1 (61)	29.0 (55)	33.3 (18)	32.7 (17)	28.8 (13)
45	27.7 (70)	28.0 (66)	29.4 (56)	30.8 (50)	36.9 (16)	36.2 (15)	31.9 (11)
50	28.3 (66)	28.9 (62)	31.0 (52)	32.9 (46)	40.5 (14)	39.7 (14)	35.0 (10)
55	29.1 (62)	29.9 (58)	32.8 (48)	35.4 (41)	44.0 (13)	43.2 (12)	38.0 (9)
60	30.0 (58)	31.2 (54)	35.0 (44)	38.1 (38)	47.6 (12)	46.6 (11)	41.0 (8)
65	31.2 (55)	32.7 (50)	37.3 (40)	41.0 (35)	51.0 (11)	50.0 (10)	43.9 (7)
70	32.6 (51)	34.4 (46)	39.9 (37)	44.1 (32)	54.5 (10)	53.4 (9)	46.8 (7)
75	34.1 (48)	36.3 (43)	42.7 (34)	47.4 (29)	57.9 (9)	56.7 (8)	49.6 (6)
80	35.8 (45)	38.5 (40)	45.7 (31)	50.8 (27)	61.2 (8)	60.0 (8)	52.4 (6)
85	37.7 (42)	40.7 (37)	48.8 (29)	54.4 (25)	64.6 (8)	63.2 (7)	55.1 (5)
90	39.8 (39)	43.2 (35)	52.1 (27)	58.1 (23)	67.8 (7)	66.3 (7)	57.8 (5)
95	42.0 (36)	45.8 (32)	55.4 (25)	61.8 (22)	71.0 (7)	69.5 (6)	60.4 (4)
100	44.3 (34)	48.5 (30)	58.9 (23)	65.7 (20)	74.2 (6)	72.6 (6)	63.1 (4)
105	46.8 (32)	51.4 (28)	62.5 (22)	69.6 (19)	77.4 (6)	75.6 (5)	65.6 (4)
110	49.4 (30)	54.3 (27)	66.2 (21)	73.6 (18)	80.5 (5)	78.6 (5)	68.2 (4)
115	52.1 (28)	57.4 (25)	69.9 (19)	77.7 (17)	83.5 (5)	81.6 (5)	70.7 (3)
120	54.9 (27)	60.5 (23)	73.8 (18)	81.8 (16)	86.5 (5)	84.5 (5)	73.1 (3)
125	57.8 (25)	63.8 (22)	77.6 (17)	86.0 (15)	89.5 (5)	87.4 (4)	75.6 (3)
130	60.8 (24)	67.1 (21)	81.6 (16)	90.2 (14)	92.4 (4)	90.3 (4)	78.0 (3)
135	63.9 (22)	70.5 (20)	85.6 (16)	94.4 (14)	95.4 (4)	93.1 (4)	80.4 (3)
140	67.1 (21)	74.0 (19)	89.6 (15)	98.7 (13)	98.2 (4)	95.9 (4)	82.8 (2)
145	70.3 (20)	77.5 (18)	93.7 (14)	103.0 (13)	101.1 (4)	98.6 (3)	85.1 (2)
150	73.6 (19)	81.1 (17)	97.8 (14)	107.3 (12)	103.9 (3)	101.4 (3)	87.4 (2)

Terminal total missile speeds (in m/s) and angles θ of incidence of the speeds with respect to the horizontal (in parentheses, in degrees) as functions of parameter a (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$, (in m/s) . Missiles start at 40 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

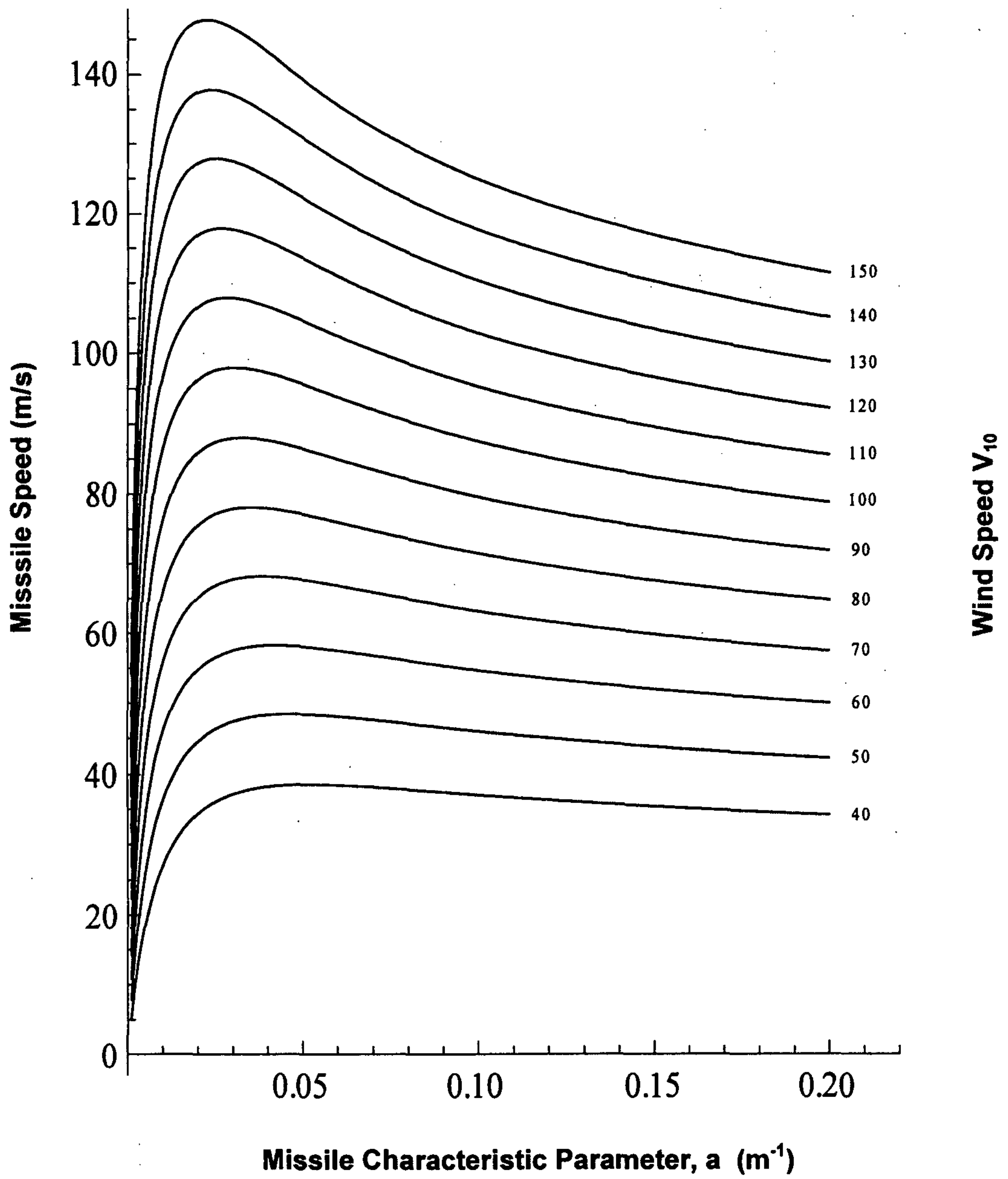

Figure 1 - Terminal horizontal missile speeds - 40 m, open terrain

Terminal horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40,50,...,150 m/s. Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

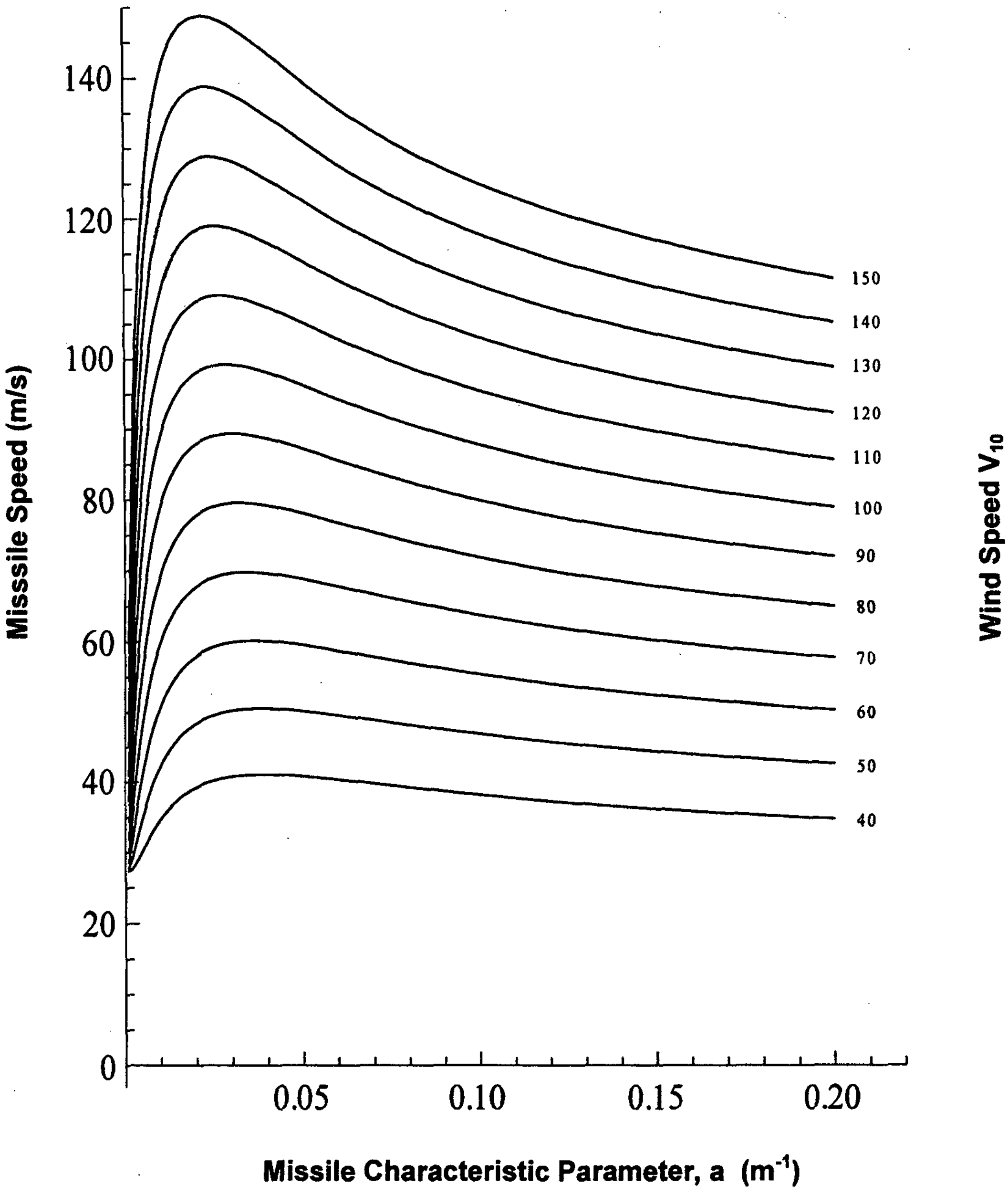

Figure 2 - Terminal total missile speeds - 40 m, open terrain

Terminal total missile speeds (in m/s) for parameters a between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,..., 150 m/s. Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

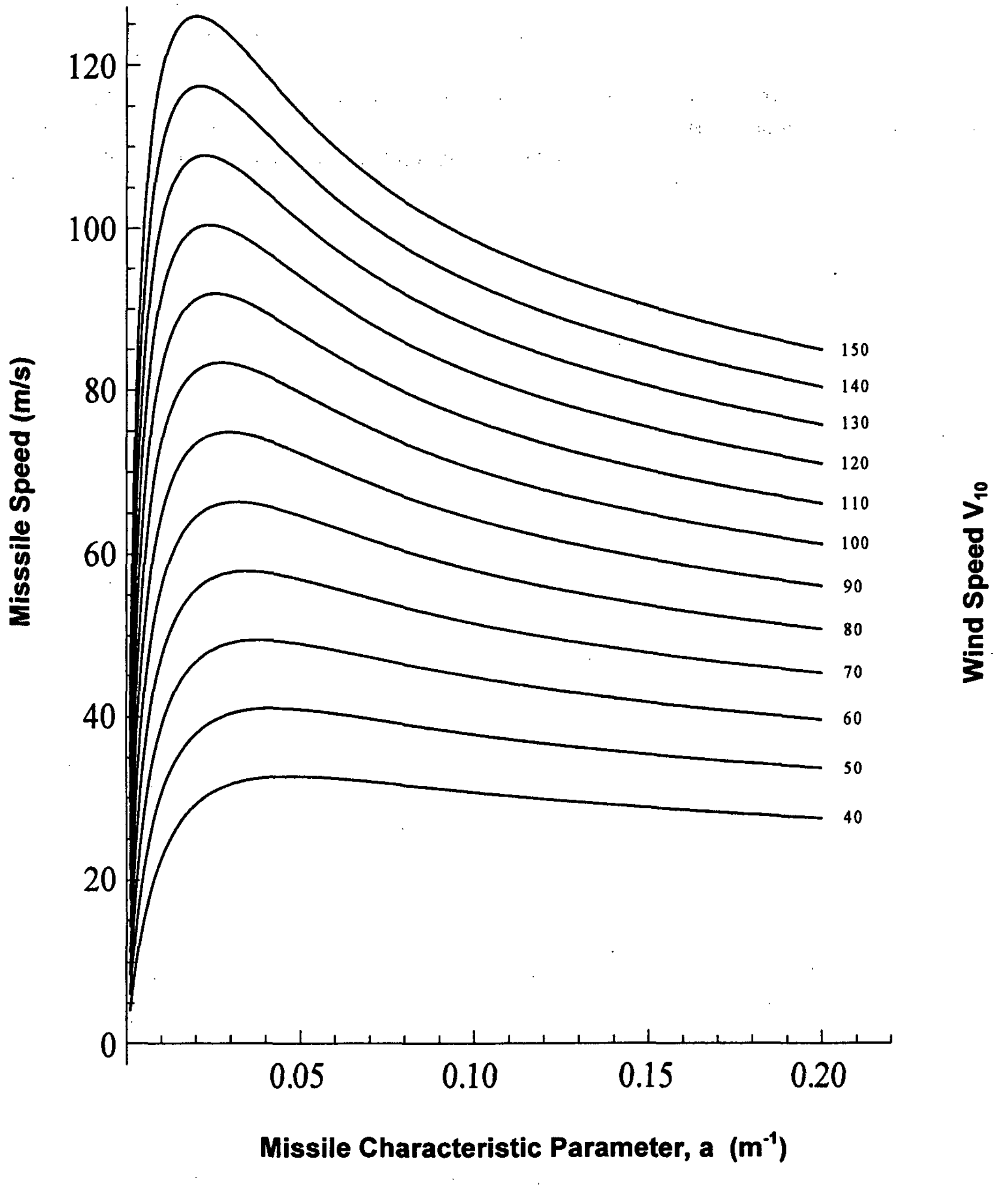

Figure 3 - Terminal horizontal missile speeds - 40 m, suburban terrain

Terminal horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\text{ m})$ = 40, 50,...,150 m/s. Missiles start at 40 m above ground level and reach ground level; flow over suburban terrain.

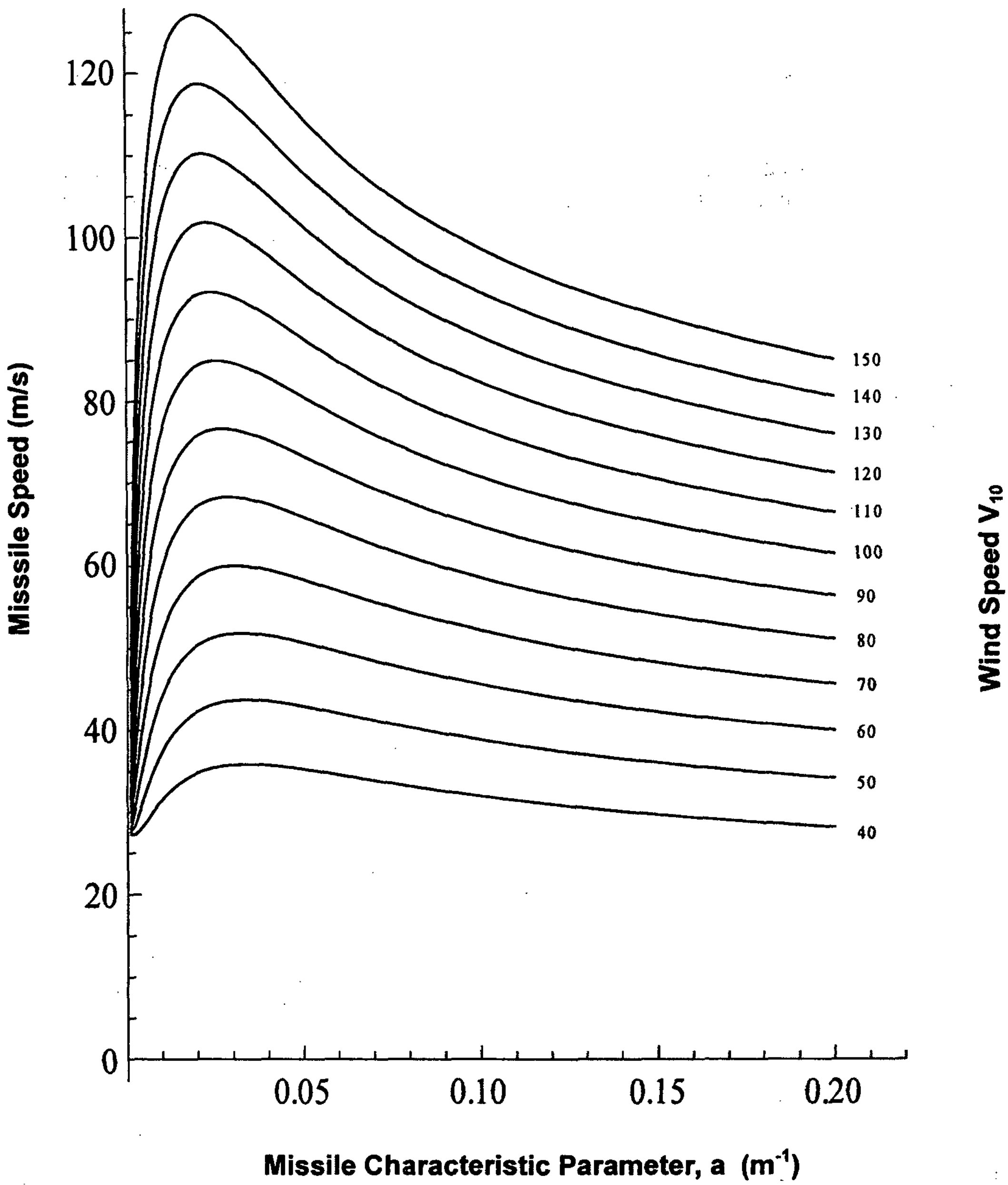

Figure 4 - Terminal total missile speeds - 40 m, suburban terrain

Terminal total missile speeds (in m/s) for parameters a between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 40 m above ground level and reach ground level; flow over suburban terrain.

Table 5 - Max horizontal missile speeds - 40 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	9.9 (0.02)	11.7 (0.02)	16.6 (0.02)	20.1 (0.02)	42.6 (18.36)	43.0 (19.81)	44.5 (27.36)
45	12.1 (0.02)	14.2 (0.02)	19.9 (0.02)	24.0 (0.02)	48.2 (19.14)	48.5 (20.55)	50.1 (27.83)
50	14.4 (0.02)	17.0 (0.02)	23.4 (0.02)	28.0 (0.04)	53.7 (19.83)	54.1 (21.21)	55.8 (28.26)
55	17.0 (0.02)	19.8 (0.02)	27.1 (0.02)	32.1 (0.05)	59.3 (20.47)	59.7 (21.81)	61.4 (28.64)
60	19.6 (0.02)	22.9 (0.02)	30.9 (0.02)	36.4 (0.09)	64.9 (21.05)	65.3 (22.36)	67.1 (28.99)
65	22.4 (0.02)	26.0 (0.02)	34.9 (0.02)	40.8 (0.13)	70.5 (21.58)	70.9 (22.86)	72.8 (29.31)
70	25.4 (0.02)	29.3 (0.02)	39.0 (0.04)	45.3 (0.16)	76.1 (22.08)	76.5 (23.32)	78.5 (29.59)
75	28.4 (0.02)	32.8 (0.02)	43.1 (0.05)	49.8 (0.21)	81.7 (22.54)	82.1 (23.75)	84.2 (29.86)
80	31.6 (0.02)	36.3 (0.02)	47.4 (0.07)	54.5 (0.25)	87.3 (22.96)	87.8 (24.15)	89.8 (30.11)
85	34.9 (0.02)	39.9 (0.02)	51.8 (0.09)	59.2 (0.33)	92.9 (23.36)	93.4 (24.52)	95.5 (30.34)
90	38.3 (0.02)	43.7 (0.02)	56.2 (0.11)	63.9 (0.39)	98.6 (23.73)	99.1 (24.87)	101.2 (30.56)
95	41.8 (0.02)	47.5 (0.02)	60.7 (0.14)	68.7 (0.47)	104.2 (24.08)	104.7 (25.20)	106.9 (30.76)
100	45.3 (0.02)	51.4 (0.02)	65.2 (0.18)	73.6 (0.54)	109.8 (24.41)	110.4 (25.51)	112.6 (30.95)
105	49.0 (0.02)	55.4 (0.02)	69.9 (0.22)	78.5 (0.63)	115.5 (24.72)	116.0 (25.80)	118.3 (31.13)
110	52.7 (0.02)	59.4 (0.04)	74.5 (0.25)	83.5 (0.72)	121.1 (25.02)	121.7 (26.07)	124.0 (31.31)
115	56.5 (0.02)	63.6 (0.04)	79.2 (0.29)	88.4 (0.83)	126.8 (25.30)	127.3 (26.33)	129.7 (31.47)
120	60.4 (0.02)	67.7 (0.04)	84.0 (0.34)	93.4 (0.92)	132.5 (25.57)	133.0 (26.58)	135.5 (31.62)
125	64.3 (0.02)	72.0 (0.05)	88.8 (0.40)	98.5 (1.03)	138.1 (25.82)	138.7 (26.82)	141.2 (31.76)
130	68.3 (0.02)	76.3 (0.07)	93.6 (0.43)	103.6 (1.16)	143.8 (26.06)	144.4 (27.04)	146.9 (31.90)
135	72.3 (0.02)	80.6 (0.07)	98.5 (0.51)	108.7 (1.27)	149.5 (26.29)	150.0 (27.26)	152.6 (32.04)
140	76.4 (0.04)	85.0 (0.09)	103.4 (0.57)	113.8 (1.40)	155.1 (26.51)	155.7 (27.47)	158.3 (32.17)
145	80.6 (0.04)	89.5 (0.11)	108.3 (0.62)	118.9 (1.52)	160.8 (26.72)	161.4 (27.66)	164.0 (32.29)
150	84.8 (0.04)	94.0 (0.11)	113.3 (0.69)	124.1 (1.66)	166.5 (26.92)	167.1 (27.85)	169.8 (32.40)

Maximum horizontal missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table 6 - Max total missile speeds - 40 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	27.7 (0.02)	28.0 (0.02)	29.5 (0.02)	31.0 (0.02)	44.0 (17.71)	44.2 (19.27)	45.1 (27.19)
45	28.4 (0.02)	29.1 (0.02)	31.4 (0.02)	33.5 (0.02)	49.4 (18.54)	49.6 (20.05)	50.7 (27.67)
50	29.4 (0.02)	30.3 (0.02)	33.6 (0.02)	36.4 (0.02)	54.8 (19.28)	55.1 (20.75)	56.3 (28.11)
55	30.6 (0.02)	31.9 (0.02)	36.2 (0.02)	39.6 (0.02)	60.3 (19.95)	60.6 (21.37)	61.9 (28.49)
60	32.0 (0.02)	33.8 (0.02)	39.0 (0.02)	43.1 (0.02)	65.8 (20.57)	66.1 (21.95)	67.5 (28.85)
65	33.7 (0.02)	35.9 (0.02)	42.2 (0.02)	46.8 (0.02)	71.3 (21.13)	71.6 (22.47)	73.2 (29.18)
70	35.7 (0.02)	38.3 (0.02)	45.5 (0.02)	50.7 (0.02)	76.8 (21.65)	77.2 (22.96)	78.8 (29.47)
75	37.8 (0.02)	40.9 (0.02)	49.1 (0.02)	54.8 (0.02)	82.4 (22.13)	82.8 (23.40)	84.5 (29.74)
80	40.2 (0.02)	43.7 (0.02)	52.8 (0.02)	59.0 (0.02)	87.9 (22.57)	88.3 (23.82)	90.1 (30.00)
85	42.8 (0.02)	46.7 (0.02)	56.7 (0.02)	63.3 (0.02)	93.5 (22.99)	93.9 (24.21)	95.8 (30.23)
90	45.5 (0.02)	49.9 (0.02)	60.8 (0.02)	67.8 (0.04)	99.1 (23.38)	99.6 (24.58)	101.5 (30.46)
95	48.5 (0.02)	53.3 (0.02)	64.9 (0.02)	72.3 (0.05)	104.7 (23.75)	105.2 (24.91)	107.2 (30.66)
100	51.5 (0.02)	56.7 (0.02)	69.2 (0.02)	76.9 (0.07)	110.3 (24.09)	110.8 (25.24)	112.9 (30.86)
105	54.7 (0.02)	60.3 (0.02)	73.5 (0.02)	81.6 (0.13)	116.0 (24.42)	116.4 (25.54)	118.6 (31.05)
110	58.0 (0.02)	64.1 (0.02)	78.0 (0.02)	86.4 (0.16)	121.6 (24.72)	122.1 (25.82)	124.2 (31.22)
115	61.5 (0.02)	67.9 (0.02)	82.5 (0.04)	91.2 (0.22)	127.2 (25.02)	127.7 (26.10)	129.9 (31.38)
120	65.0 (0.02)	71.8 (0.02)	87.0 (0.04)	96.0 (0.27)	132.9 (25.29)	133.4 (26.35)	135.6 (31.54)
125	68.7 (0.02)	75.8 (0.02)	91.7 (0.05)	100.9 (0.34)	138.5 (25.56)	139.0 (26.60)	141.4 (31.69)
130	72.4 (0.02)	79.9 (0.02)	96.3 (0.07)	105.9 (0.42)	144.1 (25.81)	144.7 (26.83)	147.1 (31.83)
135	76.2 (0.02)	84.0 (0.02)	101.1 (0.11)	110.9 (0.51)	149.8 (26.05)	150.3 (27.05)	152.8 (31.96)
140	80.1 (0.02)	88.2 (0.02)	105.8 (0.14)	115.9 (0.60)	155.5 (26.28)	156.0 (27.26)	158.5 (32.09)
145	84.0 (0.02)	92.5 (0.02)	110.7 (0.16)	120.9 (0.69)	161.1 (26.50)	161.7 (27.47)	164.2 (32.22)
150	88.1 (0.02)	96.8 (0.02)	115.5 (0.22)	126.0 (0.81)	166.8 (26.71)	167.3 (27.67)	169.9 (32.33)

Maximum total missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s) . Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table 7- Max horizontal missile speeds - 40 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	7.9 (0.02)	9.4 (0.02)	13.5 (0.02)	16.5 (0.07)	37.4 (19.76)	37.8 (21.13)	39.4 (28.17)
45	9.7 (0.02)	11.5 (0.02)	16.2 (0.02)	19.7 (0.09)	42.3 (20.51)	42.7 (21.84)	44.4 (28.64)
50	11.6 (0.02)	13.6 (0.02)	19.1 (0.04)	23.0 (0.14)	47.3 (21.19)	47.7 (22.48)	49.4 (29.05)
55	13.6 (0.02)	16.0 (0.02)	22.2 (0.05)	26.5 (0.19)	52.2 (21.81)	52.6 (23.07)	54.5 (29.42)
60	15.8 (0.02)	18.4 (0.02)	25.3 (0.07)	30.1 (0.25)	57.2 (22.38)	57.6 (23.60)	59.5 (29.76)
65	18.0 (0.02)	21.0 (0.02)	28.6 (0.11)	33.8 (0.32)	62.1 (22.90)	62.6 (24.09)	64.6 (30.06)
70	20.4 (0.02)	23.7 (0.02)	32.0 (0.13)	37.6 (0.39)	67.1 (23.37)	67.6 (24.54)	69.6 (30.34)
75	22.9 (0.02)	26.5 (0.02)	35.5 (0.16)	41.4 (0.48)	72.1 (23.82)	72.6 (24.95)	74.7 (30.61)
80	25.5 (0.02)	29.4 (0.04)	39.1 (0.22)	45.3 (0.59)	77.1 (24.23)	77.6 (25.33)	79.8 (30.85)
85	28.2 (0.02)	32.4 (0.04)	42.7 (0.25)	49.3 (0.70)	82.1 (24.61)	82.6 (25.69)	84.9 (31.07)
90	30.9 (0.02)	35.5 (0.05)	46.5 (0.31)	53.4 (0.81)	87.1 (24.98)	87.6 (26.03)	89.9 (31.28)
95	33.8 (0.02)	38.7 (0.05)	50.2 (0.36)	57.5 (0.94)	92.1 (25.31)	92.6 (26.35)	95.0 (31.48)
100	36.7 (0.04)	41.9 (0.07)	54.1 (0.43)	61.7 (1.06)	97.1 (25.63)	97.7 (26.65)	100.1 (31.66)
105	39.7 (0.04)	45.2 (0.09)	58.0 (0.49)	65.9 (1.21)	102.2 (25.93)	102.7 (26.92)	105.2 (31.83)
110	42.8 (0.04)	48.6 (0.11)	62.0 (0.56)	70.1 (1.35)	107.2 (26.22)	107.7 (27.19)	110.3 (31.99)
115	45.9 (0.05)	52.0 (0.13)	66.0 (0.63)	74.4 (1.50)	112.2 (26.49)	112.8 (27.44)	115.4 (32.15)
120	49.1 (0.05)	55.5 (0.14)	70.0 (0.72)	78.7 (1.64)	117.3 (26.74)	117.8 (27.68)	120.5 (32.30)
125	52.4 (0.07)	59.1 (0.16)	74.1 (0.81)	83.1 (1.80)	122.3 (26.98)	122.9 (27.90)	125.6 (32.44)
130	55.7 (0.07)	62.7 (0.19)	78.3 (0.90)	87.5 (1.97)	127.3 (27.21)	127.9 (28.12)	130.7 (32.57)
135	59.1 (0.09)	66.4 (0.22)	82.4 (1.00)	91.9 (2.13)	132.4 (27.43)	133.0 (28.33)	135.8 (32.70)
140	62.5 (0.11)	70.1 (0.24)	86.6 (1.09)	96.3 (2.30)	137.5 (27.64)	138.1 (28.52)	140.9 (32.82)
145	66.0 (0.13)	73.8 (0.28)	90.9 (1.20)	100.8 (2.47)	142.5 (27.84)	143.1 (28.71)	146.0 (32.94)
150	69.5 (0.14)	77.6 (0.31)	95.1 (1.29)	105.2 (2.63)	147.6 (28.03)	148.2 (28.89)	151.1 (33.04)

Maximum horizontal missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 40 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table 8- Max total missile speeds - 40 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	27.2 (0.02)	27.4 (0.02)	28.1 (0.02)	29.0 (0.02)	38.9 (18.98)	39.1 (20.47)	40.1 (27.97)
45	27.7 (0.02)	28.0 (0.02)	29.4 (0.02)	30.8 (0.02)	43.7 (19.80)	43.9 (21.24)	45.0 (28.44)
50	28.3 (0.02)	28.9 (0.02)	31.0 (0.02)	32.9 (0.02)	48.5 (20.54)	48.7 (21.93)	50.0 (28.86)
55	29.1 (0.02)	29.9 (0.02)	32.8 (0.02)	35.4 (0.02)	53.3 (21.20)	53.6 (22.55)	55.0 (29.25)
60	30.0 (0.02)	31.2 (0.02)	35.0 (0.02)	38.1 (0.02)	58.1 (21.81)	58.5 (23.12)	60.0 (29.59)
65	31.2 (0.02)	32.7 (0.02)	37.3 (0.02)	41.0 (0.02)	63.0 (22.36)	63.4 (23.64)	65.0 (29.91)
70	32.6 (0.02)	34.4 (0.02)	39.9 (0.02)	44.1 (0.02)	67.9 (22.87)	68.3 (24.11)	70.0 (30.20)
75	34.1 (0.02)	36.3 (0.02)	42.7 (0.02)	47.4 (0.02)	72.8 (23.34)	73.2 (24.55)	75.1 (30.46)
80	35.8 (0.02)	38.5 (0.02)	45.7 (0.02)	50.8 (0.02)	77.8 (23.79)	78.2 (24.96)	80.1 (30.71)
85	37.7 (0.02)	40.7 (0.02)	48.8 (0.02)	54.4 (0.04)	82.7 (24.19)	83.2 (25.33)	85.2 (30.95)
90	39.8 (0.02)	43.2 (0.02)	52.1 (0.02)	58.1 (0.07)	87.7 (24.57)	88.2 (25.69)	90.2 (31.15)
95	42.0 (0.02)	45.8 (0.02)	55.4 (0.02)	61.8 (0.11)	92.7 (24.93)	93.1 (26.02)	95.3 (31.36)
100	44.3 (0.02)	48.5 (0.02)	58.9 (0.02)	65.7 (0.16)	97.7 (25.26)	98.1 (26.33)	100.4 (31.55)
105	46.8 (0.02)	51.4 (0.02)	62.5 (0.02)	69.7 (0.22)	102.7 (25.58)	103.2 (26.62)	105.4 (31.72)
110	49.4 (0.02)	54.3 (0.02)	66.2 (0.04)	73.7 (0.29)	107.7 (25.88)	108.2 (26.90)	110.5 (31.89)
115	52.1 (0.02)	57.4 (0.02)	69.9 (0.05)	77.7 (0.38)	112.7 (26.17)	113.2 (27.16)	115.6 (32.05)
120	54.9 (0.02)	60.5 (0.02)	73.8 (0.09)	81.9 (0.48)	117.7 (26.43)	118.2 (27.41)	120.7 (32.20)
125	57.8 (0.02)	63.8 (0.02)	77.6 (0.13)	86.0 (0.60)	122.7 (26.69)	123.3 (27.65)	125.8 (32.35)
130	60.8 (0.02)	67.1 (0.02)	81.6 (0.16)	90.3 (0.71)	127.7 (26.93)	128.3 (27.87)	130.8 (32.48)
135	63.9 (0.02)	70.5 (0.02)	85.6 (0.20)	94.5 (0.84)	132.8 (27.16)	133.3 (28.09)	135.9 (32.61)
140	67.1 (0.02)	74.0 (0.02)	89.6 (0.25)	98.8 (0.99)	137.8 (27.38)	138.4 (28.30)	141.0 (32.74)
145	70.3 (0.02)	77.5 (0.02)	93.7 (0.31)	103.1 (1.13)	142.8 (27.59)	143.4 (28.49)	146.1 (32.85)
150	73.6 (0.02)	81.1 (0.02)	97.8 (0.38)	107.5 (1.28)	147.9 (27.79)	148.5 (28.68)	151.2 (32.97)

Maximum total missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s) . Missiles start at 40 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

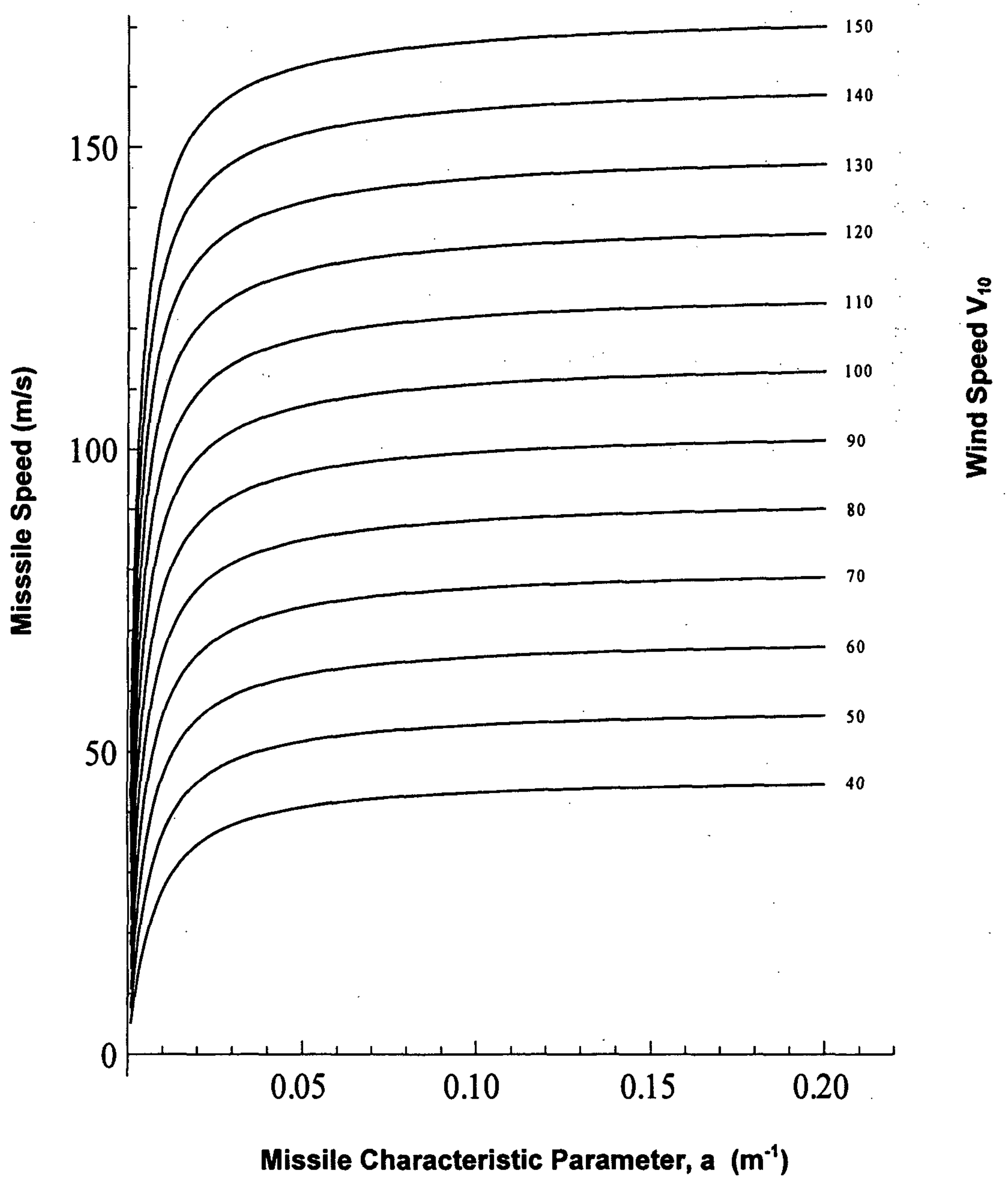

Figure 5 - Max horizontal missile speeds - 40 m, open terrain

Maximum horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

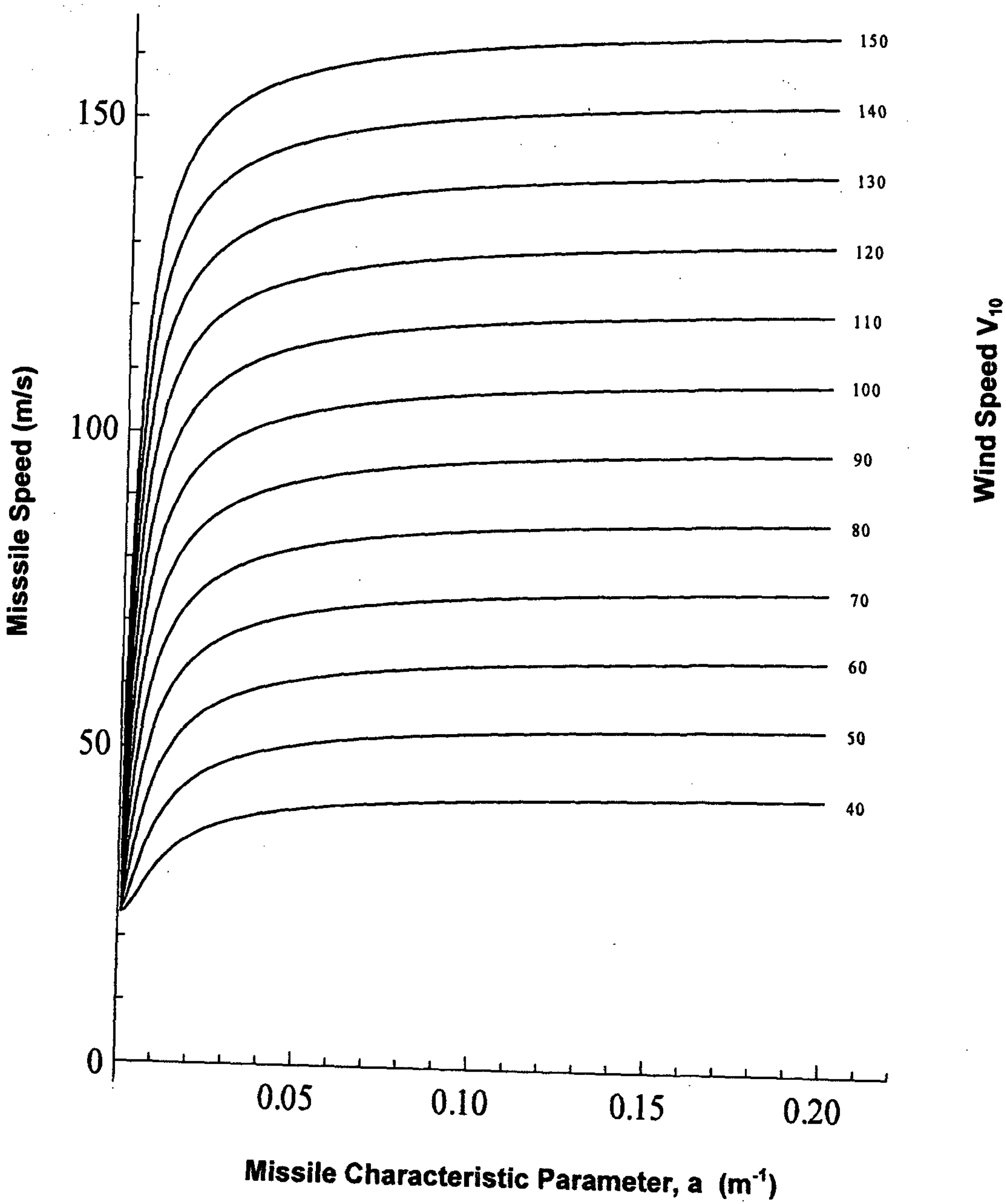

Figure 6 - Max total missile speeds - 40 m, open terrain

Maximum total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

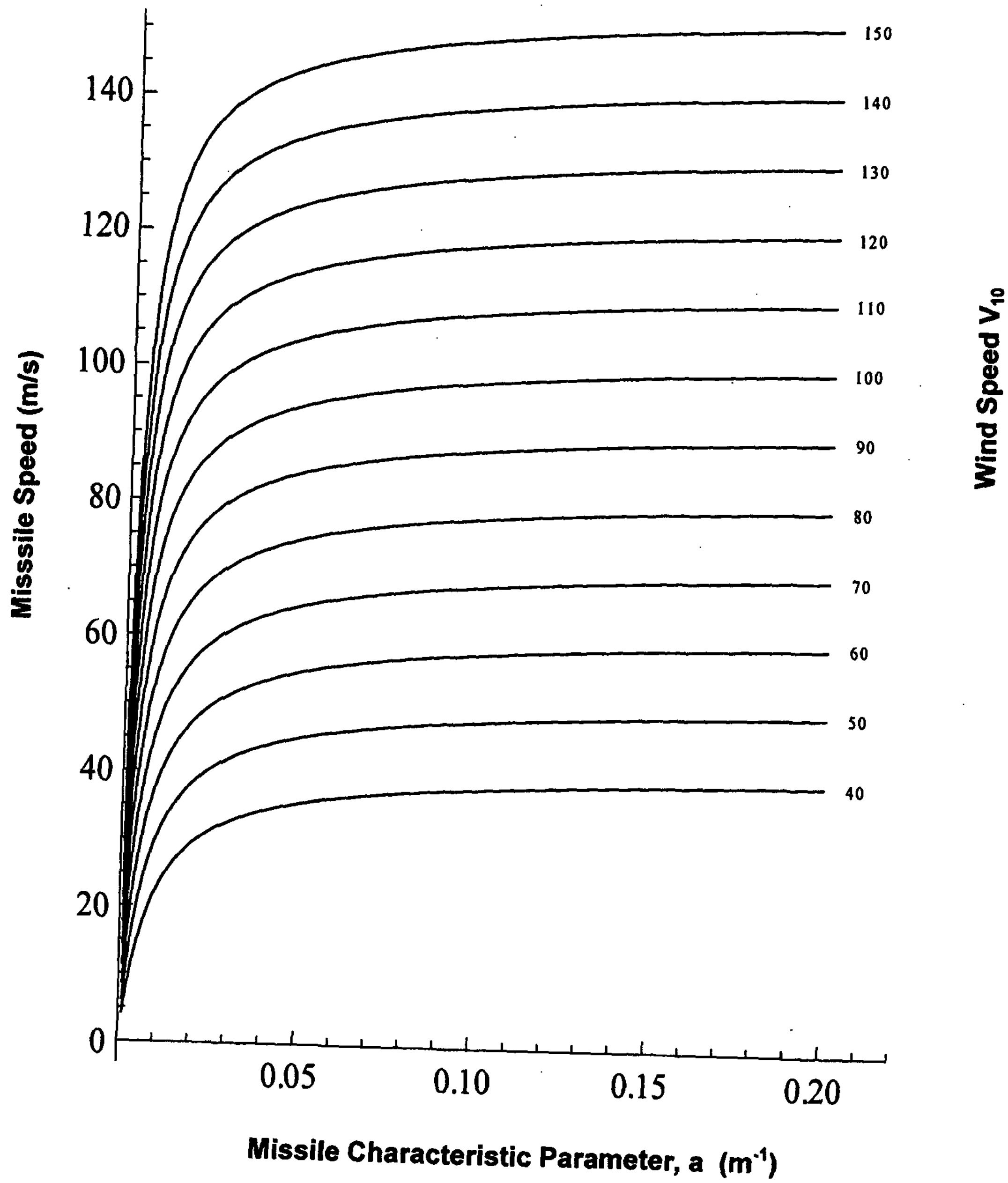

Figure 7- Max horizontal missile speeds - 40 m, suburban terrain

Maximum horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m) = 40, 50,...,150$ m/s. Missiles start at 40 m above ground level and reach ground level; flow over suburban terrain.

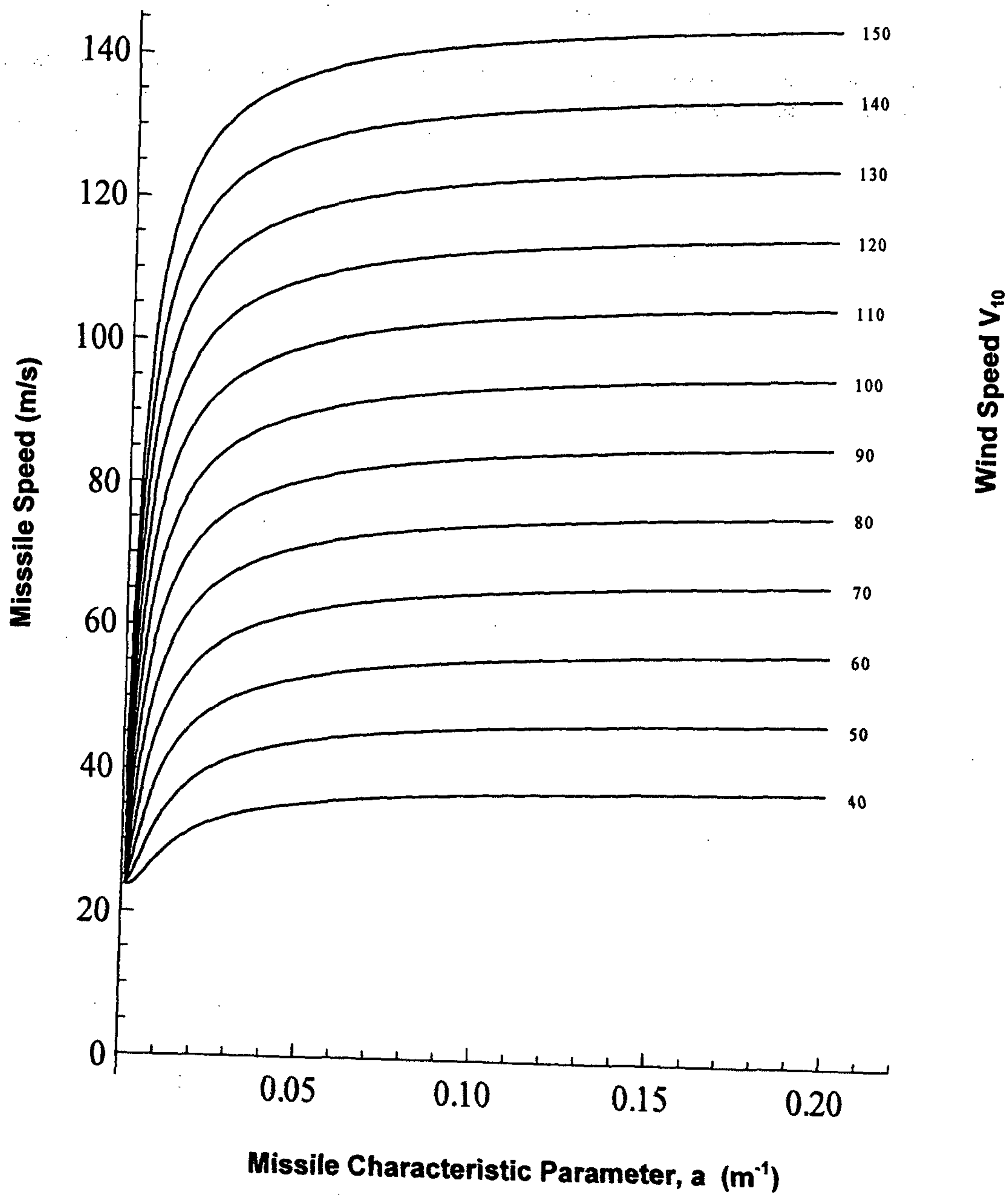

Figure 8 - Max total missile speeds – 40 m, suburban terrain

Maximum total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 40 m above ground level and reach ground level; flow over suburban terrain.

6. CONCLUSIONS

This report presents results of calculations of hurricane-borne missile speeds using the same assumptions pertaining to the missile properties (i.e., geometry, drag force and mass) and the initial conditions of the missile motion as were used in developing the tornado-borne missile speeds presented in Regulatory Guide 1.76. Tables 1a, 1b, 2a, and 2b and Figs. 1a, 1b, 2a, and 2b show the terminal missile speeds attained at the time the missiles reach ground level for wind fields with speeds that vary with height above ground in accordance with the power law provided in Eqs. 3a and 3c. For missiles with parameter $a < 0.006\ m^{-1}$ (such as those covered by Regulatory Guide 1.76), the missiles' terminal speeds do not differ significantly from the missiles' maximum speeds. For missiles with larger values of the parameter a the terminal speeds can be significantly lower than the maximum missile speeds. Appendix A contains closed form expressions yielding the missile speeds as functions of time in flows with speeds that are invariant with height above ground. Because in such flows the missile speed is at all times lower than the wind speed, the maximum missile speed is attained when the missile reaches ground level.

According to the results presented in Section 5, *for 125 m/s (280 mph) 3-s hurricane wind speeds at 10 m above ground in open terrain*, for missiles with parameters

a=0.0021 m^{-1} (solid steel sphere with diameter 0.025 m and assumed drag coefficient C_D=0.41),
a=0.0026 m^{-1} (Schedule 40 pipe),
a=0.0042 m^{-1} (5 m automobile, tornado Regions I and II),
a=0.0057 m^{-1} (4.5 m automobile, tornado Region III),

the calculated maximum horizontal missile speeds over open terrain are approximately

64 m/s (solid steel sphere),
72 m/s (Schedule 40 pipe),
89 m/s (5 m automobile, tornado Regions I and II),
98 m/s (4.5 m automobile, tornado Region III).

In contrast, the design-basis tornado-borne missile horizontal speeds specified in Regulatory Guide 1.76 have the following values:

Region I (*design-basis maximum tornado wind speed 103 m/s (230 mph)*

8 m/s (solid steel sphere),
41 m/s (Schedule 40 pipe),
41 m/s (5 m automobile, tornado Regions I and II).

Region II (*design basis maximum tornado wind speed 89 m/s (200 mph)*

7 m/s (solid steel sphere)
34 m/s (Schedule 40 pipe)
34 m/s (5 m automobile, Regions I and II).

Region III (*design-basis maximum tornado wind speed 72 m/s (160 mph)*

6 m/s (solid steel sphere)
24 m/s (Schedule 40 pipe)
24 m/s (4.5 m automobile, Region III).

For *230 mph (103 m/s) 3-s hurricane wind speeds* at 10 m above ground in open terrain, the calculated maximum horizontal wind speeds over open terrain are approximately:

48 m/s (solid steel sphere), vs. 8 m/s for tornadoes
54 m/s (Schedule 40 pipe), vs. 41 m/s for tornadoes
68 m/s (5 m automobile, tornado Regions I and II), vs. 41 m/s for tornadoes.
76 m/s (4.5 m automobile, Region III).

For *200 mph (89 m/s) 3-s hurricane wind speeds* at 10 m above ground in open terrain, the calculated maximum horizontal wind speeds over open terrain are approximately:

38 m/s (solid steel sphere), vs. 7 m/s for tornadoes
44 m/s (Schedule 40 pipe), vs. 34 m/s for tornadoes
56 m/s (5 m automobile, tornado Regions I and II), vs. 34 m/s for tornadoes.
64 m/s (4.5 m automobile, tornado Region III).

For *160 mph (72 m/s) 3-s hurricane wind speeds* at 10 m above ground in open terrain, the calculated maximum horizontal wind speeds over open terrain are approximately:

27 m/s (solid steel sphere), vs. 6 m/s for tornadoes
31 m/s (Schedule 40 pipe), vs. 24 m/s for tornadoes
41 m/s (5 m automobile, tornado Regions I and II)
47 m/s (4.5 m automobile, tornado Region III), vs. 24 m/s for tornadoes.

The results summarized in this section pertain to missiles for which it was assumed that the initial elevation was H=40 m above ground. The same assumption was used to calculate the missile speeds listed in Regulatory Guide 1.76. However, to enable decisions on design basis tornado speeds to be made under assumptions concerning the initial elevation H that may be different for hurricanes than for tornadoes, Appendices B, C, and D contain results based on initial elevations H equal to 30 m, 20 m, and 10 m, respectively.

The software used to calculate the missile speeds presented in this report is available on www.nist.gov/wind. Possible refinements in the modeling of missile aerodynamic and dynamic behavior would result in missile speeds that would differ from those based on the assumptions used in this report. Such refinements are beyond the scope of this work.

For the same nominal wind speeds and initial positions of the missiles, missile speeds are considerably higher in hurricanes than in tornadoes. This is explained by the fact that tornado dimensions are small, and following a strong impact induced by tornado winds on a missile, the missile travels in regions of lower wind speeds. In contrast, in hurricanes the missile is affected by strong winds for a longer period of time. In addition, due to the variation of wind speeds with height in hurricanes, at initial elevations $H > 10$ m the wind speeds are larger than the corresponding wind speeds at the standard 10 m elevation.

7. REFERENCES

(1) *ASCE 7-05 Standard, Minimum Design Loads for Buildings and Other Structures* (2006), American Society of Civil Engineers, Reston, Virginia.

(2) *Regulatory Guide 1.76, Design Basis Tornado and Tornado Missiles for Nuclear Power Plants, Revision 1* (2007), U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research.

(3) Simiu, E. and Scanlan, R.H. (1996), *Wind Effects on Structures,* 3rd edition, New York: John Wiley and Sons, Inc.

APPENDIX A. CLOSED FORM SOLUTIONS FOR SIMPLIFIED FLOW FIELD MODELS

Before proceeding to numerical calculations based on the flow field described by Eqs. 3a or 3c, we derived closed form equations for the simpler case in which the hurricane velocities do not vary with height above ground and are equal to the velocities at the 10 m elevation. Such closed form equations offer a means to verify the numerical procedures being used and develop "a feel" for the hurricane-borne missile behavior.

Under the assumption that wind speeds do not vary with height above ground we consider two cases: (1) the vertical drag force D_v is negligible, and (2) $D_v = amv_{mv}^2$, where v_{mv} is the vertical speed of the missile.

Ia. Wind speeds independent of height above ground, parameter a independent of missile velocity, vertical drag force D_v = 0.

The equation of horizontal motion of the missile (Eq. 1a) can be written as:

$$\frac{dv_{mh}}{dt} = a(v_h - v_{mh})^2 .$$

(5)

In this Section the superscripts "open" and "sub" used in Section 3, item 3 are omitted.

Equation 5 can be written as follows:

$$-\frac{d(v_h - v_{mh})}{dt} = a(v_h - v_{mh})^2 \quad (6)$$

Let v_h - v_{mh} = y. Equation 6 becomes

$$-\frac{dy}{dt} = ay^2 \quad (7)$$

$$-\frac{dy}{y^2} = adt \quad (8)$$

$$\frac{1}{y} = at + C \quad (9)$$

$$v_h - v_{mh} = \frac{1}{at + C} \quad (10)$$

$$v_{mh} = v_h - \frac{1}{at + C} \tag{11}$$

t=0, v=0; $C=1/v_h$. Therefore,

$$v_{mh} = v_h - \frac{v_h}{av_h t + 1}\ . \tag{11a}$$

Assume that the missile motion starts from an elevation H = 40 m.

The time required for the missile to reach a zero elevation is

t_{max}= $(2 \times 40/9.81)^{1/2} \approx 2.86$ s.

For example, for v_h=100 m/s, a=0.0042 m^{-1}, t= 2.86 s, v_m=100 -100 /(1.20+1) = 54.6 m/s.
v_h= 50 m/s, a=0.0042 m^{-1}, t= 2.86 s, v_m= 50 - 50/(0.57+1) = 18.2 m/s.

To show that during the motion of the missile the hurricane wind speed acting on the missile is indeed very nearly constant, we calculate the distance x traveled by the missile. Assuming the radius of maximum wind speeds is 1.5 km or greater, if the distance traveled by the missile is small compared to that radius, the variation of v_h during the missile travel time can indeed be assumed to be negligible.

We have

$$\frac{dx}{dt} = v_h - \frac{1}{at + \frac{1}{v_h}} \tag{12}$$

We denote

$$t+1/(av_h)=\tau. \tag{13}$$

Then

$$\frac{dx}{d\tau} = v_h - \frac{1}{a\tau} \tag{14}$$

Integration yields

$$x = v_h\tau - (1/a)\log\frac{\tau}{\tau_0} + B\,, \tag{15}$$

where we wrote the integration constant C in the form $C=B+(1/a)\ln \tau_0$, and τ_0 is the value taken on by τ for t=0.

For t=0, x=0, so

$0=1/a-(1/a)\log\frac{\tau_0}{\tau_0}+B,$ (15a)

hence $B = -1/a$. We rewrite Eq. 15 in the form

$$x = Vt - \frac{1}{a}\ln\frac{t+\frac{1}{aV}}{\frac{1}{aV}}. \quad (16)$$

$$x = v_h t - \frac{1}{a}\log(1+av_h t). \quad (17)$$

We are interested in results for t=2.86 s.

For v_h=100 m/s, a=0.0042 m^{-1}, t=2.86 s, x=286–(1/0.0042) log (1+2.86x0.0042x100)=98 m;

v_h= 50 m/s, a=0.0042 m^{-1}, t=2.86 s, x=143–(1/0.0042) log (1+2.86x0.0042x50) = 31 m.

Table AI - 1 lists maximum missile speeds v_m (initial elevation h = 40 m) calculated by using Eq. 11a for various speeds v_h independent of height above ground. The speeds v_h represent wind speeds in open terrain at 40 m elevation that would correspond to wind speeds v_h(10 m) listed in the table caption. A comparison with Table 1a (Section 5) shows that Eq. 11a yields results that in many cases are reasonable first approximations to results obtained for flows over open terrain.

I b. Wind speeds independent of height above ground, parameter a independent of missile velocity, vertical drag $D_v \approx amv_{mv}^2$.

The simplified calculations in section 5.1 did not account for the fact that, in its downward motion, the missile is slowed by an upward vertical drag force with absolute value

$D_v=(1/2)\rho C_D A v^2_{mv}$ (18)

where $v_{mv}(z)$ is the vertical missile velocity (i.e., the relative missile velocity with respect to the vertical flow speed, the latter being assumed to be zero).

The time of flight for a missile with initial conditions t=0, $z(0)=H$, $v_{mh}=v_{mv}$=0 is obtained by solving the equation of vertical motion of the missile

$F=m\frac{dv_{mv}}{dt}$ (19)

$F(\varsigma)=mg - amv_{mv}^2(\varsigma)$,

where we denoted the downward vertical distance from elevation h by ς. It follows that

$$\frac{dv_{mv}}{dt} = g - av_{mv}^2(\varsigma) \tag{20}$$

$$\frac{dv_{mv}}{(g/a) - v_{mv}^2} = a\,dt \tag{21}$$

$$\frac{1}{\sqrt{g/a}} \tanh^{-1} \frac{v_{mv}}{\sqrt{g/a}} = at + C \tag{22}$$

t=0, v_{mv}=0, C=0.

$$\tanh^{-1} \frac{v_{mv}}{\sqrt{g/a}} = at\sqrt{g/a}. \tag{23}$$

$$v_{mv} \equiv d\varsigma/dt = (g/a)^{1/2} \tanh[(ga)^{1/2} t] \tag{24}$$

Denote $t' = (ga)^{1/2} t$.

$$d\varsigma/dt' = (1/a) \tanh t' \tag{25}$$

$$\varsigma = (1/a) \log [\cosh t'] + \text{const} \tag{26}$$

$$= (1/a) \log \{\cosh [(ga)^{1/2} t]\} + \text{const} \tag{26a}$$

t=0, ς=0, const=0.

$$\varsigma = (1/a) \log \{\cosh [(ga)^{1/2} t]\} \tag{27}$$

$$\varsigma = h, \quad \log \{\cosh [(1/a)^{1/2} t_{max}]\} = h \tag{28}$$

$$\cosh [(ga)^{1/2} t_{max}] = e^{ah} \tag{30}$$

$$t_{max} = (\cosh^{-1} e^{ah}) / (ga)^{1/2} \tag{31}$$

For example, for a=0.0042 and H=40 m, t_{max}=2.94 s, instead of t_{max}=2.86 s, as is the case for D_v=0. It is seen that the influence on the time of flight of the vertical drag due to the missile's vertical velocity is small.

Table A - 1 - Terminal horizontal missile speeds and wind speeds - height ind., open

v_h^{open}(10 m)	Missile Characteristic, a (in m^{-1})					
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Slab*	*Plank*
40	10.1	11.8	16.5	19.9	42.6	44.4
45	12.4	14.5	20.0	23.9	48.4	50.2
50	14.9	17.4	23.7	28.1	54.2	55.9
55	17.6	20.4	27.5	32.4	59.9	61.7
60	20.4	23.6	31.5	36.8	65.7	67.5
65	23.4	27.0	35.7	41.4	71.5	73.3
70	26.5	30.4	39.9	46.1	77.2	79.1
75	29.7	34.0	44.3	50.8	83.0	84.8
80	33.0	37.7	48.7	55.6	88.8	90.6
85	36.5	41.5	53.2	60.5	94.6	96.4
90	40.0	45.4	57.8	65.5	100.3	102.2
95	43.7	49.4	62.5	70.5	106.1	108.0
100	47.4	53.5	67.3	75.6	111.9	113.8
105	51.2	57.6	72.1	80.7	117.7	119.5
110	55.1	61.8	76.9	85.8	123.4	125.3
115	59.1	66.1	81.8	91.0	129.2	131.1
120	63.1	70.5	86.8	96.3	135.0	136.9
125	67.2	74.9	91.8	101.5	140.8	142.7
130	71.3	79.4	96.8	106.8	146.6	148.5
135	75.6	83.9	101.8	112.1	152.4	154.2
140	79.8	88.5	107.0	117.5	158.1	160.0
145	84.1	93.1	112.1	122.8	163.9	165.8
150	88.5	97.7	117.2	128.2	169.7	171.6

Terminal horizontal missile speeds in m/s as functions of parameter a in m^{-1} and wind speeds v_h^{open}(10 m) in m/s (missiles reach ground level, flow over open terrain; wind speeds $v_h \equiv v_h^{open}(40\ m) = (40/10)^{1/9.5}\, v_h^{open}(10\ m)$ independent of height.

APPENDIX B. MISSILE SPEEDS CALCULATED FOR INITIAL ELEVATION H = 30 m

This Appendix contains tables and figures similar to those included in the body of the report, except that the initial elevation of the missiles was assumed to be H = 30 m, rather than H = 40 m.

Table B - 1- Terminal horizontal missile speeds - 30 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	8.2	9.8	14.1	17.3	37.4	37.2	34.7
45	10.1	12.0	17.0	20.8	42.0	41.7	38.8
50	12.1	14.3	20.2	24.4	46.6	46.3	42.9
55	14.3	16.8	23.5	28.2	51.2	50.8	46.9
60	16.6	19.5	26.9	32.1	55.7	55.2	50.8
65	19.1	22.3	30.5	36.1	60.2	59.6	54.7
70	21.6	25.2	34.2	40.2	64.7	64.0	58.5
75	24.3	28.2	38.0	44.5	69.1	68.3	62.3
80	27.1	31.4	41.9	48.8	73.4	72.5	66.0
85	30.0	34.6	45.9	53.1	77.8	76.7	69.7
90	33.0	38.0	49.9	57.6	82.0	80.9	73.3
95	36.1	41.4	54.1	62.1	86.3	85.0	76.9
100	39.3	44.9	58.3	66.7	90.4	89.1	80.4
105	42.5	48.5	62.6	71.3	94.6	93.1	83.9
110	45.9	52.2	66.9	75.9	98.7	97.1	87.4
115	49.3	56.0	71.3	80.6	102.7	101.1	90.8
120	52.7	59.8	75.7	85.3	106.8	105.0	94.2
125	56.3	63.6	80.2	90.1	110.7	108.9	97.5
130	59.9	67.6	84.7	94.9	114.7	112.7	100.8
135	63.6	71.6	89.3	99.7	118.6	116.5	104.1
140	67.3	75.6	93.9	104.6	122.4	120.2	107.4
145	71.1	79.7	98.5	109.4	126.3	124.0	110.7
150	74.9	83.8	103.2	114.3	130.1	127.7	113.9

Terminal horizontal missile speeds (in m/s) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 30 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, m^{-1} = 0.3048 ft^{-1}

Table B - 2- Terminal total missile speeds - 30 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	24.2 (70)	24.5 (66)	25.8 (57)	27.2 (50)	38.8 (16)	38.5 (15)	35.4 (11)
45	24.7 (66)	25.3 (62)	27.4 (52)	29.4 (45)	43.3 (14)	42.9 (13)	39.4 (9)
50	25.5 (62)	26.4 (57)	29.3 (47)	32.0 (40)	47.8 (12)	47.3 (12)	43.4 (8)
55	26.5 (57)	27.7 (53)	31.6 (42)	34.9 (36)	52.2 (11)	51.6 (11)	47.3 (7)
60	27.8 (53)	29.3 (48)	34.1 (38)	38.0 (32)	56.6 (10)	56.0 (10)	51.2 (7)
65	29.2 (49)	31.2 (44)	37.0 (34)	41.4 (29)	61.0 (9)	60.3 (9)	55.0 (6)
70	30.9 (46)	33.2 (41)	40.0 (31)	45.0 (27)	65.4 (8)	64.6 (8)	58.8 (5)
75	32.8 (42)	35.5 (37)	43.3 (29)	48.8 (24)	69.7 (8)	68.8 (7)	62.5 (5)
80	34.8 (39)	38.0 (34)	46.7 (26)	52.7 (22)	74.0 (7)	73.0 (7)	66.2 (5)
85	37.1 (36)	40.7 (32)	50.2 (24)	56.8 (21)	78.3 (7)	77.2 (6)	69.9 (4)
90	39.5 (33)	43.5 (29)	54.0 (22)	60.9 (19)	82.5 (6)	81.3 (6)	73.5 (4)
95	42.1 (31)	46.5 (27)	57.8 (21)	65.2 (18)	86.7 (6)	85.4 (5)	77.0 (4)
100	44.8 (29)	49.7 (25)	61.7 (19)	69.5 (17)	90.8 (5)	89.5 (5)	80.5 (3)
105	47.6 (27)	52.9 (23)	65.8 (18)	74.0 (16)	95.0 (5)	93.5 (5)	84.0 (3)
110	50.6 (25)	56.3 (22)	69.9 (17)	78.4 (15)	99.0 (5)	97.4 (4)	87.5 (3)
115	53.7 (23)	59.7 (21)	74.1 (16)	83.0 (14)	103.1 (4)	101.3 (4)	90.9 (3)
120	56.9 (22)	63.3 (19)	78.4 (15)	87.6 (13)	107.0 (4)	105.2 (4)	94.3 (3)
125	60.1 (21)	67.0 (18)	82.7 (14)	92.2 (12)	111.0 (4)	109.1 (4)	97.6 (2)
130	63.5 (19)	70.7 (17)	87.1 (13)	96.9 (12)	114.9 (4)	112.9 (3)	100.9 (2)
135	67.0 (18)	74.5 (16)	91.5 (13)	101.6 (11)	118.8 (4)	116.7 (3)	104.2 (2)
140	70.5 (17)	78.4 (15)	96.0 (12)	106.4 (11)	122.6 (3)	120.4 (3)	107.5 (2)
145	74.1 (16)	82.3 (14)	100.5 (11)	111.2 (10)	126.5 (3)	124.1 (3)	110.7 (2)
150	77.8 (16)	86.3 (14)	105.1 (11)	116.0 (10)	130.2 (3)	127.8 (3)	113.9 (2)

Terminal total missile speeds (in m/s) and angles θ of incidence of the speeds with respect to the horizontal (in parentheses, in degrees) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 30 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, m^{-1} = 0.3048 ft^{-1}

Table B - 3 - Terminal horizontal missile speeds - 30 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	6.4	7.7	11.2	13.9	31.1	30.8	28.1
45	7.9	9.4	13.6	16.7	35.0	34.6	31.3
50	9.5	11.3	16.1	19.6	38.8	38.3	34.5
55	11.2	13.2	18.7	22.7	42.5	41.9	37.6
60	13.0	15.3	21.5	25.9	46.2	45.5	40.6
65	14.9	17.6	24.4	29.2	49.8	49.0	43.6
70	17.0	19.9	27.4	32.6	53.4	52.5	46.5
75	19.1	22.3	30.5	36.1	56.9	55.9	49.3
80	21.3	24.8	33.7	39.7	60.4	59.3	52.1
85	23.6	27.5	37.0	43.3	63.8	62.6	54.9
90	26.0	30.2	40.3	47.1	67.2	65.9	57.6
95	28.5	32.9	43.8	50.8	70.5	69.1	60.3
100	31.0	35.8	47.2	54.6	73.7	72.2	62.9
105	33.7	38.7	50.8	58.5	77.0	75.3	65.5
110	36.4	41.7	54.4	62.4	80.1	78.4	68.0
115	39.1	44.8	58.1	66.4	83.2	81.4	70.6
120	41.9	47.9	61.8	70.4	86.3	84.4	73.0
125	44.8	51.0	65.5	74.4	89.4	87.3	75.5
130	47.7	54.3	69.3	78.5	92.4	90.2	77.9
135	50.7	57.5	73.1	82.5	95.3	93.0	80.3
140	53.8	60.9	77.0	86.7	98.2	95.9	82.7
145	56.8	64.2	80.9	90.8	101.1	98.7	85.0
150	60.0	67.6	84.8	95.0	104.0	101.4	87.4

Terminal horizontal missile speeds (in m/s) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\text{ m})$ (in m/s). Missiles start at 30 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, m^{-1} = 0.3048 ft^{-1}

Table B - 4- Terminal total missile speeds - 30 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	23.8 (74)	23.9 (71)	24.5 (63)	25.3 (57)	32.8 (19)	32.4 (18)	28.8 (13)
45	24.1 (71)	24.4 (67)	25.6 (58)	26.9 (52)	36.5 (16)	35.9 (16)	31.9 (11)
50	24.6 (67)	25.0 (63)	26.9 (53)	28.7 (47)	40.1 (15)	39.4 (14)	35.0 (10)
55	25.2 (64)	25.9 (59)	28.4 (49)	30.8 (43)	43.6 (13)	42.9 (12)	38.0 (9)
60	26.0 (60)	26.9 (55)	30.3 (45)	33.2 (39)	47.2 (12)	46.4 (11)	41.0 (8)
65	26.9 (56)	28.2 (51)	32.3 (41)	35.8 (35)	50.7 (11)	49.8 (10)	43.9 (7)
70	28.0 (53)	29.6 (48)	34.6 (38)	38.5 (32)	54.2 (10)	53.2 (9)	46.8 (7)
75	29.3 (49)	31.3 (44)	37.1 (35)	41.5 (30)	57.6 (9)	56.6 (9)	49.6 (6)
80	30.7 (46)	33.0 (41)	39.7 (32)	44.6 (27)	61.0 (8)	59.9 (8)	52.4 (6)
85	32.3 (43)	35.0 (38)	42.5 (29)	47.9 (25)	64.4 (8)	63.1 (7)	55.1 (5)
90	34.1 (40)	37.1 (36)	45.4 (27)	51.2 (23)	67.7 (7)	66.3 (7)	57.8 (5)
95	35.9 (38)	39.4 (33)	48.4 (25)	54.7 (22)	71.0 (7)	69.5 (6)	60.5 (4)
100	38.0 (35)	41.7 (31)	51.6 (24)	58.2 (20)	74.2 (6)	72.6 (6)	63.1 (4)
105	40.1 (33)	44.2 (29)	54.8 (22)	61.9 (19)	77.4 (6)	75.7 (6)	65.6 (4)
110	42.3 (31)	46.8 (27)	58.2 (21)	65.6 (18)	80.5 (6)	78.7 (5)	68.2 (4)
115	44.7 (29)	49.6 (25)	61.6 (19)	69.3 (17)	83.6 (5)	81.7 (5)	70.7 (3)
120	47.1 (27)	52.4 (24)	65.1 (18)	73.2 (16)	86.6 (5)	84.6 (5)	73.1 (3)
125	49.7 (26)	55.3 (23)	68.6 (17)	77.0 (15)	89.7 (5)	87.5 (4)	75.6 (3)
130	52.3 (24)	58.2 (21)	72.2 (16)	80.9 (14)	92.6 (4)	90.4 (4)	78.0 (3)
135	55.0 (23)	61.3 (20)	75.9 (16)	84.9 (14)	95.6 (4)	93.3 (4)	80.4 (3)
140	57.8 (22)	64.4 (19)	79.6 (15)	88.9 (13)	98.5 (4)	96.1 (4)	82.8 (2)
145	60.7 (21)	67.6 (18)	83.4 (14)	92.9 (12)	101.3 (4)	98.8 (3)	85.1 (2)
150	63.6 (20)	70.8 (17)	87.2 (13)	97.0 (12)	104.2 (4)	101.6 (3)	87.4 (2)

Terminal total missile speeds (in m/s) and angles θ of incidence of the speeds with respect to the horizontal (in parentheses, in degrees) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s) . Missiles start at 30 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table B - 5 - Max horizontal missile speeds - 30 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	8.2 (0.02)	9.8 (0.02)	14.1 (0.02)	17.3 (0.02)	40.6 (11.51)	41.0 (12.64)	42.7 (18.79)
45	10.1 (0.02)	12.0 (0.02)	17.0 (0.02)	20.8 (0.02)	45.9 (12.17)	46.4 (13.27)	48.2 (19.22)
50	12.1 (0.02)	14.3 (0.02)	20.2 (0.02)	24.4 (0.02)	51.3 (12.76)	51.7 (13.84)	53.7 (19.62)
55	14.3 (0.02)	16.8 (0.02)	23.5 (0.02)	28.2 (0.01)	56.7 (13.30)	57.1 (14.36)	59.2 (19.97)
60	16.6 (0.02)	19.5 (0.02)	26.9 (0.02)	32.1 (0.03)	62.1 (13.80)	62.5 (14.84)	64.6 (20.28)
65	19.1 (0.02)	22.3 (0.02)	30.5 (0.02)	36.1 (0.04)	67.5 (14.25)	68.0 (15.26)	70.1 (20.57)
70	21.6 (0.02)	25.2 (0.02)	34.2 (0.02)	40.2 (0.05)	72.9 (14.68)	73.4 (15.67)	75.6 (20.84)
75	24.3 (0.02)	28.2 (0.02)	38.0 (0.01)	44.5 (0.07)	78.3 (15.07)	78.8 (16.04)	81.1 (21.08)
80	27.1 (0.02)	31.4 (0.02)	41.9 (0.03)	48.8 (0.10)	83.7 (15.43)	84.3 (16.39)	86.6 (21.31)
85	30.0 (0.02)	34.6 (0.02)	45.9 (0.03)	53.1 (0.12)	89.2 (15.78)	89.7 (16.71)	92.1 (21.52)
90	33.0 (0.02)	38.0 (0.02)	49.9 (0.04)	57.6 (0.15)	94.6 (16.10)	95.2 (17.01)	97.7 (21.72)
95	36.1 (0.02)	41.4 (0.02)	54.1 (0.05)	62.1 (0.18)	100.1 (16.40)	100.6 (17.30)	103.2 (21.90)
100	39.3 (0.02)	44.9 (0.02)	58.3 (0.05)	66.7 (0.21)	105.5 (16.69)	106.1 (17.57)	108.7 (22.08)
105	42.5 (0.02)	48.5 (0.02)	62.6 (0.07)	71.3 (0.26)	111.0 (16.95)	111.6 (17.82)	114.2 (22.24)
110	45.9 (0.02)	52.2 (0.02)	66.9 (0.10)	75.9 (0.30)	116.5 (17.21)	117.1 (18.06)	119.7 (22.39)
115	49.3 (0.02)	56.0 (0.02)	71.3 (0.11)	80.6 (0.34)	121.9 (17.45)	122.5 (18.29)	125.3 (22.54)
120	52.7 (0.02)	59.8 (0.01)	75.7 (0.12)	85.4 (0.39)	127.4 (17.67)	128.0 (18.50)	130.8 (22.68)
125	56.3 (0.02)	63.6 (0.01)	80.2 (0.15)	90.1 (0.45)	132.9 (17.89)	133.5 (18.71)	136.3 (22.81)
130	59.9 (0.02)	67.6 (0.01)	84.8 (0.16)	94.9 (0.50)	138.4 (18.11)	139.0 (18.91)	141.9 (22.94)
135	63.6 (0.02)	71.6 (0.03)	89.3 (0.19)	99.8 (0.56)	143.9 (18.30)	144.5 (19.10)	147.4 (23.06)
140	67.3 (0.02)	75.6 (0.03)	93.9 (0.23)	104.6 (0.63)	149.4 (18.50)	150.0 (19.27)	152.9 (23.17)
145	71.1 (0.02)	79.7 (0.04)	98.6 (0.26)	109.5 (0.70)	154.9 (18.68)	155.5 (19.44)	158.5 (23.29)
150	74.9 (0.01)	83.8 (0.04)	103.2 (0.28)	114.4 (0.77)	160.4 (18.85)	161.0 (19.61)	164.0 (23.39)

Maximum horizontal missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 30 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table B - 6 - Max total missile speeds - 30 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	24.1 (0.02)	24.4 (0.02)	25.8 (0.02)	27.2 (0.02)	42.0 (10.84)	42.2 (12.06)	43.4 (18.59)
45	24.7 (0.02)	25.3 (0.02)	27.4 (0.02)	29.4 (0.02)	47.1 (11.54)	47.4 (12.74)	48.8 (19.04)
50	25.5 (0.02)	26.4 (0.02)	29.3 (0.02)	32.0 (0.02)	52.4 (12.19)	52.7 (13.35)	54.2 (19.44)
55	26.5 (0.02)	27.7 (0.02)	31.6 (0.02)	34.9 (0.01)	57.6 (12.77)	58.0 (13.90)	59.6 (19.80)
60	27.8 (0.02)	29.3 (0.02)	34.1 (0.02)	38.0 (0.01)	62.9 (13.30)	63.3 (14.41)	65.0 (20.13)
65	29.2 (0.02)	31.2 (0.02)	37.0 (0.02)	41.4 (0.01)	68.3 (13.79)	68.7 (14.87)	70.5 (20.43)
70	30.9 (0.02)	33.2 (0.02)	40.0 (0.02)	45.0 (0.01)	73.6 (14.24)	74.0 (15.29)	76.0 (20.70)
75	32.7 (0.02)	35.5 (0.02)	43.2 (0.01)	48.8 (0.01)	79.0 (14.65)	79.4 (15.68)	81.4 (20.95)
80	34.8 (0.02)	38.0 (0.02)	46.7 (0.01)	52.7 (0.01)	84.4 (15.04)	84.8 (16.05)	86.9 (21.19)
85	37.1 (0.02)	40.7 (0.02)	50.2 (0.01)	56.8 (0.01)	89.8 (15.41)	90.2 (16.39)	92.4 (21.40)
90	39.5 (0.02)	43.5 (0.02)	54.0 (0.01)	60.9 (0.01)	95.2 (15.74)	95.7 (16.72)	97.9 (21.61)
95	42.1 (0.02)	46.5 (0.02)	57.8 (0.01)	65.2 (0.01)	100.6 (16.06)	101.1 (17.01)	103.4 (21.80)
100	44.8 (0.02)	49.7 (0.02)	61.7 (0.01)	69.5 (0.01)	106.0 (16.37)	106.5 (17.29)	108.9 (21.97)
105	47.6 (0.02)	52.9 (0.02)	65.8 (0.01)	74.0 (0.03)	111.5 (16.65)	112.0 (17.55)	114.4 (22.14)
110	50.6 (0.02)	56.3 (0.02)	69.9 (0.01)	78.4 (0.04)	116.9 (16.92)	117.4 (17.81)	119.9 (22.30)
115	53.7 (0.02)	59.7 (0.02)	74.1 (0.01)	83.0 (0.07)	122.3 (17.17)	122.9 (18.05)	125.5 (22.45)
120	56.9 (0.02)	63.3 (0.01)	78.4 (0.01)	87.6 (0.08)	127.8 (17.41)	128.4 (18.27)	131.0 (22.59)
125	60.1 (0.02)	67.0 (0.01)	82.7 (0.01)	92.2 (0.12)	133.3 (17.64)	133.9 (18.49)	136.5 (22.73)
130	63.5 (0.02)	70.7 (0.01)	87.1 (0.03)	96.9 (0.15)	138.7 (17.87)	139.3 (18.70)	142.0 (22.86)
135	67.0 (0.02)	74.5 (0.01)	91.5 (0.03)	101.6 (0.18)	144.2 (18.07)	144.8 (18.89)	147.6 (22.98)
140	70.5 (0.02)	78.4 (0.01)	96.0 (0.04)	106.4 (0.22)	149.7 (18.27)	150.3 (19.08)	153.1 (23.10)
145	74.1 (0.02)	82.3 (0.01)	100.5 (0.05)	111.2 (0.28)	155.2 (18.46)	155.8 (19.26)	158.6 (23.21)
150	77.8 (0.01)	86.3 (0.01)	105.1 (0.07)	116.0 (0.32)	160.6 (18.65)	161.3 (19.42)	164.2 (23.32)

Maximum total missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 30 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table B - 7 - Max horizontal missile speeds - 30 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	6.4 (0.02)	7.7 (0.02)	11.2 (0.02)	13.9 (0.02)	35.1 (12.64)	35.5 (13.71)	37.4 (19.50)
45	7.9 (0.02)	9.4 (0.02)	13.6 (0.02)	16.7 (0.02)	39.8 (13.27)	40.2 (14.33)	42.2 (19.92)
50	9.5 (0.02)	11.3 (0.02)	16.1 (0.02)	19.6 (0.05)	44.5 (13.86)	44.9 (14.88)	47.0 (20.30)
55	11.2 (0.02)	13.2 (0.02)	18.7 (0.02)	22.7 (0.06)	49.2 (14.39)	49.7 (15.38)	51.8 (20.64)
60	13.0 (0.02)	15.3 (0.02)	21.5 (0.02)	25.9 (0.10)	53.9 (14.87)	54.4 (15.85)	56.6 (20.95)
65	14.9 (0.02)	17.6 (0.02)	24.4 (0.02)	29.2 (0.12)	58.7 (15.32)	59.2 (16.27)	61.5 (21.22)
70	17.0 (0.02)	19.9 (0.02)	27.4 (0.05)	32.6 (0.15)	63.4 (15.73)	63.9 (16.66)	66.3 (21.48)
75	19.1 (0.02)	22.3 (0.02)	30.5 (0.06)	36.1 (0.19)	68.2 (16.11)	68.7 (17.03)	71.1 (21.72)
80	21.3 (0.02)	24.8 (0.02)	33.7 (0.06)	39.7 (0.23)	72.9 (16.47)	73.5 (17.36)	76.0 (21.94)
85	23.6 (0.02)	27.5 (0.02)	37.0 (0.10)	43.4 (0.28)	77.7 (16.80)	78.3 (17.67)	80.8 (22.14)
90	26.0 (0.02)	30.2 (0.02)	40.3 (0.11)	47.1 (0.34)	82.5 (17.11)	83.1 (17.97)	85.7 (22.33)
95	28.5 (0.02)	32.9 (0.02)	43.8 (0.14)	50.8 (0.39)	87.3 (17.41)	87.9 (18.24)	90.6 (22.51)
100	31.0 (0.02)	35.8 (0.02)	47.3 (0.16)	54.7 (0.46)	92.1 (17.68)	92.7 (18.50)	95.4 (22.68)
105	33.7 (0.02)	38.7 (0.02)	50.8 (0.19)	58.5 (0.53)	96.9 (17.94)	97.5 (18.75)	100.3 (22.84)
110	36.4 (0.02)	41.7 (0.05)	54.4 (0.23)	62.5 (0.60)	101.7 (18.18)	102.3 (18.97)	105.2 (22.98)
115	39.1 (0.02)	44.8 (0.05)	58.1 (0.26)	66.4 (0.68)	106.5 (18.41)	107.2 (19.19)	110.1 (23.12)
120	41.9 (0.02)	47.9 (0.05)	61.8 (0.30)	70.4 (0.75)	111.4 (18.64)	112.0 (19.40)	114.9 (23.26)
125	44.8 (0.02)	51.0 (0.06)	65.5 (0.34)	74.5 (0.83)	116.2 (18.84)	116.8 (19.60)	119.8 (23.38)
130	47.7 (0.02)	54.3 (0.06)	69.3 (0.38)	78.5 (0.92)	121.0 (19.04)	121.7 (19.78)	124.7 (23.51)
135	50.7 (0.02)	57.5 (0.09)	73.1 (0.43)	82.6 (1.01)	125.8 (19.24)	126.5 (19.97)	129.6 (23.62)
140	53.8 (0.05)	60.9 (0.10)	77.0 (0.48)	86.8 (1.11)	130.7 (19.42)	131.4 (20.14)	134.5 (23.73)
145	56.8 (0.05)	64.2 (0.11)	80.9 (0.54)	90.9 (1.20)	135.5 (19.59)	136.2 (20.30)	139.4 (23.83)
150	60.0 (0.05)	67.6 (0.12)	84.8 (0.59)	95.1 (1.29)	140.4 (19.76)	141.1 (20.46)	144.3 (23.93)

Maximum horizontal missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\text{ m})$ (in m/s). Missiles start at 30 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table B - 8 - Max total missile speeds - 30 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	0.0026	0.0042	0.0057	0.079	0.0885	0.176
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	23.7 (0.02)	23.9 (0.02)	24.5 (0.02)	25.3 (0.02)	36.7 (11.82)	36.9 (13.02)	38.1 (19.26)
45	24.1 (0.02)	24.4 (0.02)	25.6 (0.02)	26.9 (0.02)	41.2 (12.53)	41.4 (13.69)	42.8 (19.70)
50	24.6 (0.02)	25.0 (0.02)	26.9 (0.02)	28.7 (0.02)	45.7 (13.17)	46.0 (14.30)	47.5 (20.09)
55	25.2 (0.02)	25.9 (0.02)	28.4 (0.02)	30.8 (0.02)	50.3 (13.76)	50.6 (14.84)	52.3 (20.44)
60	26.0 (0.02)	26.9 (0.02)	30.3 (0.02)	33.2 (0.01)	54.9 (14.28)	55.3 (15.34)	57.1 (20.77)
65	26.9 (0.02)	28.2 (0.02)	32.3 (0.02)	35.8 (0.01)	59.5 (14.77)	60.0 (15.80)	61.9 (21.06)
70	28.0 (0.02)	29.6 (0.02)	34.6 (0.02)	38.5 (0.01)	64.2 (15.21)	64.7 (16.23)	66.7 (21.32)
75	29.3 (0.02)	31.2 (0.02)	37.0 (0.02)	41.5 (0.01)	68.9 (15.63)	69.4 (16.61)	71.5 (21.57)
80	30.7 (0.02)	33.0 (0.02)	39.7 (0.02)	44.6 (0.01)	73.6 (16.01)	74.1 (16.97)	76.3 (21.79)
85	32.3 (0.02)	35.0 (0.02)	42.5 (0.01)	47.9 (0.01)	78.4 (16.37)	78.9 (17.30)	81.2 (22.01)
90	34.1 (0.02)	37.1 (0.02)	45.4 (0.01)	51.2 (0.01)	83.1 (16.71)	83.6 (17.62)	86.0 (22.20)
95	35.9 (0.02)	39.4 (0.02)	48.4 (0.01)	54.7 (0.01)	87.9 (17.01)	88.4 (17.91)	90.8 (22.39)
100	37.9 (0.02)	41.7 (0.02)	51.6 (0.01)	58.2 (0.04)	92.6 (17.31)	93.2 (18.19)	95.7 (22.56)
105	40.1 (0.02)	44.2 (0.02)	54.8 (0.01)	61.9 (0.05)	97.4 (17.58)	98.0 (18.44)	100.6 (22.72)
110	42.3 (0.02)	46.8 (0.02)	58.2 (0.01)	65.6 (0.08)	102.2 (17.85)	102.8 (18.69)	105.4 (22.88)
115	44.7 (0.02)	49.6 (0.02)	61.6 (0.01)	69.3 (0.12)	107.0 (18.10)	107.6 (18.92)	110.3 (23.02)
120	47.1 (0.02)	52.4 (0.02)	65.1 (0.01)	73.2 (0.15)	111.8 (18.33)	112.4 (19.15)	115.1 (23.16)
125	49.7 (0.02)	55.2 (0.02)	68.6 (0.03)	77.0 (0.21)	116.6 (18.55)	117.2 (19.35)	120.0 (23.29)
130	52.3 (0.02)	58.2 (0.02)	72.2 (0.04)	81.0 (0.25)	121.4 (18.77)	122.0 (19.55)	124.9 (23.41)
135	55.0 (0.02)	61.3 (0.02)	75.9 (0.06)	84.9 (0.32)	126.2 (18.97)	126.9 (19.73)	129.8 (23.53)
140	57.8 (0.02)	64.4 (0.01)	79.6 (0.08)	89.0 (0.37)	131.0 (19.16)	131.7 (19.92)	134.7 (23.64)
145	60.7 (0.02)	67.6 (0.01)	83.4 (0.10)	93.0 (0.44)	135.9 (19.35)	136.5 (20.08)	139.5 (23.75)
150	63.6 (0.02)	70.8 (0.01)	87.2 (0.12)	97.1 (0.52)	140.7 (19.52)	141.4 (20.25)	144.4 (23.85)

Maximum total missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 30 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

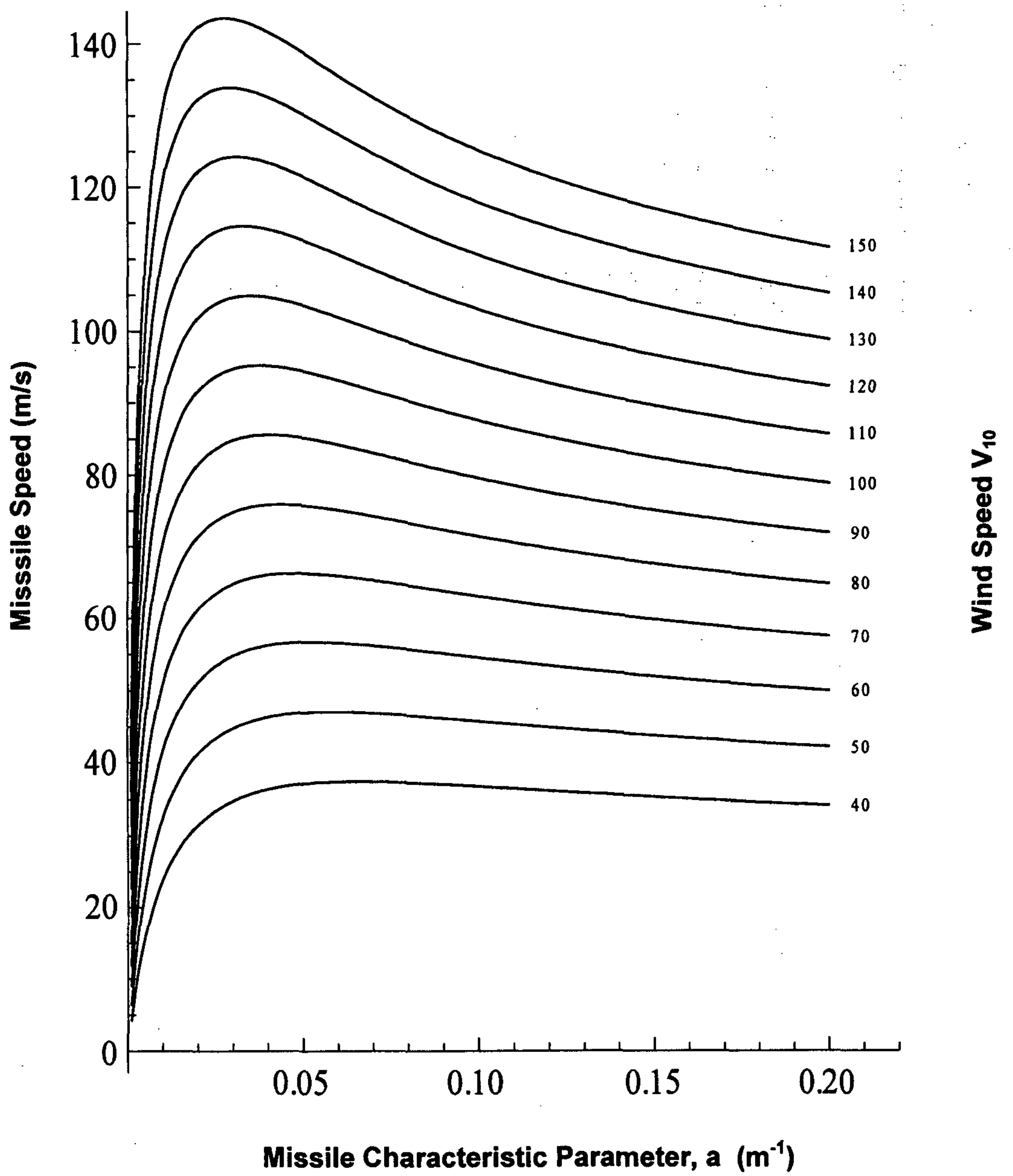

Figure B - 1- Terminal horizontal missile speeds - 30 m, open terrain

Terminal horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 30 m above ground level and reach ground level; flow over open terrain.

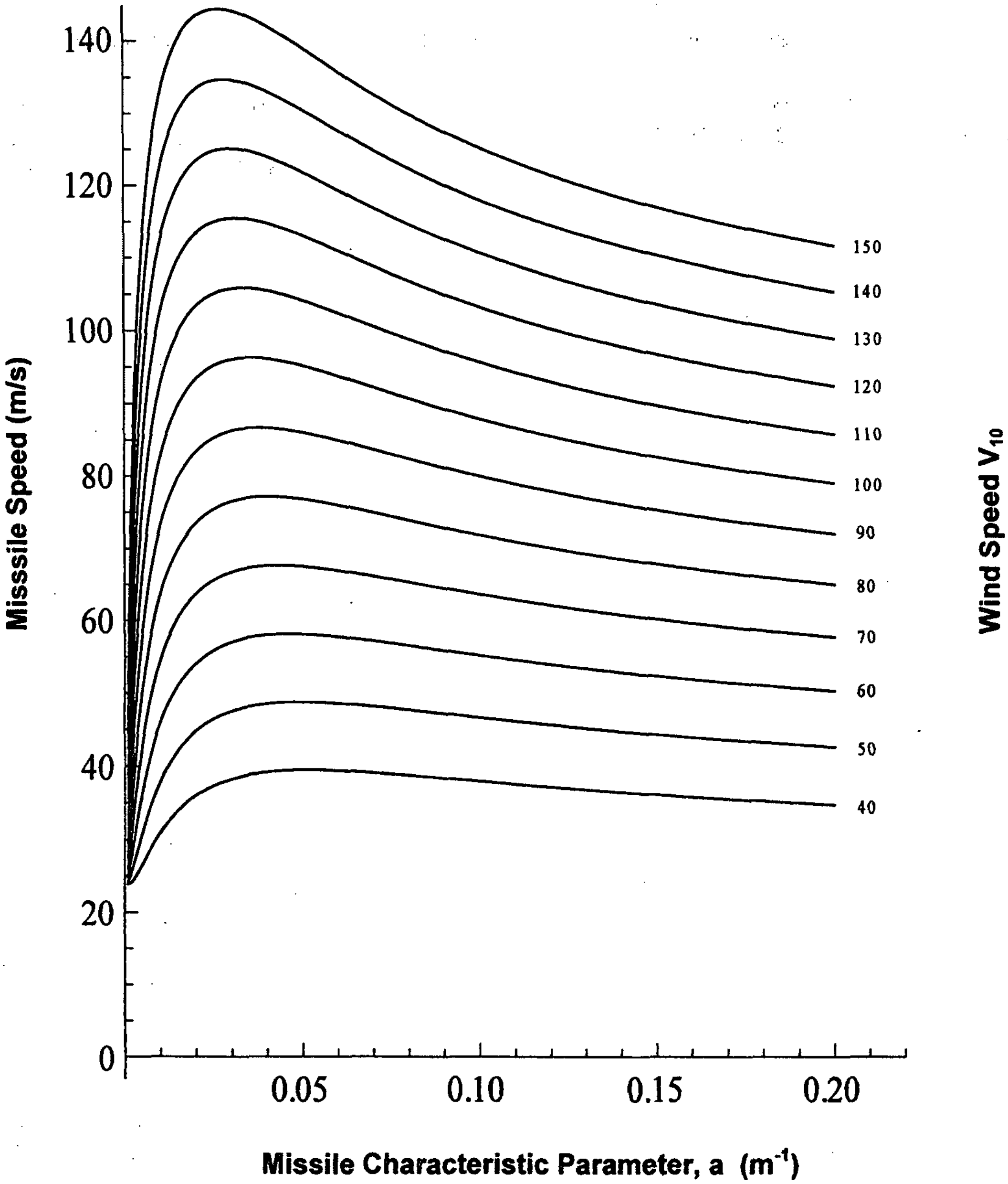

Figure B - 2- Terminal total missile speeds - 30 m, open terrain

Terminal total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 30 m above ground level and reach ground level; flow over open terrain.

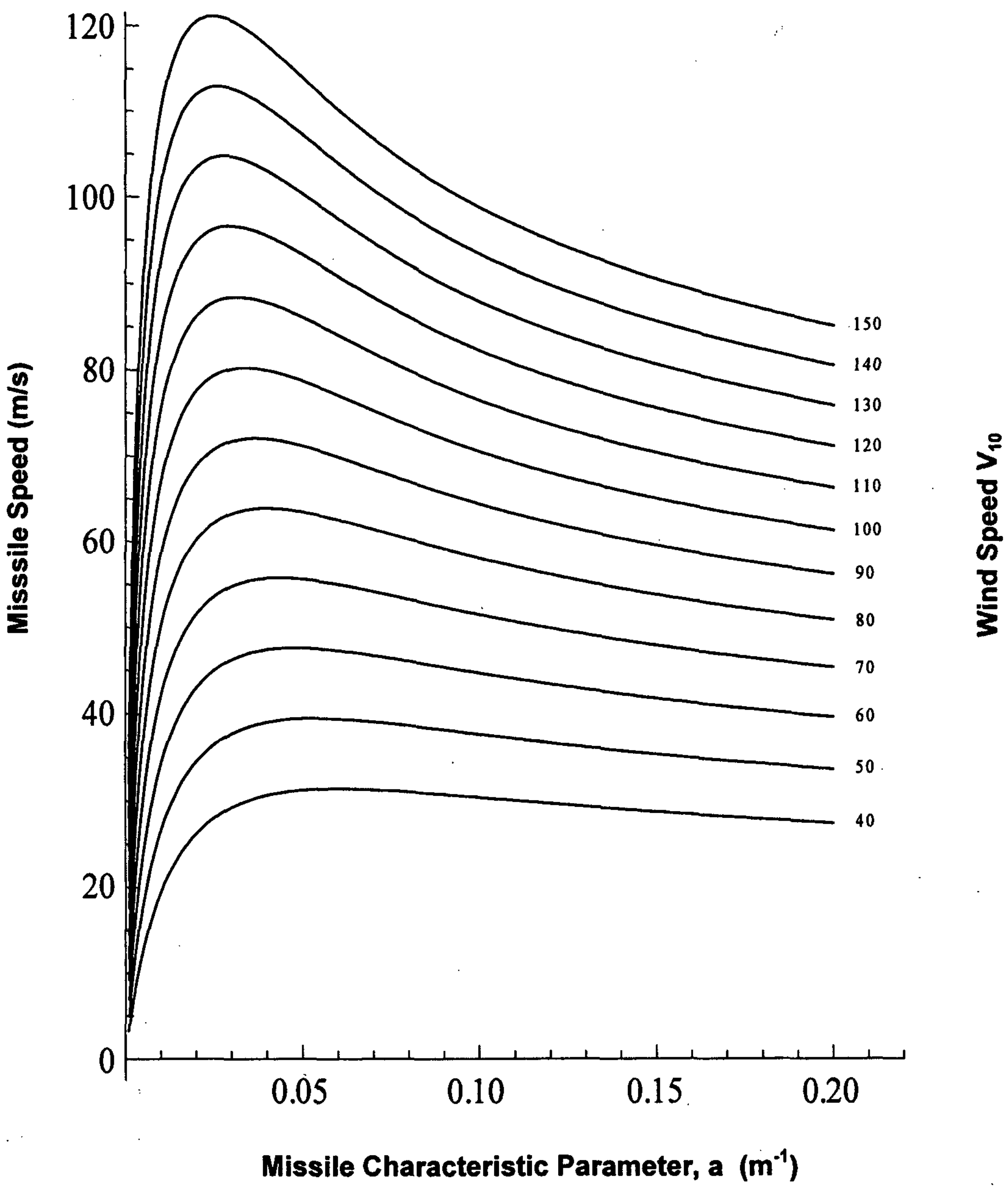

Figure B - 3- Terminal horizontal missile speeds - 30 m, suburban terrain

Terminal horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 30 m above ground level and reach ground level; flow over suburban terrain.

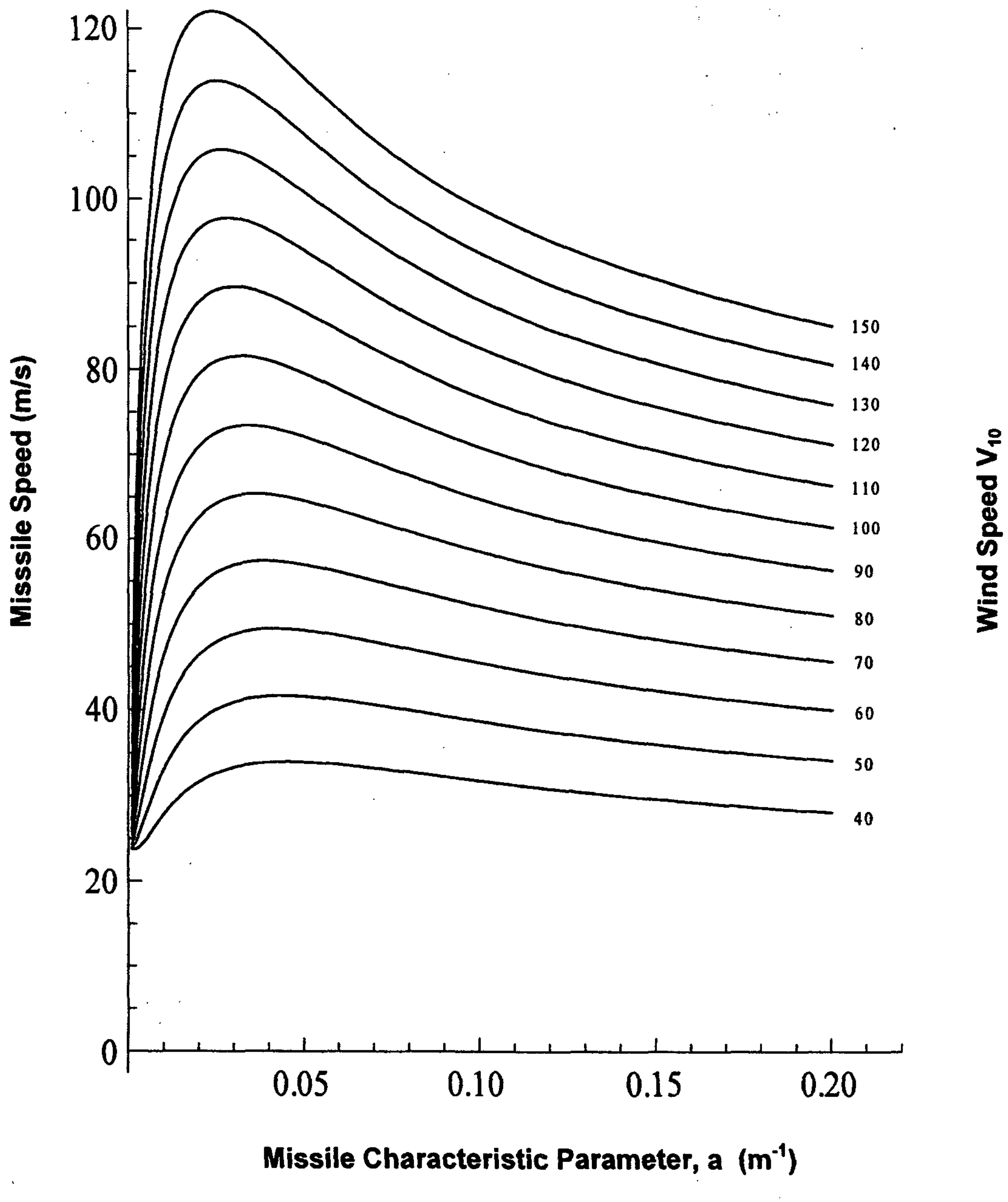

Figure B - 4- Terminal total missile speeds - 30 m, suburban terrain

Terminal total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds v_{10}=v_h^{open}(10 m) = 40, 50,...,150 m/s. Missiles start at 30 m above ground level and reach ground level; flow over suburban terrain.

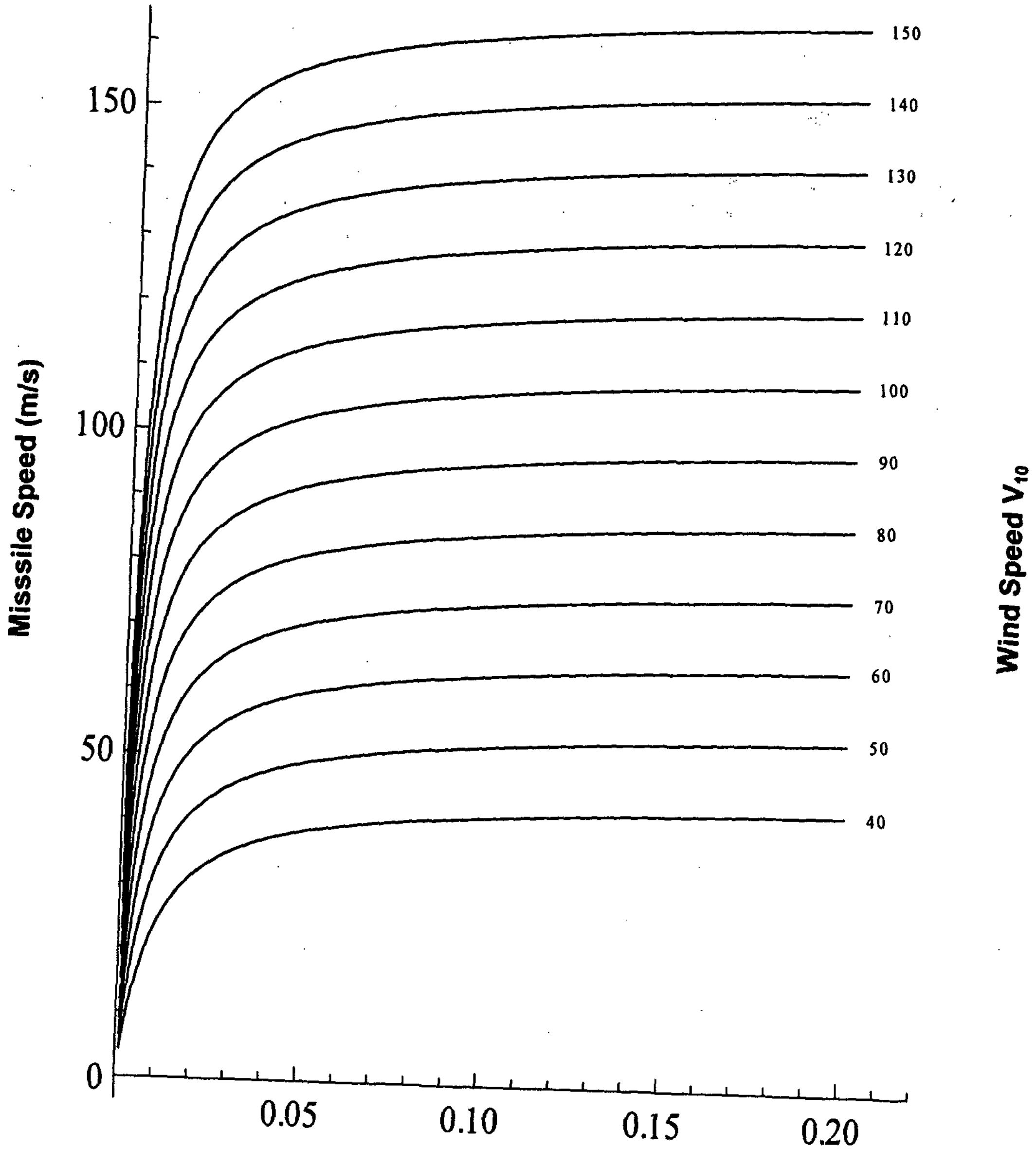

Figure B - 5- Max horizontal missile speeds - 30 m, open terrain

Maximum horizontal missile speeds (in m/s) for parameters a between 0.001 m^{-1}- 0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 30 m above ground level and reach ground level; flow over open terrain.

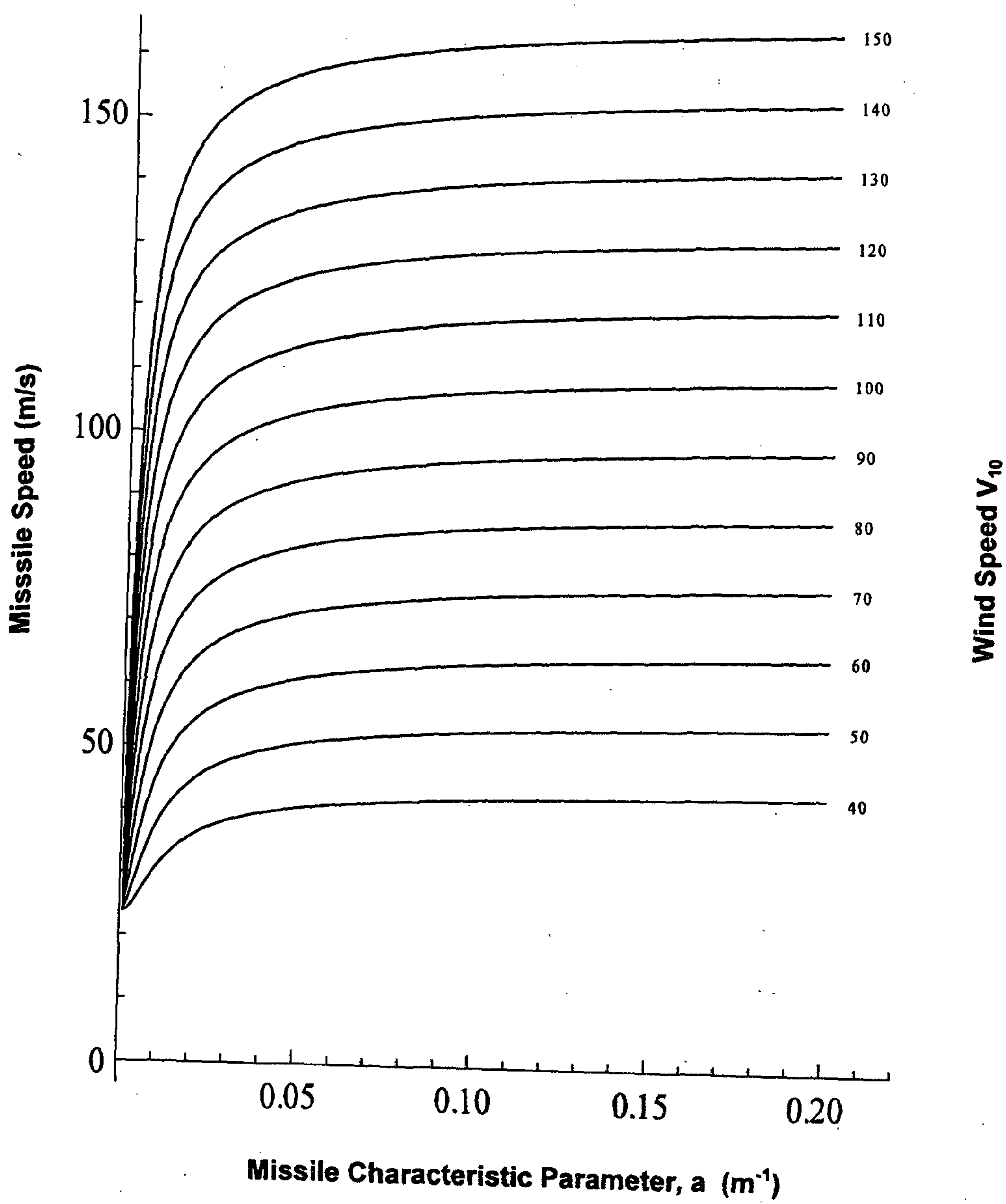

Figure B - 6- Max total missile speeds - 30 m, open terrain

Maximum total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds v_{10}=v_h^{open}(10 m) = 40, 50,...,150 m/s. Missiles start at 30 m above ground level and reach ground level; flow over open terrain.

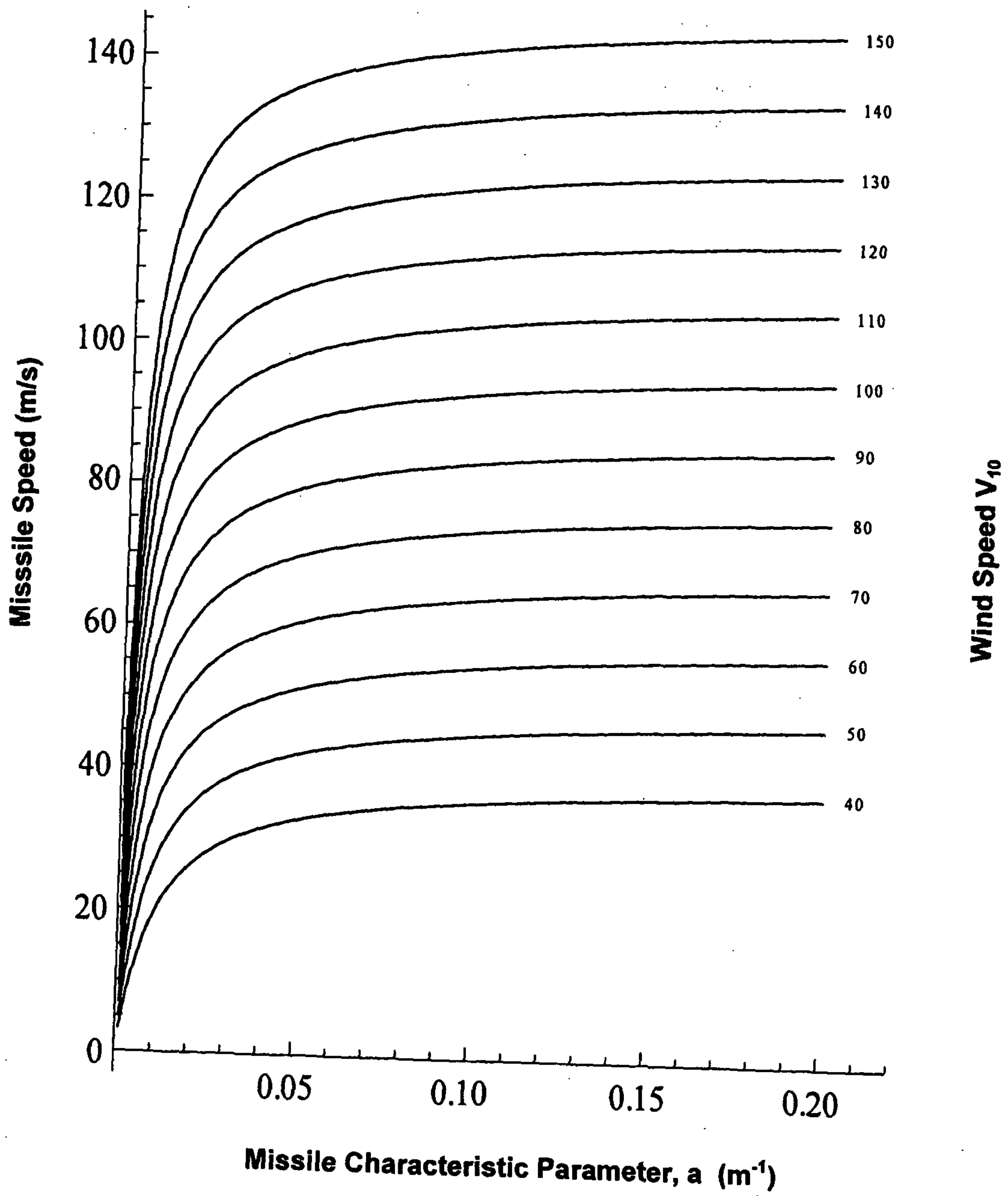

Figure B - 7- Max horizontal missile speeds - 30 m, suburban terrain

Maximum horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}- 0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 30 m above ground level and reach ground level; flow over suburban terrain.

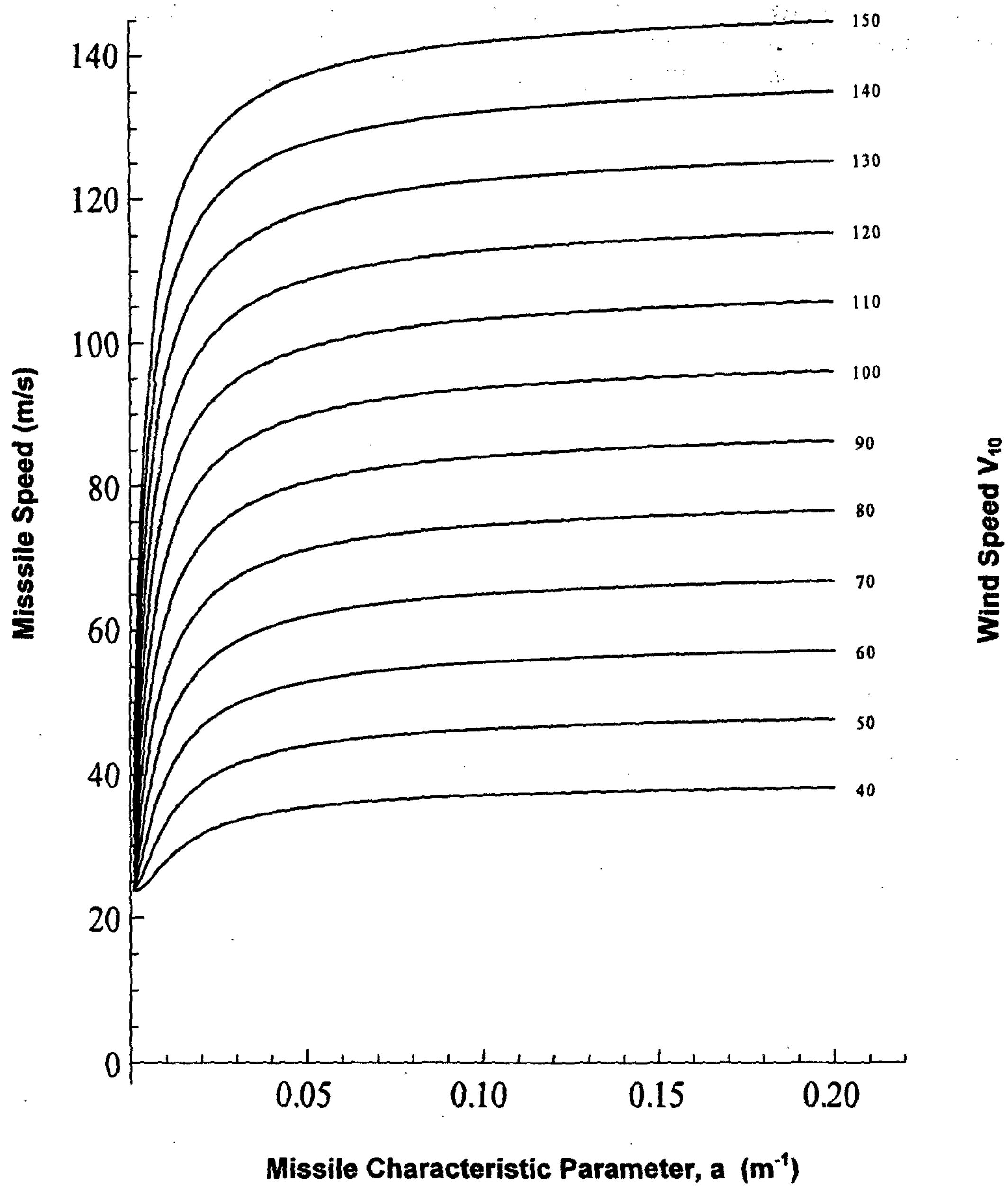

Figure B - 8- Max total missile speeds - 30 m, suburban terrain

Maximum total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 *m/s*. Missiles start at 30 m above ground level and reach ground level; flow over suburban terrain.

APPENDIX C. MISSILE SPEEDS CALCULATED FOR INITIAL ELEVATION H = 20 m

This Appendix contains tables and figures similar to those included in the body of the report, except that the initial elevation of the missiles was assumed to be H = 20 m, rather than H = 40 m.

Table C - 1 - Terminal horizontal missile speeds - 20 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	6.3	7.6	11.1	13.9	36.0	36.1	34.6
45	7.8	9.3	13.6	16.8	40.6	40.6	38.8
50	9.4	11.2	16.2	19.9	45.2	45.2	42.8
55	11.2	13.3	18.9	23.2	49.8	49.7	46.8
60	13.0	15.4	21.9	26.5	54.4	54.2	50.8
65	15.0	17.7	24.9	30.1	58.9	58.6	54.7
70	17.1	20.1	28.1	33.7	63.4	63.0	58.5
75	19.3	22.7	31.3	37.4	67.9	67.4	62.3
80	21.6	25.3	34.7	41.2	72.3	71.7	66.0
85	24.0	28.0	38.2	45.1	76.7	76.0	69.7
90	26.5	30.8	41.8	49.1	81.0	80.3	73.3
95	29.0	33.7	45.4	53.2	85.3	84.5	76.9
100	31.7	36.7	49.1	57.3	89.6	88.6	80.5
105	34.4	39.8	52.9	61.5	93.8	92.7	84.0
110	37.2	43.0	56.8	65.7	98.0	96.8	87.4
115	40.1	46.2	60.7	69.9	102.1	100.8	90.8
120	43.1	49.5	64.6	74.3	106.3	104.8	94.2
125	46.1	52.8	68.7	78.6	110.3	108.8	97.6
130	49.2	56.2	72.7	83.0	114.3	112.7	100.9
135	52.3	59.7	76.8	87.4	118.3	116.5	104.2
140	55.5	63.2	81.0	91.9	122.3	120.4	107.5
145	58.8	66.8	85.2	96.4	126.2	124.2	110.7
150	62.1	70.4	89.4	100.9	130.1	127.9	113.9

Terminal horizontal missile speeds (in m/s) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 20 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table C - 2 - Terminal total missile speeds - 20 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	19.8 (71)	20.1 (68)	21.2 (58)	22.4 (52)	37.5 (16)	37.4 (15)	35.3 (11)
45	20.3 (67)	20.7 (63)	22.5 (53)	24.3 (46)	41.9 (14)	41.8 (14)	39.3 (10)
50	20.9 (63)	21.6 (59)	24.1 (48)	26.4 (41)	46.4 (13)	46.2 (12)	43.3 (8)
55	21.7 (59)	22.6 (54)	25.9 (43)	28.9 (37)	50.9 (12)	50.6 (11)	47.2 (8)
60	22.6 (55)	23.9 (50)	28.1 (39)	31.6 (33)	55.3 (10)	55.0 (10)	51.1 (7)
65	23.7 (51)	25.4 (46)	30.4 (35)	34.6 (30)	59.8 (10)	59.4 (9)	55.0 (6)
70	25.1 (47)	27.1 (42)	33.0 (32)	37.7 (27)	64.2 (9)	63.7 (8)	58.8 (6)
75	26.6 (43)	28.9 (38)	35.8 (29)	41.0 (24)	68.6 (8)	68.0 (8)	62.5 (5)
80	28.2 (40)	31.0 (35)	38.8 (26)	44.5 (22)	72.9 (7)	72.3 (7)	66.2 (5)
85	30.1 (37)	33.2 (32)	41.9 (24)	48.1 (20)	77.2 (7)	76.5 (7)	69.9 (4)
90	32.0 (34)	35.6 (30)	45.1 (22)	51.9 (19)	81.5 (6)	80.7 (6)	73.5 (4)
95	34.2 (32)	38.1 (28)	48.5 (21)	55.7 (17)	85.8 (6)	84.9 (6)	77.1 (4)
100	36.4 (29)	40.7 (26)	52.0 (19)	59.6 (16)	90.0 (6)	89.0 (5)	80.6 (3)
105	38.8 (27)	43.5 (24)	55.5 (18)	63.6 (15)	94.2 (5)	93.1 (5)	84.1 (3)
110	41.3 (26)	46.4 (22)	59.2 (17)	67.7 (14)	98.4 (5)	97.1 (5)	87.5 (3)
115	43.9 (24)	49.4 (21)	63.0 (15)	71.8 (13)	102.5 (5)	101.1 (4)	90.9 (3)
120	46.6 (22)	52.4 (19)	66.8 (15)	76.0 (12)	106.6 (4)	105.1 (4)	94.3 (3)
125	49.4 (21)	55.6 (18)	70.7 (14)	80.3 (12)	110.6 (4)	109.0 (4)	97.7 (2)
130	52.2 (20)	58.8 (17)	74.6 (13)	84.6 (11)	114.6 (4)	112.9 (4)	101.0 (2)
135	55.2 (19)	62.1 (16)	78.6 (12)	88.9 (11)	118.6 (4)	116.7 (3)	104.3 (2)
140	58.2 (17)	65.5 (15)	82.7 (12)	93.3 (10)	122.5 (4)	120.6 (3)	107.5 (2)
145	61.3 (17)	69.0 (14)	86.8 (11)	97.8 (10)	126.4 (3)	124.3 (3)	110.8 (2)
150	64.5 (16)	72.5 (14)	91.0 (10)	102.2 (9)	130.3 (3)	128.1 (3)	114.0 (2)

Terminal total missile speeds (in m/s) and angles θ of incidence of the speeds with respect to the horizontal (in parentheses, in degrees) as functions of parameter a (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\text{ m})$ (in m/s). Missiles start at 20 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table C - 3 - Terminal horizontal missile speeds - 20 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	4.8	5.7	8.5	10.8	29.8	29.8	28.0
45	5.9	7.1	10.4	13.0	33.6	33.5	31.2
50	7.1	8.5	12.4	15.5	37.4	37.3	34.4
55	8.4	10.1	14.6	18.0	41.2	40.9	37.5
60	9.9	11.7	16.9	20.7	44.9	44.6	40.6
65	11.4	13.5	19.2	23.5	48.6	48.2	43.6
70	13.0	15.4	21.7	26.4	52.2	51.7	46.5
75	14.7	17.3	24.3	29.4	55.8	55.2	49.4
80	16.4	19.3	27.0	32.5	59.4	58.6	52.2
85	18.3	21.5	29.8	35.6	62.9	62.0	54.9
90	20.2	23.7	32.6	38.8	66.3	65.4	57.7
95	22.2	25.9	35.5	42.1	69.7	68.7	60.3
100	24.2	28.3	38.5	45.5	73.1	71.9	63.0
105	26.3	30.7	41.5	48.9	76.4	75.1	65.5
110	28.5	33.2	44.6	52.3	79.7	78.2	68.1
115	30.8	35.7	47.8	55.8	82.9	81.3	70.6
120	33.1	38.3	51.0	59.3	86.1	84.4	73.1
125	35.5	40.9	54.3	62.9	89.2	87.4	75.5
130	37.9	43.6	57.6	66.5	92.3	90.4	78.0
135	40.3	46.4	60.9	70.2	95.4	93.3	80.4
140	42.9	49.2	64.3	73.9	98.4	96.2	82.7
145	45.4	52.0	67.7	77.6	101.3	99.0	85.1
150	48.0	54.9	71.2	81.3	104.3	101.8	87.4

Terminal horizontal missile speeds (in m/s) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 20 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table C - 4- Terminal total missile speeds - 20 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	19.5 (76)	19.6 (73)	20.1 (65)	20.8 (59)	31.5 (19)	31.4 (18)	28.7 (13)
45	19.8 (73)	20.0 (69)	20.9 (60)	22.0 (54)	35.1 (17)	34.9 (16)	31.9 (12)
50	20.1 (69)	20.4 (65)	21.9 (55)	23.4 (49)	38.8 (15)	38.5 (14)	35.0 (10)
55	20.5 (66)	21.1 (61)	23.1 (51)	25.1 (44)	42.4 (14)	42.0 (13)	38.0 (9)
60	21.1 (62)	21.9 (58)	24.5 (47)	27.1 (40)	46.0 (12)	45.5 (12)	41.0 (8)
65	21.8 (59)	22.8 (54)	26.2 (43)	29.2 (36)	49.5 (11)	49.0 (11)	43.9 (7)
70	22.6 (55)	23.9 (50)	28.0 (39)	31.5 (33)	53.1 (10)	52.5 (10)	46.8 (7)
75	23.6 (52)	25.1 (46)	30.0 (36)	34.0 (30)	56.6 (10)	55.9 (9)	49.6 (6)
80	24.7 (48)	26.5 (43)	32.2 (33)	36.7 (28)	60.1 (9)	59.3 (8)	52.4 (6)
85	25.9 (45)	28.1 (40)	34.5 (30)	39.5 (26)	63.5 (8)	62.6 (8)	55.2 (5)
90	27.2 (42)	29.7 (37)	37.0 (28)	42.4 (24)	66.9 (8)	65.9 (7)	57.9 (5)
95	28.7 (39)	31.5 (35)	39.5 (26)	45.4 (22)	70.3 (7)	69.1 (7)	60.5 (4)
100	30.3 (37)	33.5 (32)	42.2 (24)	48.5 (20)	73.6 (7)	72.3 (6)	63.1 (4)
105	32.0 (35)	35.5 (30)	45.0 (23)	51.7 (19)	76.9 (6)	75.5 (6)	65.7 (4)
110	33.8 (32)	37.6 (28)	47.8 (21)	54.9 (18)	80.1 (6)	78.6 (5)	68.2 (4)
115	35.7 (30)	39.9 (26)	50.8 (20)	58.3 (17)	83.3 (6)	81.7 (5)	70.7 (3)
120	37.6 (28)	42.2 (25)	53.8 (19)	61.6 (16)	86.4 (5)	84.7 (5)	73.2 (3)
125	39.7 (27)	44.6 (23)	56.9 (17)	65.1 (15)	89.5 (5)	87.7 (5)	75.6 (3)
130	41.9 (25)	47.0 (22)	60.0 (16)	68.6 (14)	92.6 (5)	90.6 (4)	78.1 (3)
135	44.1 (24)	49.6 (21)	63.2 (16)	72.1 (13)	95.6 (4)	93.5 (4)	80.4 (3)
140	46.4 (23)	52.2 (20)	66.5 (15)	75.7 (13)	98.6 (4)	96.4 (4)	82.8 (3)
145	48.8 (21)	54.9 (19)	69.8 (14)	79.3 (12)	101.6 (4)	99.2 (4)	85.2 (2)
150	51.2 (20)	57.6 (18)	73.2 (13)	83.0 (11)	104.5 (4)	102.0 (3)	87.5 (2)

Terminal total missile speeds (in m/s) and angles θ of incidence of the speeds with respect to the horizontal (in parentheses, in degrees) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 20 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table C - 5 - Max horizontal missile speeds - 20 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	6.3 (0.01)	7.6 (0.01)	11.1 (0.01)	13.9 (0.01)	37.6 (5.62)	38.1 (6.36)	40.3 (10.73)
45	7.8 (0.01)	9.3 (0.01)	13.6 (0.01)	16.8 (0.01)	42.7 (6.11)	43.2 (6.84)	45.5 (11.10)
50	9.4 (0.01)	11.2 (0.01)	16.2 (0.01)	19.9 (0.01)	47.8 (6.54)	48.3 (7.27)	50.7 (11.43)
55	11.2 (0.01)	13.3 (0.01)	18.9 (0.01)	23.2 (0.01)	52.9 (6.95)	53.5 (7.66)	55.9 (11.73)
60	13.0 (0.01)	15.4 (0.01)	21.9 (0.01)	26.5 (0.01)	58.1 (7.32)	58.6 (8.03)	61.2 (12.00)
65	15.0 (0.01)	17.7 (0.01)	24.9 (0.01)	30.1 (0.01)	63.2 (7.67)	63.8 (8.36)	66.4 (12.25)
70	17.1 (0.01)	20.1 (0.01)	28.1 (0.01)	33.7 (0.01)	68.4 (7.99)	69.0 (8.68)	71.6 (12.47)
75	19.3 (0.01)	22.7 (0.01)	31.3 (0.01)	37.4 (0.01)	73.5 (8.28)	74.1 (8.97)	76.9 (12.69)
80	21.6 (0.01)	25.3 (0.01)	34.7 (0.01)	41.2 (0.01)	78.7 (8.57)	79.3 (9.24)	82.2 (12.88)
85	24.0 (0.01)	28.0 (0.01)	38.2 (0.01)	45.1 (0.03)	83.9 (8.83)	84.5 (9.49)	87.4 (13.06)
90	26.5 (0.01)	30.8 (0.01)	41.8 (0.01)	49.1 (0.03)	89.1 (9.08)	89.7 (9.74)	92.7 (13.23)
95	29.0 (0.01)	33.7 (0.01)	45.4 (0.01)	53.2 (0.04)	94.3 (9.31)	95.0 (9.96)	98.0 (13.38)
100	31.7 (0.01)	36.7 (0.01)	49.1 (0.01)	57.3 (0.06)	99.5 (9.54)	100.2 (10.17)	103.2 (13.53)
105	34.4 (0.01)	39.8 (0.01)	52.9 (0.01)	61.5 (0.06)	104.7 (9.75)	105.4 (10.37)	108.5 (13.67)
110	37.2 (0.01)	43.0 (0.01)	56.8 (0.01)	65.7 (0.08)	109.9 (9.94)	110.6 (10.56)	113.8 (13.80)
115	40.1 (0.01)	46.2 (0.01)	60.7 (0.03)	69.9 (0.09)	115.2 (10.13)	115.9 (10.74)	119.1 (13.92)
120	43.1 (0.01)	49.5 (0.01)	64.6 (0.03)	74.3 (0.10)	120.4 (10.31)	121.1 (10.91)	124.4 (14.04)
125	46.1 (0.01)	52.8 (0.01)	68.7 (0.03)	78.6 (0.11)	125.6 (10.48)	126.4 (11.07)	129.7 (14.16)
130	49.2 (0.01)	56.2 (0.01)	72.7 (0.04)	83.0 (0.15)	130.9 (10.65)	131.6 (11.23)	134.9 (14.26)
135	52.3 (0.01)	59.7 (0.01)	76.9 (0.04)	87.5 (0.16)	136.1 (10.81)	136.8 (11.38)	140.2 (14.36)
140	55.5 (0.01)	63.2 (0.01)	81.0 (0.06)	91.9 (0.18)	141.3 (10.95)	142.1 (11.52)	145.5 (14.46)
145	58.8 (0.01)	66.8 (0.01)	85.2 (0.06)	96.4 (0.21)	146.6 (11.10)	147.4 (11.66)	150.8 (14.55)
150	62.1 (0.01)	70.4 (0.01)	89.4 (0.08)	100.9 (0.23)	151.8 (11.23)	152.6 (11.79)	156.1 (14.64)

Maximum horizontal missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s) . Missiles start at 20 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table C - 6 - Max total missile speeds - 20 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	19.8 (0.01)	20.1 (0.01)	21.2 (0.01)	22.4 (0.01)	39.0 (4.97)	39.4 (5.78)	40.9 (10.50)
45	20.3 (0.01)	20.7 (0.01)	22.5 (0.01)	24.2 (0.01)	43.9 (5.51)	44.3 (6.30)	46.1 (10.90)
50	20.9 (0.01)	21.6 (0.01)	24.1 (0.01)	26.4 (0.01)	48.9 (5.99)	49.3 (6.78)	51.2 (11.24)
55	21.6 (0.01)	22.6 (0.01)	25.9 (0.01)	28.9 (0.01)	53.9 (6.43)	54.3 (7.21)	56.4 (11.55)
60	22.6 (0.01)	23.9 (0.01)	28.1 (0.01)	31.6 (0.01)	58.9 (6.84)	59.4 (7.61)	61.6 (11.84)
65	23.7 (0.01)	25.4 (0.01)	30.4 (0.01)	34.6 (0.01)	64.0 (7.22)	64.5 (7.98)	66.8 (12.09)
70	25.1 (0.01)	27.0 (0.01)	33.0 (0.01)	37.7 (0.01)	69.1 (7.57)	69.6 (8.31)	72.0 (12.33)
75	26.6 (0.01)	28.9 (0.01)	35.8 (0.01)	41.0 (0.01)	74.2 (7.89)	74.7 (8.63)	77.2 (12.55)
80	28.2 (0.01)	31.0 (0.01)	38.8 (0.01)	44.5 (0.01)	79.3 (8.20)	79.9 (8.92)	82.5 (12.75)
85	30.1 (0.01)	33.2 (0.01)	41.9 (0.01)	48.1 (0.01)	84.5 (8.49)	85.0 (9.19)	87.7 (12.93)
90	32.0 (0.01)	35.6 (0.01)	45.1 (0.01)	51.9 (0.01)	89.6 (8.75)	90.2 (9.44)	92.9 (13.11)
95	34.2 (0.01)	38.1 (0.01)	48.5 (0.01)	55.7 (0.01)	94.8 (9.00)	95.4 (9.68)	98.2 (13.27)
100	36.4 (0.01)	40.7 (0.01)	52.0 (0.01)	59.6 (0.01)	100.0 (9.24)	100.6 (9.91)	103.5 (13.42)
105	38.8 (0.01)	43.5 (0.01)	55.5 (0.01)	63.6 (0.01)	105.1 (9.46)	105.8 (10.12)	108.7 (13.56)
110	41.3 (0.01)	46.4 (0.01)	59.2 (0.01)	67.7 (0.01)	110.3 (9.68)	111.0 (10.32)	114.0 (13.70)
115	43.9 (0.01)	49.4 (0.01)	63.0 (0.01)	71.8 (0.01)	115.5 (9.87)	116.2 (10.51)	119.3 (13.83)
120	46.6 (0.01)	52.4 (0.01)	66.8 (0.01)	76.0 (0.01)	120.8 (10.06)	121.4 (10.70)	124.5 (13.96)
125	49.3 (0.01)	55.6 (0.01)	70.7 (0.01)	80.3 (0.01)	126.0 (10.25)	126.7 (10.87)	129.8 (14.07)
130	52.2 (0.01)	58.8 (0.01)	74.6 (0.01)	84.6 (0.03)	131.2 (10.42)	131.9 (11.04)	135.1 (14.18)
135	55.2 (0.01)	62.1 (0.01)	78.6 (0.01)	89.0 (0.04)	136.4 (10.59)	137.1 (11.19)	140.4 (14.29)
140	58.2 (0.01)	65.5 (0.01)	82.7 (0.01)	93.3 (0.04)	141.6 (10.74)	142.4 (11.34)	145.7 (14.38)
145	61.3 (0.01)	69.0 (0.01)	86.8 (0.01)	97.8 (0.06)	146.9 (10.90)	147.6 (11.48)	151.0 (14.48)
150	64.5 (0.01)	72.5 (0.01)	91.0 (0.01)	102.2 (0.08)	152.1 (11.04)	152.9 (11.62)	156.3 (14.57)

Maximum total missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s) . Missiles start at 20 m above ground level and reach ground level; flow over open terrain

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table C - 7- Max horizontal missile speeds - 20 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	0.0026	0.0042	0.0057	0.079	0.0885	0.176
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	4.8 (0.01)	5.7 (0.01)	8.5 (0.01)	10.8 (0.01)	31.9 (6.38)	32.3 (7.11)	34.6 (11.29)
45	5.9 (0.01)	7.1 (0.01)	10.4 (0.01)	13.0 (0.01)	36.2 (6.86)	36.7 (7.58)	39.0 (11.65)
50	7.1 (0.01)	8.5 (0.01)	12.4 (0.01)	15.5 (0.01)	40.6 (7.30)	41.1 (8.00)	43.6 (11.97)
55	8.4 (0.01)	10.1 (0.01)	14.6 (0.01)	18.0 (0.01)	45.0 (7.70)	45.5 (8.40)	48.1 (12.26)
60	9.9 (0.01)	11.7 (0.01)	16.9 (0.01)	20.7 (0.01)	49.4 (8.07)	50.0 (8.76)	52.6 (12.52)
65	11.4 (0.01)	13.5 (0.01)	19.2 (0.01)	23.5 (0.03)	53.8 (8.42)	54.4 (9.09)	57.1 (12.76)
70	13.0 (0.01)	15.4 (0.01)	21.7 (0.01)	26.4 (0.03)	58.3 (8.73)	58.9 (9.39)	61.7 (12.98)
75	14.7 (0.01)	17.3 (0.01)	24.3 (0.01)	29.4 (0.04)	62.8 (9.02)	63.4 (9.68)	66.2 (13.18)
80	16.4 (0.01)	19.3 (0.01)	27.0 (0.01)	32.5 (0.06)	67.2 (9.30)	67.9 (9.94)	70.8 (13.37)
85	18.3 (0.01)	21.5 (0.01)	29.8 (0.01)	35.6 (0.08)	71.7 (9.56)	72.4 (10.19)	75.4 (13.54)
90	20.2 (0.01)	23.7 (0.01)	32.6 (0.03)	38.8 (0.09)	76.2 (9.80)	76.9 (10.42)	79.9 (13.70)
95	22.2 (0.01)	25.9 (0.01)	35.5 (0.03)	42.1 (0.10)	80.7 (10.03)	81.4 (10.64)	84.5 (13.85)
100	24.2 (0.01)	28.3 (0.01)	38.5 (0.04)	45.5 (0.13)	85.2 (10.24)	85.9 (10.85)	89.1 (14.00)
105	26.3 (0.01)	30.7 (0.01)	41.5 (0.04)	48.9 (0.15)	89.7 (10.45)	90.4 (11.04)	93.7 (14.13)
110	28.5 (0.01)	33.2 (0.01)	44.6 (0.06)	52.3 (0.18)	94.2 (10.64)	94.9 (11.23)	98.2 (14.25)
115	30.8 (0.01)	35.7 (0.01)	47.8 (0.06)	55.8 (0.20)	98.8 (10.82)	99.5 (11.40)	102.8 (14.38)
120	33.1 (0.01)	38.3 (0.01)	51.0 (0.08)	59.4 (0.22)	103.3 (11.00)	104.0 (11.56)	107.4 (14.48)
125	35.5 (0.01)	40.9 (0.01)	54.3 (0.09)	62.9 (0.25)	107.8 (11.16)	108.6 (11.72)	112.0 (14.59)
130	37.9 (0.01)	43.6 (0.01)	57.6 (0.10)	66.6 (0.30)	112.3 (11.32)	113.1 (11.87)	116.6 (14.70)
135	40.3 (0.01)	46.4 (0.01)	60.9 (0.12)	70.2 (0.32)	116.9 (11.47)	117.7 (12.01)	121.2 (14.79)
140	42.9 (0.01)	49.2 (0.01)	64.3 (0.13)	73.9 (0.35)	121.4 (11.61)	122.2 (12.15)	125.8 (14.88)
145	45.4 (0.01)	52.0 (0.03)	67.7 (0.15)	77.6 (0.40)	126.0 (11.75)	126.8 (12.28)	130.4 (14.97)
150	48.0 (0.01)	54.9 (0.03)	71.2 (0.18)	81.4 (0.43)	130.5 (11.88)	131.3 (12.41)	135.0 (15.06)

Maximum horizontal missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s) . Missiles start at 20 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table C - 8- Max total missile speeds - 20 m, suburban terrain

v_{10}	Missile Characteristic, a (in 1/m)						
	0.0021	0.0026	0.0042	0.0057	0.079	0.0885	0.176
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	19.5 (0.01)	19.6 (0.01)	20.1 (0.01)	20.8 (0.01)	33.4 (5.58)	33.8 (6.40)	35.3 (11.01)
45	19.8 (0.01)	20.0 (0.01)	20.9 (0.01)	22.0 (0.01)	37.6 (6.13)	38.0 (6.93)	39.7 (11.40)
50	20.1 (0.01)	20.4 (0.01)	21.9 (0.01)	23.4 (0.01)	41.8 (6.63)	42.2 (7.42)	44.1 (11.74)
55	20.5 (0.01)	21.1 (0.01)	23.1 (0.01)	25.1 (0.01)	46.1 (7.08)	46.5 (7.85)	48.6 (12.05)
60	21.1 (0.01)	21.8 (0.01)	24.5 (0.01)	27.0 (0.01)	50.4 (7.50)	50.9 (8.25)	53.1 (12.32)
65	21.8 (0.01)	22.8 (0.01)	26.2 (0.01)	29.2 (0.01)	54.7 (7.88)	55.2 (8.62)	57.6 (12.57)
70	22.6 (0.01)	23.9 (0.01)	28.0 (0.01)	31.5 (0.01)	59.1 (8.23)	59.6 (8.96)	62.1 (12.81)
75	23.6 (0.01)	25.1 (0.01)	30.0 (0.01)	34.0 (0.01)	63.5 (8.56)	64.1 (9.27)	66.6 (13.02)
80	24.7 (0.01)	26.5 (0.01)	32.2 (0.01)	36.7 (0.01)	67.9 (8.86)	68.5 (9.56)	71.1 (13.21)
85	25.9 (0.01)	28.1 (0.01)	34.5 (0.01)	39.5 (0.01)	72.3 (9.15)	72.9 (9.83)	75.7 (13.40)
90	27.2 (0.01)	29.7 (0.01)	36.9 (0.01)	42.4 (0.01)	76.8 (9.41)	77.4 (10.08)	80.2 (13.57)
95	28.7 (0.01)	31.5 (0.01)	39.5 (0.01)	45.4 (0.01)	81.2 (9.66)	81.9 (10.32)	84.8 (13.72)
100	30.3 (0.01)	33.5 (0.01)	42.2 (0.01)	48.5 (0.01)	85.7 (9.90)	86.4 (10.54)	89.3 (13.87)
105	32.0 (0.01)	35.5 (0.01)	45.0 (0.01)	51.7 (0.01)	90.2 (10.12)	90.9 (10.76)	93.9 (14.01)
110	33.8 (0.01)	37.6 (0.01)	47.8 (0.01)	54.9 (0.01)	94.7 (10.33)	95.4 (10.95)	98.5 (14.14)
115	35.7 (0.01)	39.9 (0.01)	50.8 (0.01)	58.3 (0.01)	99.2 (10.52)	99.9 (11.14)	103.1 (14.27)
120	37.6 (0.01)	42.2 (0.01)	53.8 (0.01)	61.7 (0.03)	103.7 (10.72)	104.4 (11.32)	107.6 (14.38)
125	39.7 (0.01)	44.6 (0.01)	56.9 (0.01)	65.1 (0.03)	108.2 (10.89)	108.9 (11.48)	112.2 (14.50)
130	41.9 (0.01)	47.0 (0.01)	60.0 (0.01)	68.6 (0.04)	112.7 (11.06)	113.4 (11.64)	116.8 (14.60)
135	44.1 (0.01)	49.6 (0.01)	63.2 (0.01)	72.1 (0.06)	117.2 (11.22)	118.0 (11.80)	121.4 (14.70)
140	46.4 (0.01)	52.2 (0.01)	66.5 (0.01)	75.7 (0.08)	121.8 (11.38)	122.5 (11.94)	126.0 (14.80)
145	48.8 (0.01)	54.9 (0.01)	69.8 (0.01)	79.4 (0.11)	126.3 (11.52)	127.1 (12.08)	130.6 (14.89)
150	51.2 (0.01)	57.6 (0.01)	73.2 (0.01)	83.0 (0.13)	130.8 (11.67)	131.6 (12.22)	135.2 (14.98)

Maximum total missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 20 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

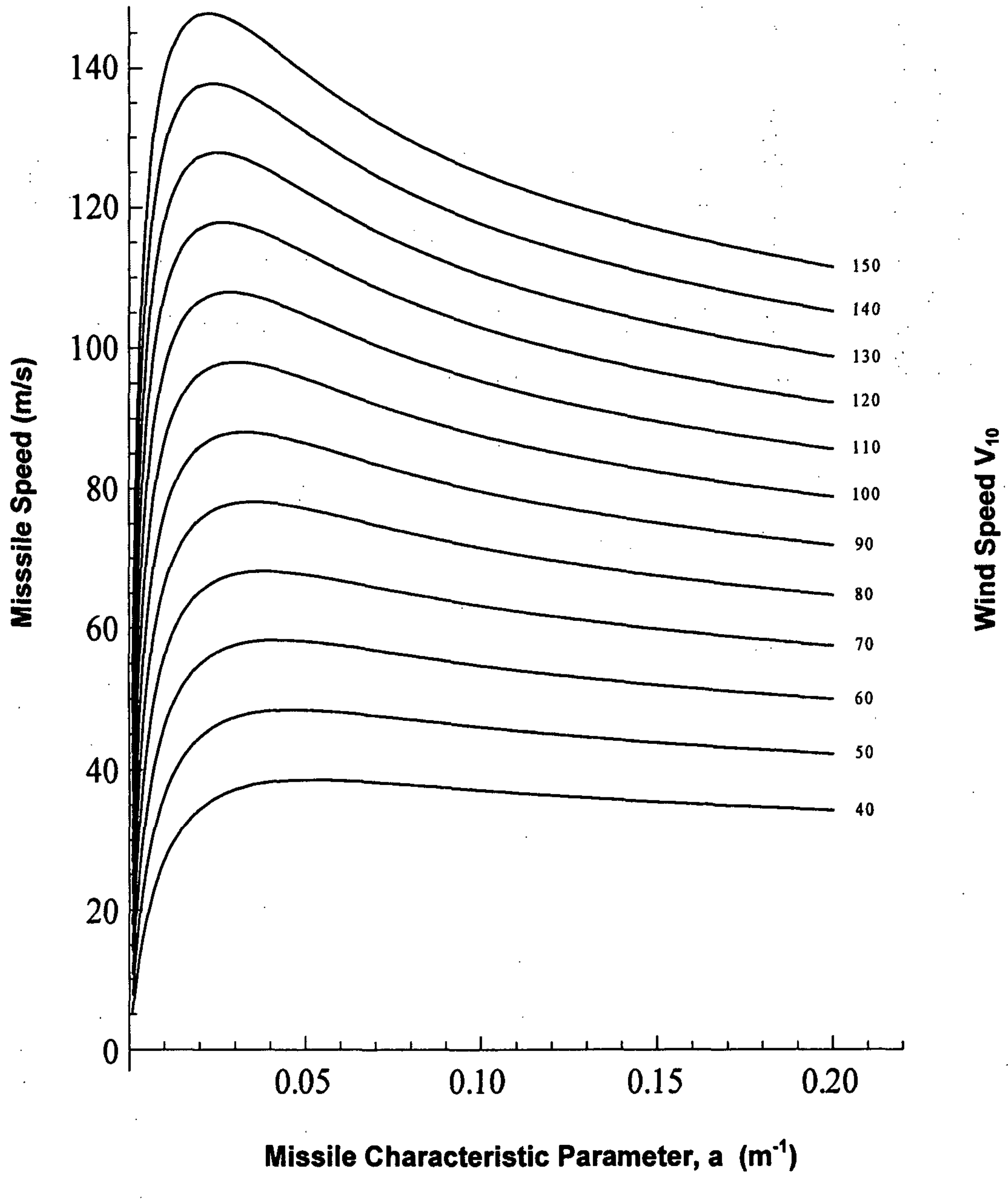

Figure C - 1 - Terminal horizontal missile speeds - 20 m, open terrain

Terminal horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 20 m above ground level and reach ground level; flow over open terrain.

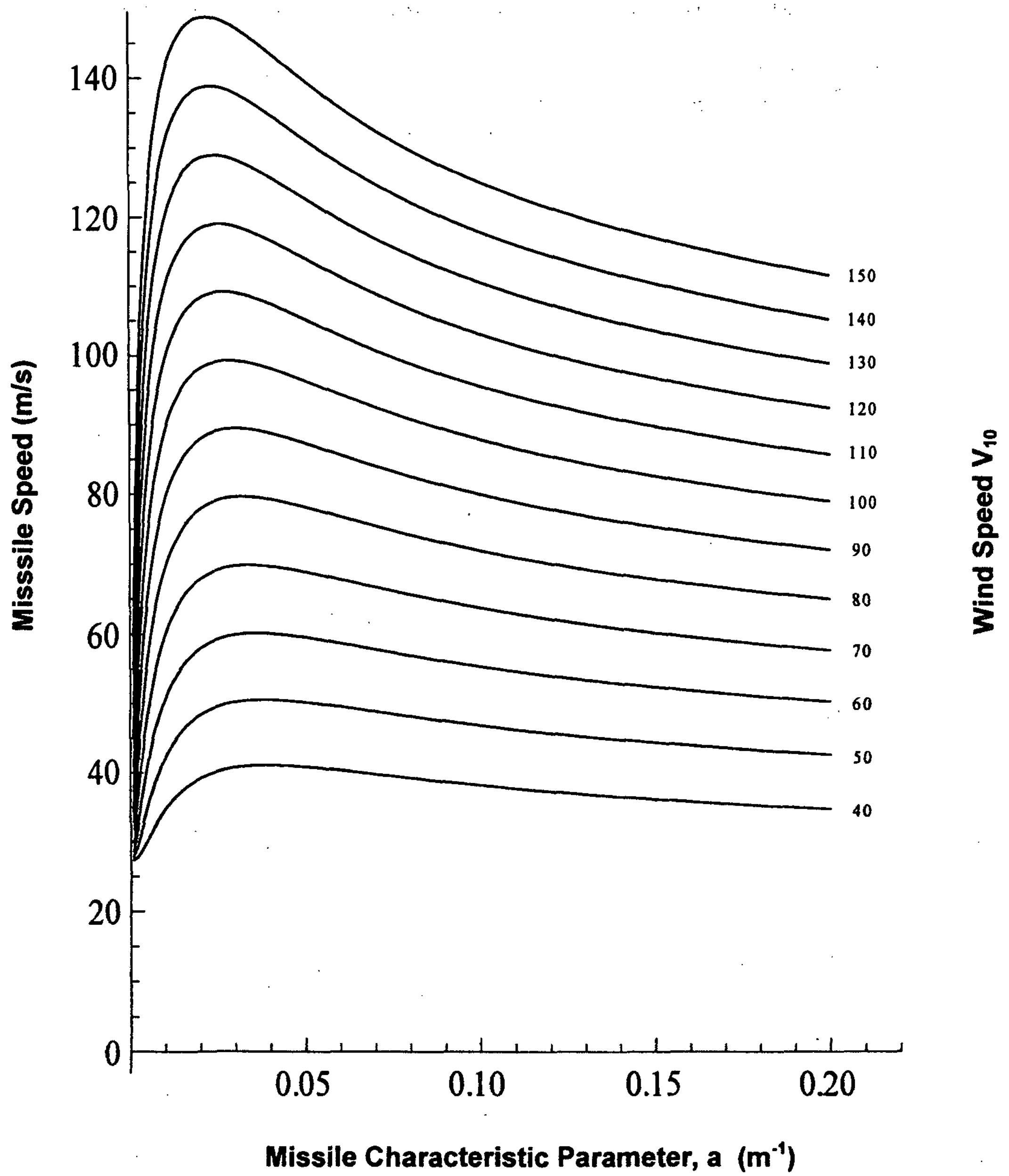

Figure C - 2 - Terminal total missile speeds - 20 m, open terrain

Terminal total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds v_{10}=v_h^{open}(10 m) = 40, 50,...,150 m/s. Missiles start at 20 m above ground level and reach ground level; flow over open terrain.

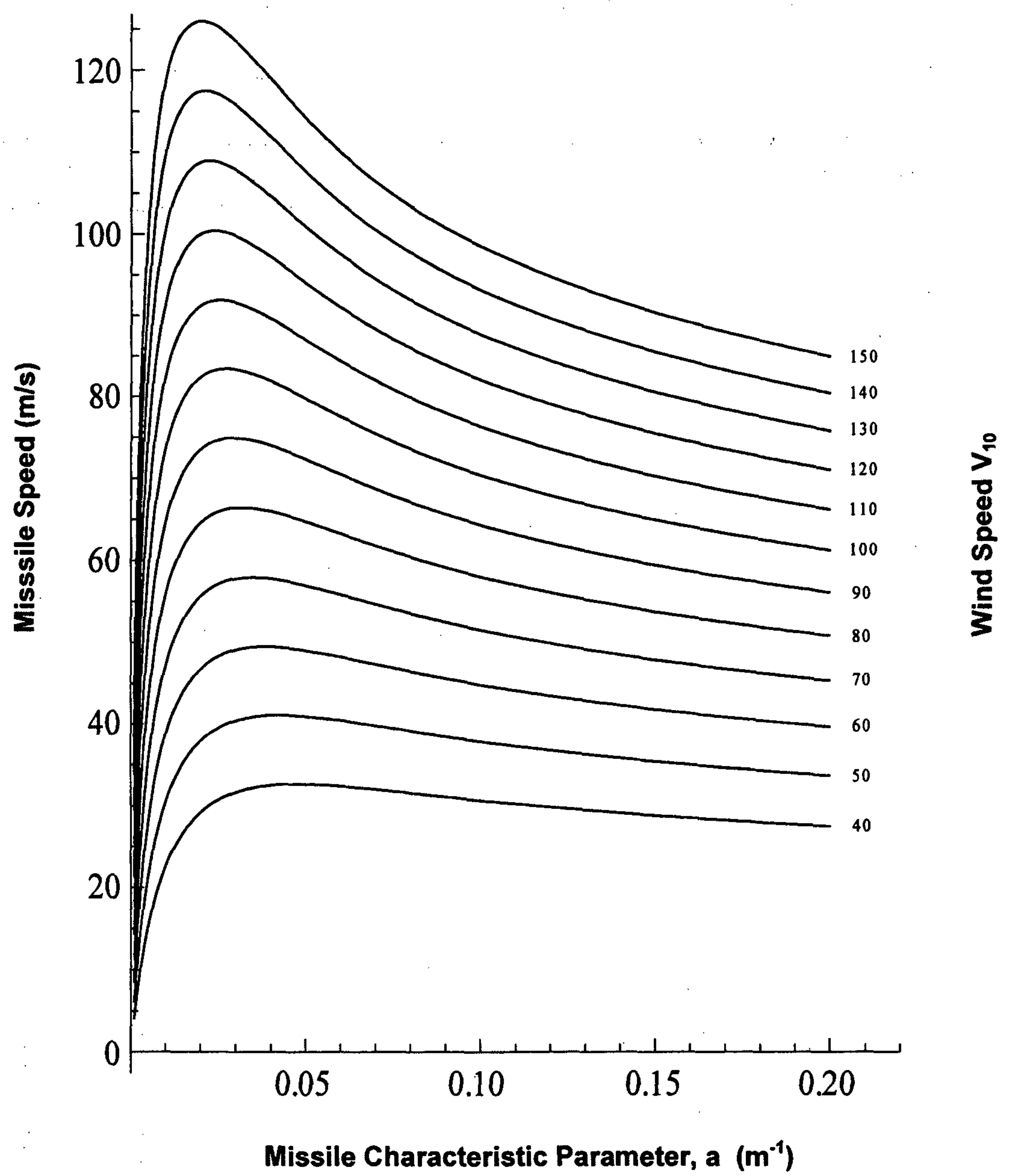

Figure C - 3- Terminal horizontal missile speeds - 20 m, suburban terrain

Terminal horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = *40, 50,...,150 m/s*. Missiles start at 20 *m* above ground level and reach ground level; flow over suburban terrain.

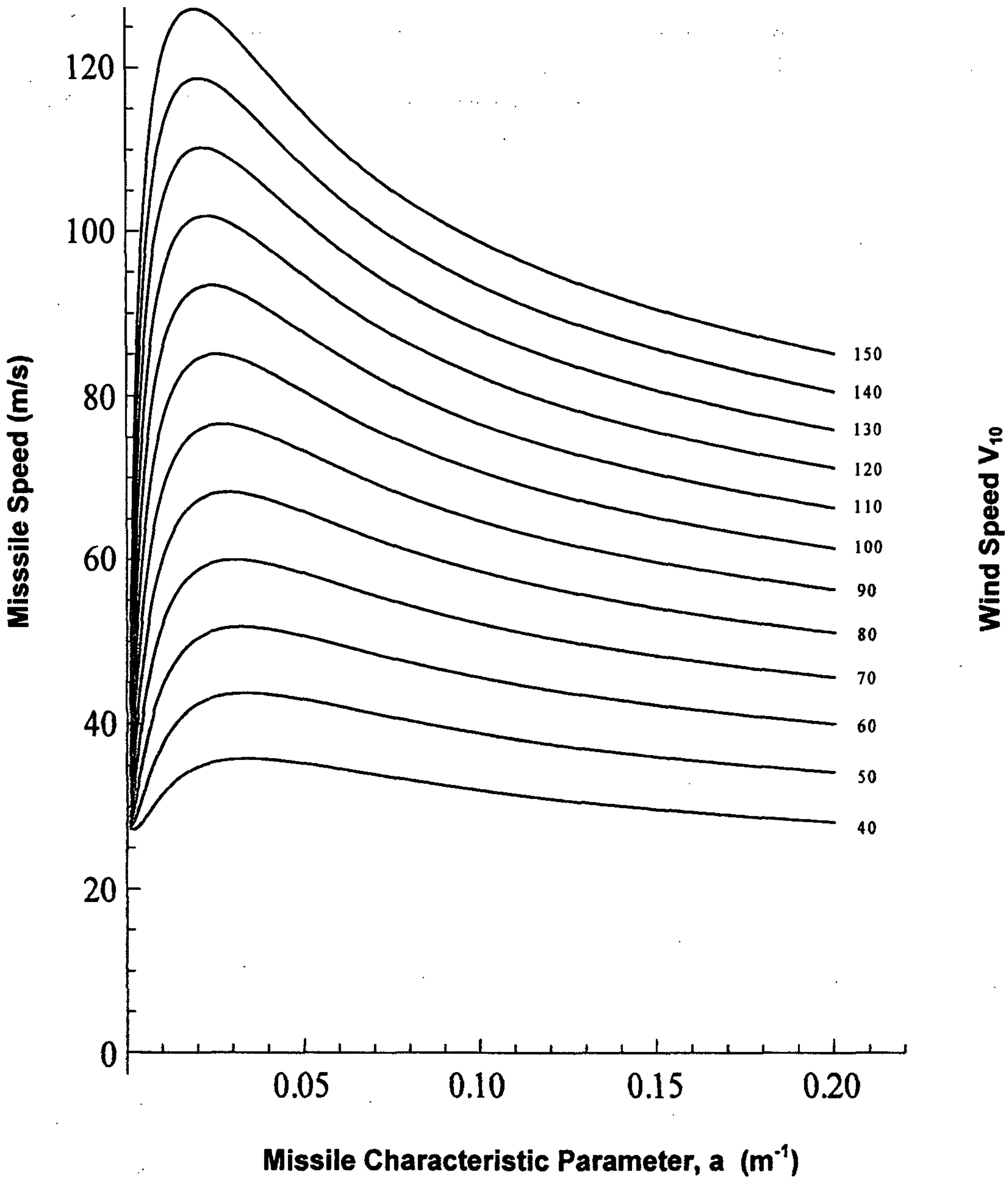

Figure C - 4- Terminal total missile speeds - 20 m, suburban terrain

Terminal total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 20 m above ground level and reach ground level; flow over suburban terrain.

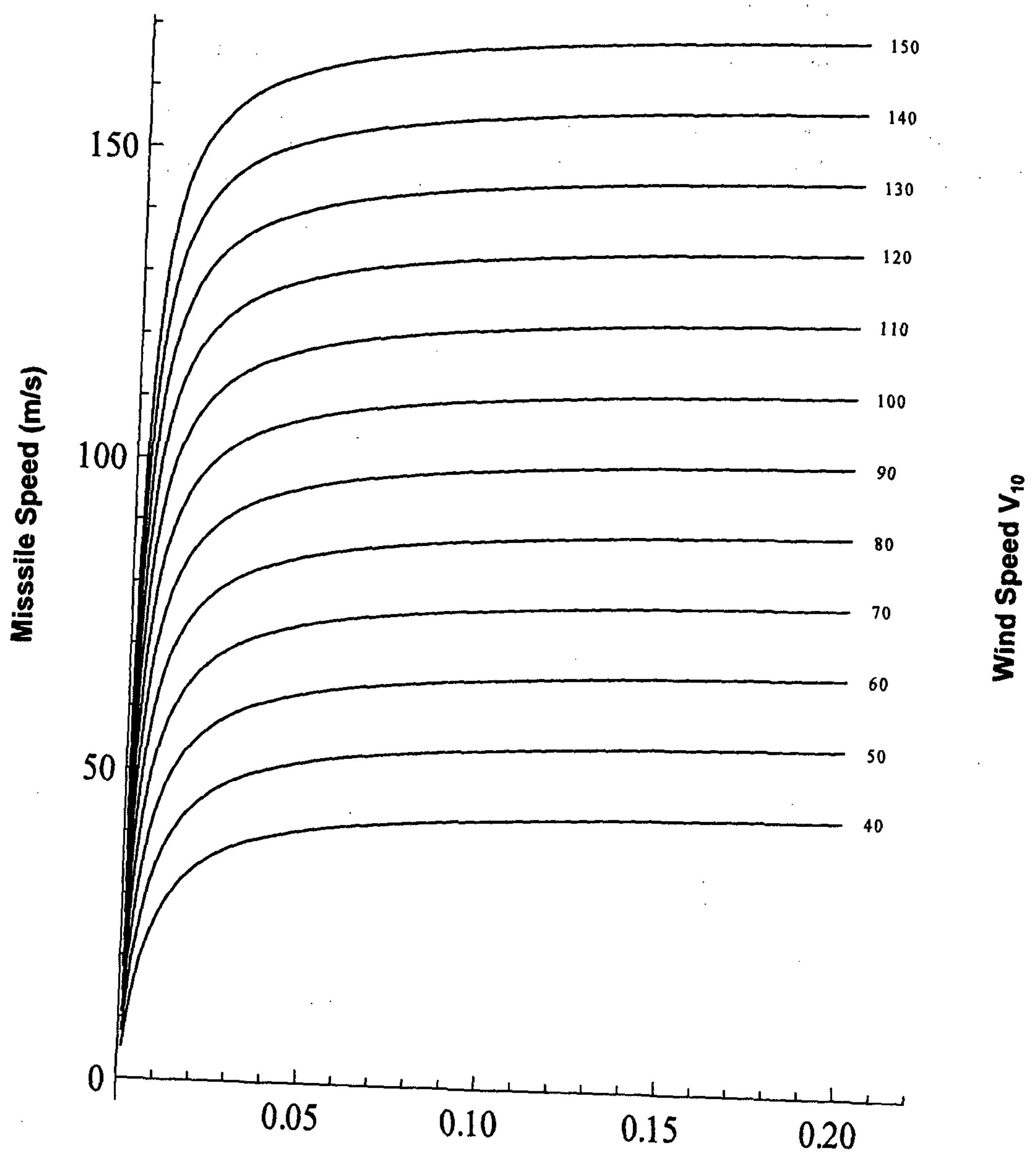

Figure C - 5 - Max horizontal missile speeds - 20 m, open terrain

Maximum horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}- 0.200 m^{-1} and wind speeds v_{10}=v_h^{open}(10 m) = 40, 50,...,150 m/s. Missiles start at 20 m above ground level and reach ground level; flow over open terrain.

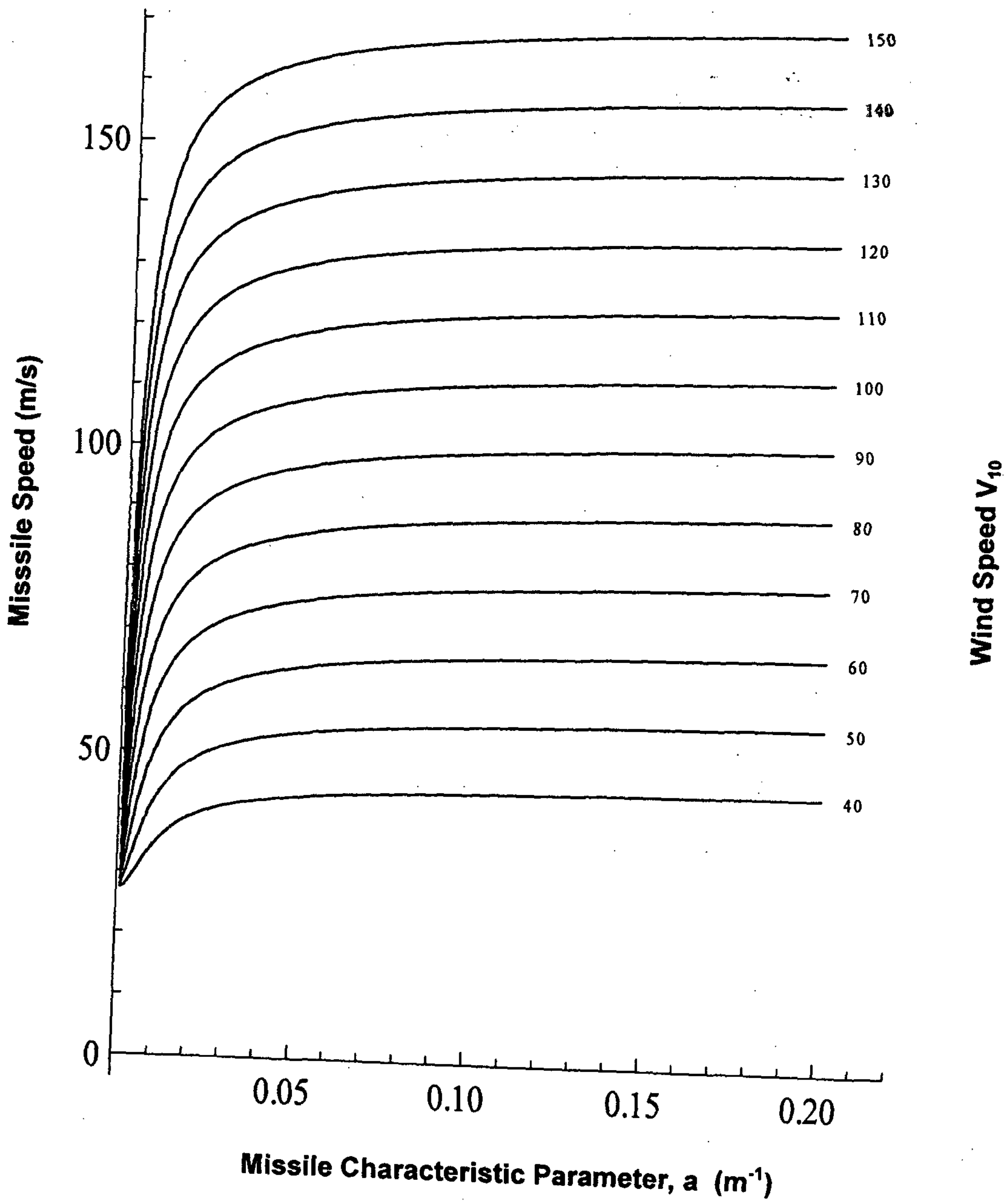

Figure C - 6 - Max total missile speeds - 20 m, open terrain

Maximum total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 20 m above ground level and reach ground level; flow over open terrain.

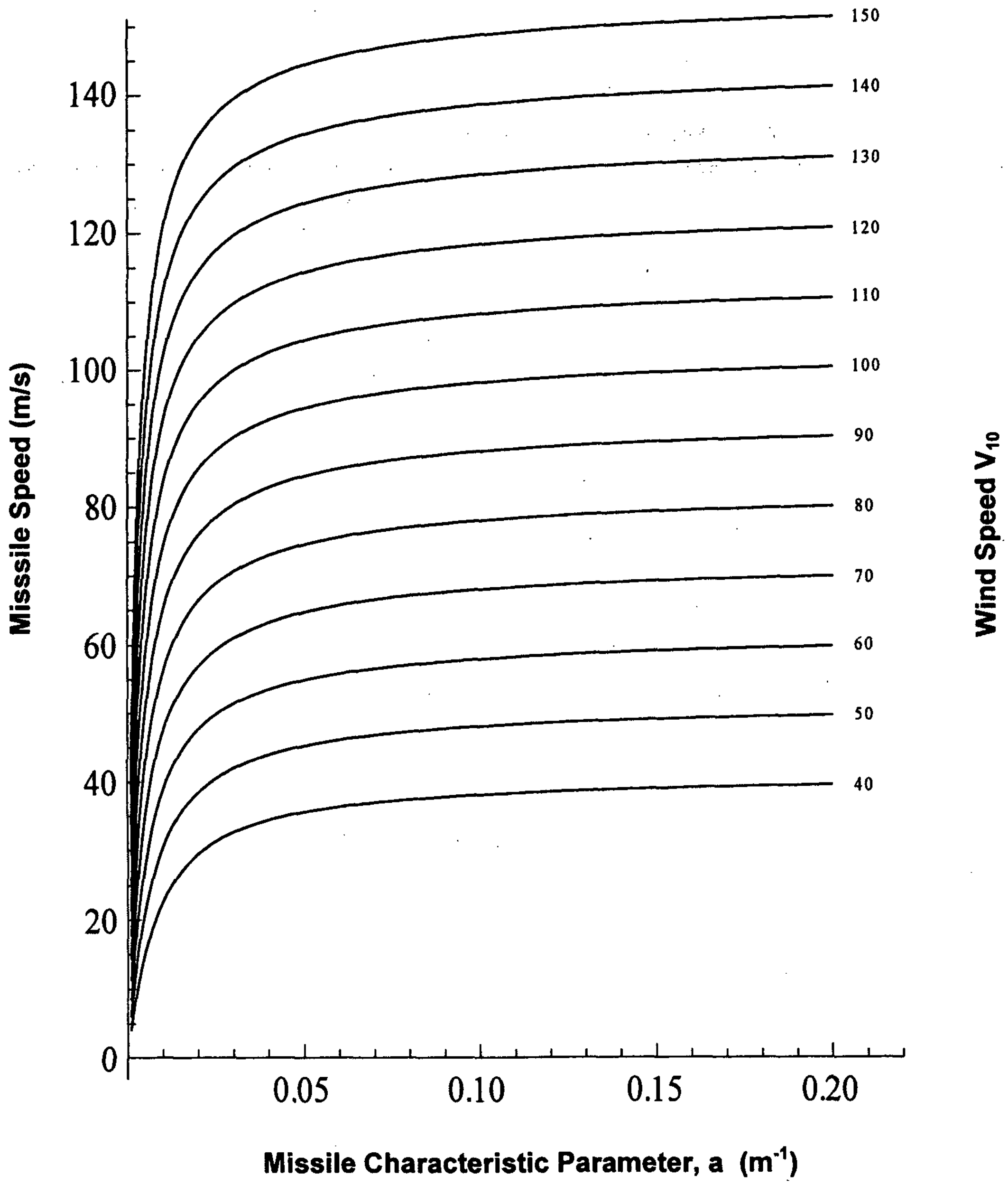

Figure C - 7 - Max horizontal missile speeds - 20 m, suburban terrain

Maximum horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}- 0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 20 m above ground level and reach ground level; flow over suburban terrain.

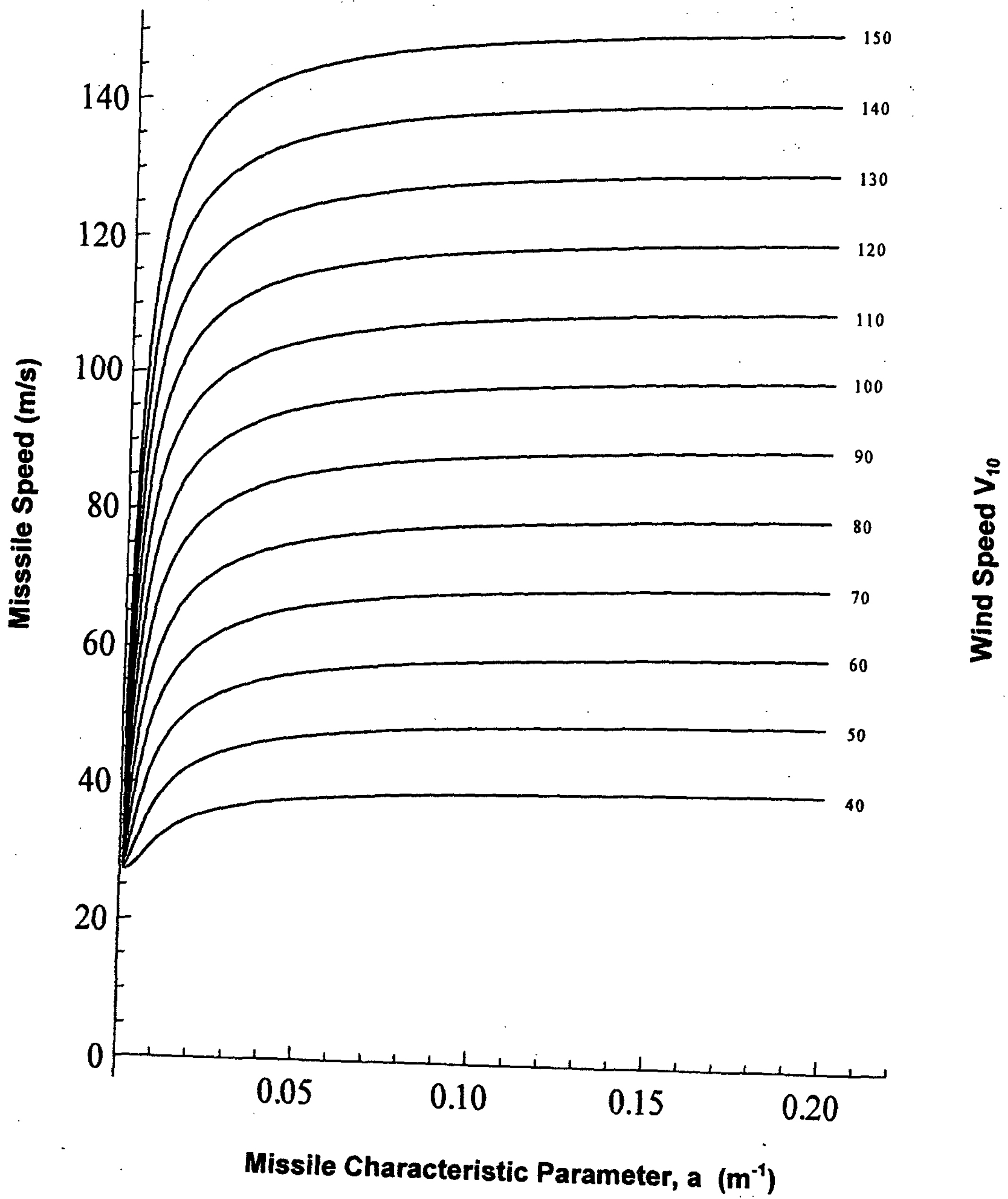

Figure C - 8 - Max total missile speeds - 20 m, suburban terrain

Maximum total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 20 m above ground level and reach ground level; flow over suburban terrain.

APPENDIX D. MISSILE SPEEDS CALCULATED FOR INITIAL ELEVATION H = 10 m

This Appendix contains tables and figures similar to those included in the body of the report, except that the initial elevation of the missiles was assumed to be H = 10 m, rather than H = 40 m.

Table D - 1 - Terminal horizontal missile speeds - 10 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	4.0	4.8	7.3	9.3	32.1	32.6	33.6
45	5.0	6.0	9.0	11.4	36.6	37.0	37.8
50	6.0	7.3	10.8	13.7	41.1	41.5	41.9
55	7.2	8.6	12.8	16.1	45.5	46.0	46.0
60	8.4	10.1	14.9	18.6	50.0	50.4	50.1
65	9.8	11.7	17.1	21.3	54.5	54.9	54.1
70	11.2	13.4	19.5	24.1	59.0	59.3	58.0
75	12.7	15.2	21.9	27.0	63.4	63.7	61.9
80	14.3	17.0	24.4	29.9	67.8	68.0	65.7
85	16.0	19.0	27.0	33.0	72.2	72.4	69.5
90	17.7	21.0	29.8	36.2	76.6	76.7	73.2
95	19.5	23.1	32.5	39.4	81.0	81.0	76.9
100	21.4	25.3	35.4	42.7	85.3	85.2	80.5
105	23.3	27.5	38.4	46.1	89.6	89.5	84.1
110	25.4	29.8	41.4	49.5	93.9	93.7	87.7
115	27.4	32.2	44.5	53.0	98.1	97.8	91.2
120	29.6	34.6	47.6	56.6	102.4	102.0	94.6
125	31.8	37.1	50.8	60.2	106.6	106.1	98.0
130	34.0	39.7	54.0	63.8	110.8	110.1	101.4
135	36.3	42.3	57.4	67.5	114.9	114.2	104.8
140	38.7	45.0	60.7	71.3	119.0	118.2	108.1
145	41.1	47.7	64.1	75.0	123.1	122.2	111.3
150	43.5	50.5	67.6	78.9	127.2	126.1	114.6

Terminal horizontal missile speeds (in m/s) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 10 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table D - 2 - Terminal total missile speeds - 10 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	14.1 (74)	14.3 (70)	15.0 (61)	15.9 (54)	33.4 (16)	33.8 (16)	34.3 (11)
45	14.4 (70)	14.7 (66)	15.9 (56)	17.2 (48)	37.7 (14)	38.1 (14)	38.4 (10)
50	14.7 (66)	15.2 (61)	16.9 (50)	18.7 (43)	42.1 (13)	42.5 (12)	42.5 (9)
55	15.2 (62)	15.8 (57)	18.2 (45)	20.5 (38)	46.5 (12)	46.8 (11)	46.5 (8)
60	15.8 (58)	16.7 (53)	19.7 (41)	22.5 (34)	50.9 (10)	51.2 (10)	50.5 (7)
65	16.5 (54)	17.6 (48)	21.4 (37)	24.7 (30)	55.3 (10)	55.6 (9)	54.4 (6)
70	17.4 (50)	18.8 (44)	23.3 (33)	27.1 (27)	59.7 (9)	59.9 (8)	58.3 (6)
75	18.4 (46)	20.0 (41)	25.3 (30)	29.7 (25)	64.0 (8)	64.2 (8)	62.1 (5)
80	19.5 (43)	21.4 (37)	27.5 (27)	32.4 (22)	68.4 (8)	68.6 (7)	66.0 (5)
85	20.7 (39)	23.0 (34)	29.8 (25)	35.2 (20)	72.8 (7)	72.9 (7)	69.7 (5)
90	22.0 (37)	24.7 (32)	32.3 (23)	38.2 (19)	77.1 (7)	77.1 (6)	73.4 (4)
95	23.5 (34)	26.4 (29)	34.9 (21)	41.2 (17)	81.4 (6)	81.4 (6)	77.1 (4)
100	25.1 (31)	28.3 (27)	37.5 (19)	44.4 (16)	85.7 (6)	85.6 (5)	80.7 (4)
105	26.7 (29)	30.3 (25)	40.3 (18)	47.6 (15)	90.0 (5)	89.8 (5)	84.3 (3)
110	28.5 (27)	32.4 (23)	43.2 (17)	51.0 (14)	94.3 (5)	94.0 (5)	87.8 (3)
115	30.3 (25)	34.6 (22)	46.1 (15)	54.4 (13)	98.5 (5)	98.1 (5)	91.3 (3)
120	32.3 (24)	36.9 (20)	49.1 (14)	57.8 (12)	102.7 (5)	102.3 (4)	94.7 (3)
125	34.3 (22)	39.2 (19)	52.2 (14)	61.3 (11)	106.9 (4)	106.3 (4)	98.1 (3)
130	36.3 (21)	41.6 (18)	55.4 (13)	64.9 (11)	111.0 (4)	110.4 (4)	101.5 (2)
135	38.5 (19)	44.1 (17)	58.6 (12)	68.6 (10)	115.2 (4)	114.4 (4)	104.8 (2)
140	40.7 (18)	46.7 (16)	61.9 (11)	72.2 (9)	119.3 (4)	118.4 (4)	108.1 (2)
145	43.0 (17)	49.3 (15)	65.3 (11)	76.0 (9)	123.4 (4)	122.4 (3)	111.4 (2)
150	45.4 (16)	52.0 (14)	68.6 (10)	79.7 (9)	127.4 (3)	126.3 (3)	114.6 (2)

Terminal total missile speeds (in m/s) and angles θ of incidence of the speeds with respect to the horizontal (in parentheses, in degrees) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 10 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table D - 3 - Terminal horizontal missile speeds - 10 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	2.8	3.4	5.3	6.8	25.8	26.3	27.0
45	3.5	4.3	6.5	8.3	29.5	29.9	30.3
50	4.3	5.2	7.8	10.0	33.2	33.6	33.6
55	5.1	6.2	9.3	11.8	36.8	37.2	36.8
60	6.0	7.3	10.8	13.7	40.5	40.8	40.0
65	7.0	8.4	12.5	15.7	44.1	44.4	43.1
70	8.0	9.6	14.2	17.7	47.7	48.0	46.1
75	9.1	10.9	16.0	19.9	51.3	51.5	49.1
80	10.3	12.3	17.9	22.2	54.9	55.0	52.0
85	11.5	13.7	19.8	24.5	58.5	58.5	54.9
90	12.7	15.2	21.9	26.9	62.0	61.9	57.7
95	14.0	16.7	24.0	29.4	65.5	65.4	60.5
100	15.4	18.3	26.1	31.9	69.0	68.8	63.2
105	16.8	20.0	28.3	34.5	72.4	72.1	65.8
110	18.3	21.7	30.6	37.2	75.8	75.4	68.5
115	19.8	23.4	33.0	39.9	79.2	78.7	71.0
120	21.4	25.2	35.4	42.6	82.6	82.0	73.6
125	23.0	27.1	37.8	45.4	85.9	85.2	76.1
130	24.7	29.0	40.3	48.3	89.2	88.3	78.5
135	26.4	31.0	42.8	51.1	92.4	91.5	80.9
140	28.1	32.9	45.4	54.1	95.6	94.6	83.3
145	29.9	35.0	48.0	57.0	98.8	97.7	85.7
150	31.7	37.1	50.7	60.0	102.0	100.7	88.0

Terminal horizontal missile speeds (in m/s) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 10 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1}= 0.3048 ft^{-1}

Table D - 4- Terminal total missile speeds - 10 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	0.0026	0.0042	0.0057	0.079	0.0885	0.176
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	13.9 (78)	14.0 (76)	14.3 (68)	14.7 (63)	27.5 (20)	27.8 (19)	27.8 (14)
45	14.0 (75)	14.1 (72)	14.7 (64)	15.4 (57)	30.9 (18)	31.3 (17)	31.0 (12)
50	14.2 (72)	14.4 (69)	15.3 (59)	16.3 (52)	34.4 (16)	34.7 (15)	34.2 (11)
55	14.4 (69)	14.8 (65)	16.0 (55)	17.4 (47)	38.0 (14)	38.2 (14)	37.3 (10)
60	14.7 (66)	15.2 (61)	16.9 (50)	18.7 (43)	41.5 (13)	41.7 (12)	40.4 (9)
65	15.1 (62)	15.7 (58)	18.0 (46)	20.2 (39)	45.0 (12)	45.2 (11)	43.5 (8)
70	15.6 (59)	16.4 (54)	19.2 (42)	21.8 (36)	48.6 (11)	48.7 (10)	46.5 (7)
75	16.2 (56)	17.1 (50)	20.5 (39)	23.6 (32)	52.1 (10)	52.2 (9)	49.4 (7)
80	16.8 (52)	18.0 (47)	22.0 (36)	25.5 (30)	55.6 (9)	55.7 (9)	52.3 (6)
85	17.5 (49)	19.0 (44)	23.6 (33)	27.5 (27)	59.1 (9)	59.1 (8)	55.1 (6)
90	18.4 (46)	20.0 (41)	25.3 (30)	29.7 (25)	62.6 (8)	62.5 (8)	57.9 (5)
95	19.3 (43)	21.2 (38)	27.1 (28)	31.9 (23)	66.1 (7)	65.9 (7)	60.7 (5)
100	20.3 (41)	22.5 (35)	29.0 (26)	34.2 (21)	69.5 (7)	69.2 (7)	63.4 (4)
105	21.4 (38)	23.8 (33)	31.0 (24)	36.6 (20)	72.9 (7)	72.5 (6)	66.0 (4)
110	22.5 (36)	25.2 (31)	33.1 (22)	39.1 (18)	76.3 (6)	75.8 (6)	68.6 (4)
115	23.8 (33)	26.8 (29)	35.3 (21)	41.7 (17)	79.6 (6)	79.1 (6)	71.2 (4)
120	25.1 (31)	28.3 (27)	37.5 (19)	44.3 (16)	83.0 (6)	82.3 (5)	73.7 (3)
125	26.4 (30)	30.0 (25)	39.8 (18)	47.0 (15)	86.2 (5)	85.5 (5)	76.2 (3)
130	27.9 (28)	31.7 (24)	42.2 (17)	49.8 (14)	89.5 (5)	88.6 (5)	78.6 (3)
135	29.4 (26)	33.5 (22)	44.6 (16)	52.6 (13)	92.7 (5)	91.8 (4)	81.0 (3)
140	30.9 (25)	35.3 (21)	47.1 (15)	55.4 (13)	95.9 (5)	94.8 (4)	83.4 (3)
145	32.6 (23)	37.2 (20)	49.6 (14)	58.3 (12)	99.1 (4)	97.9 (4)	85.8 (2)
150	34.2 (22)	39.2 (19)	52.2 (14)	61.2 (11)	102.3 (4)	100.9 (4)	88.1 (2)

Terminal total missile speeds (in m/s) and angles θ of incidence of the speeds with respect to the horizontal (in parentheses, in degrees) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 10 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048/ft^{-1}

Table D - 5 - Max horizontal missile speeds - 10 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	4.0 (0.01)	4.8 (0.01)	7.3 (0.01)	9.3 (0.01)	32.5 (1.38)	33.1 (1.66)	36.0 (3.72)
45	5.0 (0.01)	6.0 (0.01)	9.0 (0.01)	11.4 (0.01)	37.1 (1.60)	37.8 (1.89)	40.8 (3.96)
50	6.0 (0.01)	7.3 (0.01)	10.8 (0.01)	13.7 (0.01)	41.8 (1.81)	42.5 (2.11)	45.6 (4.19)
55	7.2 (0.01)	8.6 (0.01)	12.8 (0.01)	16.1 (0.01)	46.4 (2.01)	47.2 (2.32)	50.4 (4.39)
60	8.4 (0.01)	10.1 (0.01)	14.9 (0.01)	18.6 (0.01)	51.2 (2.19)	51.9 (2.52)	55.3 (4.57)
65	9.8 (0.01)	11.7 (0.01)	17.1 (0.01)	21.3 (0.01)	55.9 (2.38)	56.6 (2.70)	60.1 (4.74)
70	11.2 (0.01)	13.4 (0.01)	19.5 (0.01)	24.1 (0.01)	60.6 (2.55)	61.4 (2.88)	64.9 (4.89)
75	12.7 (0.01)	15.2 (0.01)	21.9 (0.01)	27.0 (0.01)	65.4 (2.71)	66.2 (3.04)	69.8 (5.04)
80	14.3 (0.01)	17.0 (0.01)	24.4 (0.01)	29.9 (0.01)	70.1 (2.87)	70.9 (3.19)	74.6 (5.17)
85	16.0 (0.01)	19.0 (0.01)	27.0 (0.01)	33.0 (0.01)	74.9 (3.01)	75.7 (3.34)	79.5 (5.30)
90	17.7 (0.01)	21.0 (0.01)	29.8 (0.01)	36.2 (0.01)	79.7 (3.15)	80.5 (3.48)	84.4 (5.41)
95	19.5 (0.01)	23.1 (0.01)	32.5 (0.01)	39.4 (0.01)	84.5 (3.29)	85.3 (3.61)	89.2 (5.52)
100	21.4 (0.01)	25.3 (0.01)	35.4 (0.01)	42.7 (0.01)	89.3 (3.41)	90.2 (3.74)	94.1 (5.62)
105	23.3 (0.01)	27.5 (0.01)	38.4 (0.01)	46.1 (0.01)	94.1 (3.53)	95.0 (3.85)	99.0 (5.72)
110	25.4 (0.01)	29.8 (0.01)	41.4 (0.01)	49.5 (0.01)	98.9 (3.65)	99.8 (3.97)	103.9 (5.81)
115	27.4 (0.01)	32.2 (0.01)	44.5 (0.01)	53.0 (0.01)	103.7 (3.76)	104.6 (4.08)	108.8 (5.90)
120	29.6 (0.01)	34.6 (0.01)	47.6 (0.01)	56.6 (0.01)	108.6 (3.87)	109.5 (4.18)	113.7 (5.97)
125	31.8 (0.01)	37.1 (0.01)	50.8 (0.01)	60.2 (0.01)	113.4 (3.96)	114.3 (4.28)	118.6 (6.05)
130	34.0 (0.01)	39.7 (0.01)	54.0 (0.01)	63.8 (0.01)	118.2 (4.06)	119.2 (4.38)	123.5 (6.13)
135	36.3 (0.01)	42.3 (0.01)	57.4 (0.01)	67.5 (0.01)	123.1 (4.15)	124.0 (4.47)	128.4 (6.20)
140	38.7 (0.01)	45.0 (0.01)	60.7 (0.01)	71.3 (0.01)	127.9 (4.24)	128.9 (4.55)	133.3 (6.26)
145	41.1 (0.01)	47.7 (0.01)	64.1 (0.01)	75.0 (0.03)	132.8 (4.33)	133.7 (4.64)	138.2 (6.33)
150	43.5 (0.01)	50.5 (0.01)	67.6 (0.01)	78.9 (0.03)	137.6 (4.42)	138.6 (4.72)	143.1 (6.39)

Maximum horizontal missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 10 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1}= 0.3048/ft^{-1}

Table D - 6 - Max total missile speeds - 10 m, open terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	0.0026	0.0042	0.0057	0.079	0.0885	0.176
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	14.1 (0.01)	14.3 (0.01)	15.0 (0.01)	15.9 (0.01)	33.7 (0.96)	34.3 (1.25)	36.7 (3.49)
45	14.4 (0.01)	14.7 (0.01)	15.9 (0.01)	17.2 (0.01)	38.2 (1.19)	38.8 (1.51)	41.4 (3.75)
50	14.7 (0.01)	15.2 (0.01)	16.9 (0.01)	18.7 (0.01)	42.7 (1.43)	43.3 (1.75)	46.1 (4.00)
55	15.2 (0.01)	15.8 (0.01)	18.2 (0.01)	20.5 (0.01)	47.3 (1.65)	47.9 (1.98)	50.9 (4.21)
60	15.8 (0.01)	16.7 (0.01)	19.7 (0.01)	22.5 (0.01)	51.9 (1.86)	52.6 (2.20)	55.7 (4.41)
65	16.5 (0.01)	17.6 (0.01)	21.4 (0.01)	24.7 (0.01)	56.6 (2.06)	57.3 (2.41)	60.4 (4.59)
70	17.4 (0.01)	18.8 (0.01)	23.3 (0.01)	27.1 (0.01)	61.2 (2.25)	62.0 (2.60)	65.3 (4.76)
75	18.3 (0.01)	20.0 (0.01)	25.3 (0.01)	29.7 (0.01)	65.9 (2.43)	66.7 (2.78)	70.1 (4.91)
80	19.5 (0.01)	21.4 (0.01)	27.5 (0.01)	32.4 (0.01)	70.7 (2.60)	71.4 (2.95)	74.9 (5.05)
85	20.7 (0.01)	23.0 (0.01)	29.8 (0.01)	35.2 (0.01)	75.4 (2.76)	76.2 (3.11)	79.8 (5.18)
90	22.0 (0.01)	24.7 (0.01)	32.3 (0.01)	38.2 (0.01)	80.1 (2.91)	80.9 (3.26)	84.6 (5.30)
95	23.5 (0.01)	26.4 (0.01)	34.9 (0.01)	41.2 (0.01)	84.9 (3.06)	85.7 (3.40)	89.5 (5.42)
100	25.1 (0.01)	28.3 (0.01)	37.5 (0.01)	44.4 (0.01)	89.7 (3.20)	90.5 (3.54)	94.3 (5.52)
105	26.7 (0.01)	30.3 (0.01)	40.3 (0.01)	47.6 (0.01)	94.5 (3.33)	95.3 (3.67)	99.2 (5.63)
110	28.5 (0.01)	32.4 (0.01)	43.2 (0.01)	51.0 (0.01)	99.3 (3.45)	100.1 (3.79)	104.1 (5.72)
115	30.3 (0.01)	34.6 (0.01)	46.1 (0.01)	54.4 (0.01)	104.1 (3.57)	104.9 (3.91)	109.0 (5.81)
120	32.2 (0.01)	36.9 (0.01)	49.1 (0.01)	57.8 (0.01)	108.9 (3.68)	109.8 (4.02)	113.8 (5.90)
125	34.3 (0.01)	39.2 (0.01)	52.2 (0.01)	61.3 (0.01)	113.7 (3.79)	114.6 (4.13)	118.7 (5.98)
130	36.3 (0.01)	41.6 (0.01)	55.4 (0.01)	64.9 (0.01)	118.5 (3.90)	119.4 (4.23)	123.6 (6.06)
135	38.5 (0.01)	44.1 (0.01)	58.6 (0.01)	68.5 (0.01)	123.3 (4.00)	124.3 (4.33)	128.5 (6.13)
140	40.7 (0.01)	46.7 (0.01)	61.9 (0.01)	72.2 (0.01)	128.2 (4.09)	129.1 (4.42)	133.4 (6.20)
145	43.0 (0.01)	49.3 (0.01)	65.2 (0.01)	76.0 (0.01)	133.0 (4.19)	134.0 (4.51)	138.3 (6.26)
150	45.3 (0.01)	52.0 (0.01)	68.6 (0.01)	79.7 (0.01)	137.8 (4.27)	138.8 (4.59)	143.2 (6.33)

Maximum total missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s) . Missiles start at 10 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1}= 0.3048/ft^{-1}

Table D - 7- Max horizontal missile speeds - 10 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	2.8 (0.01)	3.4 (0.01)	5.3 (0.01)	6.8 (0.01)	26.3 (1.69)	26.9 (1.98)	29.8 (4.03)
45	3.5 (0.01)	4.3 (0.01)	6.5 (0.01)	8.3 (0.01)	30.2 (1.91)	30.8 (2.22)	33.8 (4.28)
50	4.3 (0.01)	5.2 (0.01)	7.8 (0.01)	10.0 (0.01)	34.0 (2.13)	34.7 (2.45)	37.9 (4.50)
55	5.1 (0.01)	6.2 (0.01)	9.3 (0.01)	11.8 (0.01)	37.9 (2.34)	38.6 (2.66)	41.9 (4.69)
60	6.0 (0.01)	7.3 (0.01)	10.8 (0.01)	13.7 (0.01)	41.9 (2.54)	42.6 (2.86)	46.0 (4.87)
65	7.0 (0.01)	8.4 (0.01)	12.5 (0.01)	15.7 (0.01)	45.8 (2.72)	46.6 (3.05)	50.0 (5.04)
70	8.0 (0.01)	9.6 (0.01)	14.2 (0.01)	17.7 (0.01)	49.8 (2.89)	50.6 (3.22)	54.1 (5.19)
75	9.1 (0.01)	10.9 (0.01)	16.0 (0.01)	19.9 (0.01)	53.8 (3.06)	54.5 (3.38)	58.2 (5.33)
80	10.3 (0.01)	12.3 (0.01)	17.9 (0.01)	22.2 (0.01)	57.8 (3.21)	58.6 (3.54)	62.3 (5.46)
85	11.5 (0.01)	13.7 (0.01)	19.8 (0.01)	24.5 (0.01)	61.8 (3.36)	62.6 (3.69)	66.4 (5.58)
90	12.7 (0.01)	15.2 (0.01)	21.9 (0.01)	26.9 (0.01)	65.8 (3.50)	66.6 (3.83)	70.5 (5.69)
95	14.0 (0.01)	16.7 (0.01)	24.0 (0.01)	29.4 (0.01)	69.8 (3.63)	70.6 (3.95)	74.6 (5.80)
100	15.4 (0.01)	18.3 (0.01)	26.1 (0.01)	31.9 (0.01)	73.8 (3.76)	74.7 (4.08)	78.7 (5.90)
105	16.8 (0.01)	20.0 (0.01)	28.3 (0.01)	34.5 (0.01)	77.9 (3.88)	78.7 (4.20)	82.8 (5.99)
110	18.3 (0.01)	21.7 (0.01)	30.6 (0.01)	37.2 (0.01)	81.9 (3.99)	82.8 (4.31)	87.0 (6.07)
115	19.8 (0.01)	23.4 (0.01)	33.0 (0.01)	39.9 (0.03)	86.0 (4.10)	86.9 (4.41)	91.1 (6.16)
120	21.4 (0.01)	25.2 (0.01)	35.4 (0.01)	42.6 (0.03)	90.0 (4.21)	91.0 (4.52)	95.2 (6.23)
125	23.0 (0.01)	27.1 (0.01)	37.8 (0.01)	45.4 (0.03)	94.1 (4.31)	95.0 (4.61)	99.4 (6.31)
130	24.7 (0.01)	29.0 (0.01)	40.3 (0.01)	48.3 (0.03)	98.2 (4.40)	99.1 (4.71)	103.5 (6.38)
135	26.4 (0.01)	31.0 (0.01)	42.8 (0.01)	51.1 (0.03)	102.2 (4.49)	103.2 (4.79)	107.7 (6.45)
140	28.1 (0.01)	32.9 (0.01)	45.4 (0.01)	54.1 (0.03)	106.3 (4.58)	107.3 (4.88)	111.8 (6.51)
145	29.9 (0.01)	35.0 (0.01)	48.0 (0.01)	57.0 (0.05)	110.4 (4.66)	111.4 (4.96)	115.9 (6.57)
150	31.7 (0.01)	37.1 (0.01)	50.7 (0.01)	60.0 (0.05)	114.5 (4.74)	115.5 (5.04)	120.1 (6.63)

Maximum horizontal missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s). Missiles start at 10 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Table D - 8 - Max total missile speeds - 10 m, suburban terrain

v_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	**0.0026**	**0.0042**	**0.0057**	**0.079**	**0.0885**	**0.176**
	Steel sph.	*Sch.40 pipe*	*5 m autom.*	*4.5 m autom.*	*Plank*	*Slab*	*Plank*
40	13.9 (0.01)	13.9 (0.01)	14.3 (0.01)	14.7 (0.01)	27.9 (1.12)	28.3 (1.44)	30.6 (3.75)
45	14.0 (0.01)	14.1 (0.01)	14.7 (0.01)	15.4 (0.01)	31.5 (1.39)	32.0 (1.72)	34.5 (4.01)
50	14.2 (0.01)	14.4 (0.01)	15.3 (0.01)	16.3 (0.01)	35.2 (1.64)	35.8 (1.99)	38.5 (4.26)
55	14.4 (0.01)	14.7 (0.01)	16.0 (0.01)	17.4 (0.01)	39.0 (1.88)	39.6 (2.23)	42.4 (4.47)
60	14.7 (0.01)	15.2 (0.01)	16.9 (0.01)	18.7 (0.01)	42.8 (2.10)	43.4 (2.46)	46.4 (4.67)
65	15.1 (0.01)	15.7 (0.01)	18.0 (0.01)	20.2 (0.01)	46.6 (2.31)	47.3 (2.67)	50.5 (4.85)
70	15.6 (0.01)	16.4 (0.01)	19.2 (0.01)	21.8 (0.01)	50.5 (2.51)	51.2 (2.87)	54.5 (5.01)
75	16.2 (0.01)	17.1 (0.01)	20.5 (0.01)	23.6 (0.01)	54.4 (2.70)	55.2 (3.06)	58.6 (5.17)
80	16.8 (0.01)	18.0 (0.01)	22.0 (0.01)	25.5 (0.01)	58.4 (2.88)	59.1 (3.24)	62.6 (5.31)
85	17.5 (0.01)	19.0 (0.01)	23.6 (0.01)	27.5 (0.01)	62.3 (3.05)	63.1 (3.40)	66.7 (5.44)
90	18.4 (0.01)	20.0 (0.01)	25.3 (0.01)	29.7 (0.01)	66.3 (3.20)	67.1 (3.55)	70.8 (5.56)
95	19.3 (0.01)	21.2 (0.01)	27.1 (0.01)	31.9 (0.01)	70.3 (3.35)	71.1 (3.70)	74.9 (5.67)
100	20.3 (0.01)	22.5 (0.01)	29.0 (0.01)	34.2 (0.01)	74.3 (3.50)	75.1 (3.84)	79.0 (5.78)
105	21.4 (0.01)	23.8 (0.01)	31.0 (0.01)	36.6 (0.01)	78.3 (3.63)	79.1 (3.97)	83.1 (5.87)
110	22.5 (0.01)	25.2 (0.01)	33.1 (0.01)	39.1 (0.01)	82.3 (3.76)	83.2 (4.10)	87.2 (5.97)
115	23.8 (0.01)	26.8 (0.01)	35.3 (0.01)	41.7 (0.01)	86.3 (3.88)	87.2 (4.21)	91.3 (6.06)
120	25.1 (0.01)	28.3 (0.01)	37.5 (0.01)	44.3 (0.01)	90.4 (3.99)	91.3 (4.32)	95.4 (6.14)
125	26.4 (0.01)	30.0 (0.01)	39.8 (0.01)	47.0 (0.01)	94.4 (4.10)	95.3 (4.43)	99.6 (6.22)
130	27.9 (0.01)	31.7 (0.01)	42.2 (0.01)	49.8 (0.01)	98.5 (4.21)	99.4 (4.53)	103.7 (6.29)
135	29.4 (0.01)	33.5 (0.01)	44.6 (0.01)	52.6 (0.01)	102.5 (4.30)	103.5 (4.63)	107.8 (6.37)
140	30.9 (0.01)	35.3 (0.01)	47.1 (0.01)	55.4 (0.01)	106.6 (4.40)	107.5 (4.72)	112.0 (6.43)
145	32.6 (0.01)	37.2 (0.01)	49.6 (0.01)	58.3 (0.01)	110.7 (4.49)	111.6 (4.81)	116.1 (6.50)
150	34.2 (0.01)	39.2 (0.01)	52.2 (0.01)	61.2 (0.01)	114.7 (4.58)	115.7 (4.89)	120.2 (6.56)

Maximum total missile speeds in m/s, and height at which they are attained (in parentheses, in m) as functions of parameter *a* (in m^{-1}) and wind speed $v_{10}=v_h^{open}(10\ m)$ (in m/s) . Missiles start at 10 m above ground level and reach ground level; flow over suburban terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1}= 0.3048 ft^{-1}

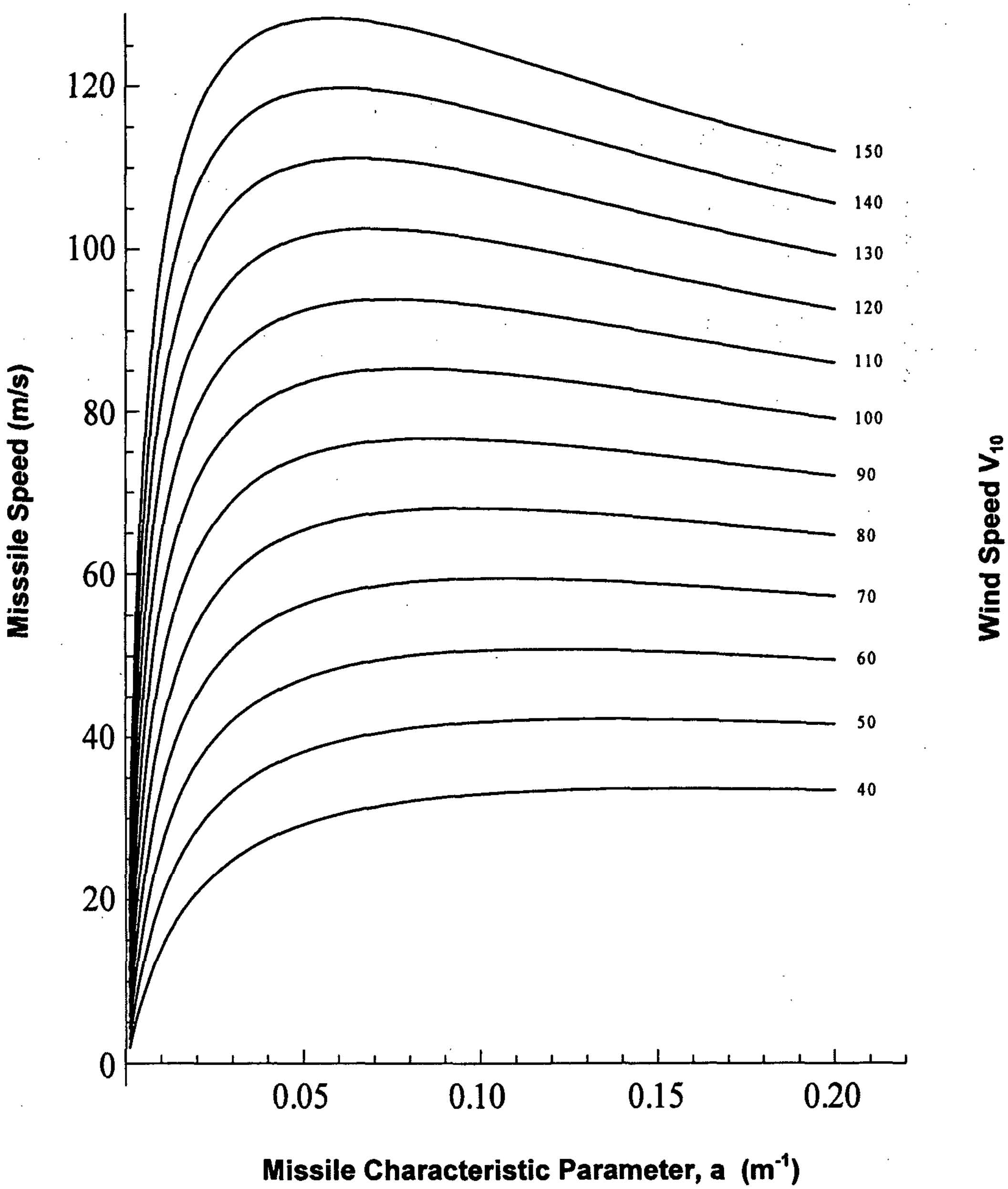

Figure D - 1- Terminal horizontal missile speeds - 10 m, open terrain

Terminal horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 10 m above ground level and reach ground level; flow over open terrain.

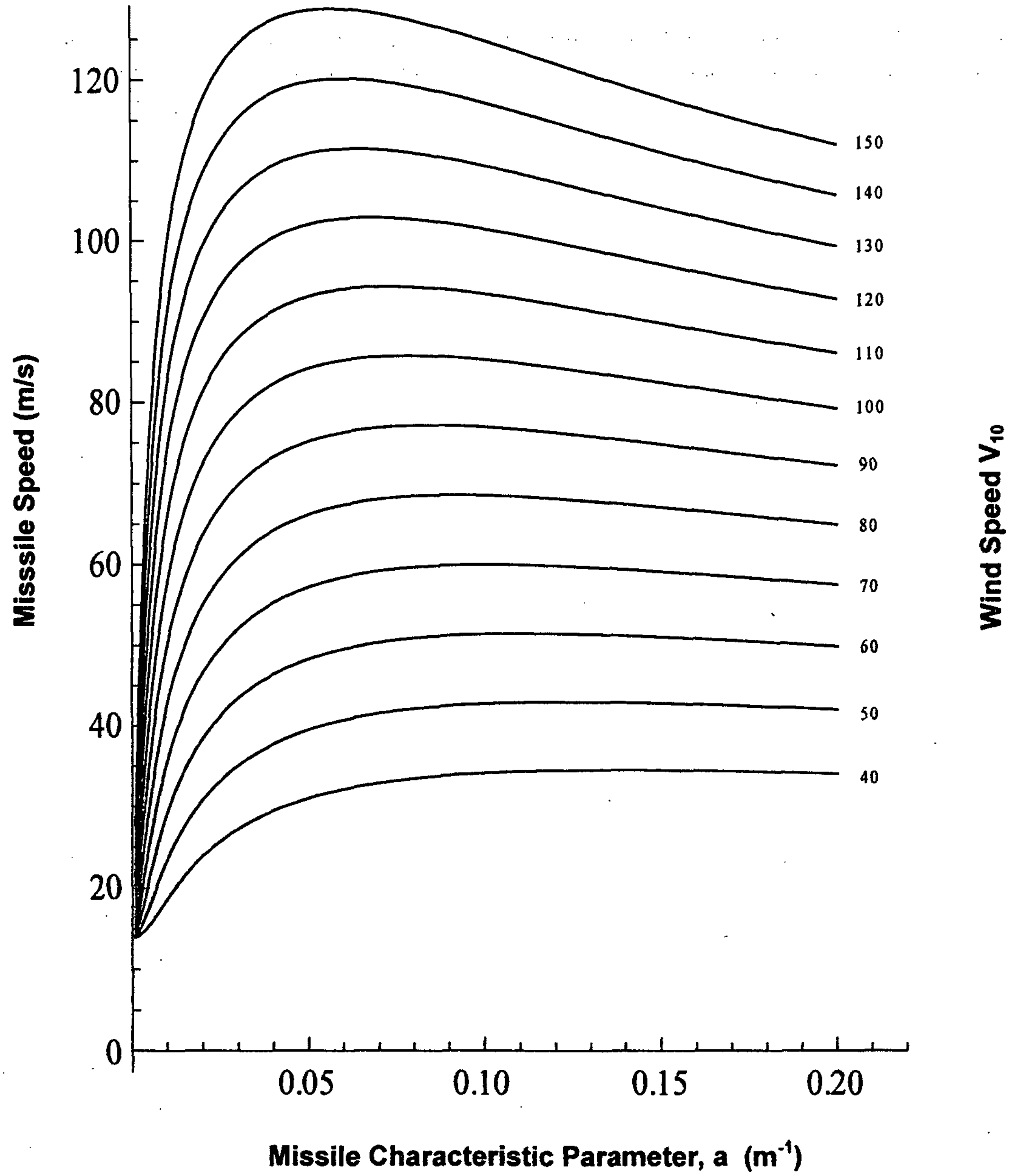

Figure D - 2- Terminal total missile speeds - 10 m, open terrain

Terminal total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 10 m above ground level and reach ground level; flow over open terrain.

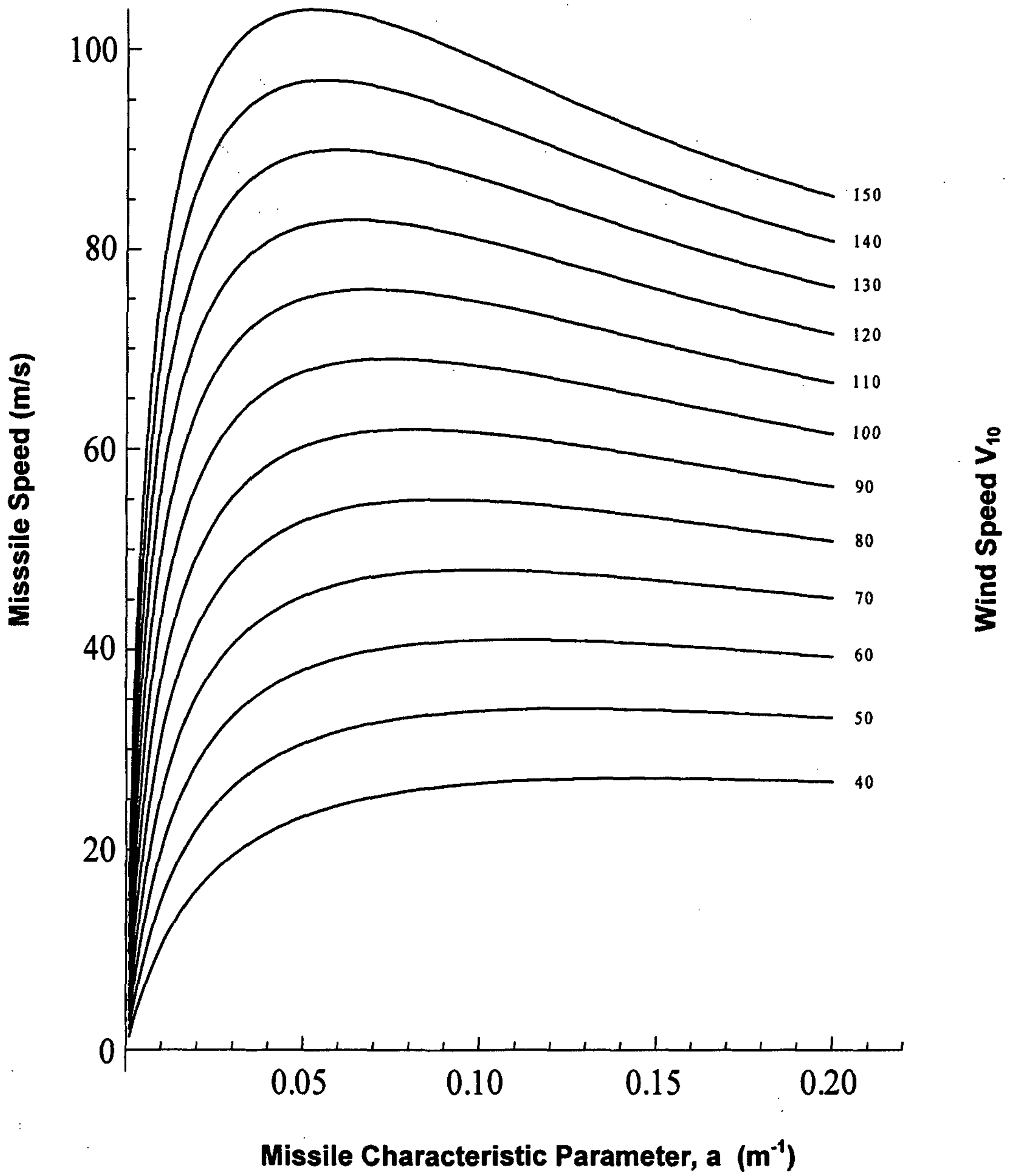

Figure D - 3- Terminal horizontal missile speeds - 10 m, suburban terrain

Terminal horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 10 m above ground level and reach ground level; flow over suburban terrain.

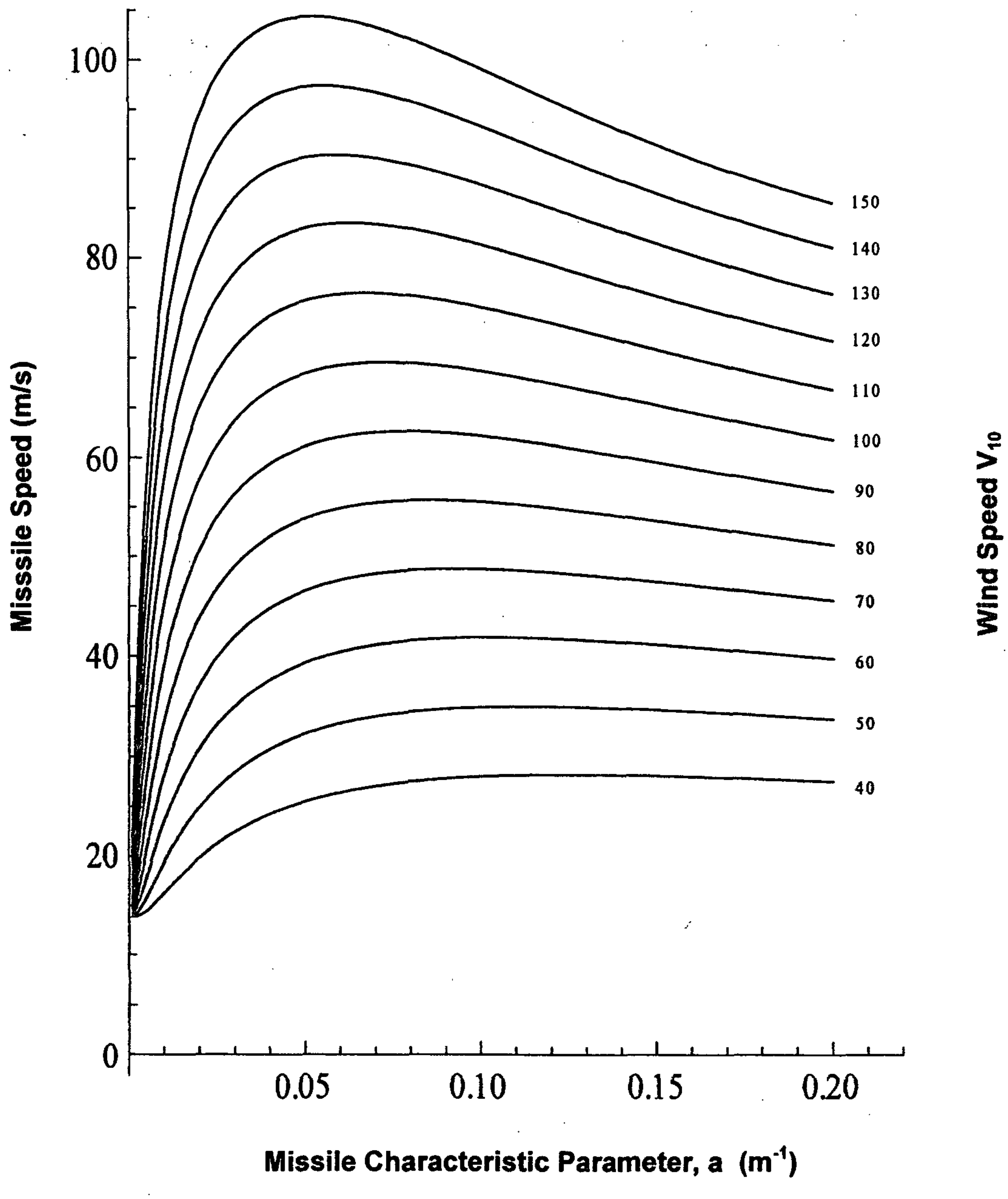

Figure D - 4- Terminal total missile speeds - 10 m, suburban terrain

Terminal total missile speeds (in m/s) for parameters a between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 10 m above ground level and reach ground level; flow over suburban terrain.

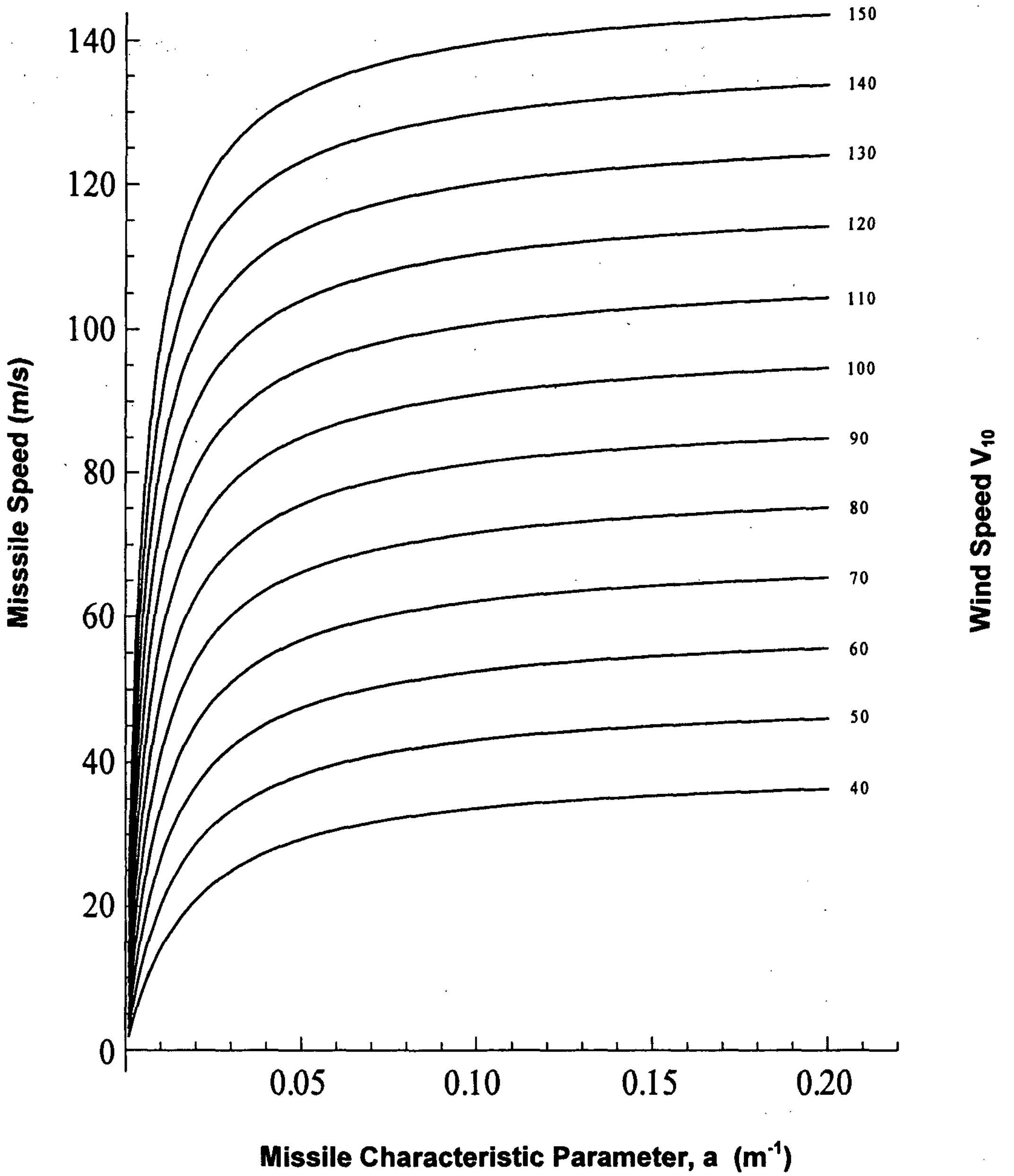

Figure D - 5- Max horizontal missile speeds - 10 m, open terrain

Maximum horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}- 0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 10 m above ground level and reach ground level; flow over open terrain.

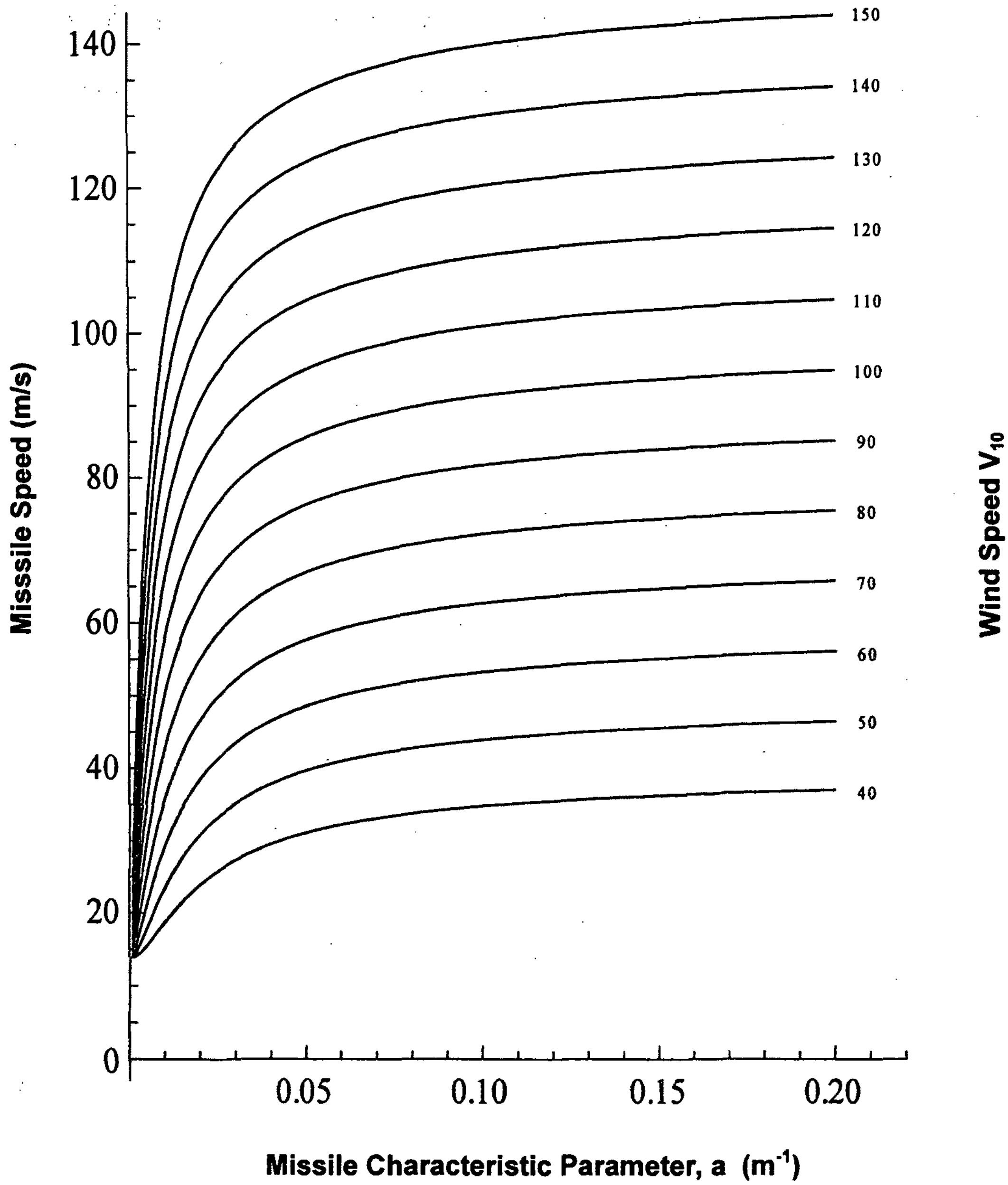

Figure D - 6- Max total missile speeds - 10 m, open terrain

Maximum total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 10 m above ground level and reach ground level; flow over open terrain.

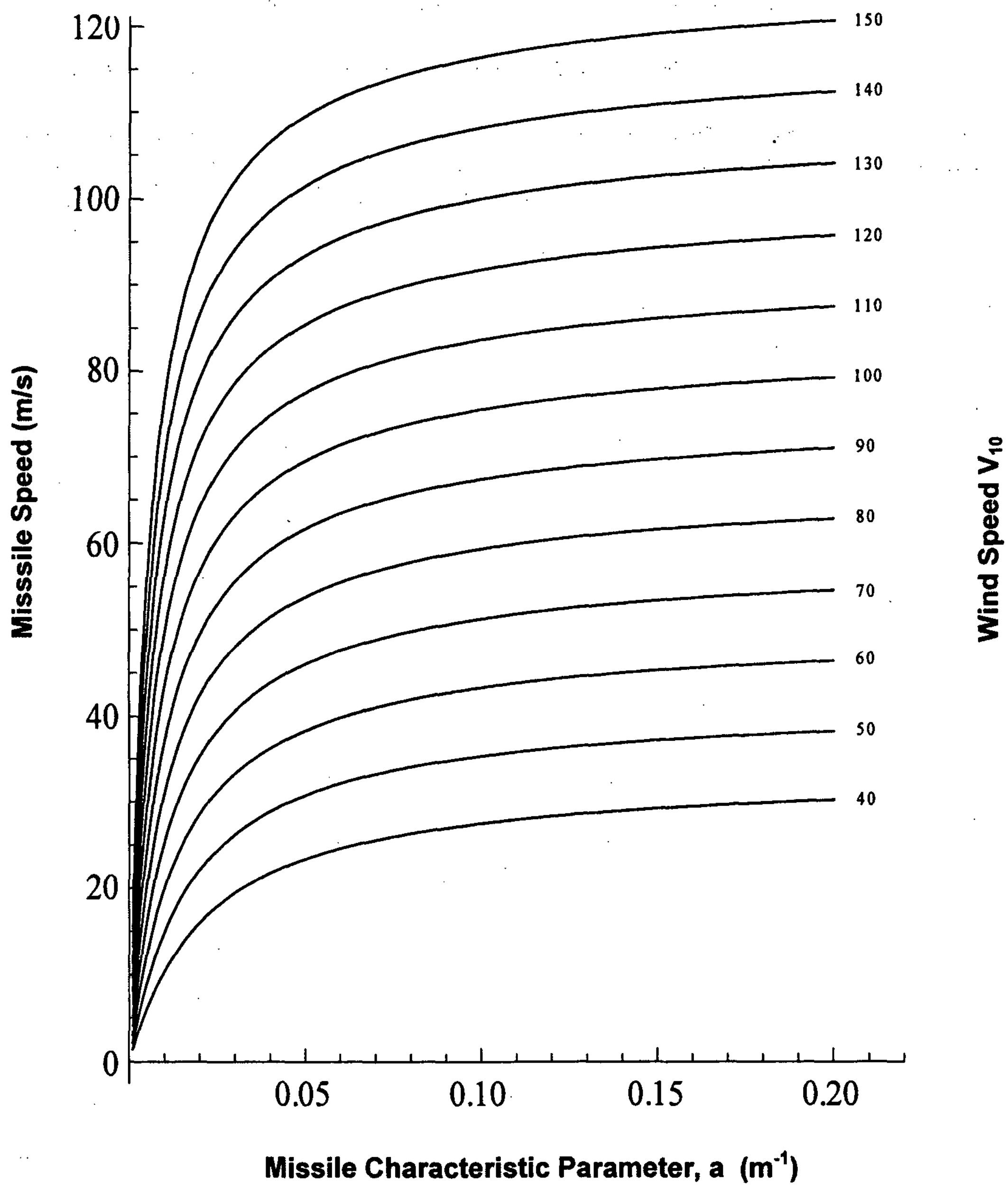

Figure D - 7 - Max horizontal missile speeds - 10 m, suburban terrain

Maximum horizontal missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}- 0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 10 m above ground level and reach ground level; flow over suburban terrain.

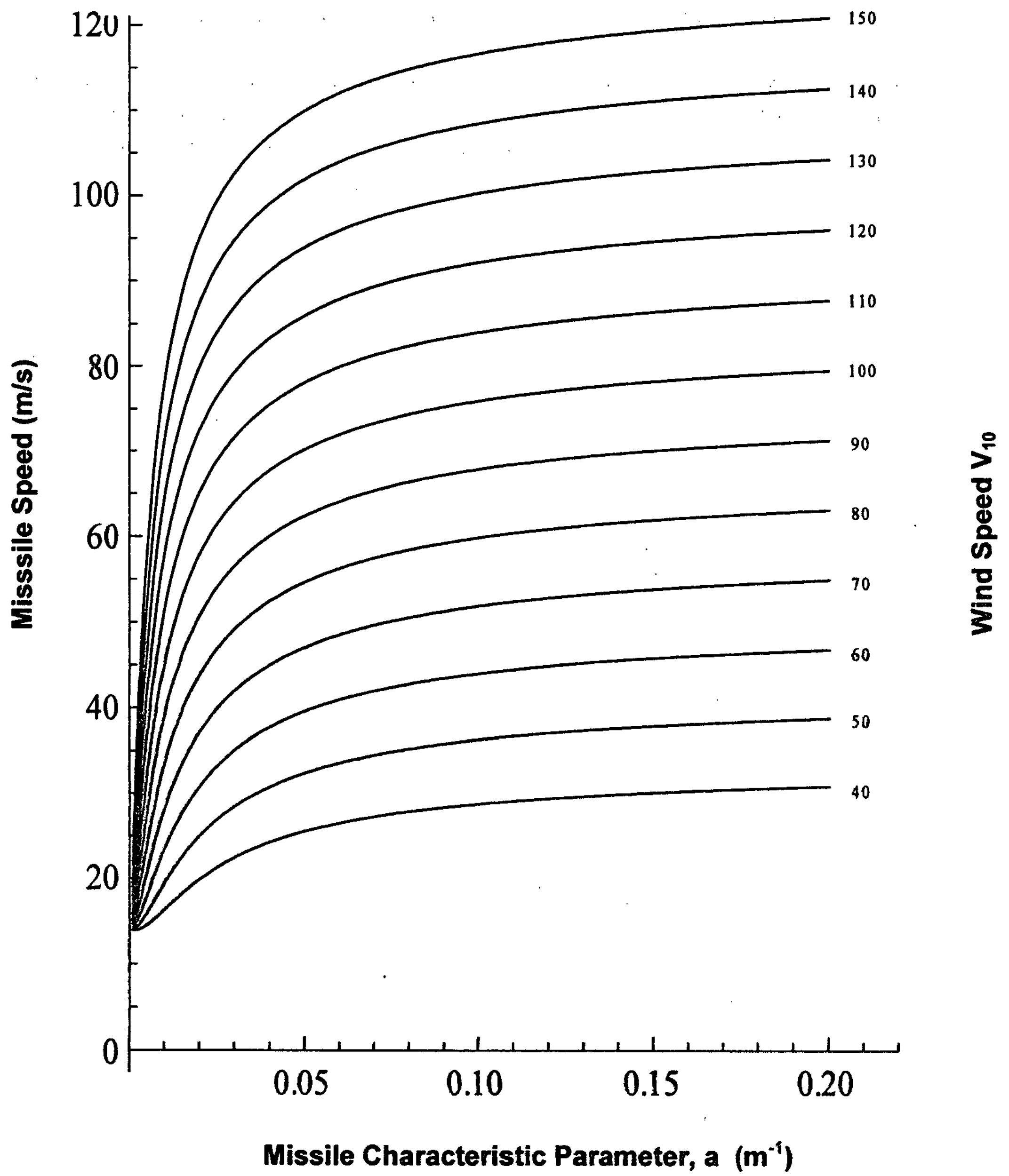

Figure D - 8 - Max total missile speeds - 10 m, suburban terrain

Maximum total missile speeds (in m/s) for parameters *a* between 0.001 m^{-1}-0.200 m^{-1} and wind speeds $v_{10}=v_h^{open}(10\ m)$ = 40, 50,...,150 m/s. Missiles start at 10 m above ground level and reach ground level; flow over open terrain.

NRC FORM 335 (9-2004) NRCMD 3.7 — U.S. NUCLEAR REGULATORY COMMISSION **BIBLIOGRAPHIC DATA SHEET** *(See instructions on the reverse)*	1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.) NUREG/CR-7004
2. TITLE AND SUBTITLE Technical Basis for Regulatory Guidance on Design-Basis Hurricane-Borne Missile Speeds for Nuclear Power Plants	3. DATE REPORT PUBLISHED MONTH: November — YEAR: 2011 4. FIN OR GRANT NUMBER N6726
5. AUTHOR(S) Emil Simiu and Florian A. Potra	6. TYPE OF REPORT final, technical 7. PERIOD COVERED *(Inclusive Dates)* 2010-2011

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8611

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Risk Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

This report is intended to provide the technical basis for a potential new regulatory guide that would provide licensees and applicants with guidance that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for use in selecting the design-basis hurricane-borne missile speeds for the design of nuclear power plants. The design must prevent undue risk to the health and safety of the public in accordance with General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena," and General Design Criterion 4, "Environmental and Dynamic Effects Design Bases," of Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10, Part 50, of the Code of Federal Regulations, "Domestic Licensing of Production and Utilization Facilities." This report documents the approach to and results of the calculation of hurricane-borne missile speeds that may be considered in the design of nuclear power plants. The missile spectrum, the assumptions on which the analyses are based -- which are similar to assumptions used for the development of Revision 1 to Regulatory Guide 1.76, "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants,"-- and the range of wind speeds being considered, were based on consultations between the authors and NRC staff. In addition, calculated missile speeds based on assumptions on the initial missile height above ground that differ from the assumption used in Revision 1 to Regulatory Guide 1.76 are included in the Appendices. The staff initiated this study because Revision 1 to Regulatory Guide 1.76 was based on the new Enhanced Fujita scale, in which tornado design-basis wind speeds are lower than in the earlier Fujita scale. This reduction in design basis tornado wind speed resulted in a potential for design basis hurricane winds to exceed the wind speeds in Regulatory Guide 1.76, Revision 1. Furthermore, the nature of hurricane winds can result in faster missile speeds than are possible for comparable tornado design basis winds.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*	
Hurricane Missiles	13. AVAILABILITY STATEMENT unlimited
	14. SECURITY CLASSIFICATION *(This Page)* unclassified *(This Report)* unclassified
	15. NUMBER OF PAGES
	16. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS