AD

405 855

This material published by the Clearinghouse for Federal Scientific and Technical Information is for use by the public and may be reprinted except that where patent questions appear to be involved the usual preliminary search is advised, and where copyrighted material is used permission should be obtained for its further publication.

CLEARINGHOUSE

FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION

OF THE

U.S. DEPARTMENT OF COMMERCE

UNCLASSIFIED

AD 405 855

DATA FOR ICBM RE-ENTRY TRAJECTORIES

Deane N. Morris, et al

The Rand Corporation
Santa Monica, California

April 1963

Processed for . . .

DEFENSE DOCUMENTATION CENTER
DEFENSE SUPPLY AGENCY

CLEARINGHOUSE
FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION

U. S. DEPARTMENT OF COMMERCE / NATIONAL BUREAU OF STANDARDS / INSTITUTE FOR APPLIED TECHNOLOGY

UNCLASSIFIED

NOTICE TO DEFENSE DOCUMENTATION CENTER USERS

This document is being distributed by the Clearinghouse for Federal Scientific and Technical Information, Department of Commerce, as a result of a recent agreement between the Department of Defense (DOD) and the Department of Commerce (DOC).

The Clearinghouse is distributing unclassified, unlimited documents which are or have been announced in the Technical Abstract Bulletin (TAB) of the Defense Documentation Center.

The price does not apply for registered users of the DDC services.

405 855

405855

MEMORANDUM
RM-3475-ARPA
APRIL 1963

PREPARED FOR:
ADVANCED RESEARCH PROJECTS AGENCY

NO OTS

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

ARPA ORDER NO. 189-61

RM

DATA FOR ICBM RE-ENTRY TRAJECTORIES

Deane N. Morris and P. Benson

DDC
RELEASED
JUN 10 1963
TISIA

:NCY

The RAND Corporation
SANTA MONICA • CALIFORNIA

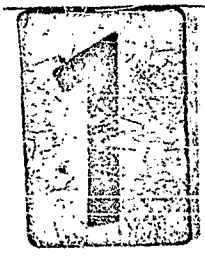
MEMORANDUM

RM-3475-ARPA

APRIL 1963

DATA FOR

This research is supported by the Advanced Research Projects Agenc
No. SD-79. Any views or conclusions contained in this Memorandu
interpreted as representing the official opinion or policy of ARPA.



ARPA ORDER NO. 189-61

DATA FOR ICBM RE-ENTRY TRAJECTORIES

Deane N. Morris and P. Benson

supported by the Advanced Research Projects Agency under Contract
y views or conclusions contained in this Memorandum should not be
epresenting the official opinion or policy of ARPA.

The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA

PREFACE

The information presented in this Memorandum was prepared originally as an aid in a study of low-altitude defense against ballistic missiles for the Advanced Research Projects Agency. This compilation of data is being published because of its general usefulness in both defense studies and ballistic-missile design.

SUMMARY

Basic trajectory data during re-entry are presented for a series of re-entry vehicles with ballistic coefficients ranging from 300 to 3000 lb/sq ft. Re-entry flight-path angles were varied from 10 to 60 deg, with re-entry velocities corresponding to a nominal ballistic range of 5500 n mi. In addition to the usual trajectory parameters, a number of other variables particularly useful in studies of low-altitude interception systems are presented.

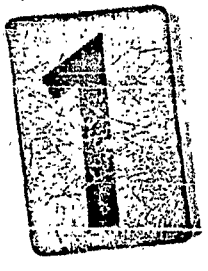
I. INTRODUCTION

In the course of design studies on the subject of low-altitude defense against ballistic missiles, it has become apparent that a compilation of detailed, accurate information on the re-entry trajectories of the target would be very useful. These data are of assistance in estimating interception loci, commitment loci, miss distance, etc. Because of the nature of the problem, the information is required for low altitudes where approximate results are invalid, and for ranges of variables for which very little information has been published. Unfortunately, the number of variables of interest, as well as the number of independent parameters, is quite large, leading to an unwieldy volume of data if all conceivable cases of interest are covered.

Several attempts were made to reduce the number of variables by plotting the data in the parametric forms suggested by the approximate theories. None of these were successful, either because the parametric forms were too complicated to be of use, or because the exact results were not correlated well enough by the approximate theoretical parameters. Consequently, it was necessary to limit the ranges of variables to those values of immediate interest to current defense studies.

The graphs presented in this Memorandum cover only those combinations of re-entry velocity and re-entry angle that correspond to a ballistic missile with a nominal range of 5500 n mi, the re-entry conditions being specified at an altitude of 400,000 ft. The re-entry vehicle itself is characterized by the ballistic coefficient, which has been varied over a range of values that is typical for most present and planned re-entry vehicle designs.

The data have been presented in as simple and straightforward a graphical form as possible, in order to allow direct reading of most variables and to reduce the labor of cross-plotting, interpolating, etc. Due to the wide variations in some of the variables, it was impossible to maintain identical scales on all of the graphs and still



provide accurate, readable results. Because of this, the reader is warned against making visual comparisons of one chart with another without carefully consulting the scales.

II. METHOD OF ANALYSIS

The calculations of the re-entry trajectories were made with a digital-computer program that simulates mathematically the motion of a body (considered to be a point mass) about the earth. For the present purposes, the earth was considered to be nonrotating and spherical, with a radius of 3440 n mi. The 1959 ARDC Model Atmosphere was used to provide atmospheric properties.*

Calculations for all of the re-entry trajectories were begun at an altitude of 400,000 ft, since this altitude was well above that for the appearance of appreciable aerodynamic forces for the types of re-entry vehicles considered here. The re-entry angle (measured from the local horizontal) at 400,000 ft was chosen arbitrarily over a range of angles from 10 to 60 deg. The corresponding re-entry velocities were then determined from the basic equations for vacuum ballistic trajectories. These values are meant to be representative, not precise. Precise velocities would depend upon the details of the trajectory during the boost phase of flight, and thus would be slightly different for each ICBM design. The following pairs of re-entry angles and re-entry velocities were used in this study.

Re-entry Angle (deg)	Re-entry Velocity (ft/sec)
10	24,300
20	23,900
30	24,000
40	25,200
50	27,300
60	31,600

*Minzner, R. A., K.S.W. Champion, and H. L. Pond, The ARDC Model Atmosphere, 1959, Air Force Cambridge Research Center, AFCRC-TR-59-267, August 1959.

The physical characteristics of the re-entry vehicle are represented by the ballistic coefficient, which is defined as the ratio of the weight of the re-entry body to the product of its hypersonic drag coefficient and its frontal area (W/C_DA). Since the re-entry body is assumed to be a point mass in the present calculations, and since lift forces are assumed to be zero, no other characteristics need be specified. A series of ballistic coefficients has been chosen for the present compilation, varying from 300 to 3000 lb/sq ft. The specific values of ballistic coefficient were chosen in uniform increments of 500 lb/sq ft, ranging from 500 to 3000 lb/sq ft, with two extra values being selected at 300 and 800 lb/sq ft in order to cover adequately the lower end of the range.

III. PRESENTATION OF DATA

Detailed graphs of the important variables are presented in the Appendix for the complete series of re-entry trajectories.

The wide variation in the shapes of the re-entry trajectories is shown in Figs. 1 through 6, where ground range is plotted against altitude for all of the cases considered. Even more important for the present application are the differences in time required for the descent. The time to impact is shown as a function of altitude for some selected values of re-entry flight-path angle and ballistic coefficient in Fig. 7.

The deceleration characteristics of the re-entry vehicle may have an important influence upon the design of the guidance and maneuvering equipment for a low-altitude interception system, and upon the method used for a kill mechanism. Profiles of the axial acceleration (i.e., the drag deceleration) as a function of altitude are shown in Figs. 8 through 13 for all of the re-entry trajectories, and the altitude for maximum deceleration is presented in Fig. 14 as a function of ballistic coefficient and re-entry angle.

The location of the interception point of the incoming re-entry vehicle can be defined by specifying the shortest acceptable slant range from the point of impact. With this slant range established,

the performance of the interceptor vehicle will determine the time of flight from launch (or commitment) of the interceptor until interception of the re-entry body. If the slant range at interception and the interceptor time of flight are specified arbitrarily, then the position of the re-entry vehicle at the time of launch of the interceptor can be determined for the various re-entry trajectories. The locus of these positions for a given re-entry vehicle and given interception parameters has been called the commitment locus. Some examples of commitment loci for a re-entry vehicle with a ballistic coefficient of 1000 lb/sq ft are shown in Fig. 15. Other commitment loci for different values of the governing parameters can be generated quite easily from the data presented in the Appendix.

Interpolation for other values of ballistic coefficient should prove to be relatively easy from the data presented in this Memorandum, since the range of values and the increments used have been selected with this in mind. Interpolation or cross-plotting for intermediate values of the re-entry angle is also rather easily accomplished, but it must be remembered that the re-entry velocity varies with re-entry angle as shown in the text on page 1 so as to keep the nominal total range equal to 5500 n mi. In other words, re-entry angle and velocity cannot be varied independently with the data presented here.

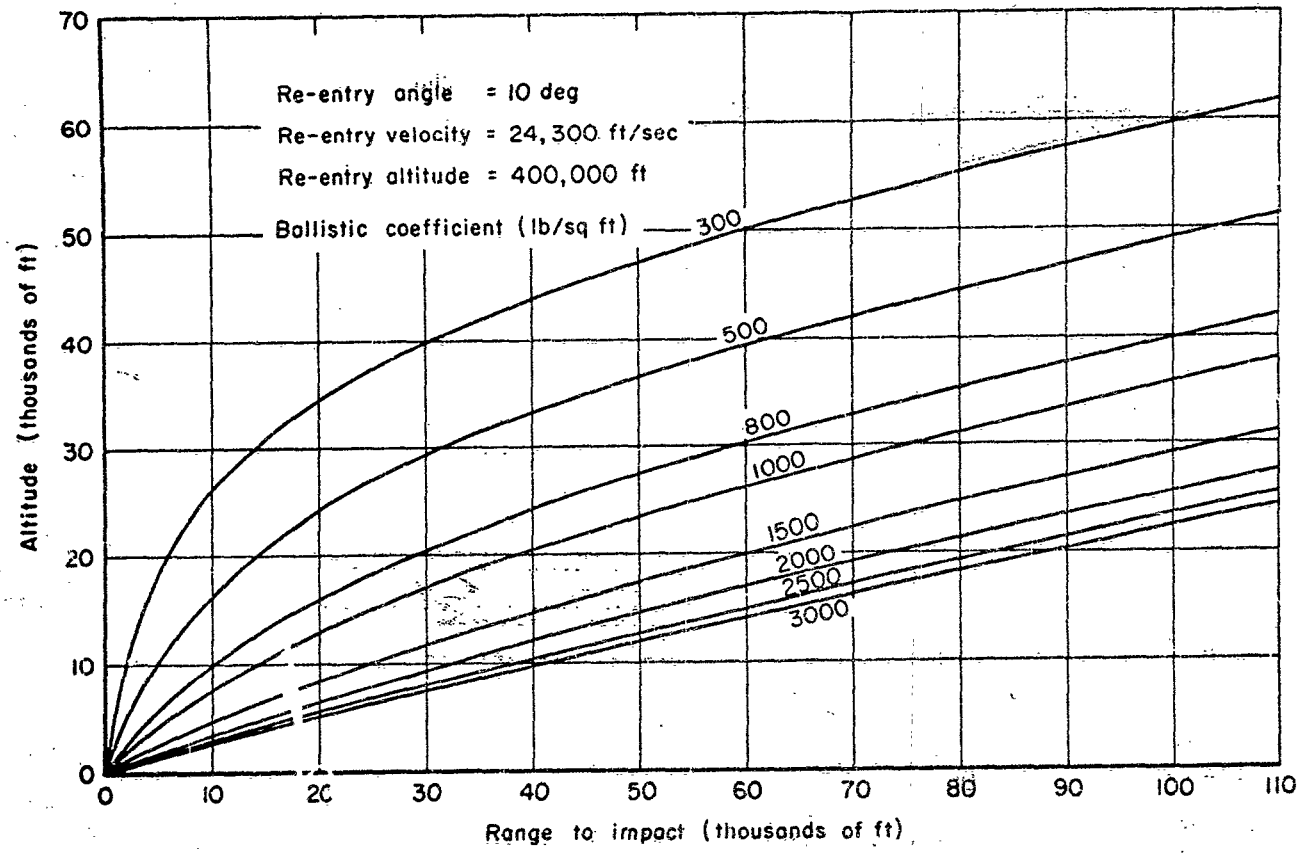


Fig. 1—Trajectory contours for 10-deg re-entry angle

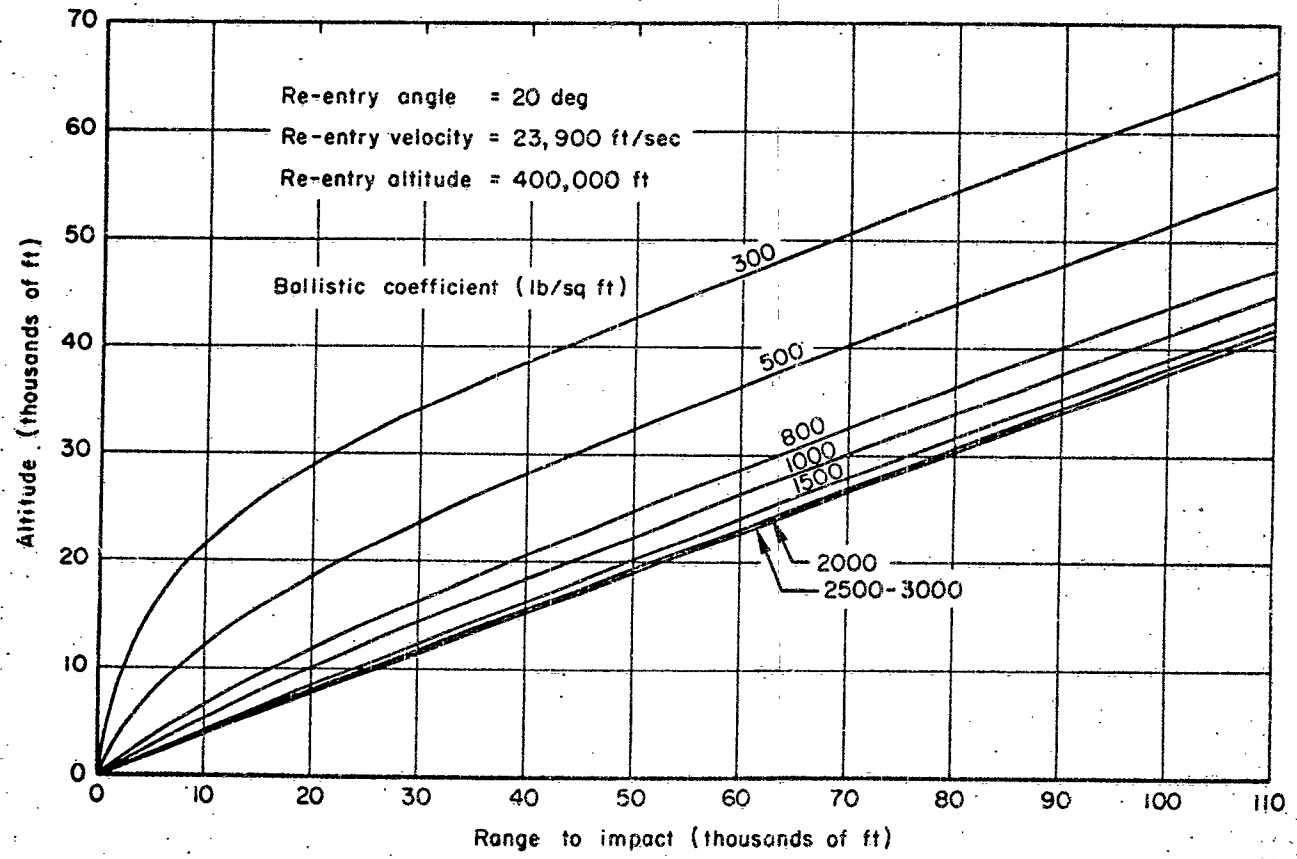


Fig. 2 — Trajectory contours for 20-deg re-entry angle

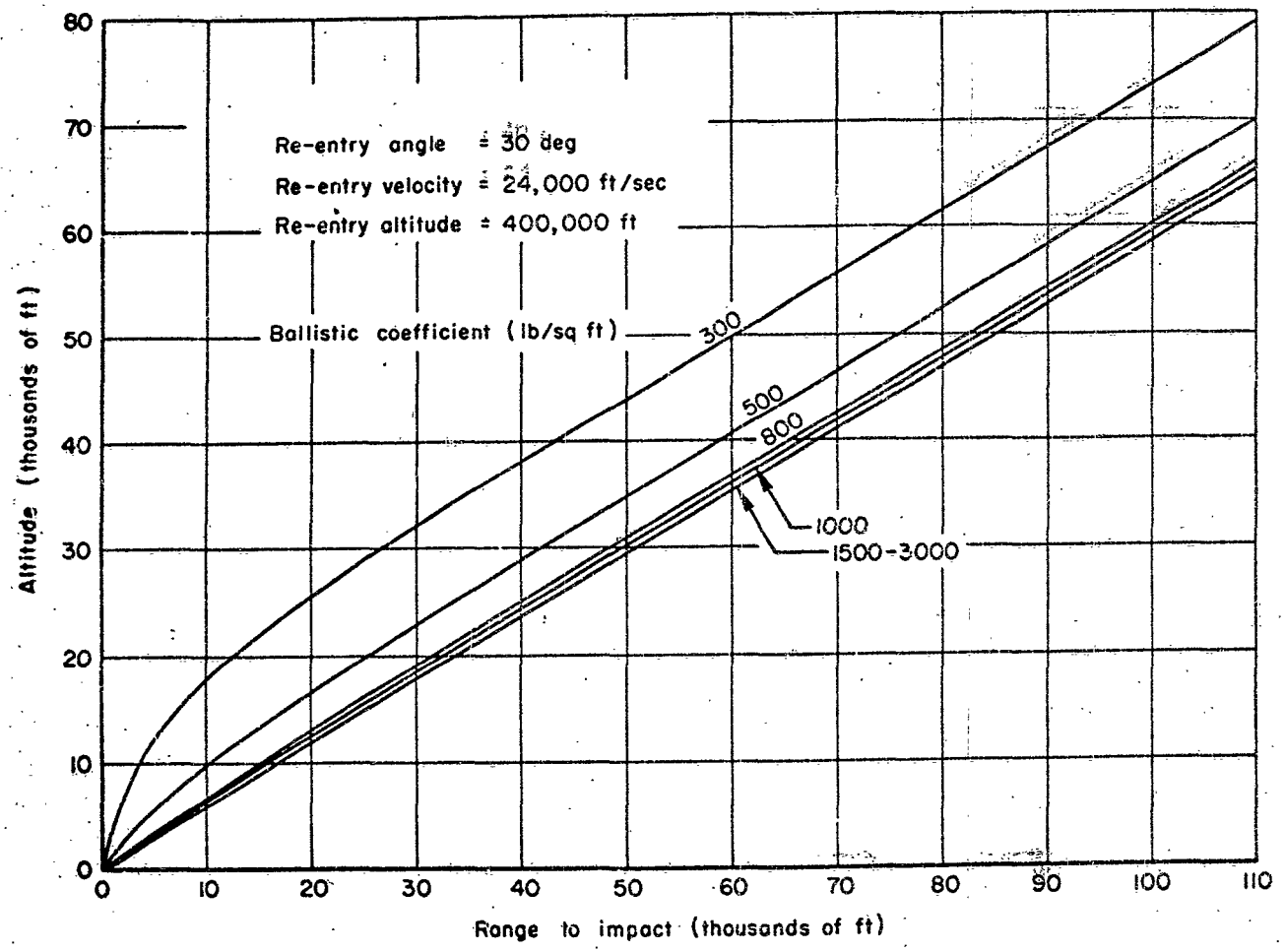


Fig. 3—Trajectory contours for 30-deg re-entry angle

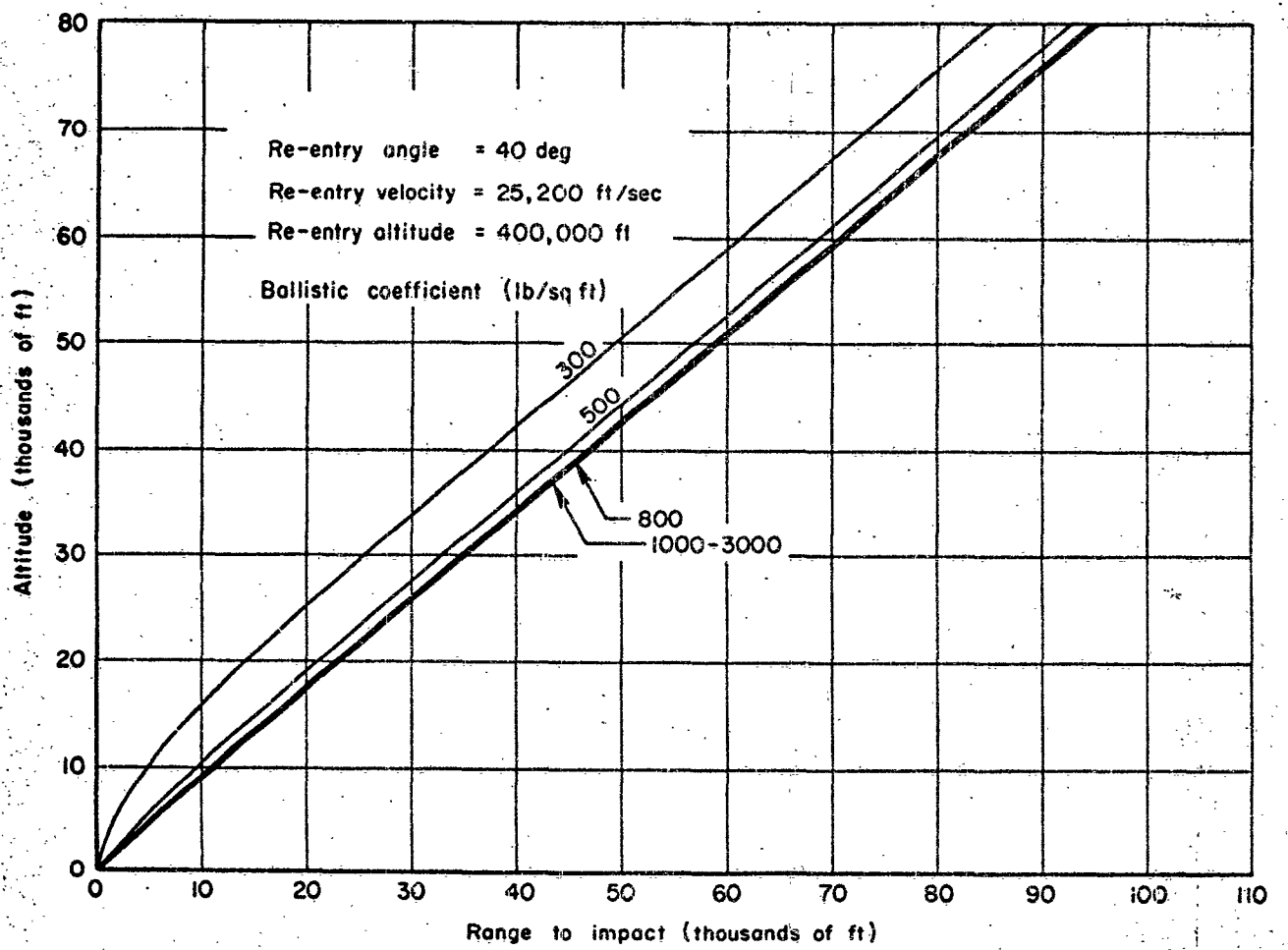


Fig. 4—Trajectory contours for 40-deg re-entry angle

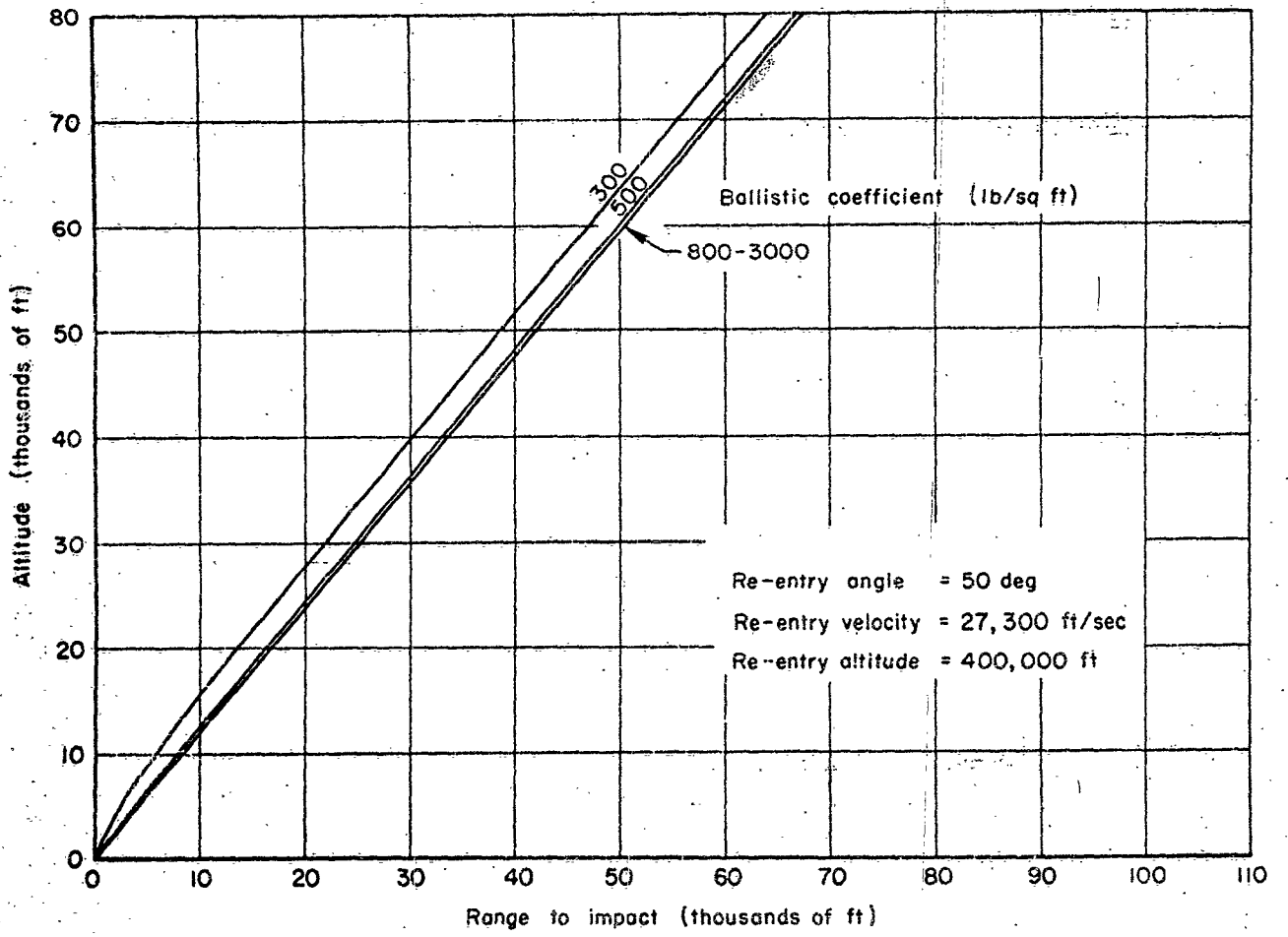


Fig. 5— Trajectory contours for 50-deg re-entry angle

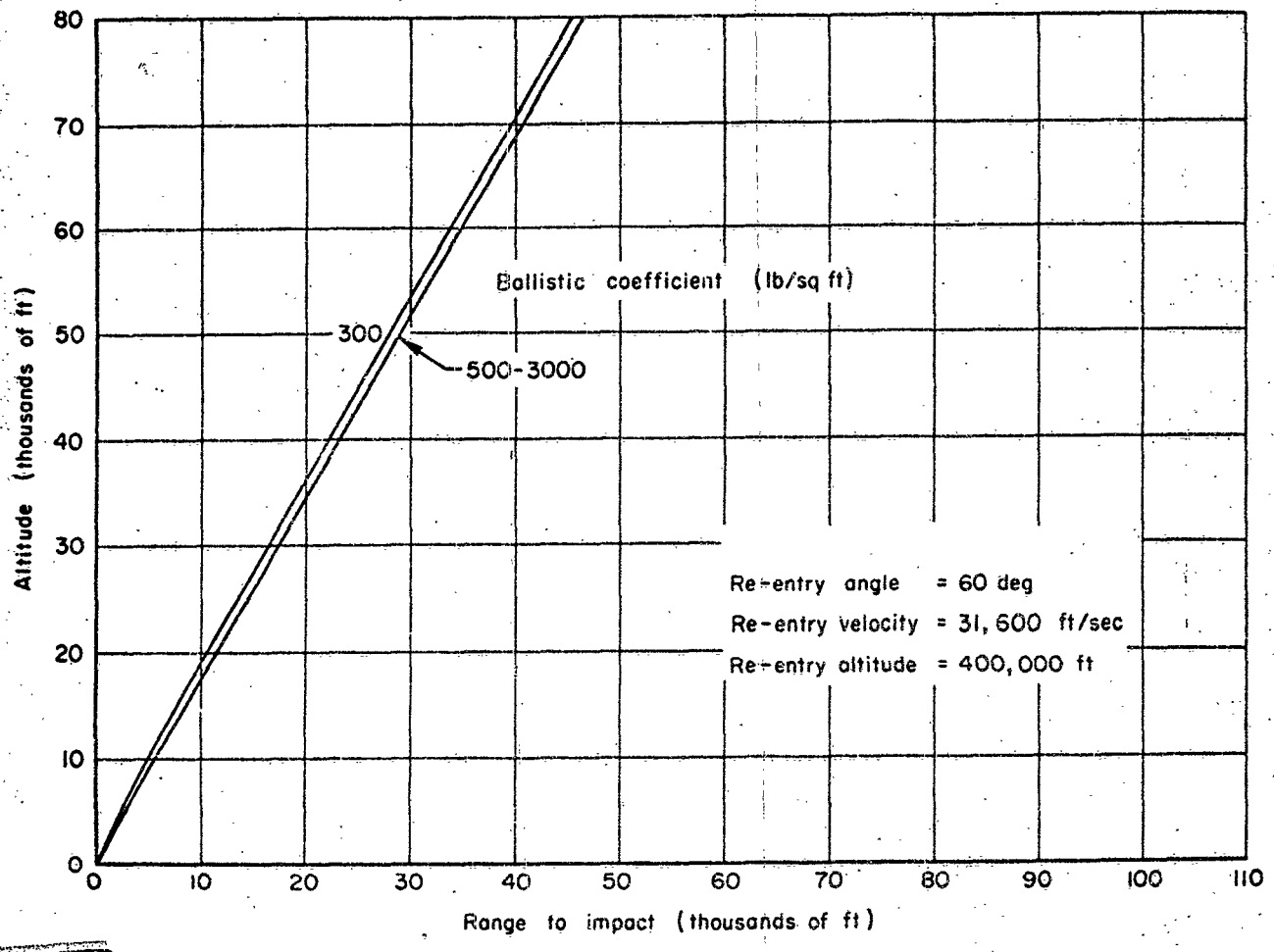


Fig. 6— Trajectory contours for 60-deg re-entry angle

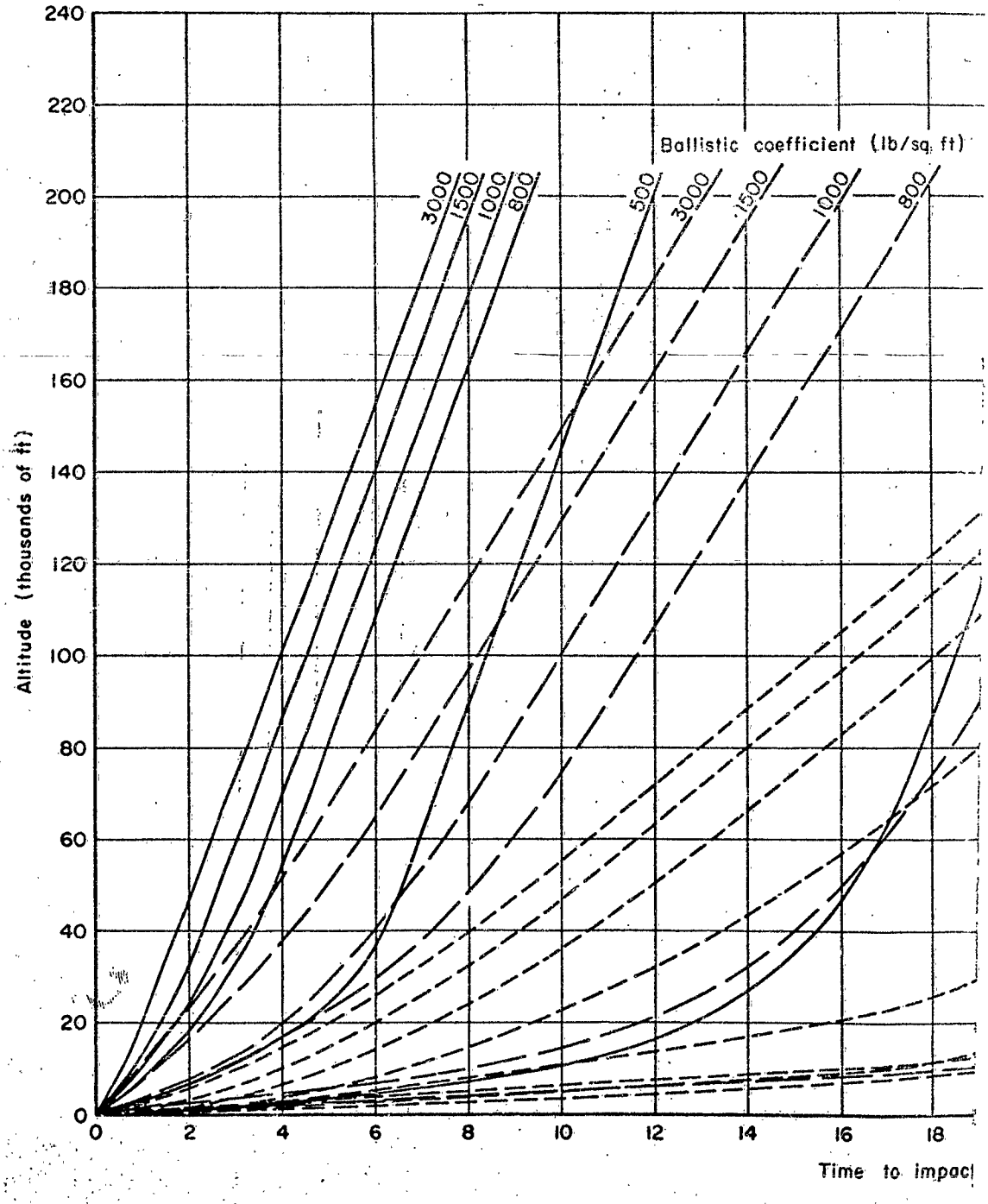


Fig. 7—Time of flight

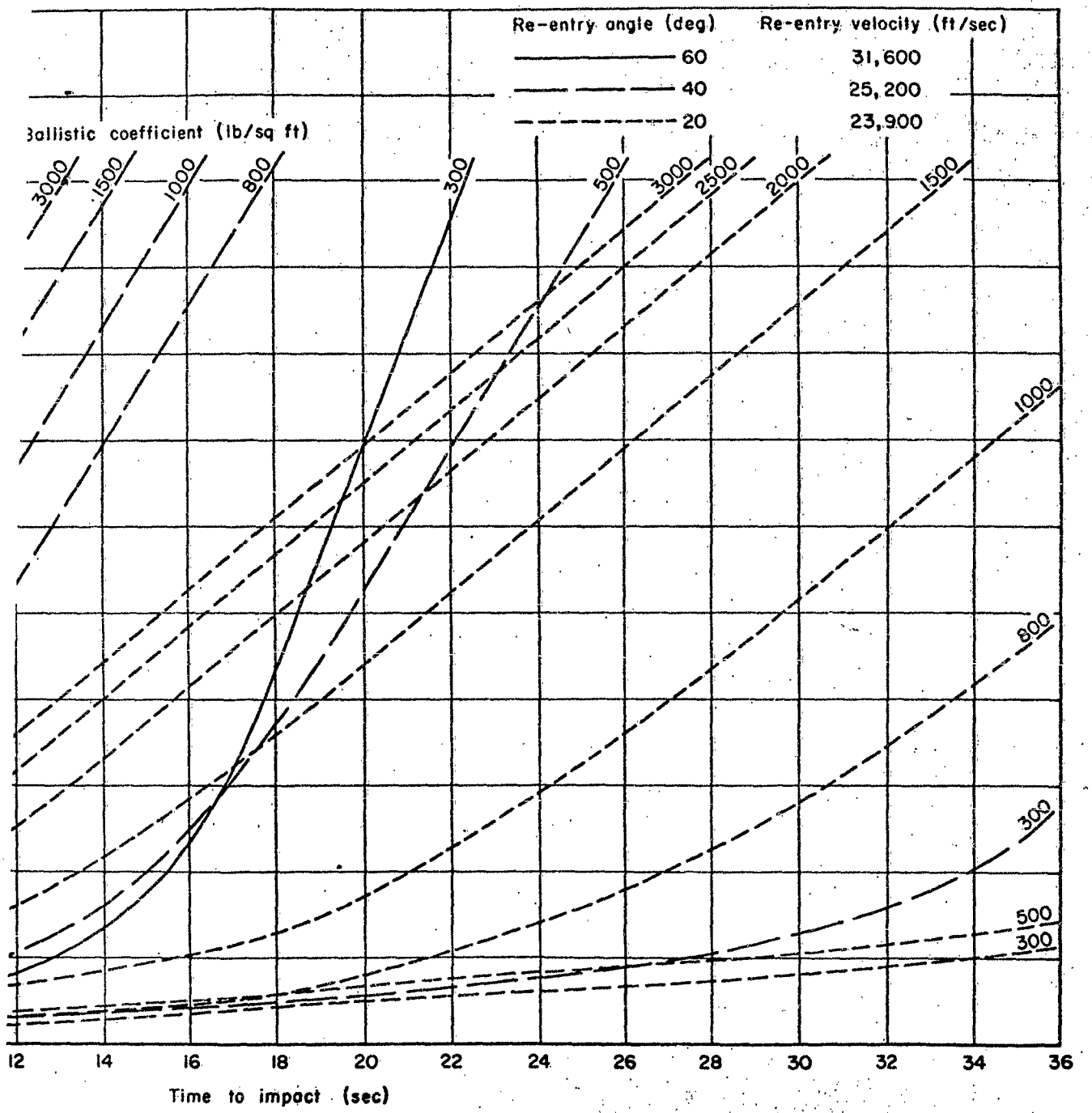


Fig. 7—Time of flight during re-entry

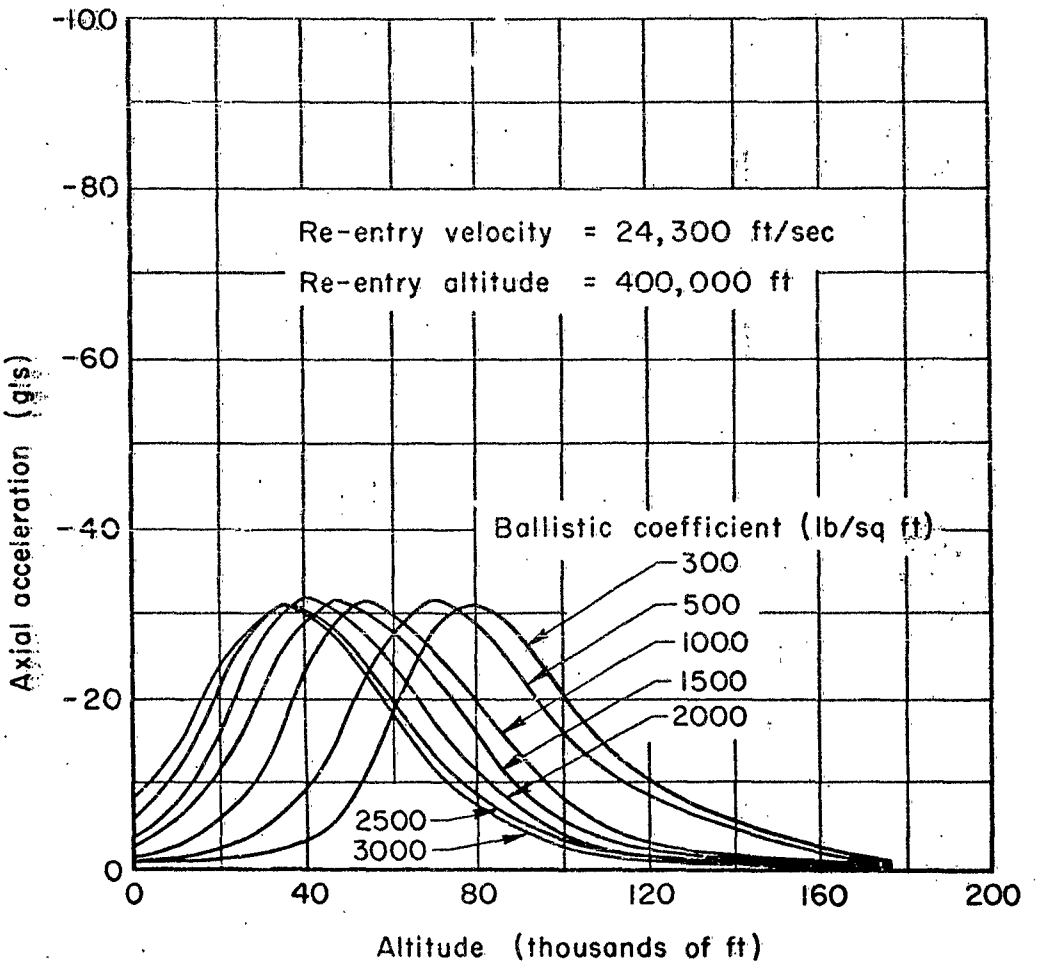


Fig. 8—Axial acceleration for 10-deg re-entry angle

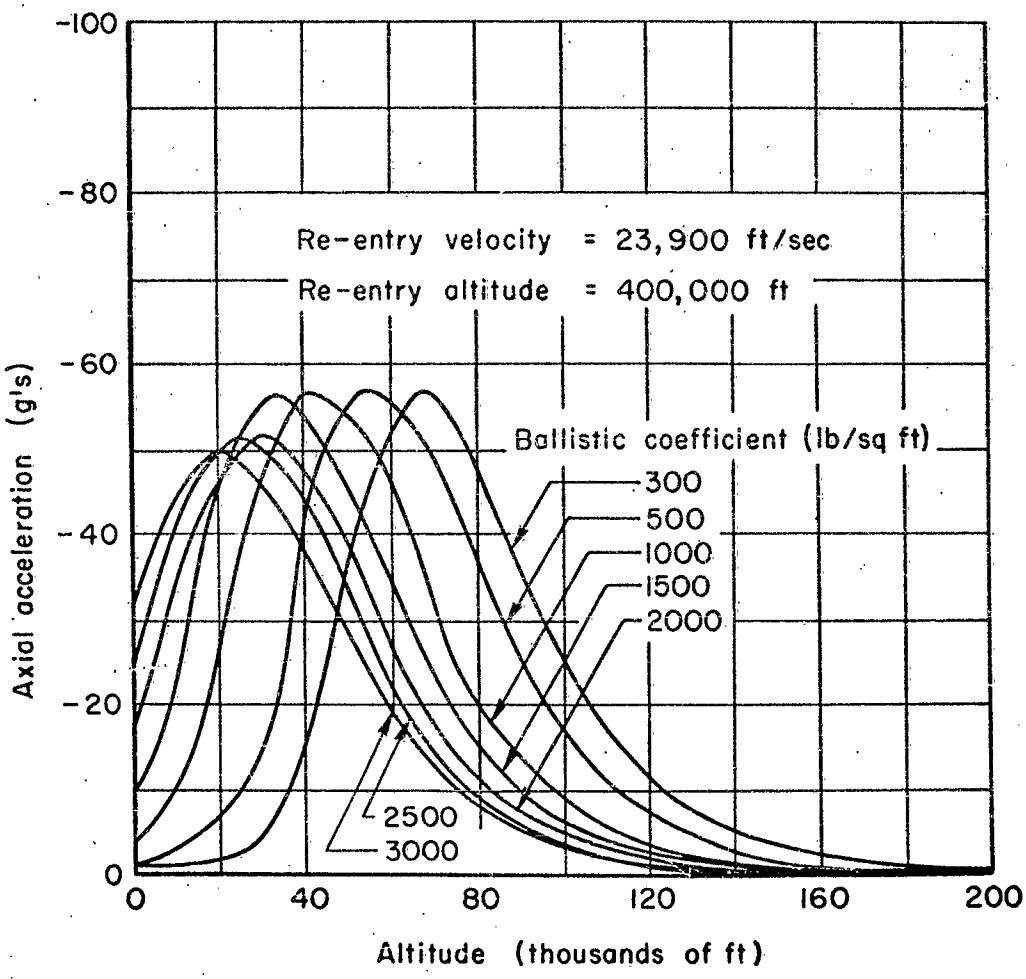


Fig. 9—Axial acceleration for 20-deg re-entry angle

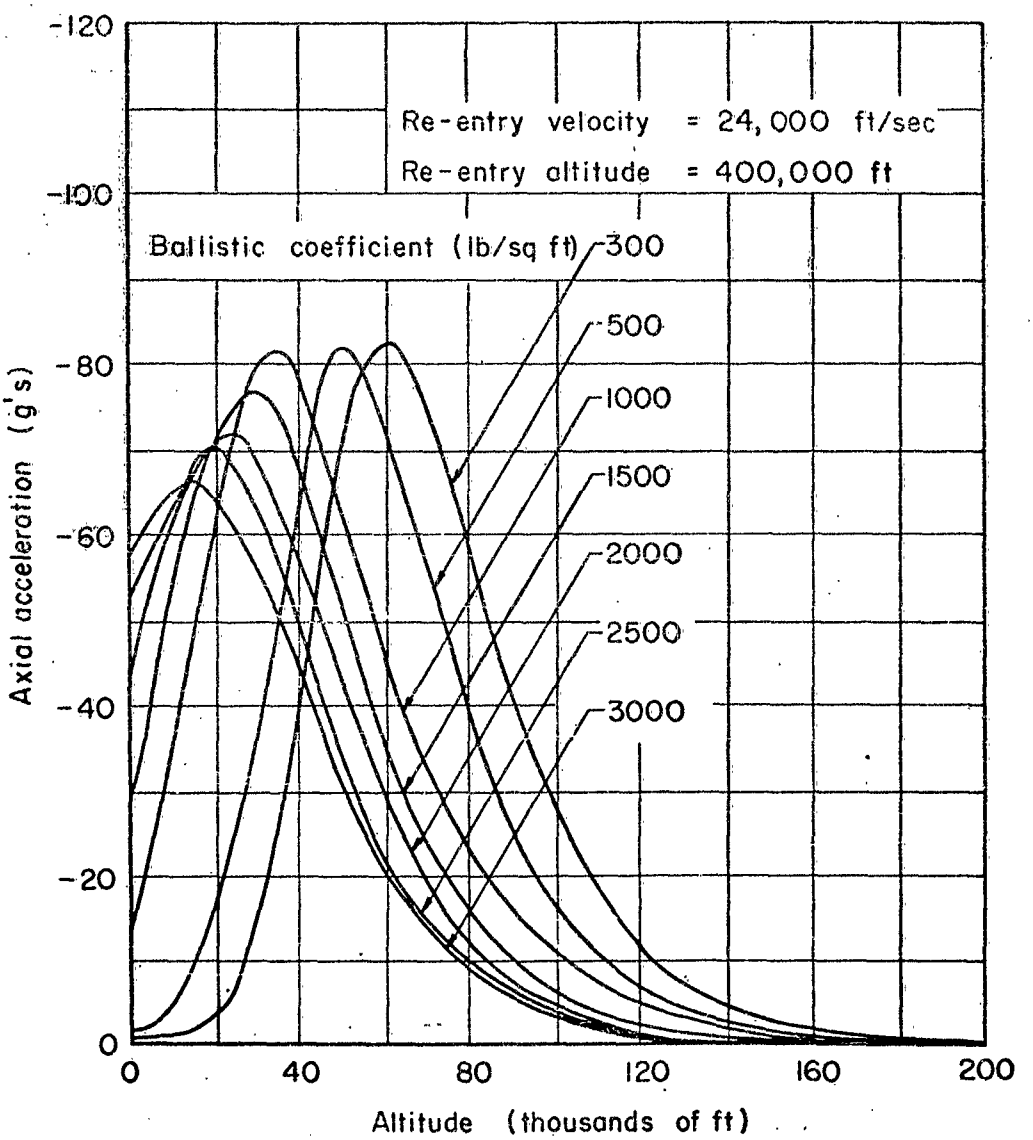


Fig. 10—Axial acceleration for 30-deg re-entry angle

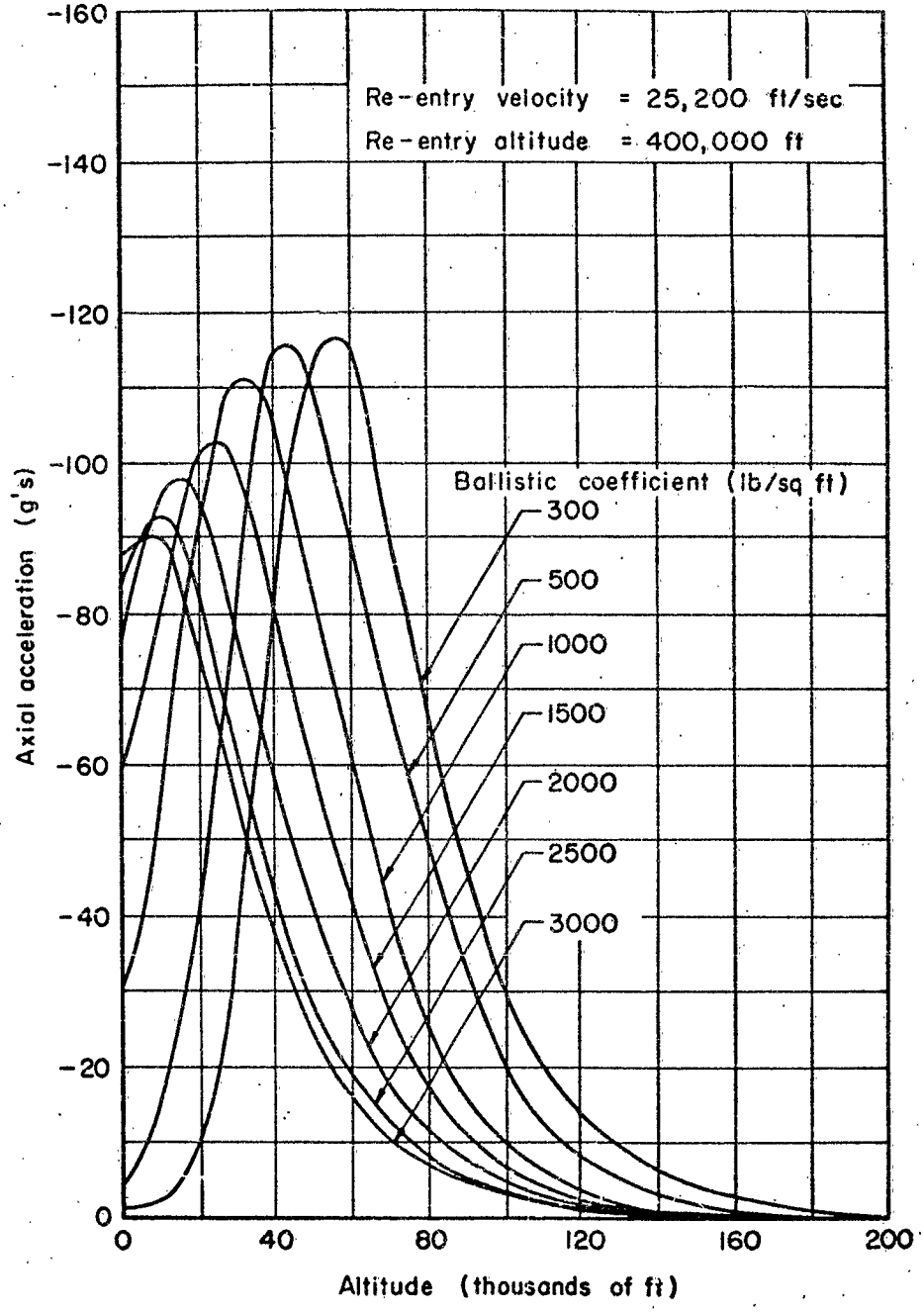


Fig. 11—Axial acceleration for 40-deg re-entry angle

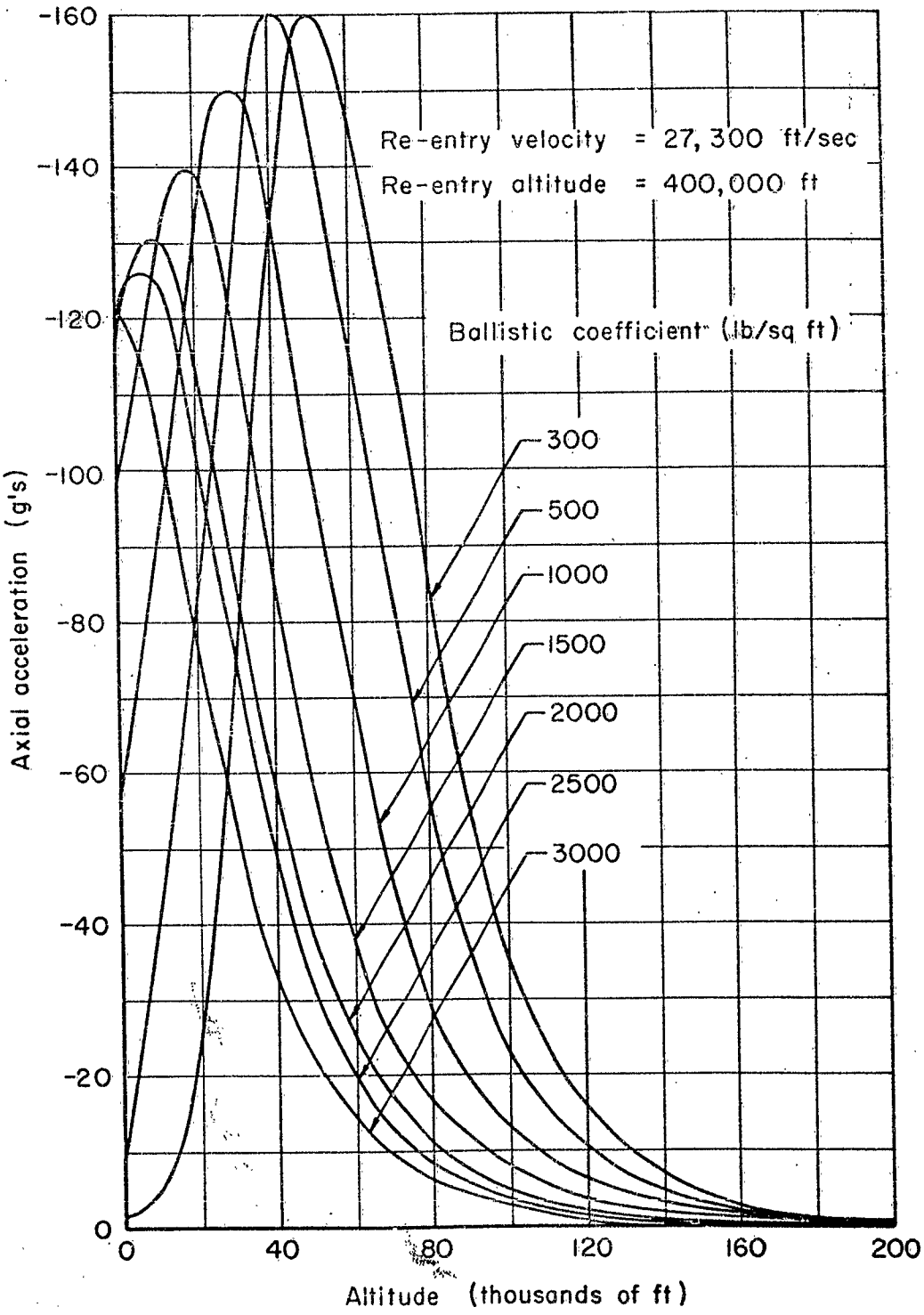


Fig. 12—Axial acceleration for 50-deg re-entry angle

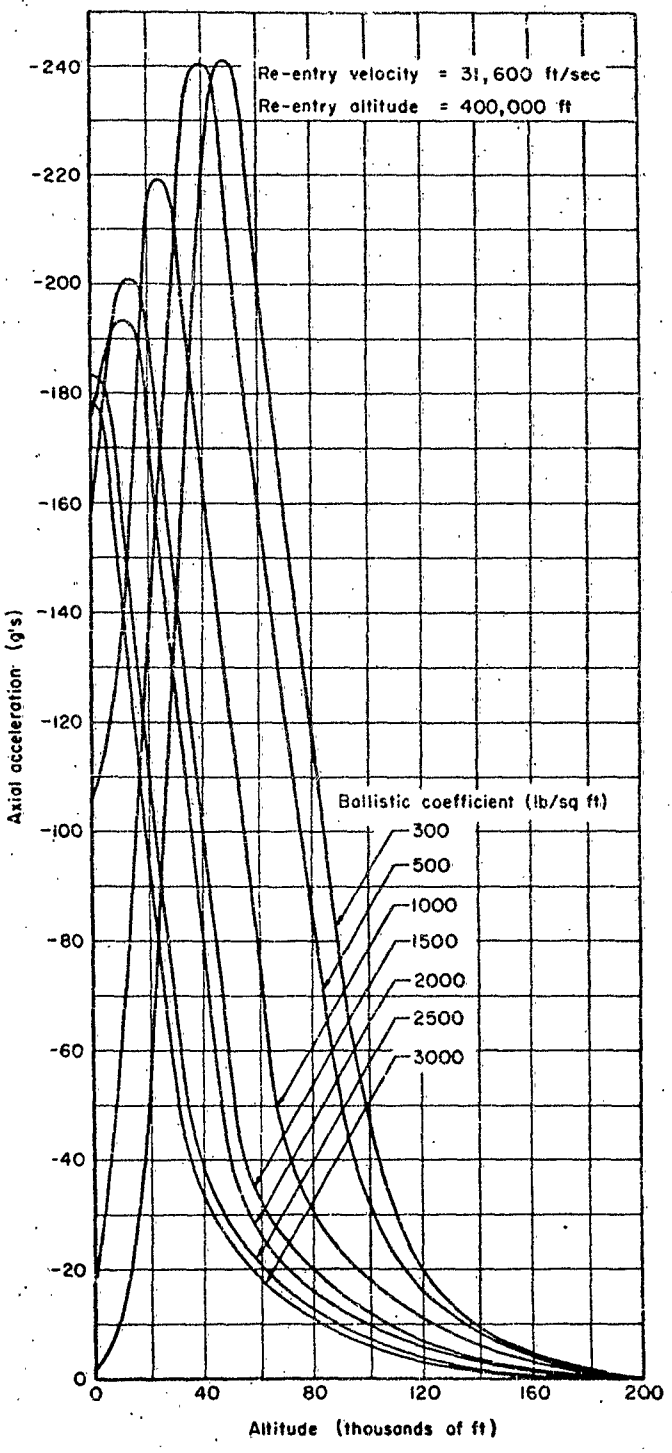


Fig.13—Axial acceleration for 60-deg re-entry angle

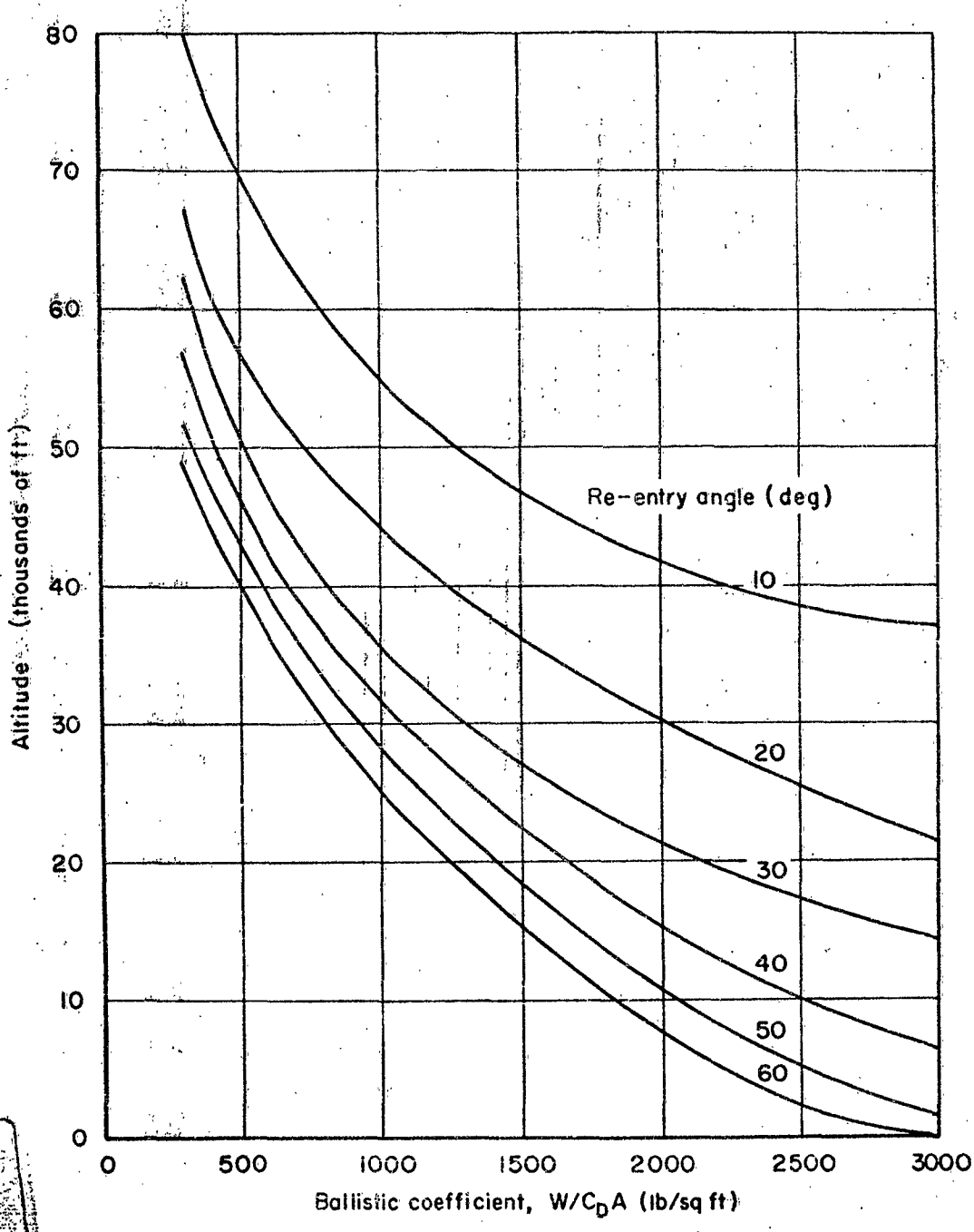


Fig. 14 — Altitude for maximum deceleration

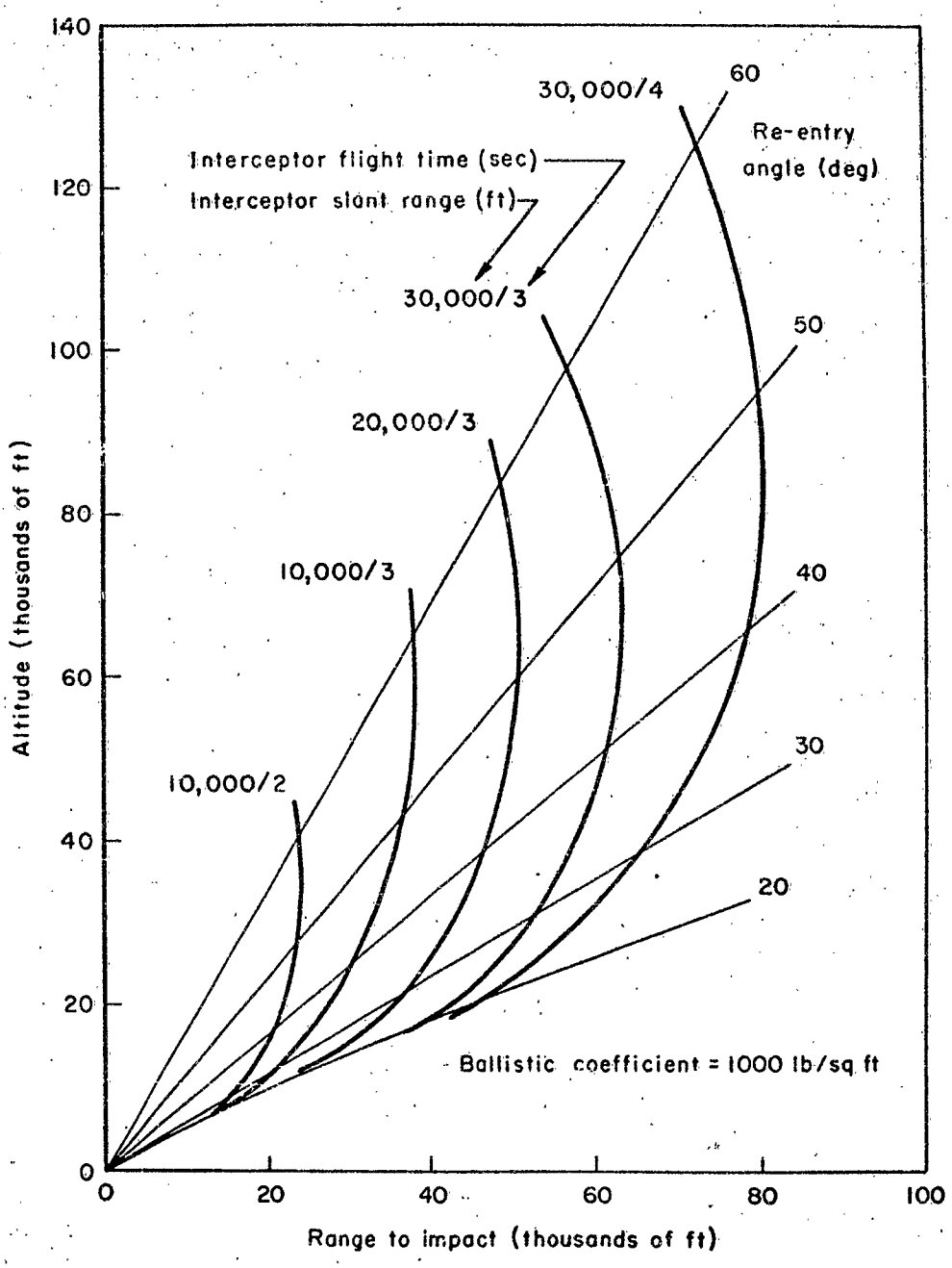


Fig. 15 —Typical interceptor commitment loci

APPENDIX

Detailed graphs of the re-entry trajectory data altitudes are presented in Figs. A-1 through A-48. portant trajectory parameters are plotted on each fi of the time to impact; these are

1. Altitude (h)
2. Range to impact (R)
3. Velocity (V)
4. Flight-path angle (γ)
5. Axial acceleration (a)
6. Slant range to impact (SR)
7. Elevation angle from the impact point (ϵ)

The scale for altitude is the same on all figur to 120,000 ft. For all other variables, the scales individually for each figure so as to cover adequate of interest with the greatest possible accuracy. Tl exception to this is in the case of the flight-path angle scales, which were not expanded beyond that re about 0.05 deg. Because of the variations in scale exercised in comparing one figure with another visu

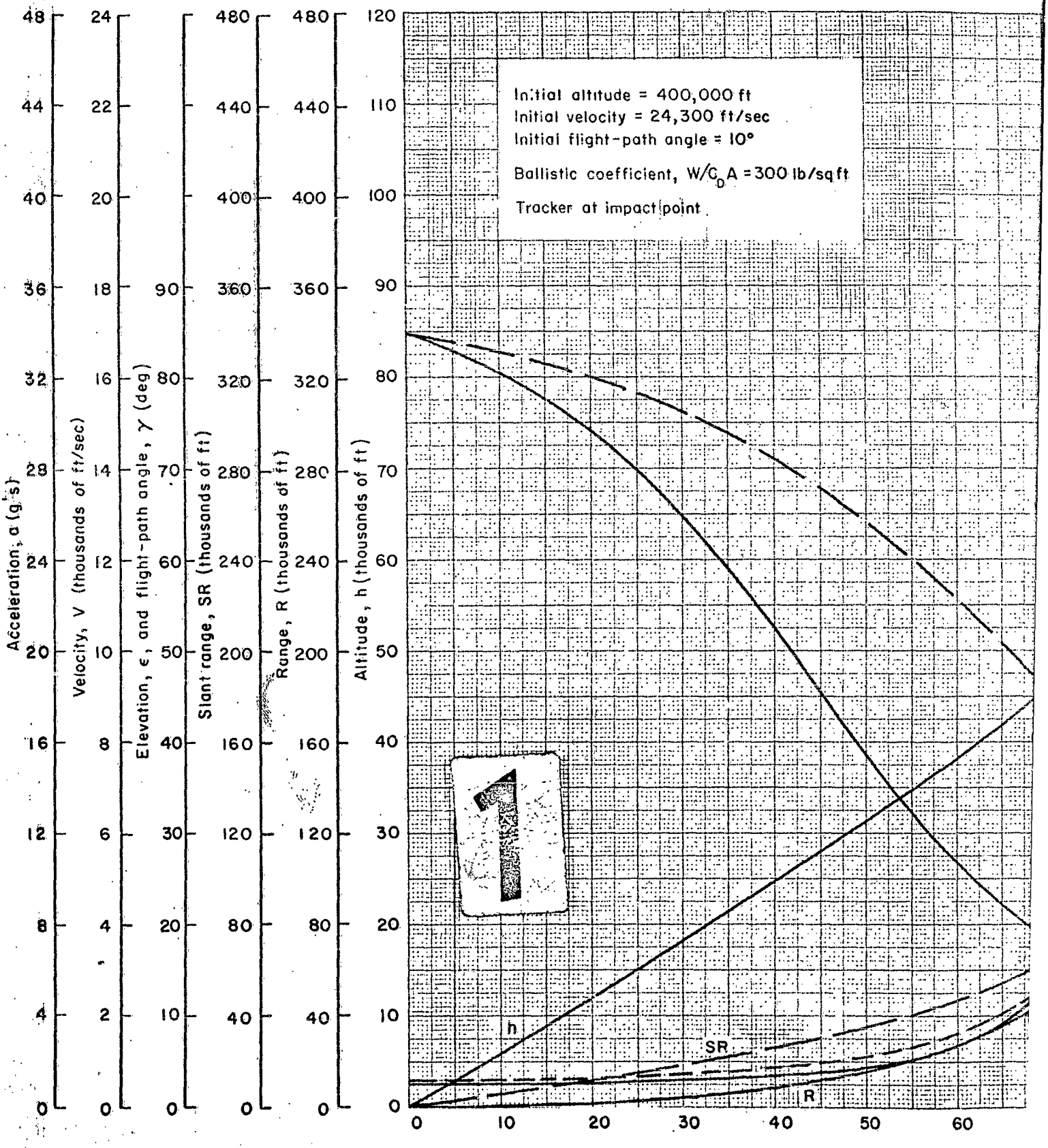
The format of the figures is essentially the s by Jones,* and the reader is referred to that publi jectory data on a number of other combinations of r velocity. It should be noted, however, that re-ent city are specified there at an altitude of 300,000 400,000 ft, and that the nominal ballistic range is in selecting the pairs of re-entry angles and veloc

*Jones, T. H., Re-Entry Trajectories for a Re General Electric Company, ASER No. 5-61, March 1961

APPENDIX

raphs of the re-entry trajectory data for the lower
resented in Figs. A-1 through A-48. Seven of the im-
ory parameters are plotted on each figure as a function
impact; these are
ide (h)
to impact (R)
.ty (V)
:-path angle (γ)
acceleration (a)
range to impact (SR)
:ion angle from the impact point (ε)
for altitude is the same on all figures and extends
For all other variables, the scales were selected
or each figure so as to cover adequately the region
th the greatest possible accuracy. The only real
nis is in the case of the flight-path and elevation
which were not expanded beyond that required to read
. Because of the variations in scales, care should be
omparing one figure with another visually.
t of the figures is essentially the same as that used
the reader is referred to that publication for tra-
n a number of other combinations of re-entry angle and
should be noted, however, that re-entry angle and velo-
.fied there at an altitude of 300,000 ft rather than
ıd that the nominal ballistic range is not held constant
:he pairs of re-entry angles and velocities.

[. H., Re-Entry Trajectories for a Representative ICBM,
:ic Company, ASER No. 5-61, March 1961.


Initial altitude = 400,000 ft
Initial velocity = 24,300 ft/sec
Initial flight-path angle = 10°
Ballistic coefficient, W/C_DA = 300 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
h
SR
R
0
10
20
30
40
50
60

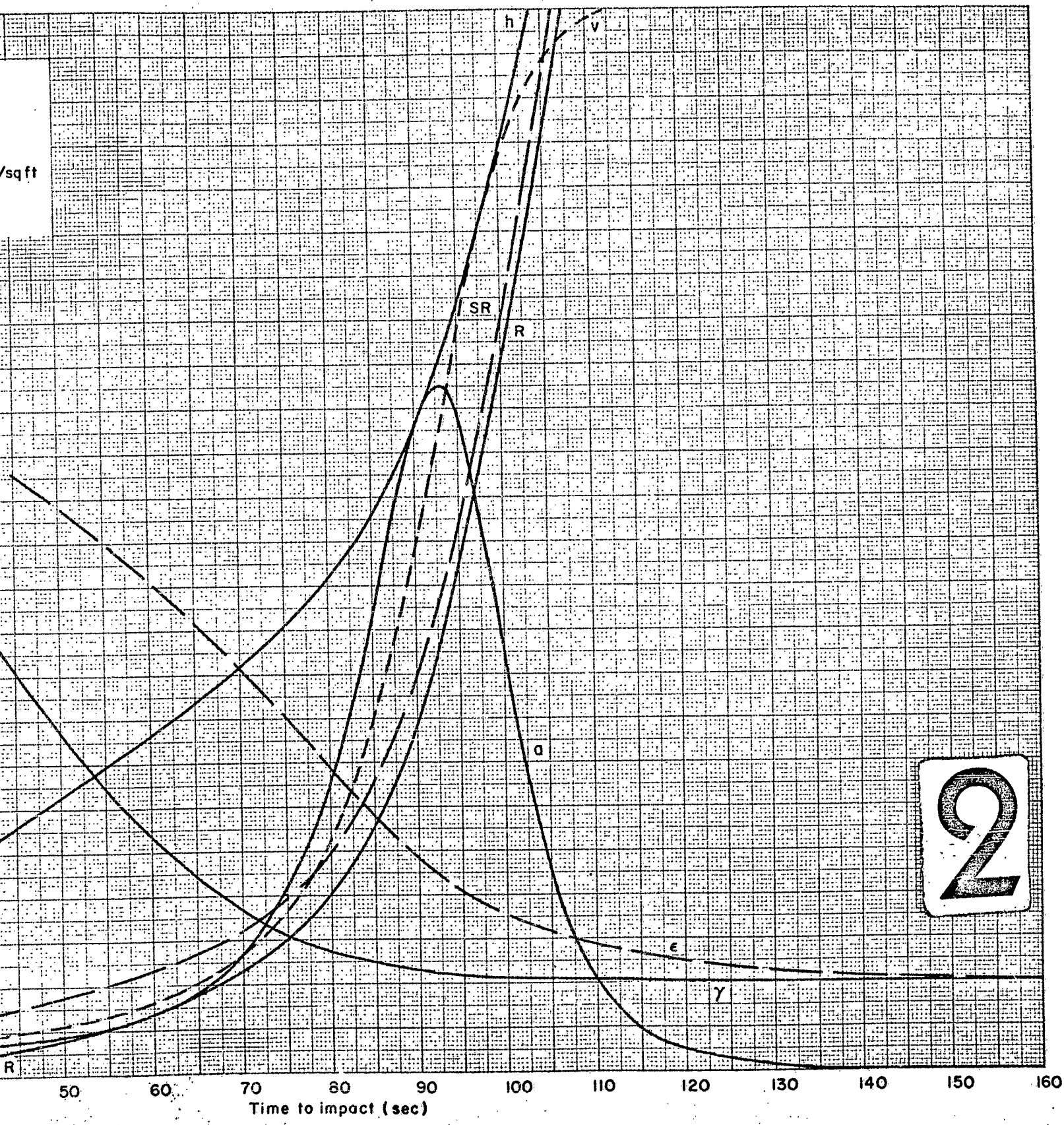
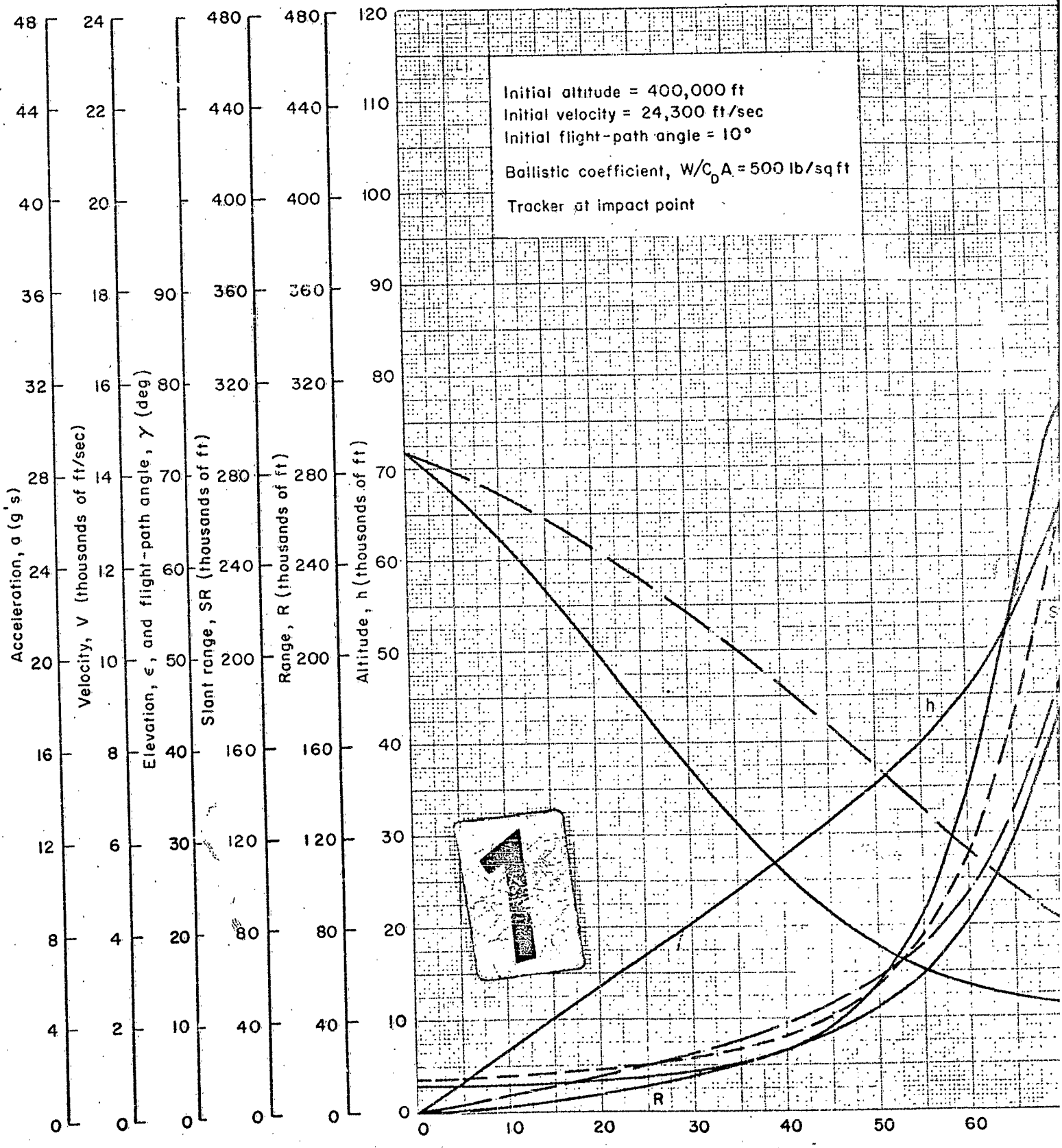

h
v
SR
R
a
ϵ
γ
R
50
60
70
80
90
100
110
120
130
140
150
160
Time to impact (sec)

Fig. A—1


Initial altitude = 400,000 ft
Initial velocity = 24,300 ft/sec
Initial flight-path angle = 10°
Ballistic coefficient, $W/C_D A$ = 500 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
h
R

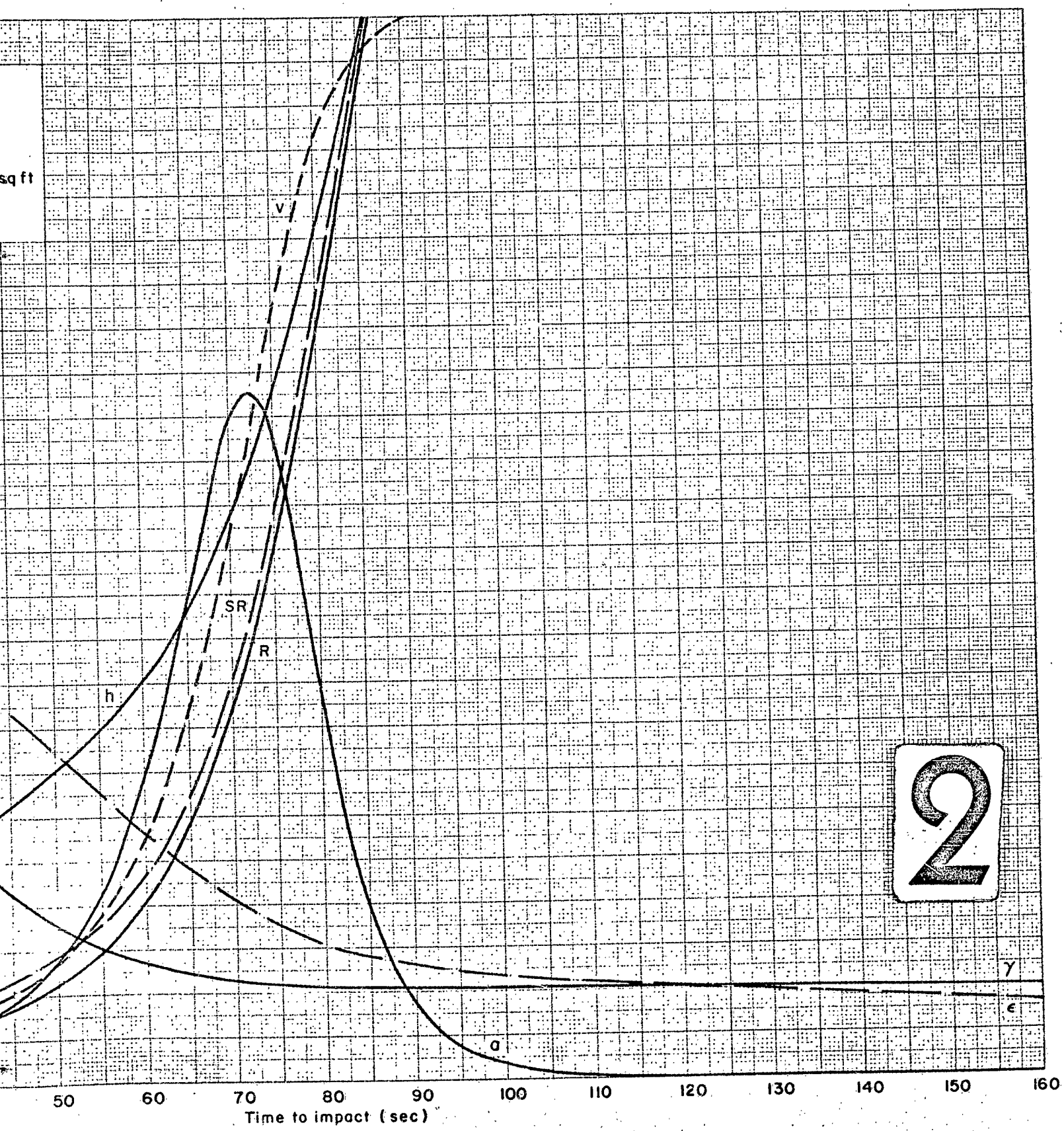
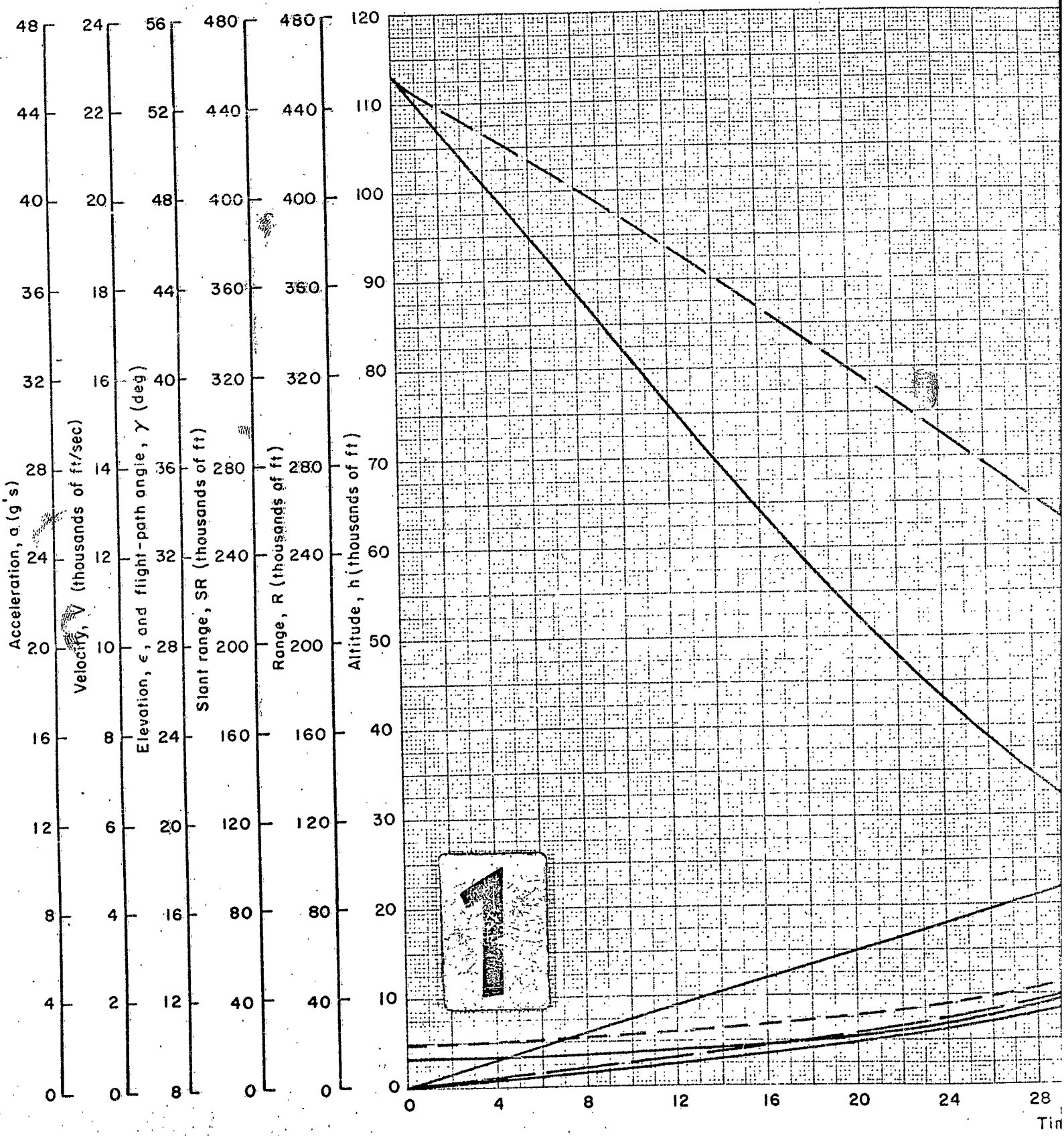

sq ft
V
SR
R
h
γ
ϵ
a
50
60
70
80
90
100
110
120
130
140
150
160
Time to impact (sec)

Fig. A—2


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Time

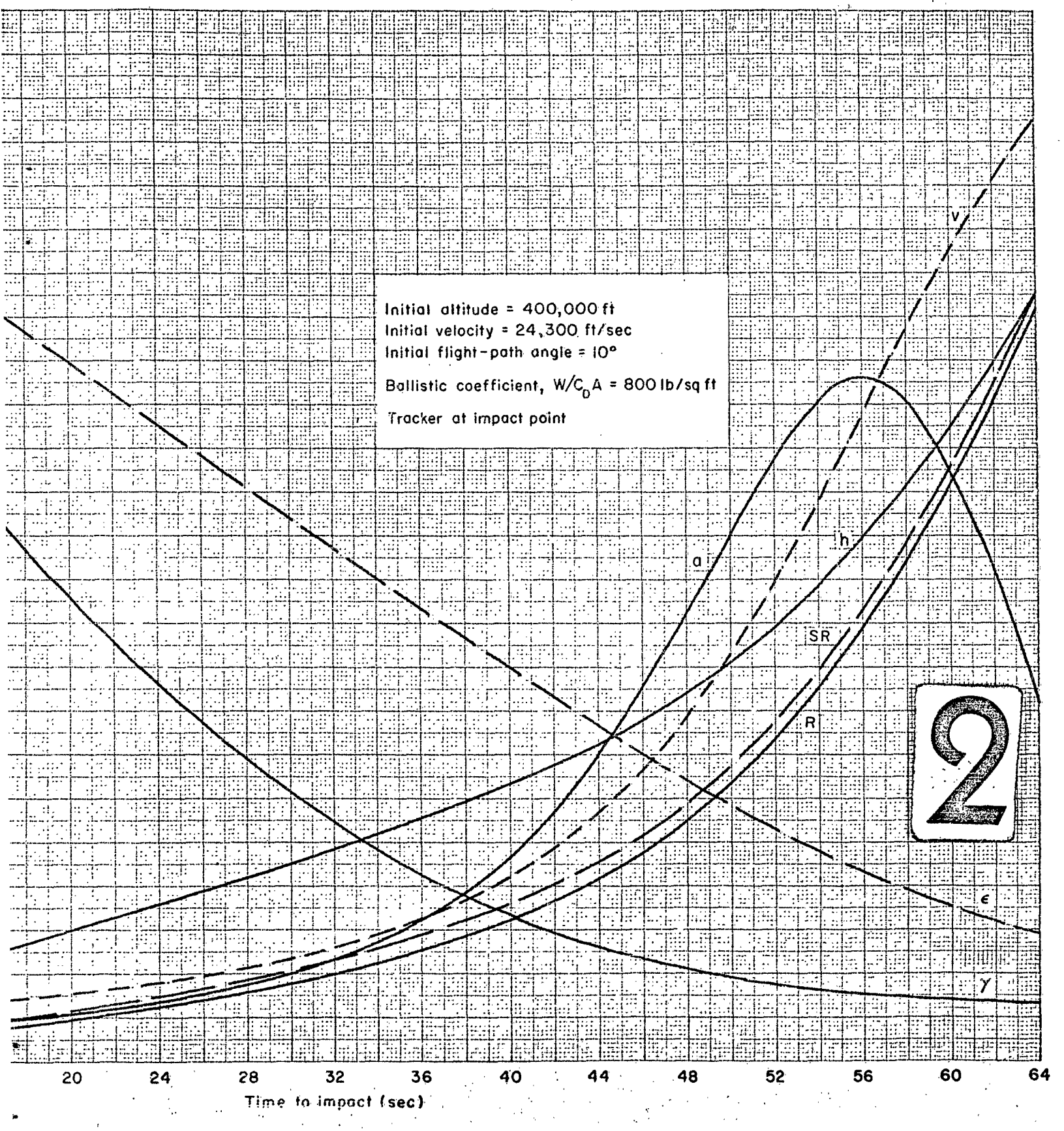
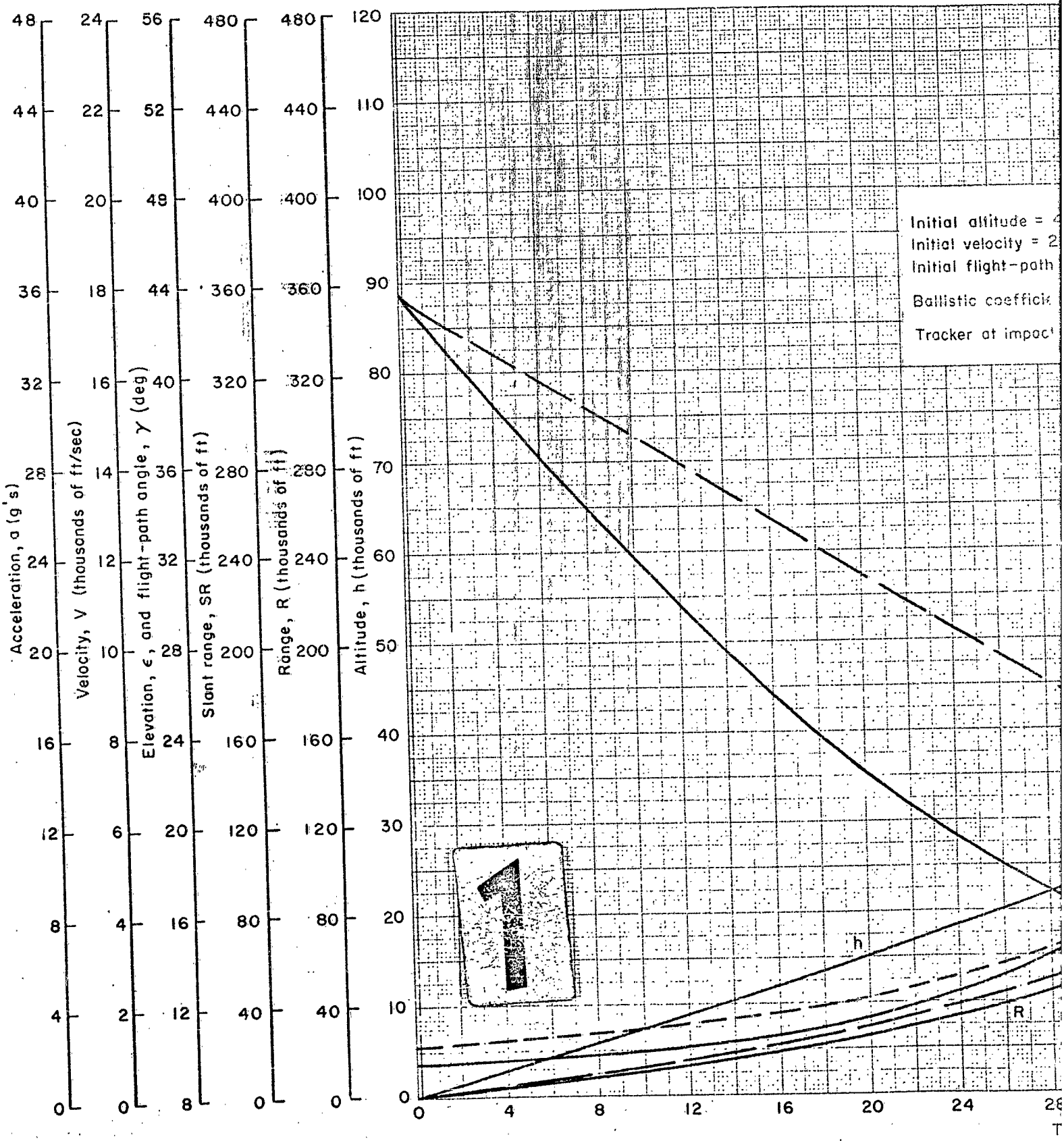

Initial altitude = 400,000 ft
Initial velocity = 24,300 ft/sec
Initial flight-path angle = 10°
Ballistic coefficient, W/C_DA = 800 lb/sq ft
Tracker at impact point
v
h
a
SR
R
ϵ
γ
2
20
24
28
32
36
40
44
48
52
56
60
64
Time to impact (sec)

Fig. A—3


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 4
Initial velocity = 2
Initial flight-path
Ballistic coefficie
Tracker at impact
h
R
0
4
8
12
16
20
24
T

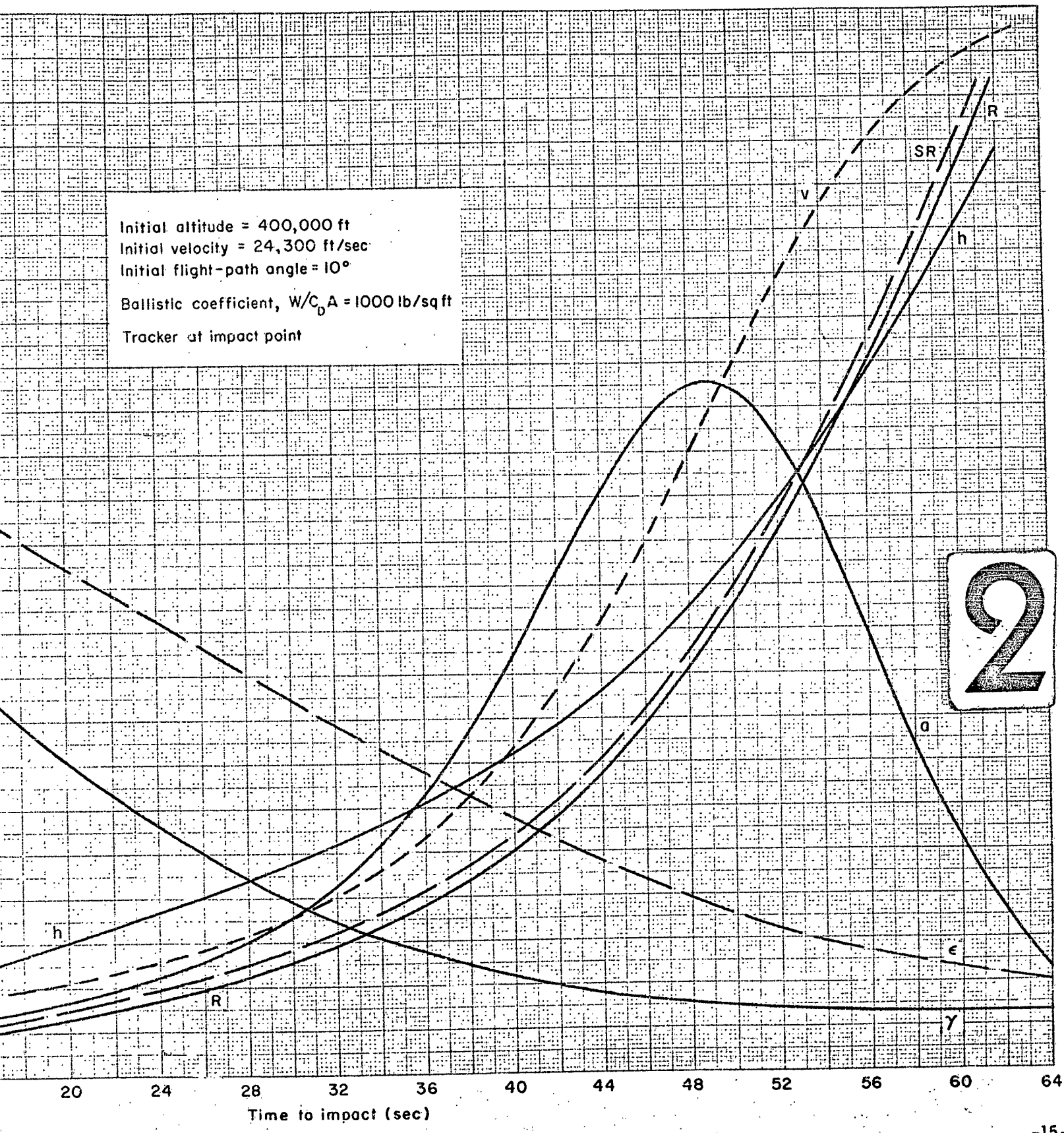
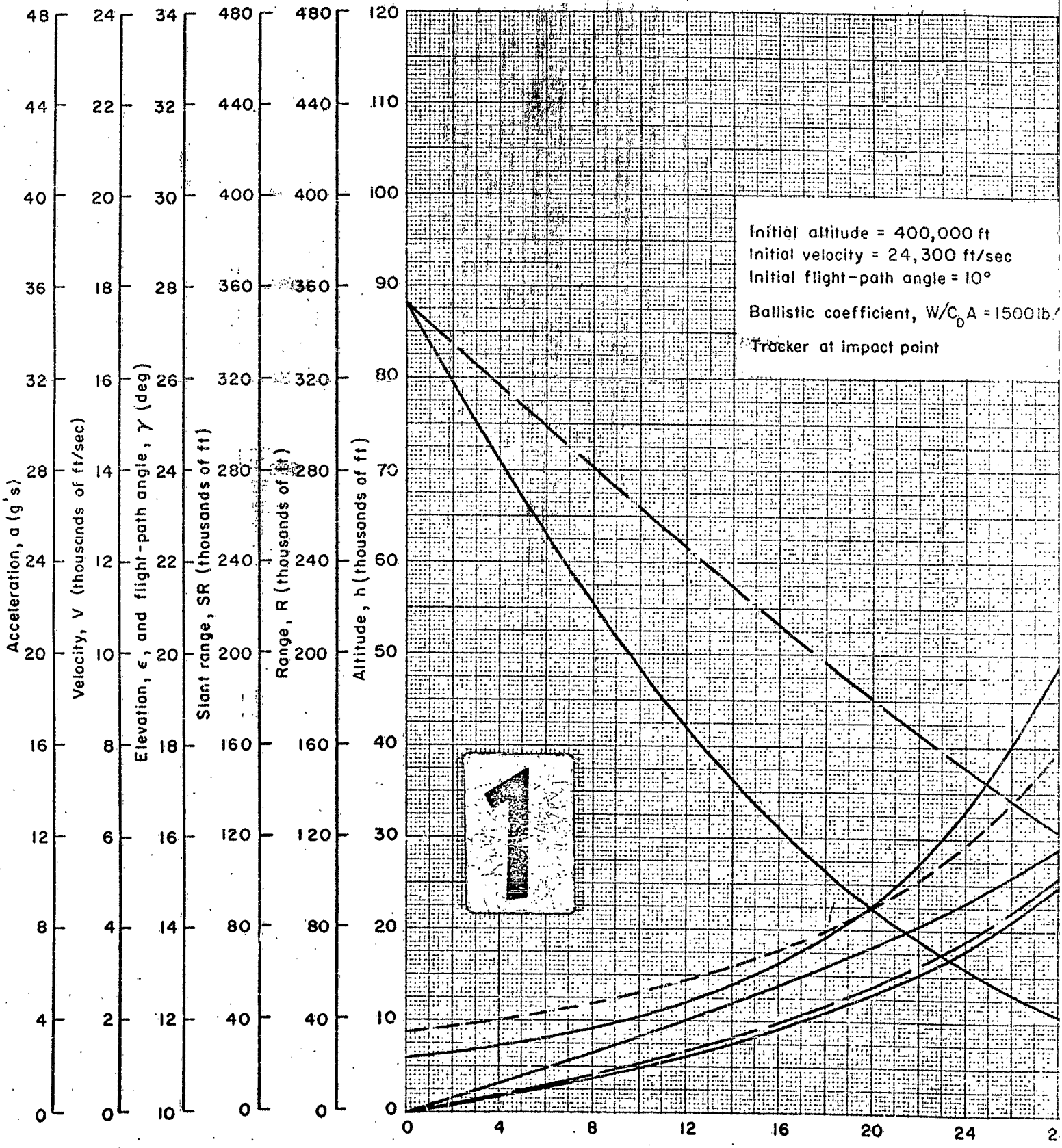

Initial altitude = 400,000 ft
Initial velocity = 24,300 ft/sec
Initial flight-path angle = 10°
Ballistic coefficient, $W/C_D A$ = 1000 lb/sq ft
Tracker at impact point
R
SR
V
h
a
h
R
ϵ
γ
20
24
28
32
36
40
44
48
52
56
60
64
Time to impact (sec)

Fig. A—4


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 24,300 ft/sec
Initial flight-path angle = 10°
Ballistic coefficient, W/C_D A = 1500 lb/
Tracker at impact point
1

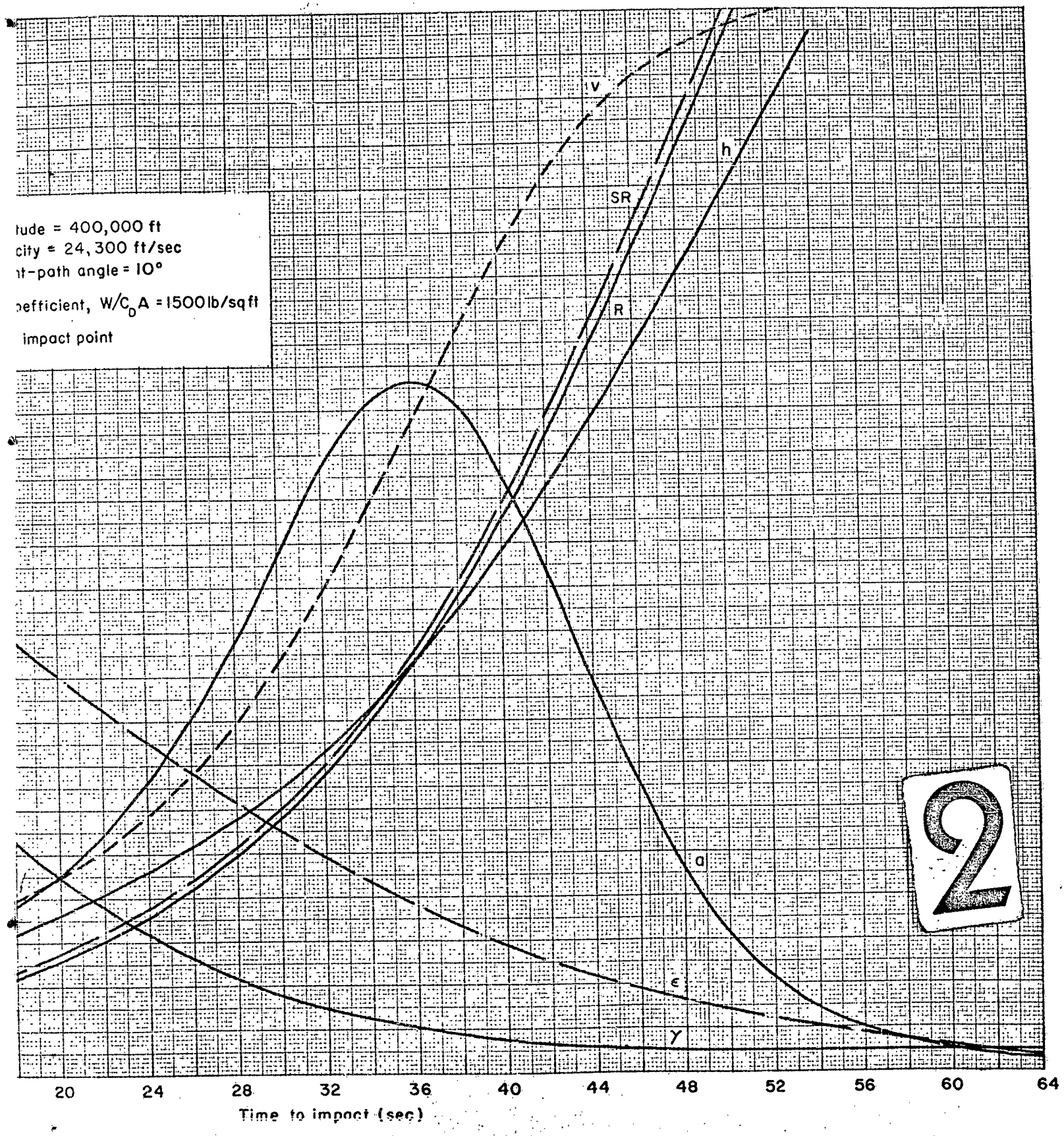
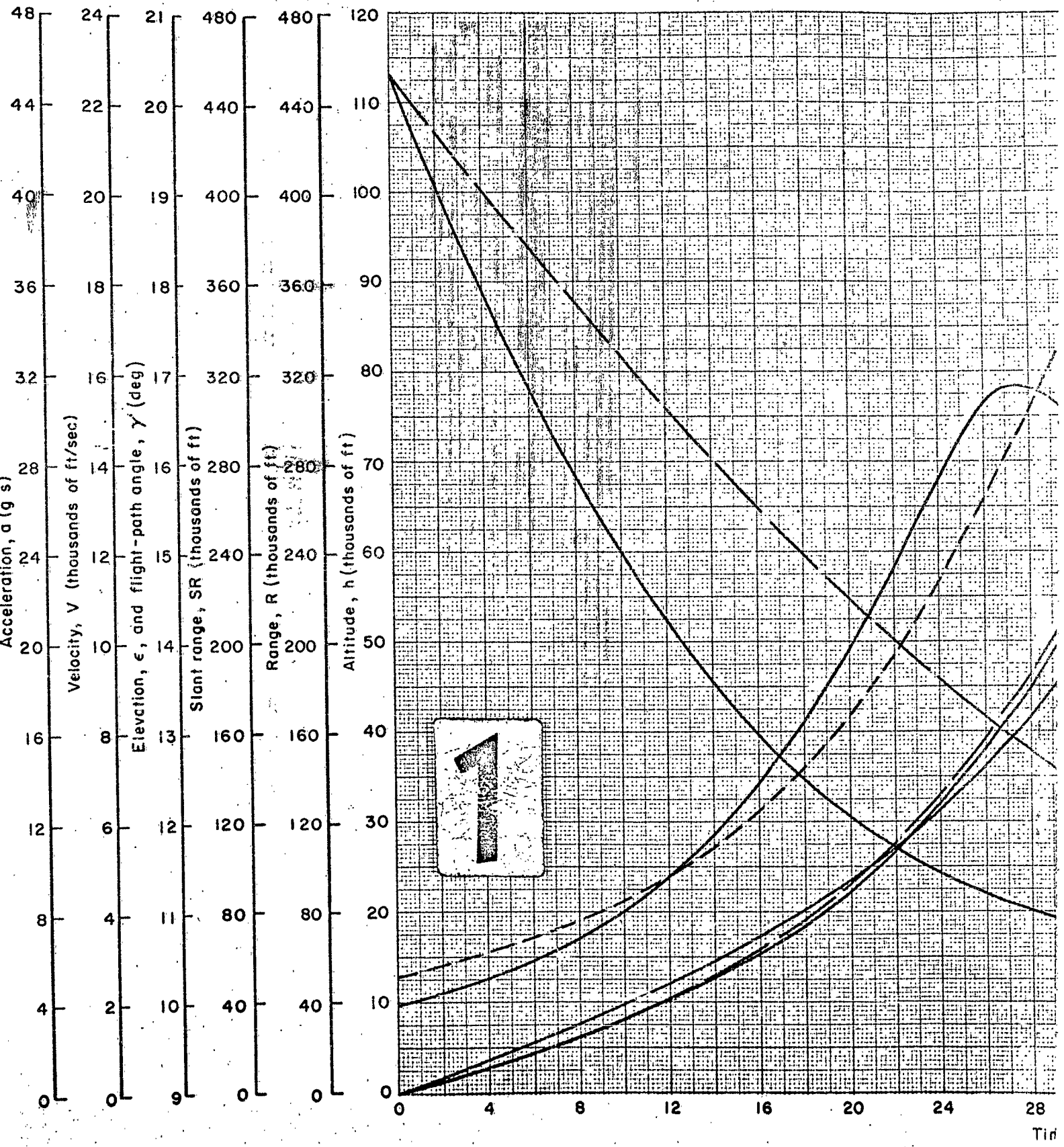

tude = 400,000 ft
city = 24,300 ft/sec
ıt-path angle = 10°
oefficient, W/C_DA = 1500 lb/sq ft
impact point
v
h
SR
R
a
ε
γ
20
24
28
32
36
40
44
48
52
56
60
64
Time to impact (sec)

Fig. A—5


Acceleration, a (g s)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ' (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Tim

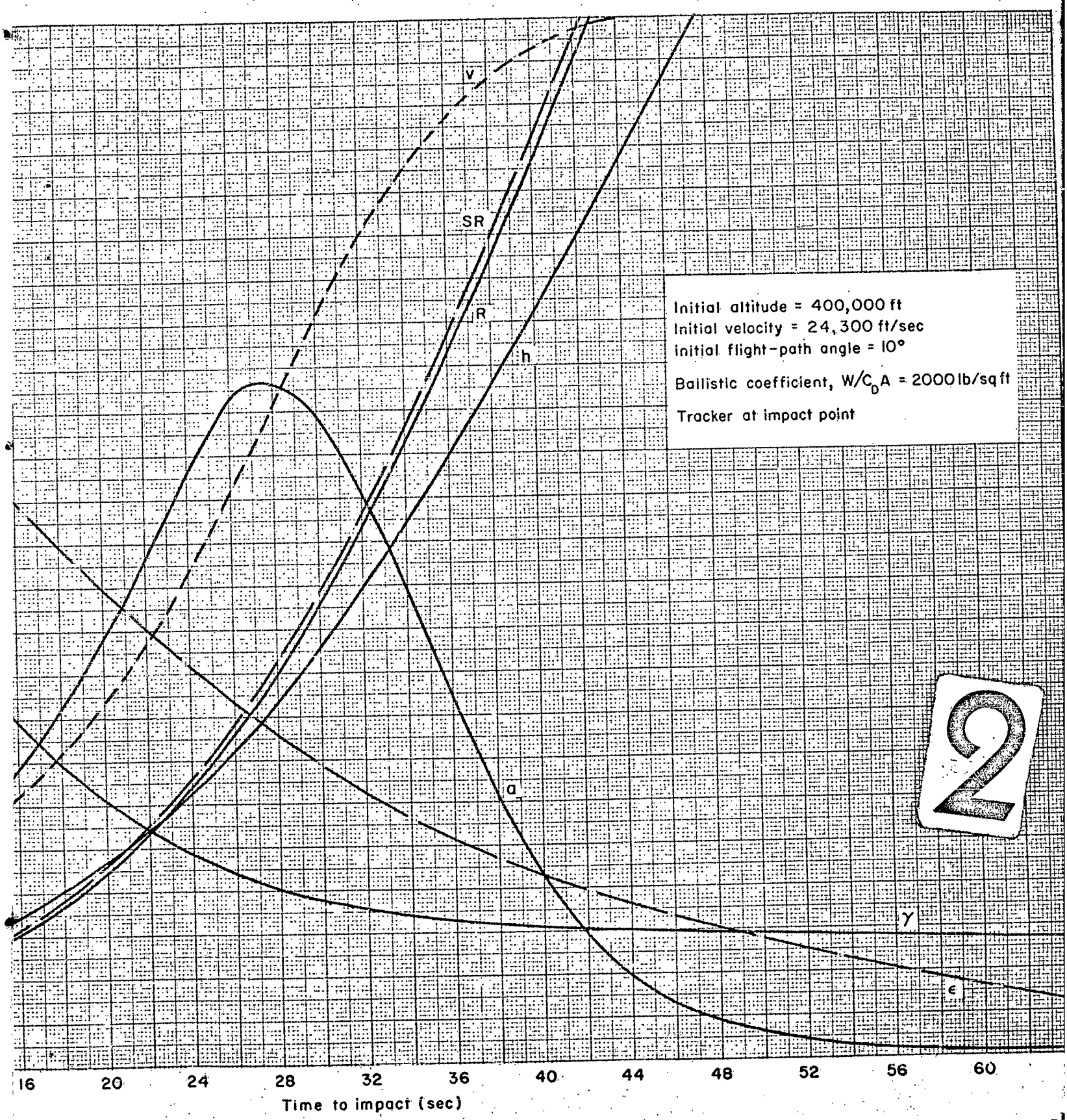

v
SR
R
h
a
γ
ε
Initial altitude = 400,000 ft
Initial velocity = 24,300 ft/sec
initial flight-path angle = 10°
Ballistic coefficient, W/C_DA = 2000 lb/sq ft
Tracker at impact point
16
20
24
28
32
36
40
44
48
52
56
60
Time to impact (sec)

Fig. A—6

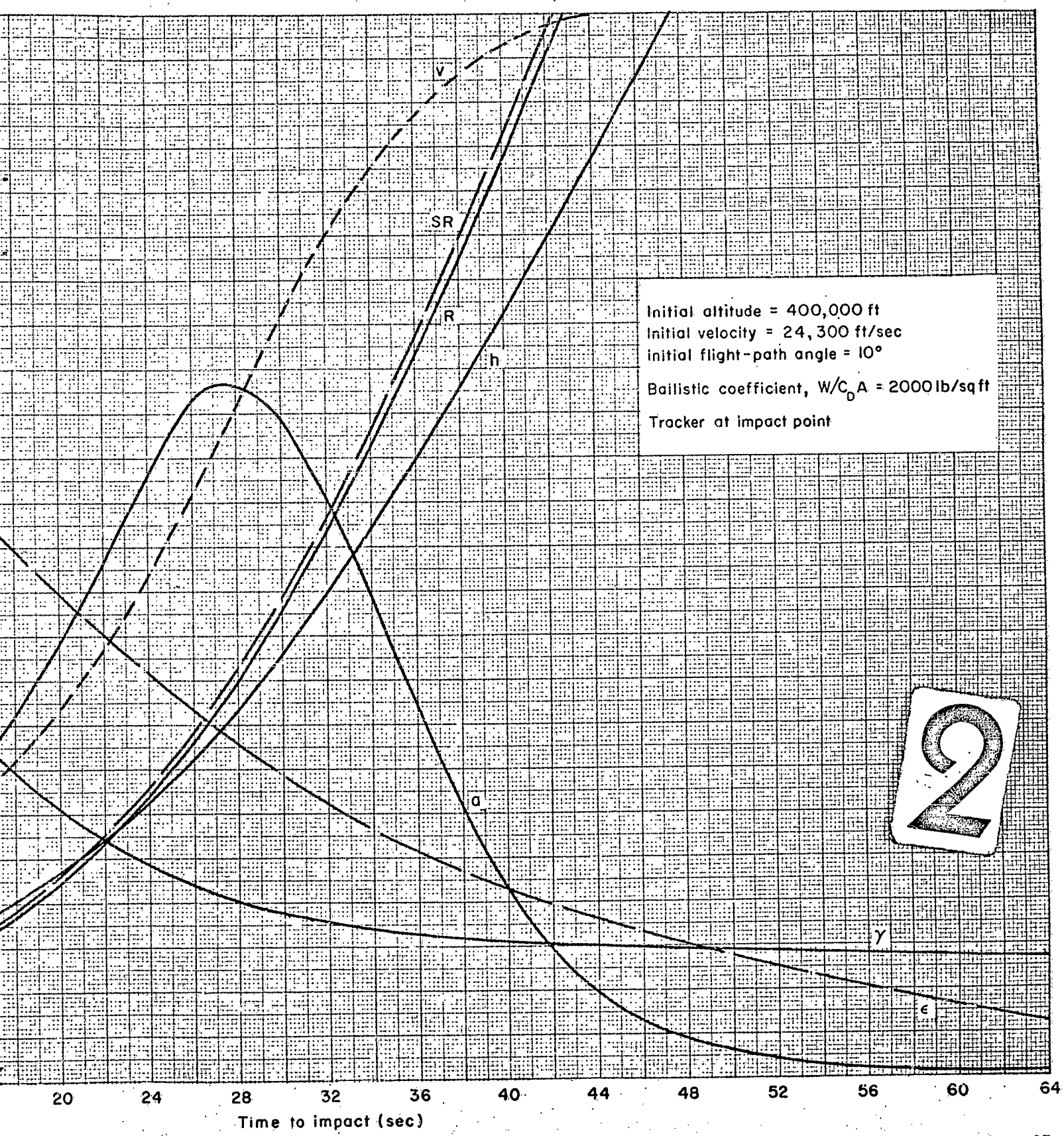
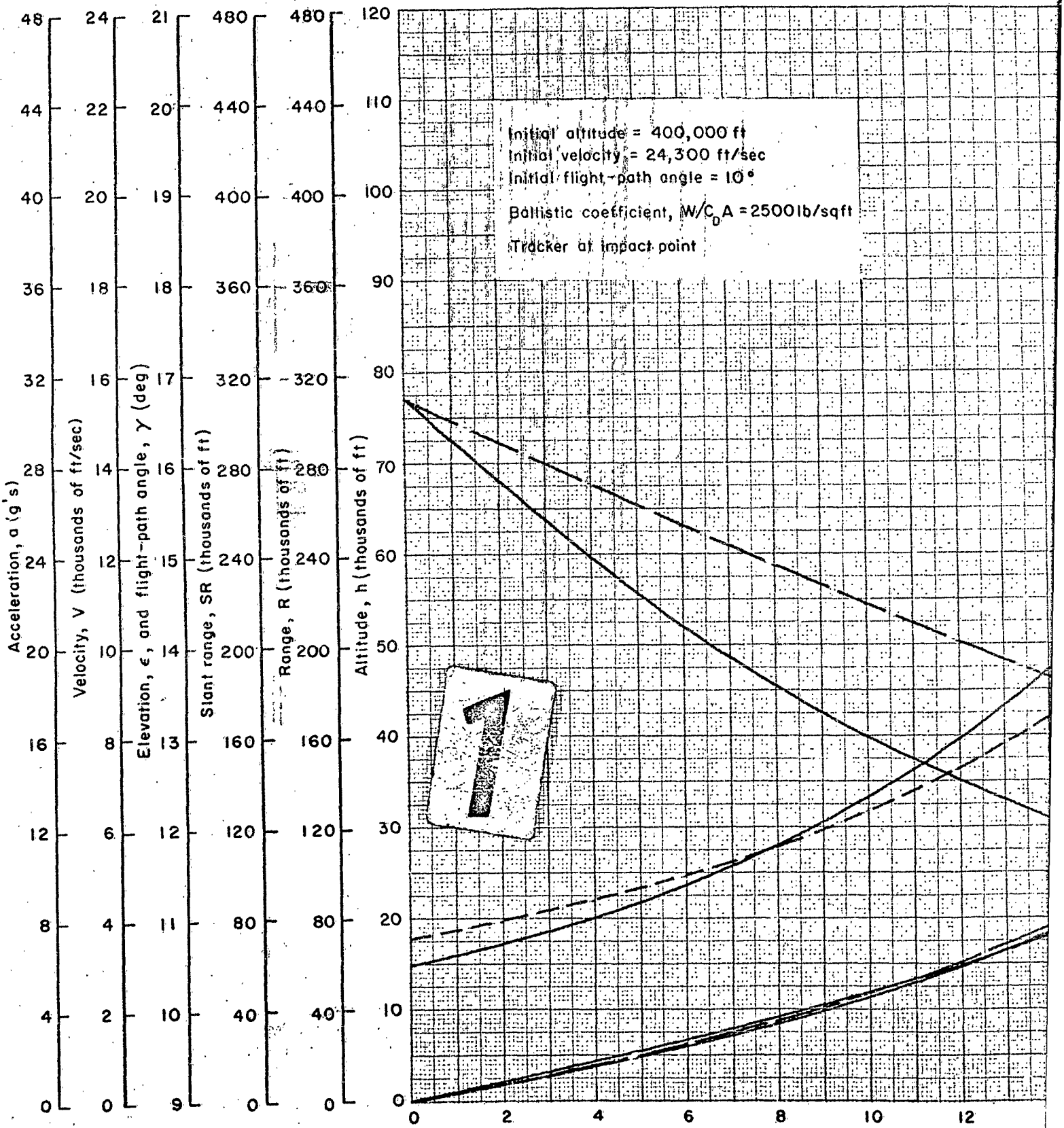

V
SR
R
h
a
γ
ε
Initial altitude = 400,000 ft
Initial velocity = 24,300 ft/sec
initial flight-path angle = 10°
Ballistic coefficient, $W/C_D A$ = 2000 lb/sq ft
Tracker at impact point
20
24
28
32
36
40
44
48
52
56
60
64
Time to impact (sec)

Fig. A—6


Initial altitude = 400,000 ft
Initial velocity = 24,300 ft/sec
Initial flight-path angle = 10°
Ballistic coefficient, $W/C_D A$ = 2500 lb/sqft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)

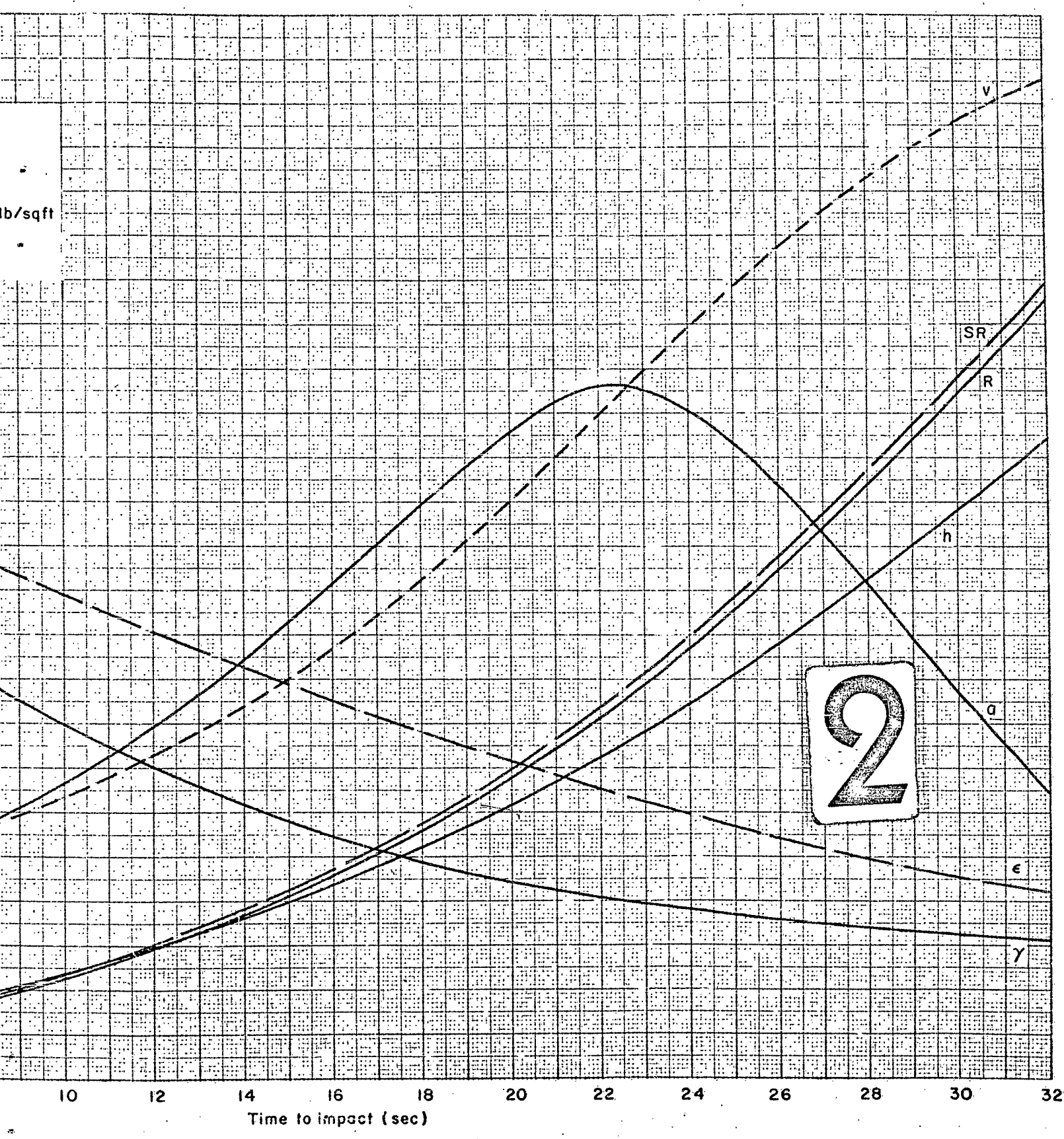
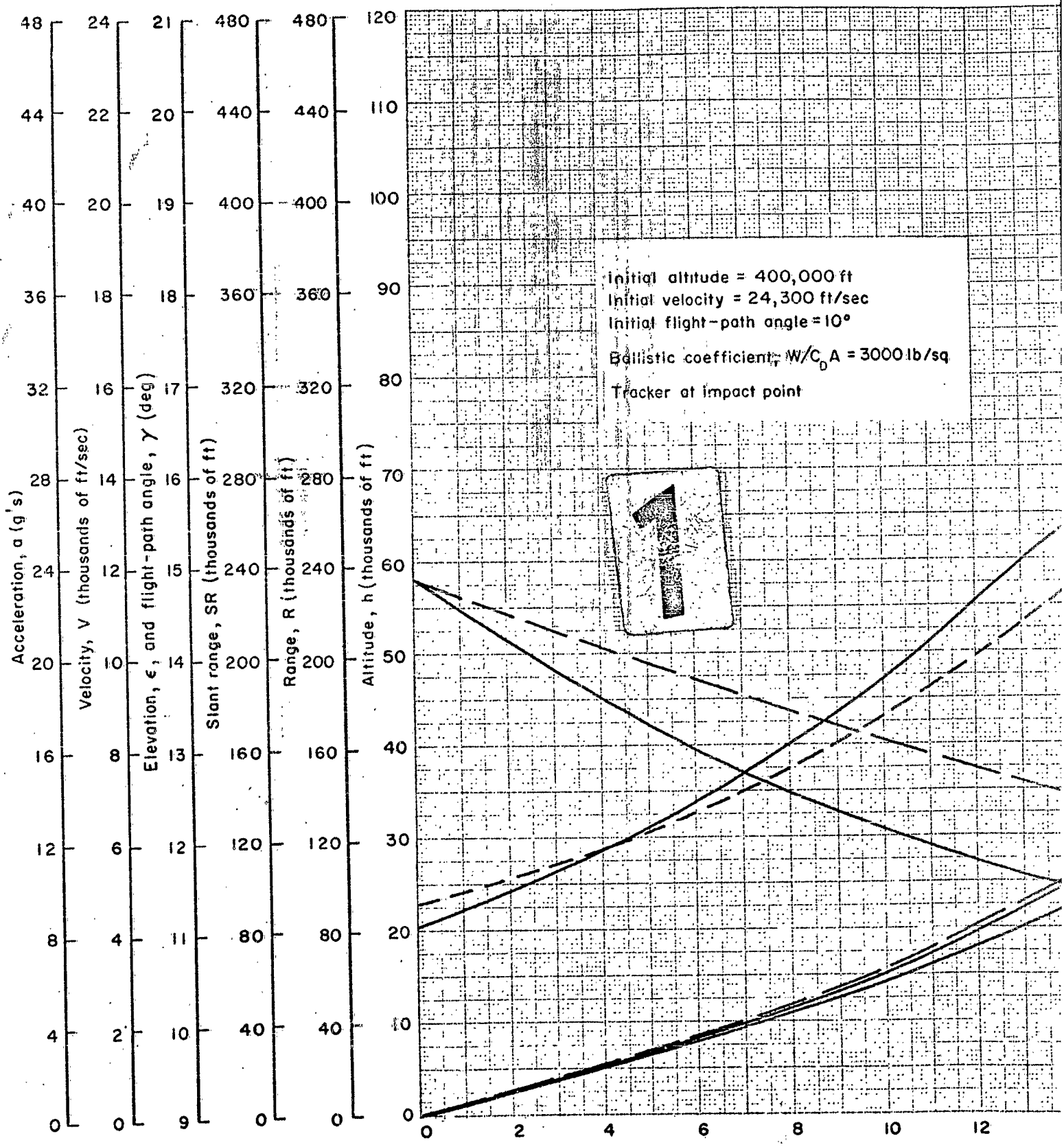

lb/sqft
V
SR
R
h
a
ϵ
γ
2
10
12
14
16
18
20
22
24
26
28
30
32
Time to impact (sec)

Fig. A—7


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 24,300 ft/sec
Initial flight-path angle = 10°
Ballistic coefficient, W/C_D A = 3000 lb/sq
Tracker at impact point

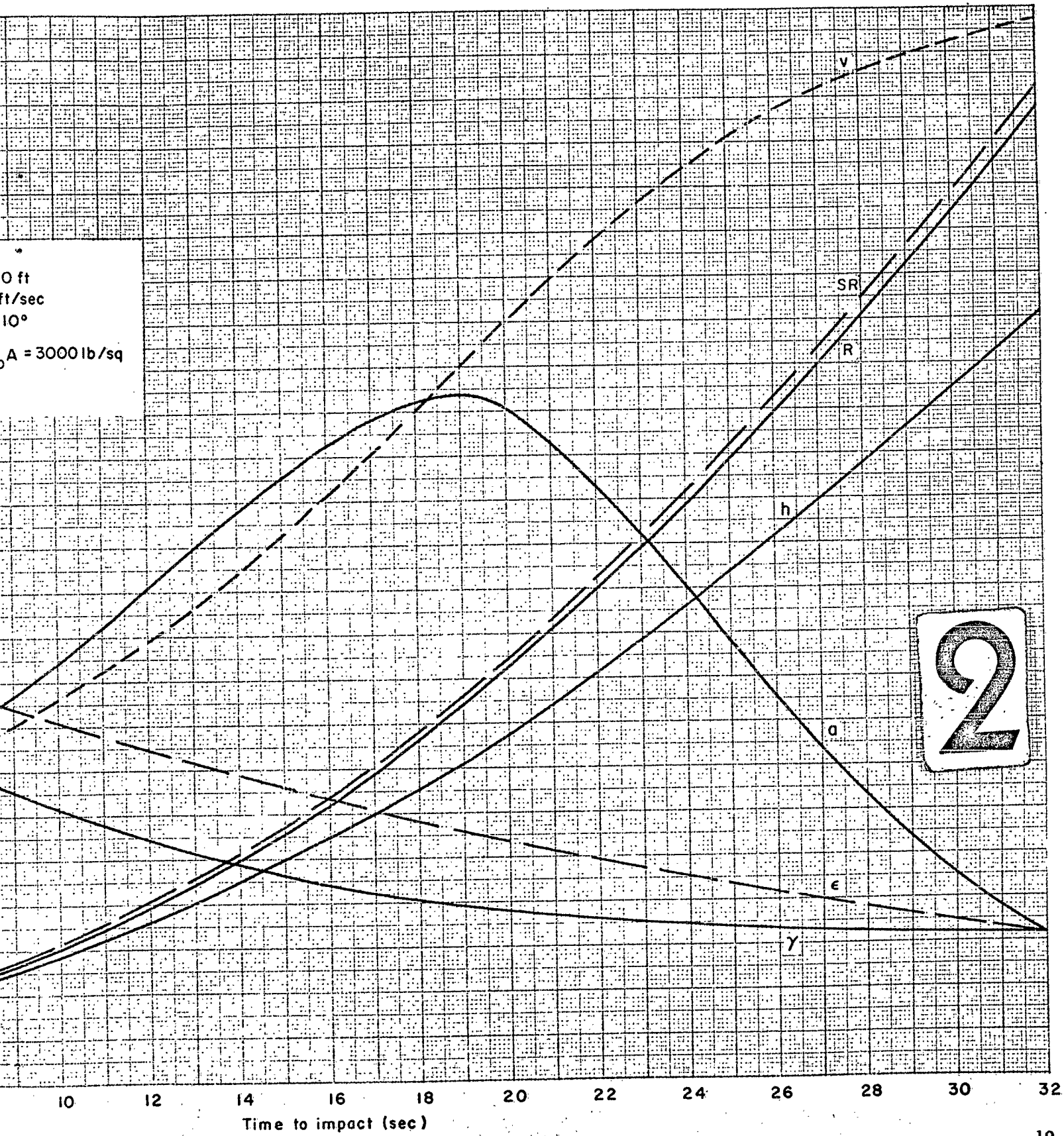
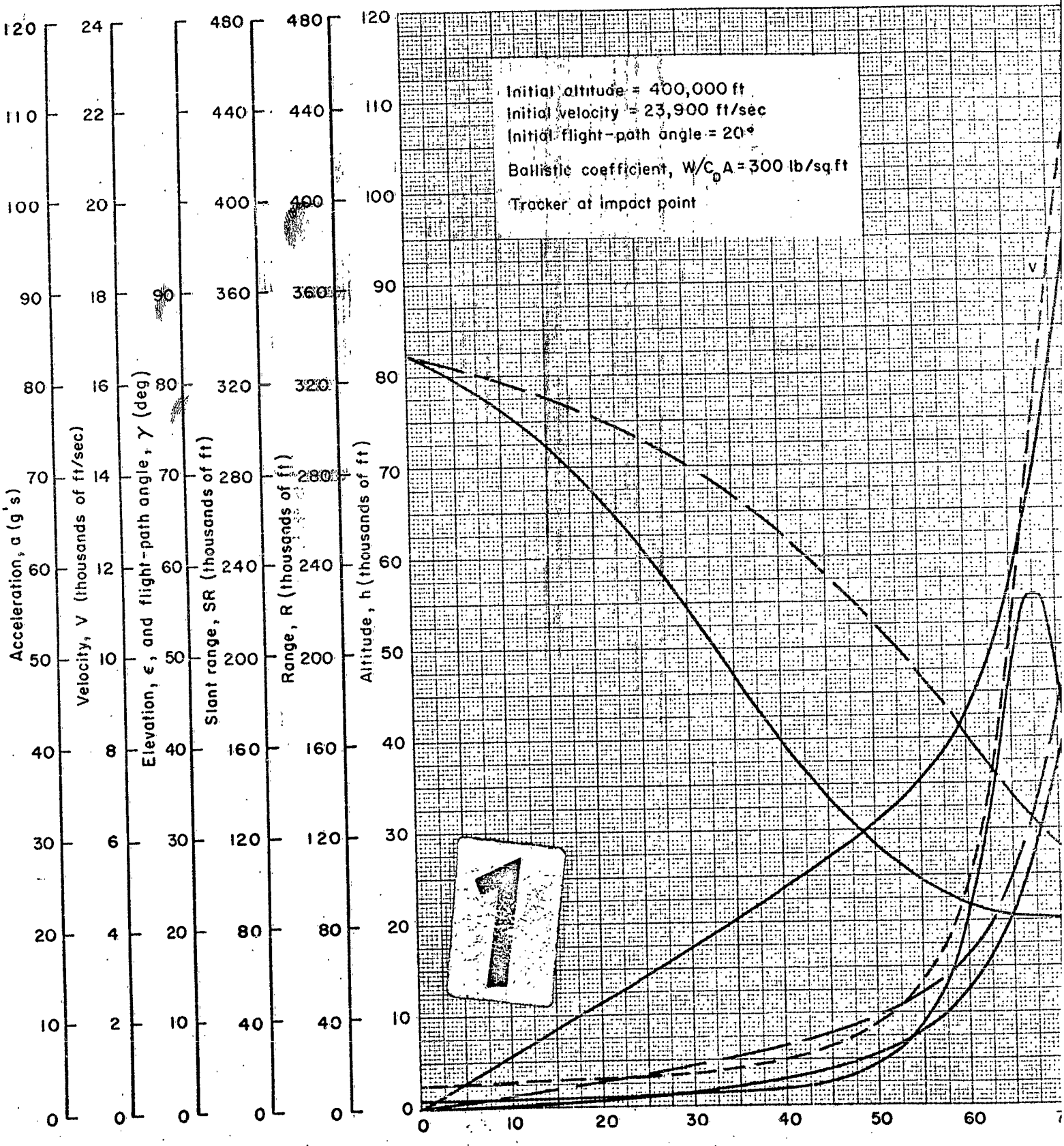

0 ft
ft/sec
10°
A = 3000 lb/sq
V
SR
R
h
a
ϵ
γ
2
10
12
14
16
18
20
22
24
26
28
30
32
Time to impact (sec)

Fig. A—8


Initial altitude = 400,000 ft
Initial velocity = 23,900 ft/sec
Initial flight-path angle = 20°
Ballistic coefficient, W/C_DA = 300 lb/sq ft
Tracker at impact point
V
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)

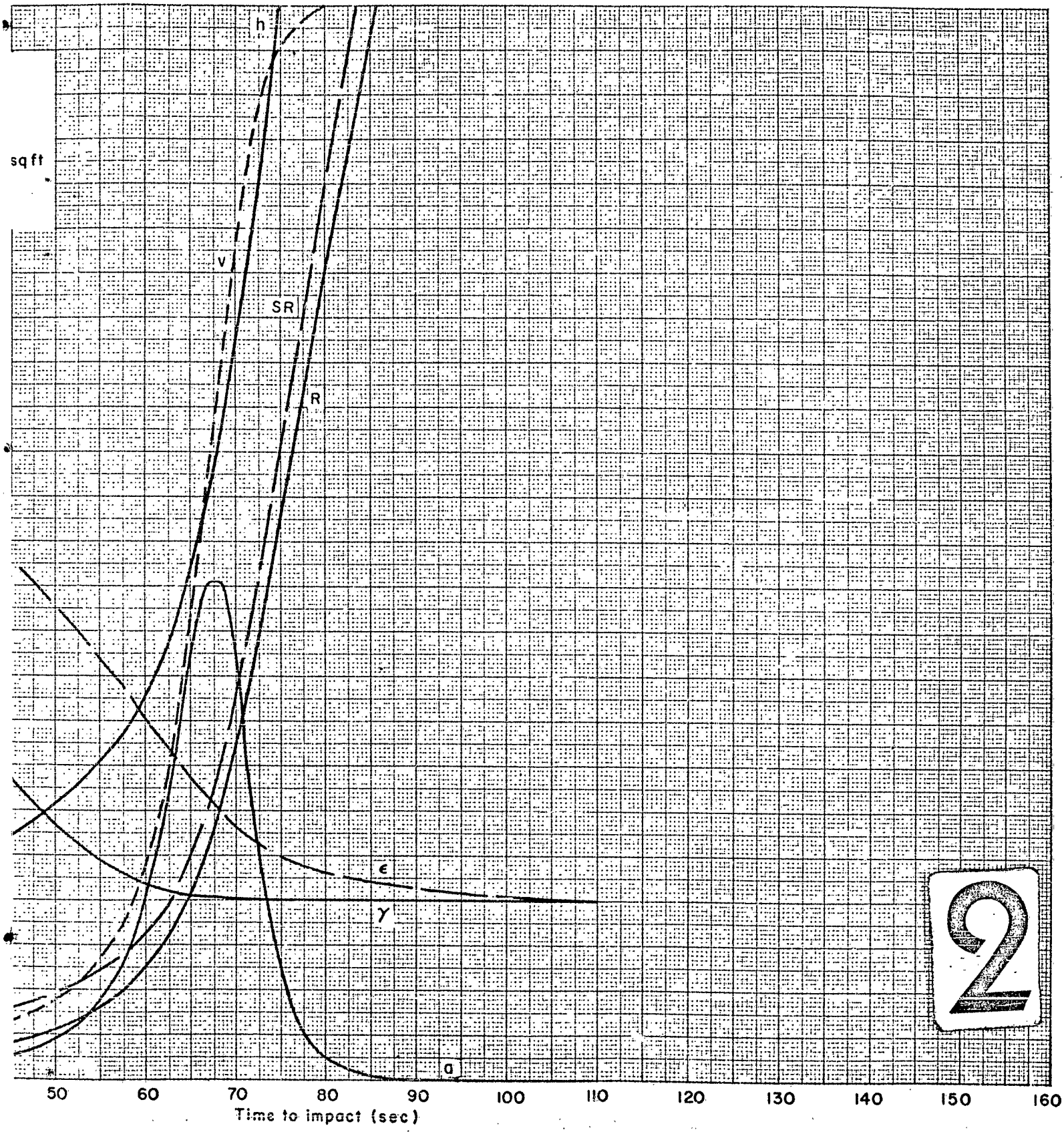
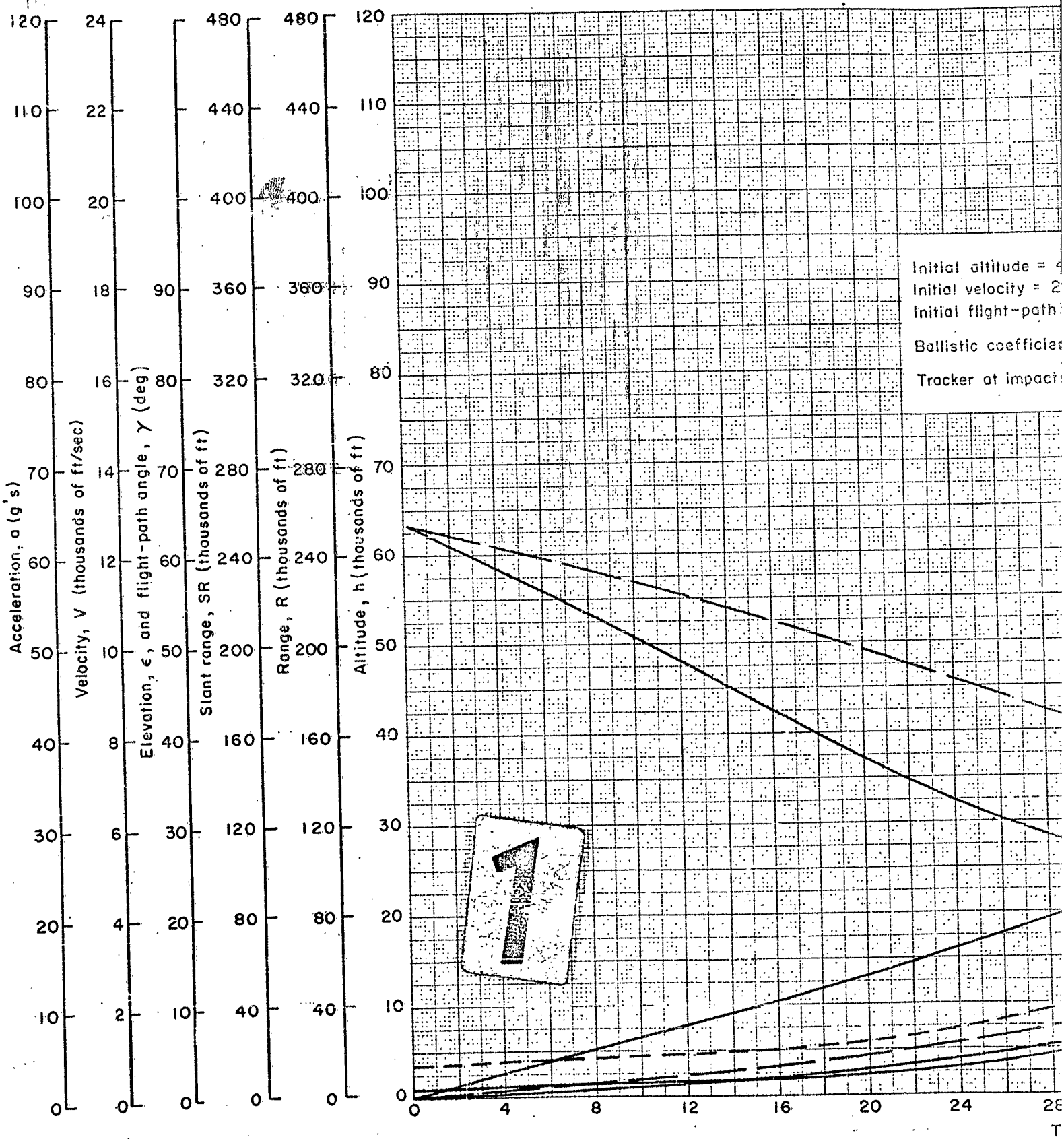

h
sq ft
v
SR
R
ϵ
γ
a
50
60
70
80
90
100
110
120
130
140
150
160
Time to impact (sec)

Fig. A—9


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 4
Initial velocity = 2
Initial flight-path
Ballistic coefficie
Tracker at impact
T

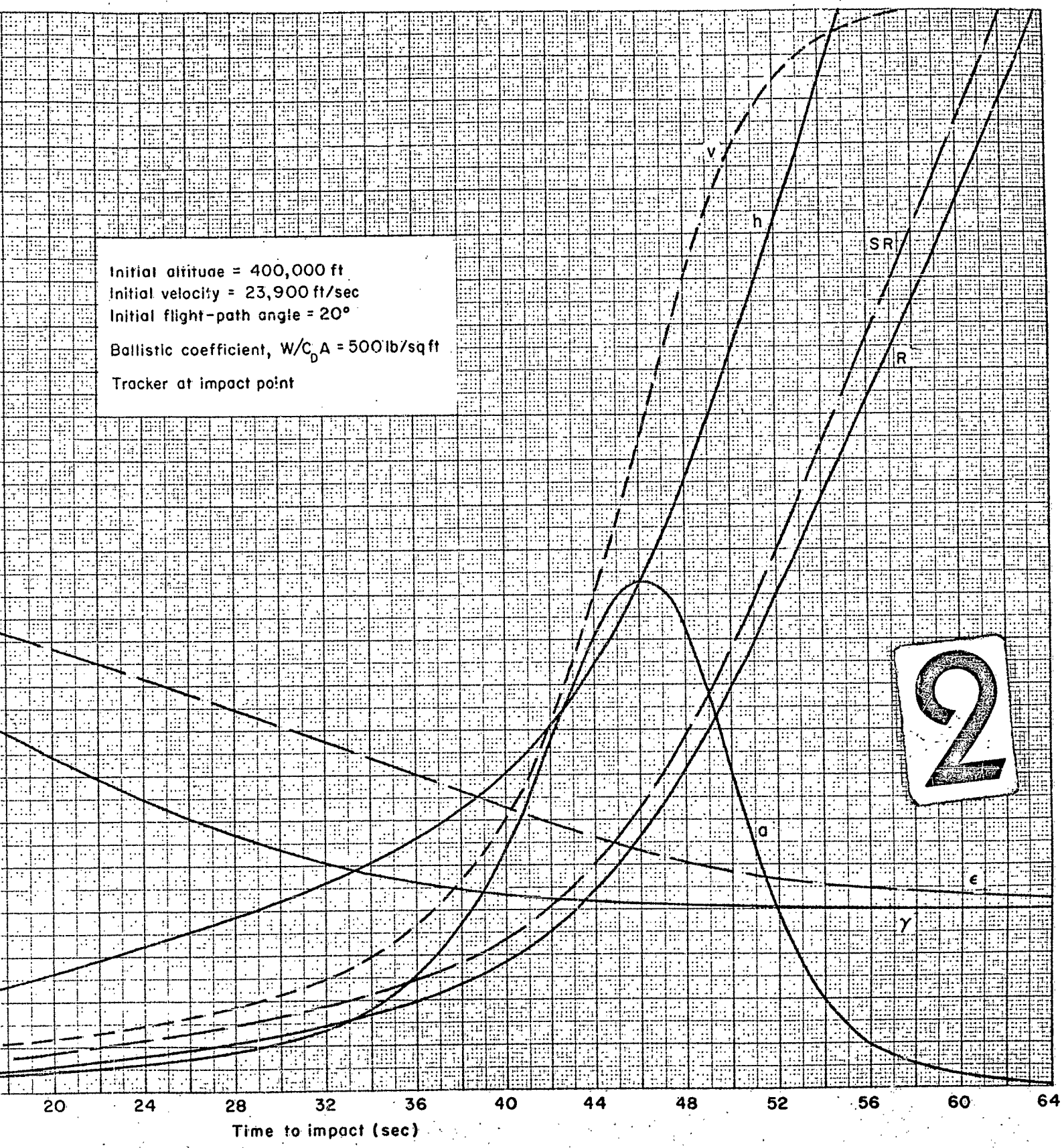
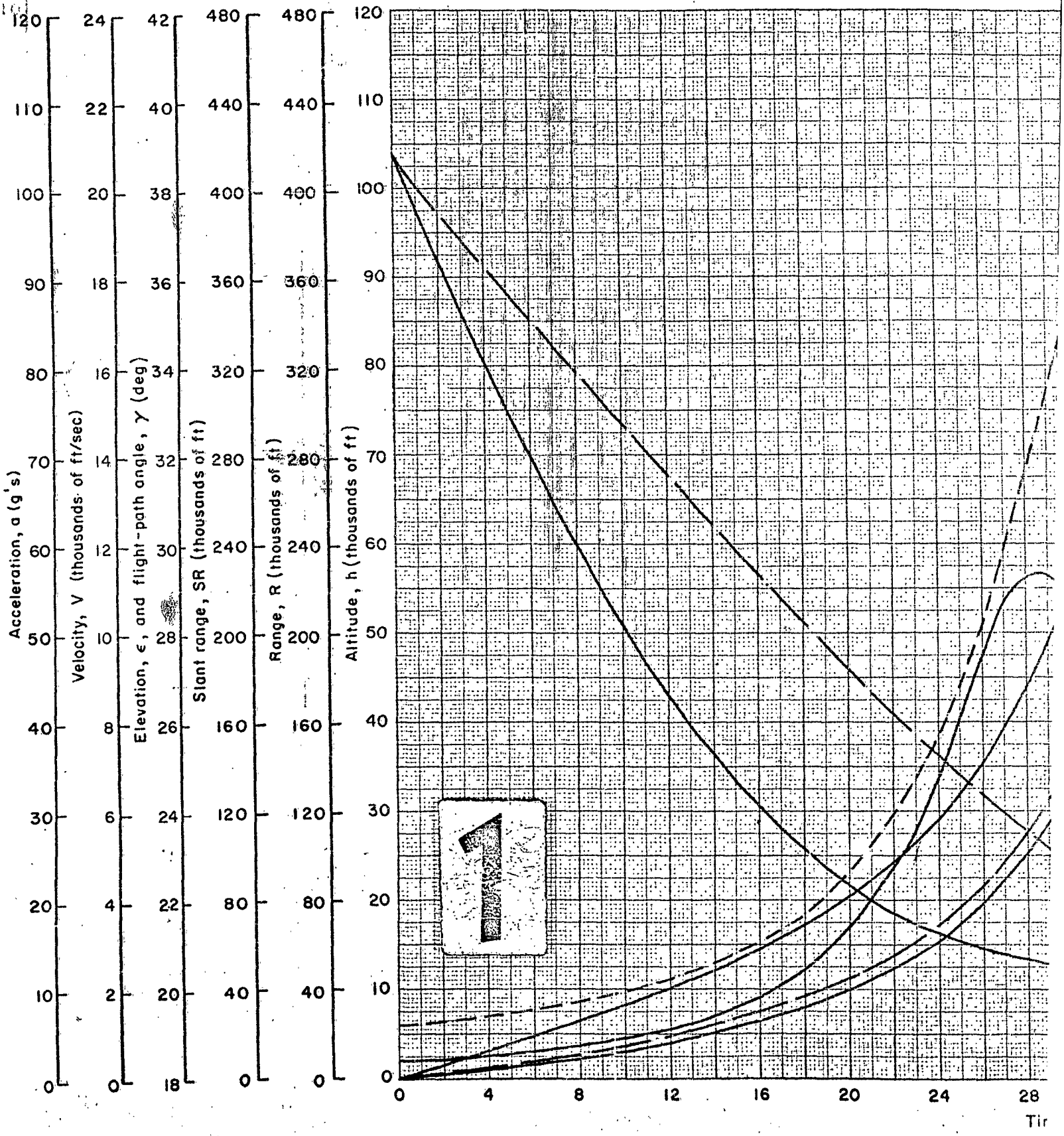

Initial altitude = 400,000 ft
Initial velocity = 23,900 ft/sec
Initial flight-path angle = 20°
Ballistic coefficient, $W/C_D A$ = 500 lb/sq ft
Tracker at impact point
V
h
SR
R
a
ϵ
γ
20
24
28
32
36
40
44
48
52
56
60
64
Time to impact (sec)

Fig. A—10


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Tir

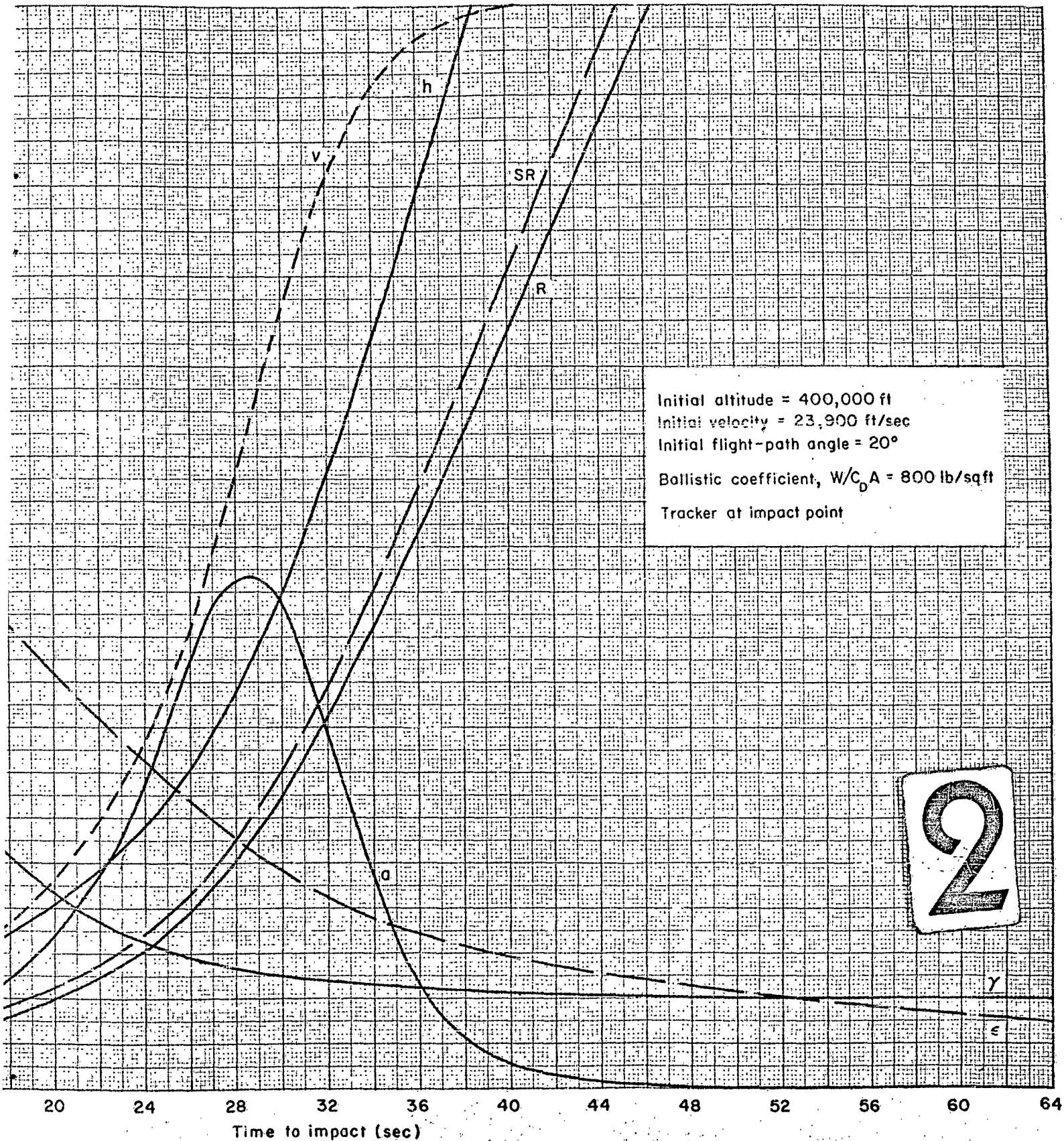
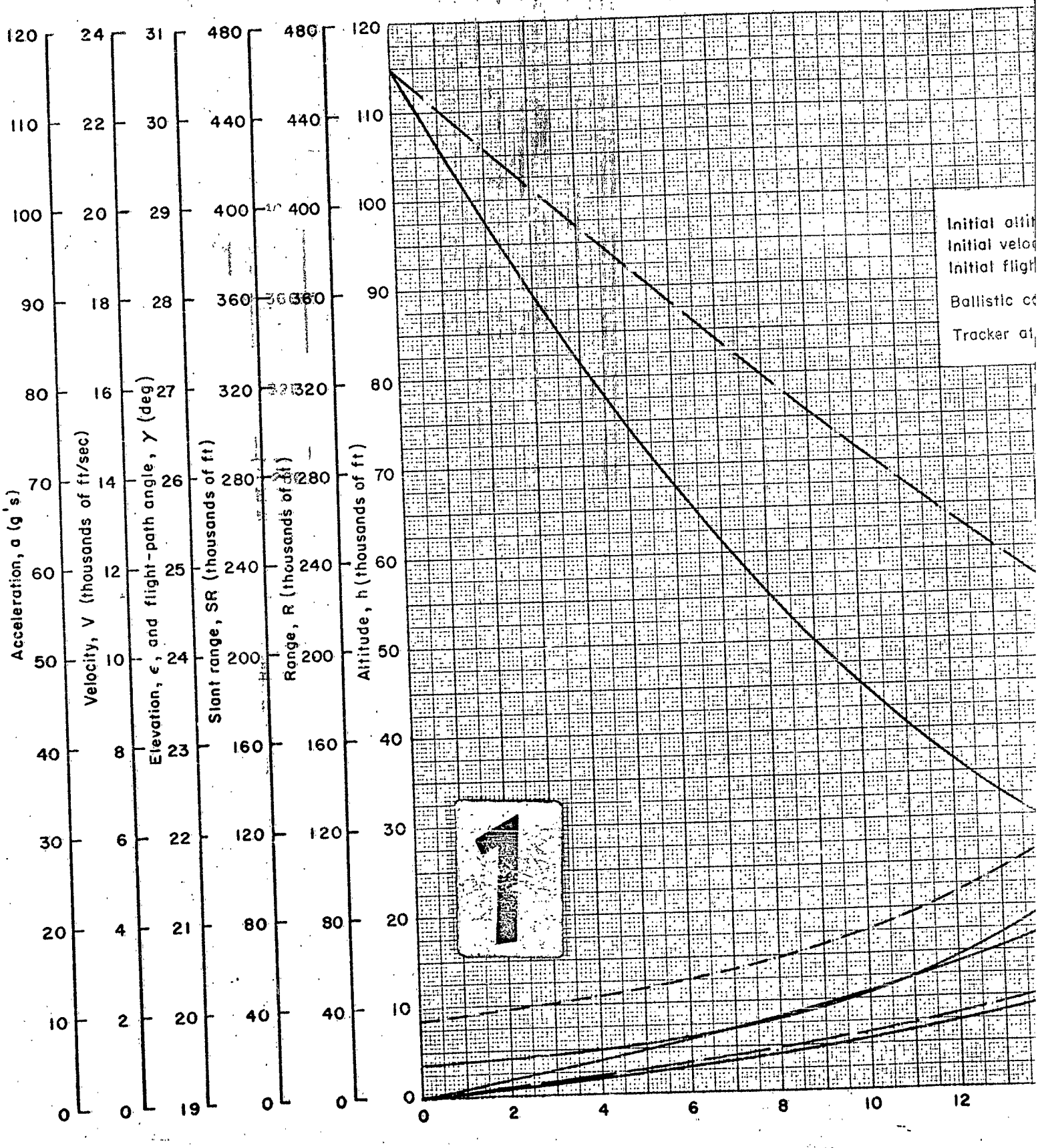

h
v
SR
R
a
γ
ε
Initial altitude = 400,000 ft
Initial velocity = 23,900 ft/sec
Initial flight-path angle = 20°
Ballistic coefficient, $W/C_D A$ = 800 lb/sqft
Tracker at impact point
2
20
24
28
32
36
40
44
48
52
56
60
64
Time to impact (sec)

Fig. A—11


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altit
Initial veloc
Initial fligh
Ballistic co
Tracker at

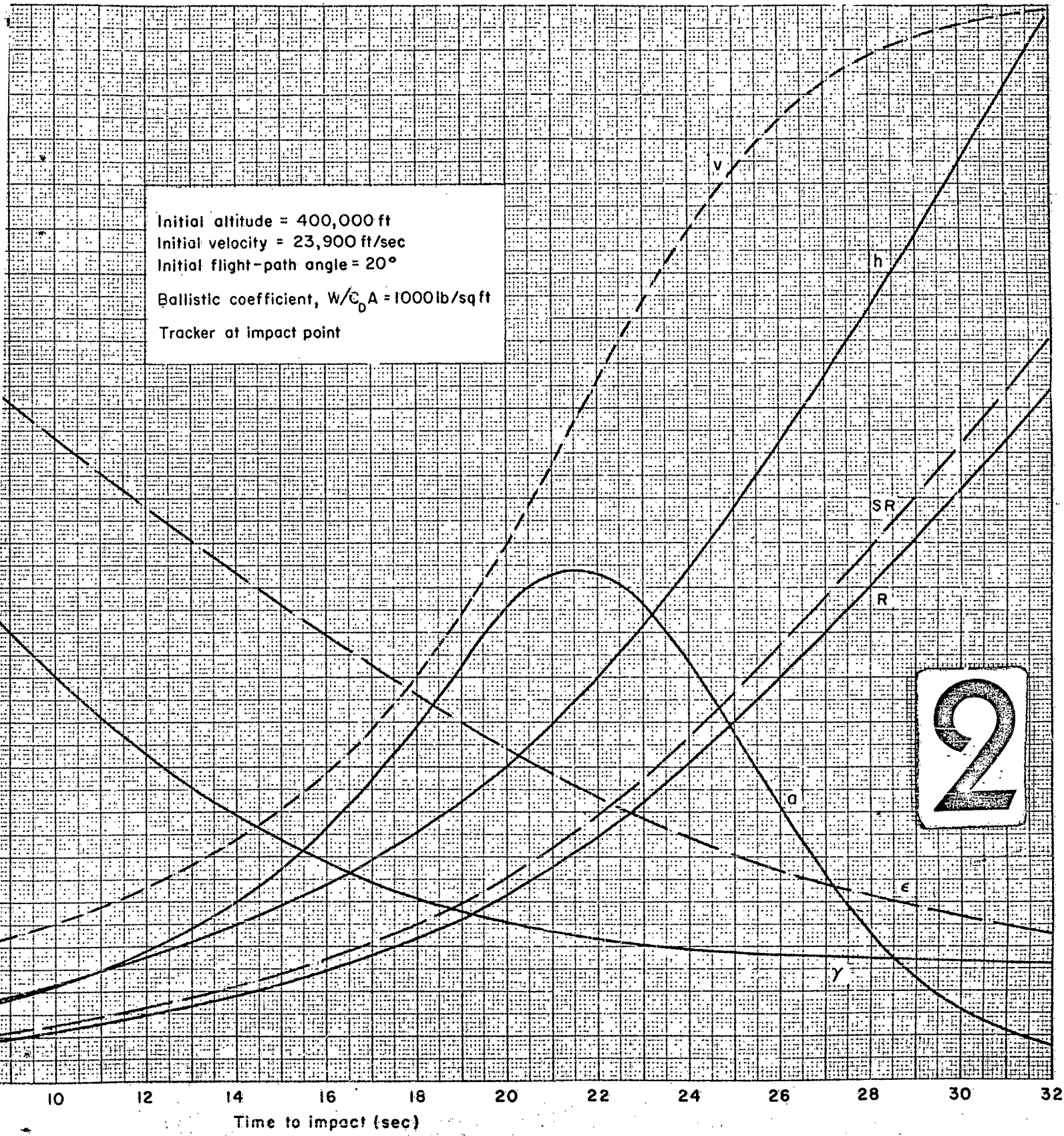
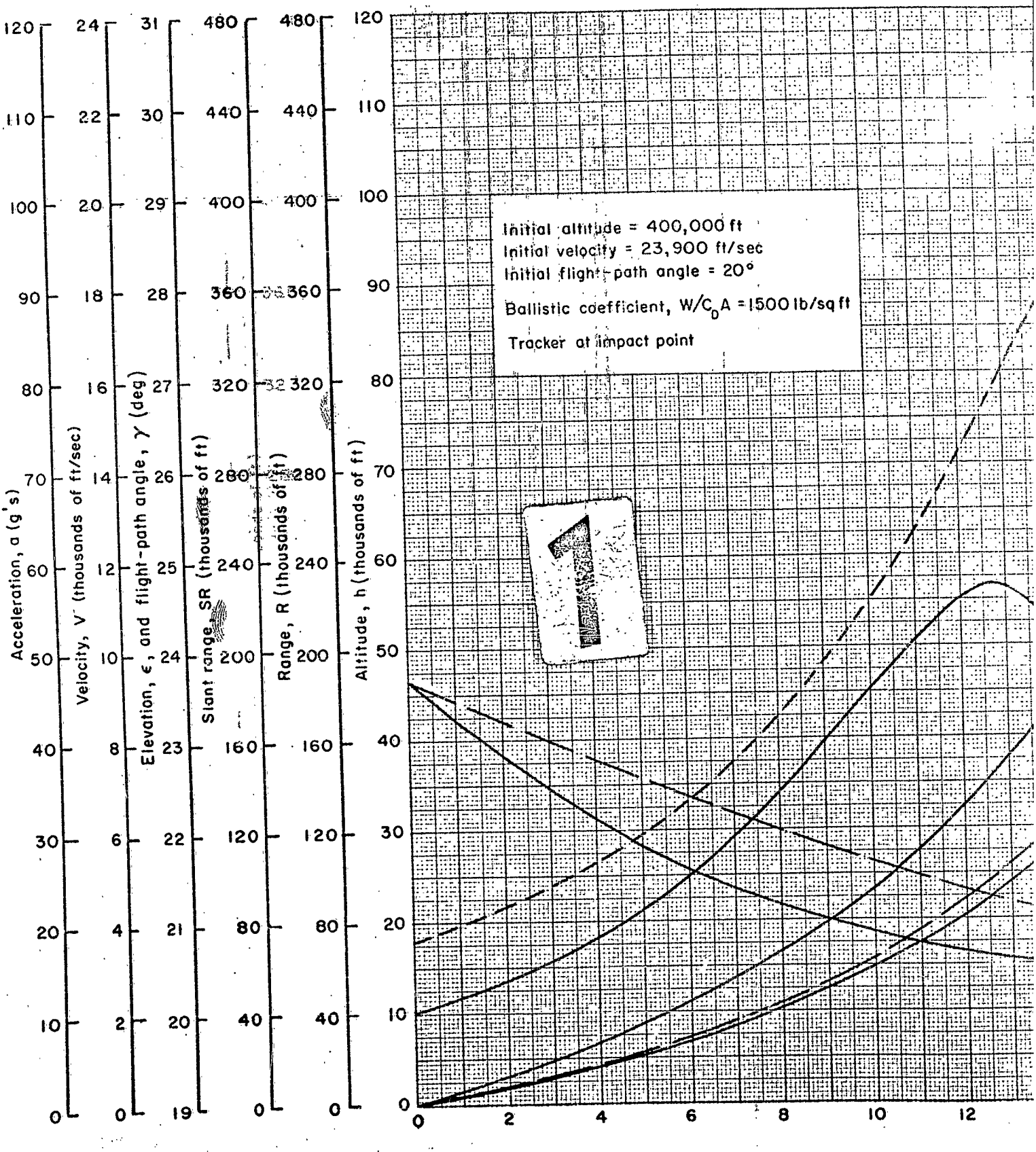

Initial altitude = 400,000 ft
Initial velocity = 23,900 ft/sec
Initial flight-path angle = 20°
Ballistic coefficient, $W/C_D A$ = 1000 lb/sq ft
Tracker at impact point
V
h
SR
R
a
ϵ
γ
2
10
12
14
16
18
20
22
24
26
28
30
32
Time to impact (sec)

Fig. A—12


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 23,900 ft/sec
Initial flight-path angle = 20°
Ballistic coefficient, W/C_DA = 1500 lb/sq ft
Tracker at impact point

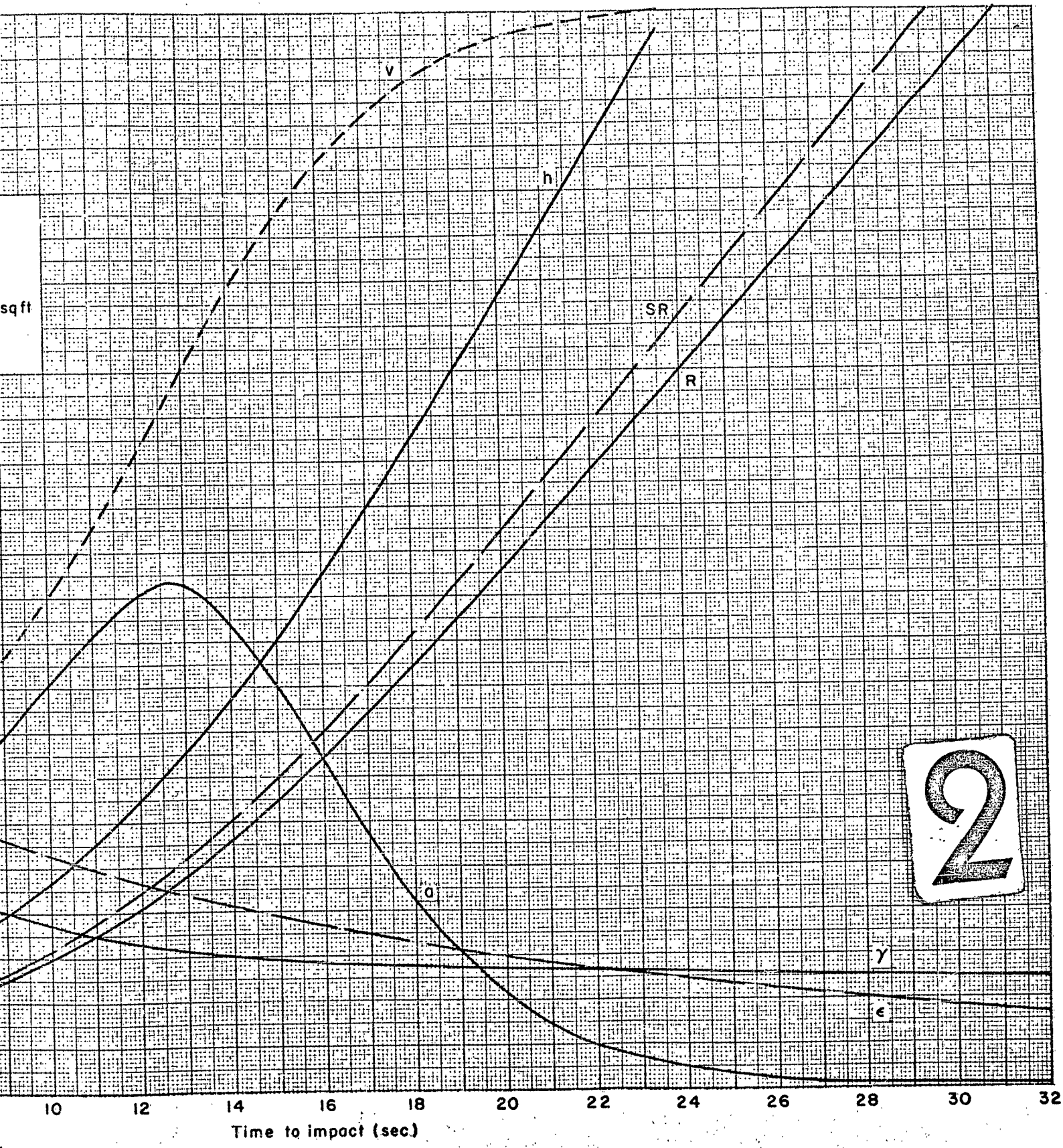
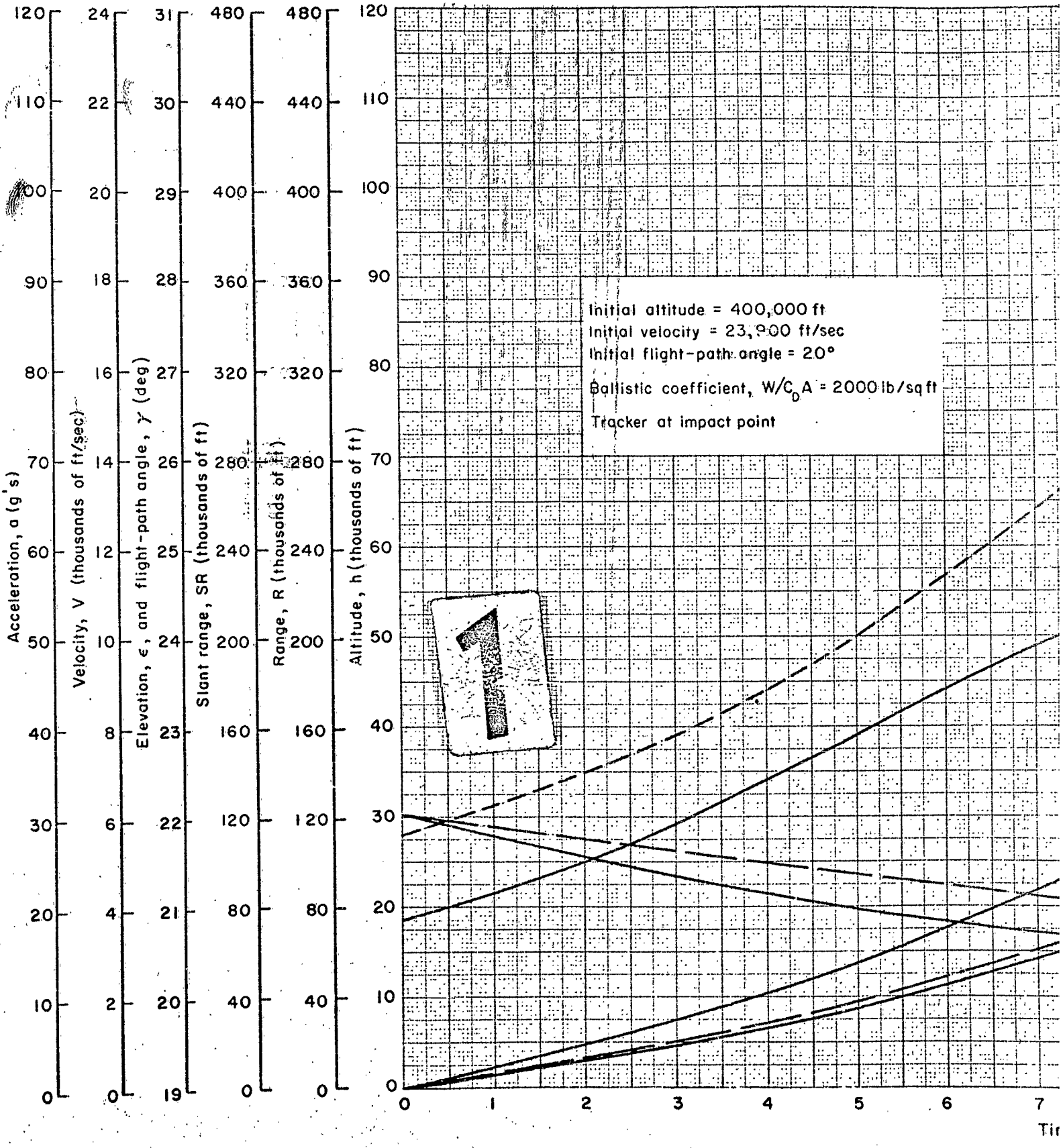

v
h
SR
R
sq ft
a
γ
ϵ
2
10
12
14
16
18
20
22
24
26
28
30
32
Time to impact (sec)

Fig. A—13


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 23,900 ft/sec
Initial flight-path angle = 20°
Ballistic coefficient, W/C_DA = 2000 lb/sq ft
Tracker at impact point
Tir

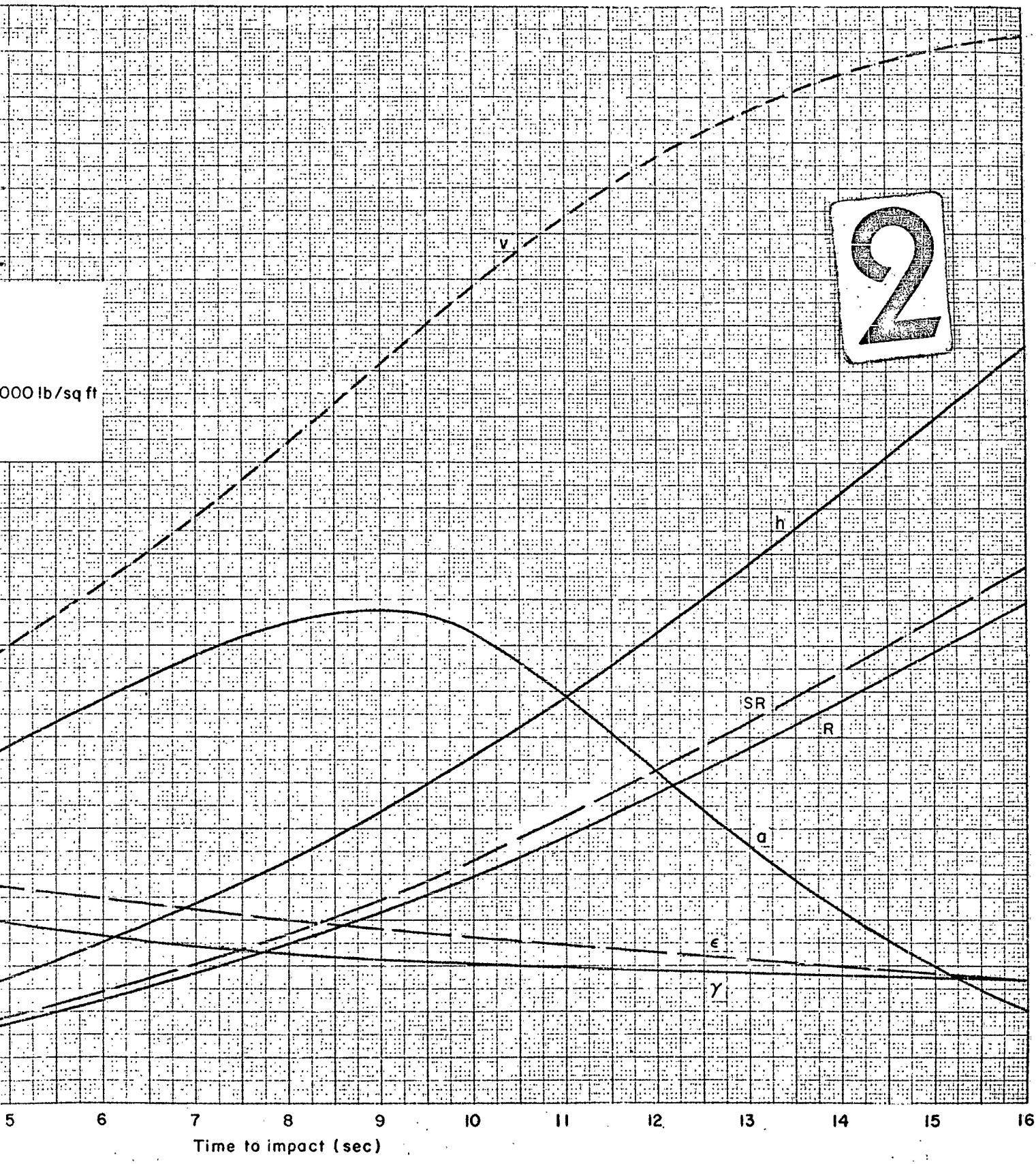
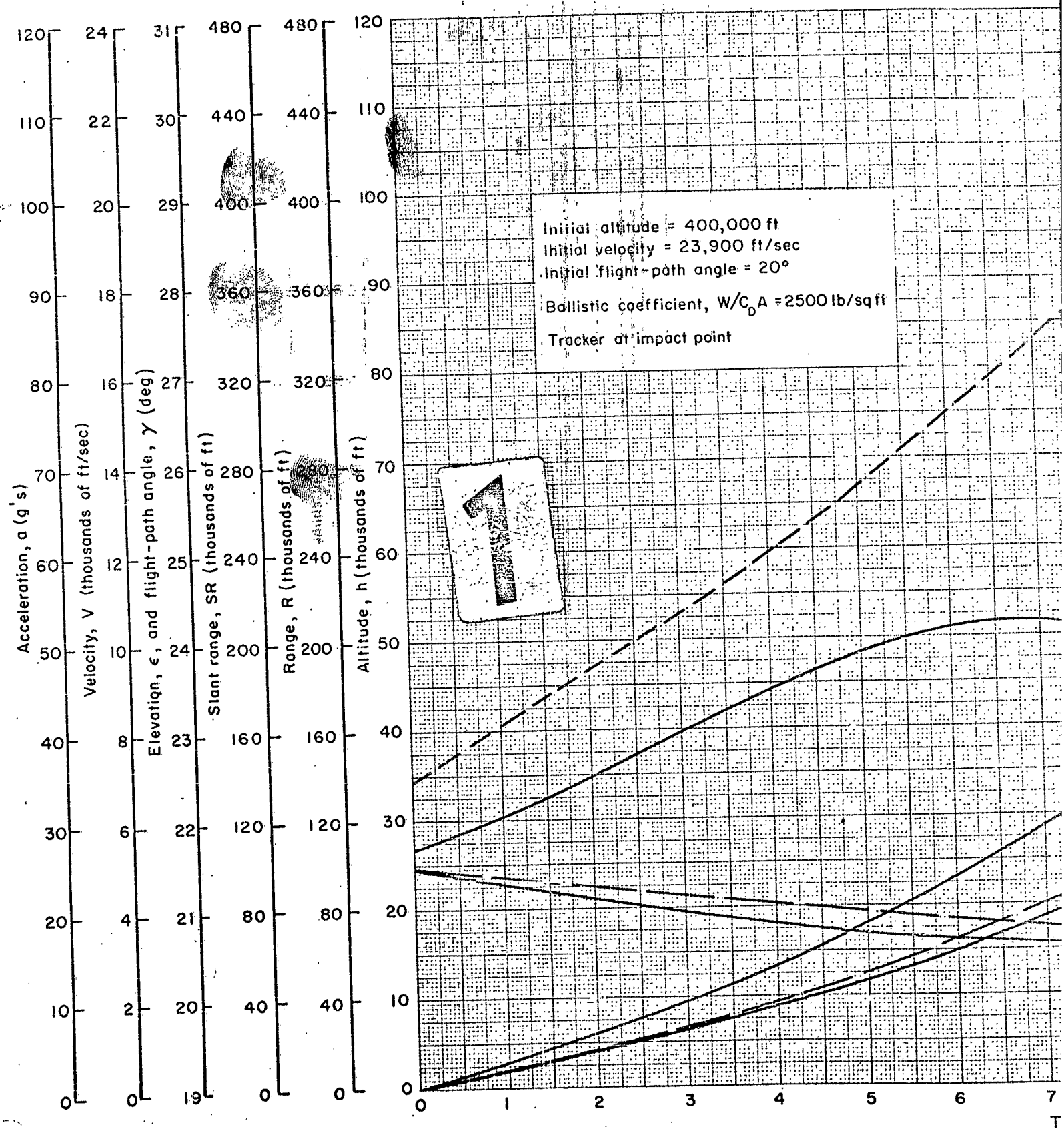

000 lb/sq ft
V
h
SR
R
a
ϵ
γ
5
6
7
8
9
10
11
12
13
14
15
16
Time to impact (sec)

Fig. A—14


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 23,900 ft/sec
Initial flight-path angle = 20°
Ballistic coefficient, W/C_D A = 2500 lb/sq ft
Tracker at impact point
T

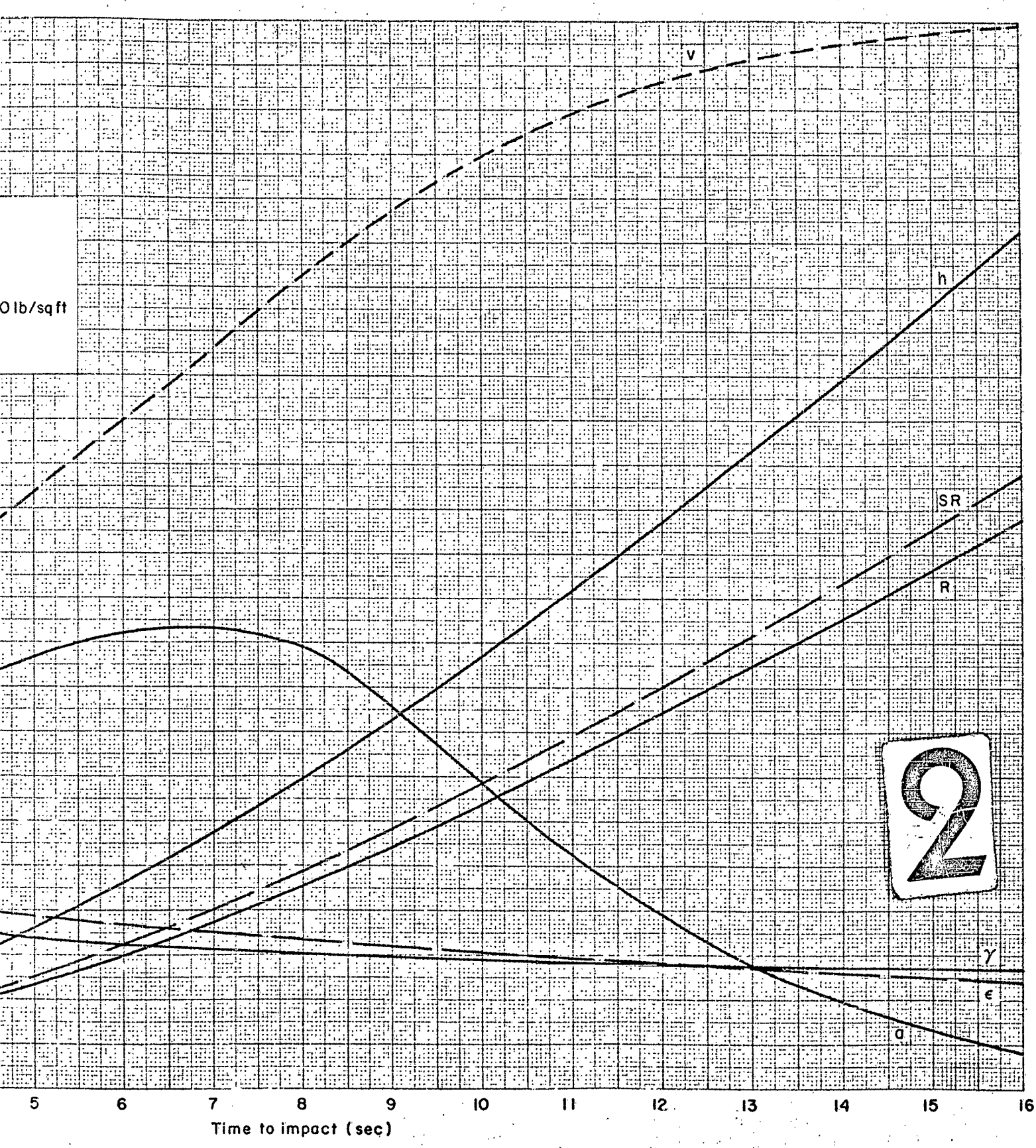
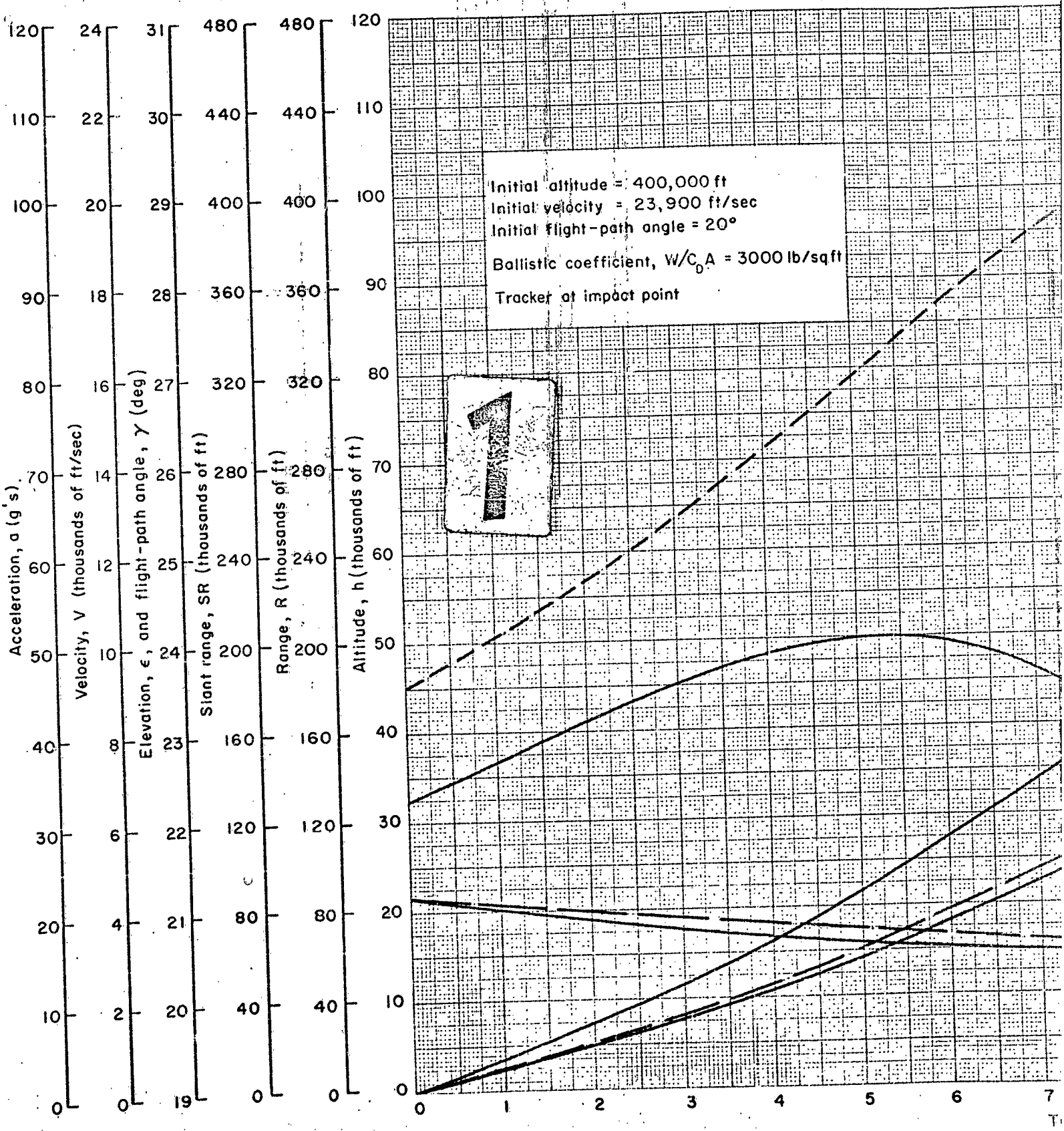


Fig. A—15


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 23,900 ft/sec
Initial flight-path angle = 20°
Ballistic coefficient, W/C_D A = 3000 lb/sq ft
Tracker at impact point
T

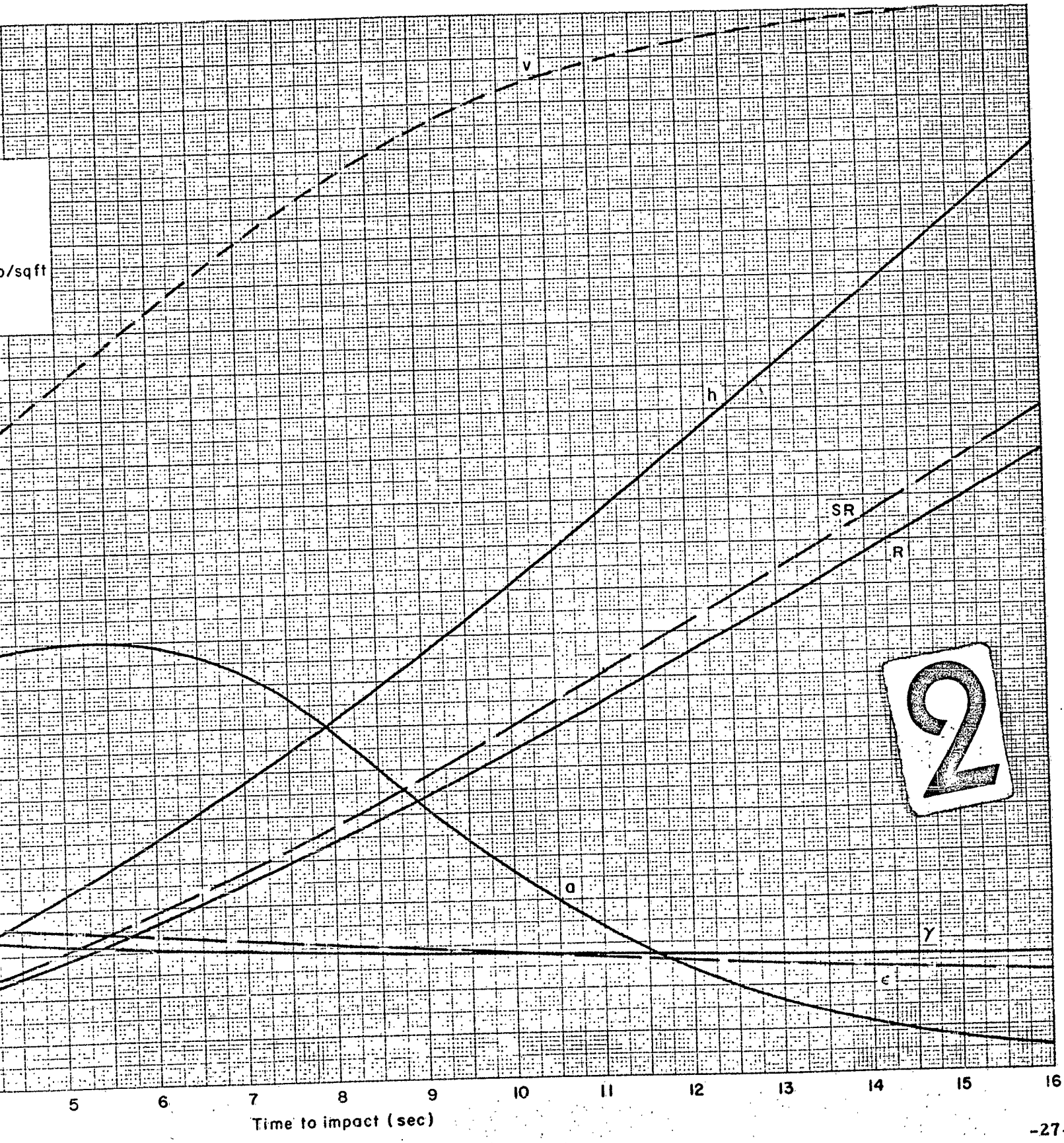
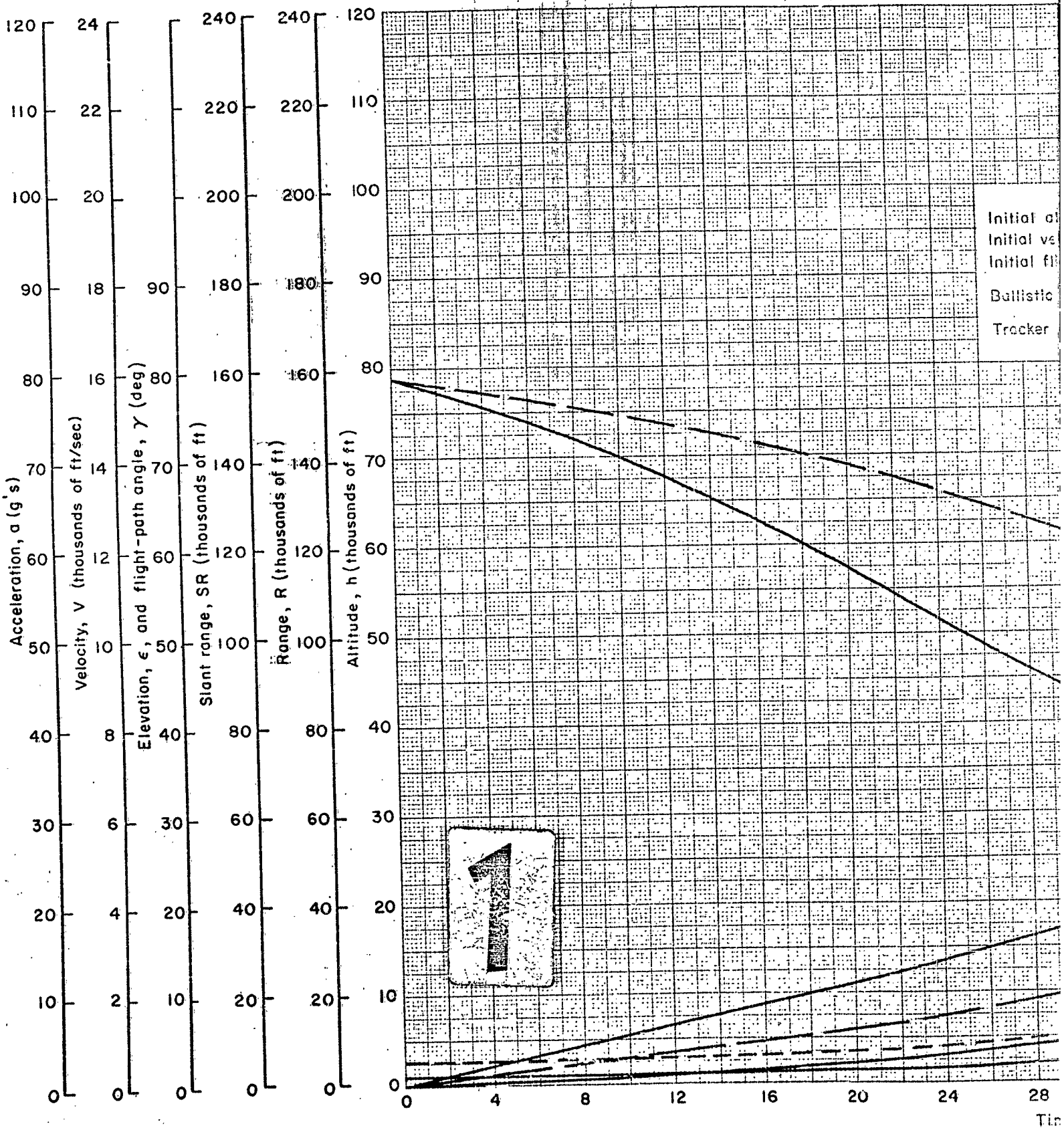


Fig. A—16


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial al
Initial ve
Initial fl
Ballistic
Tracker
Tim

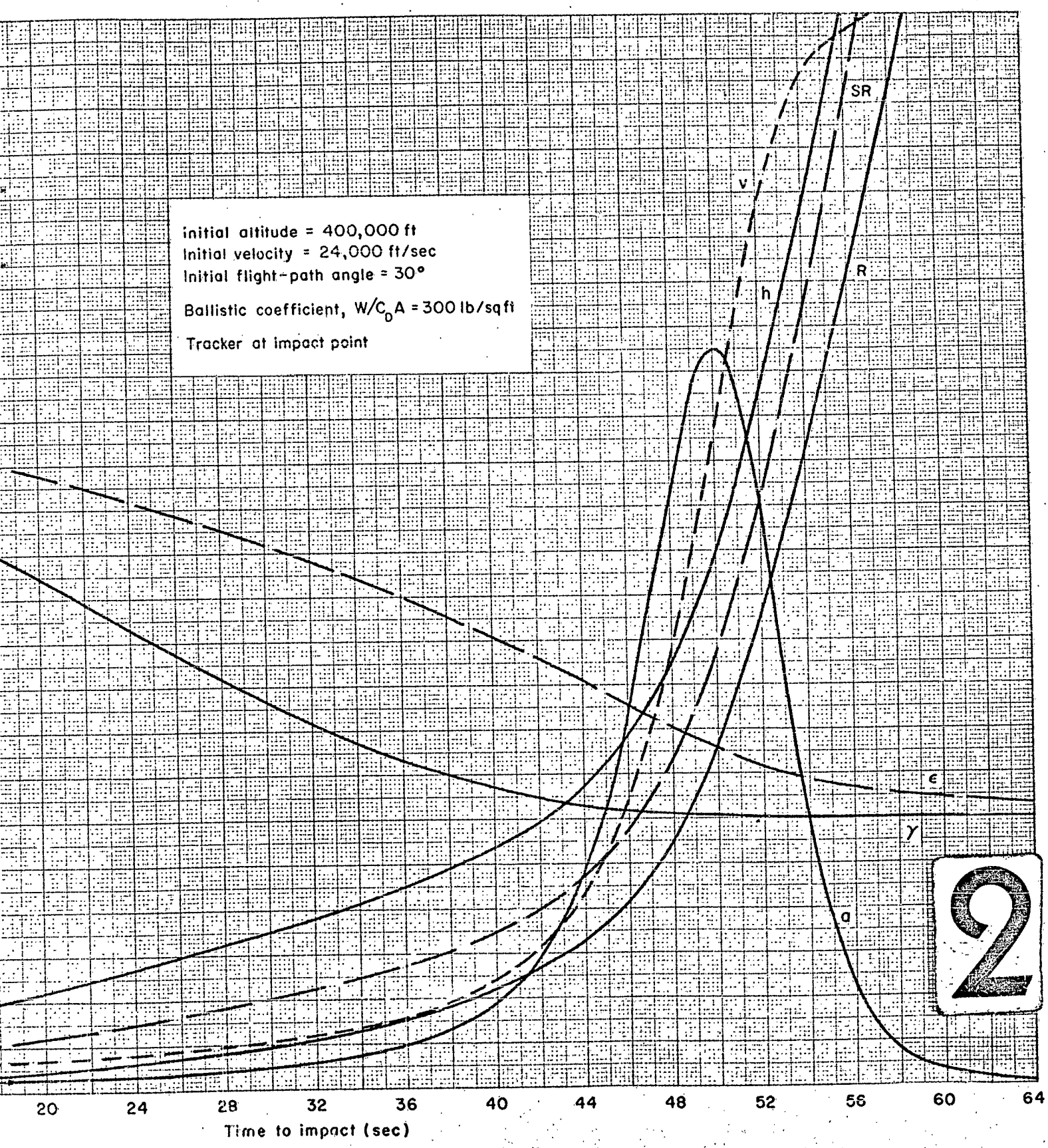
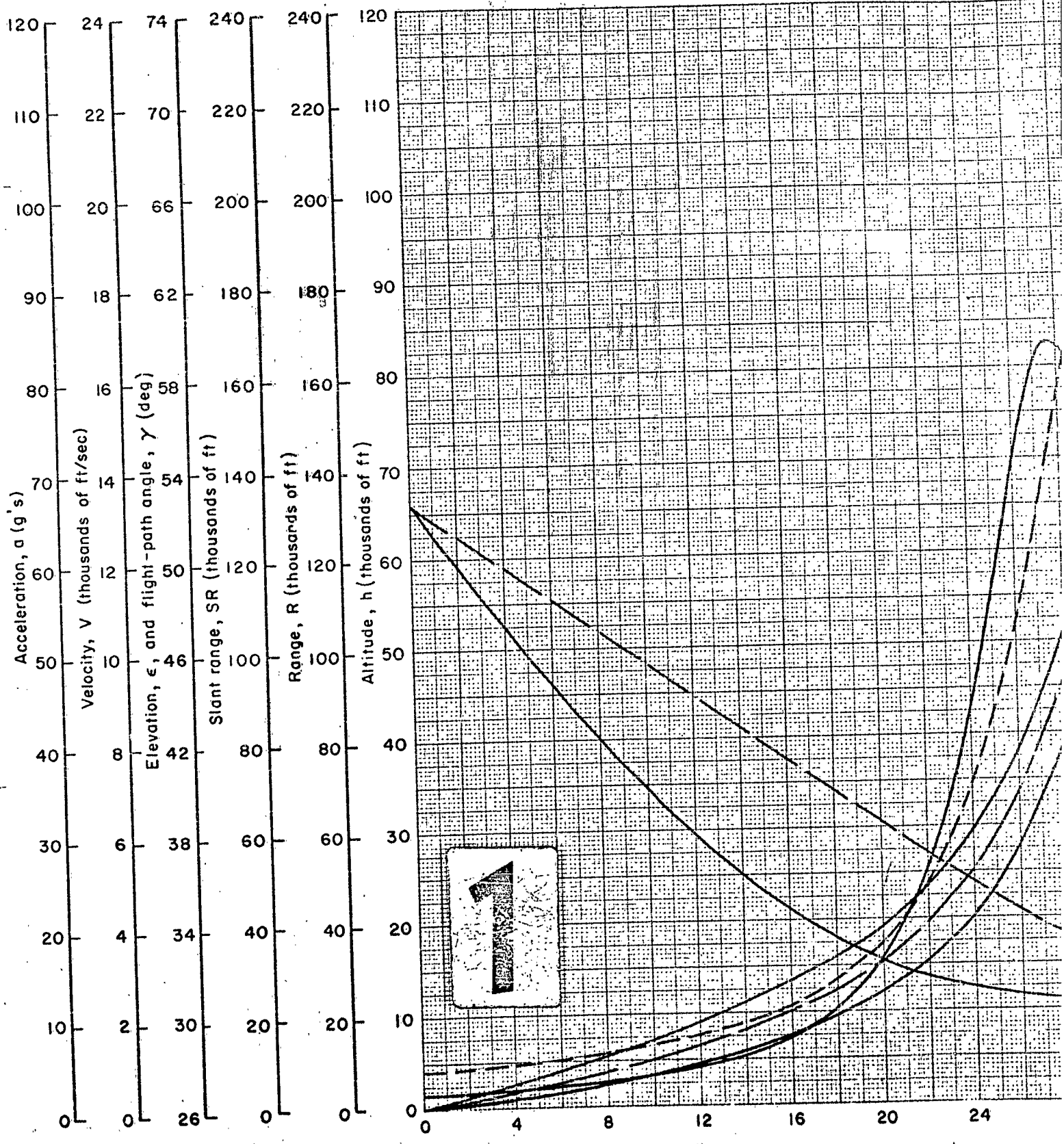

initial altitude = 400,000 ft
Initial velocity = 24,000 ft/sec
Initial flight-path angle = 30°
Ballistic coefficient, $W/C_D A$ = 300 lb/sq ft
Tracker at impact point
SR
V
R
h
ϵ
γ
a
2
20
24
28
32
36
40
44
48
52
56
60
64
Time to impact (sec)

Fig. A—17


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
1

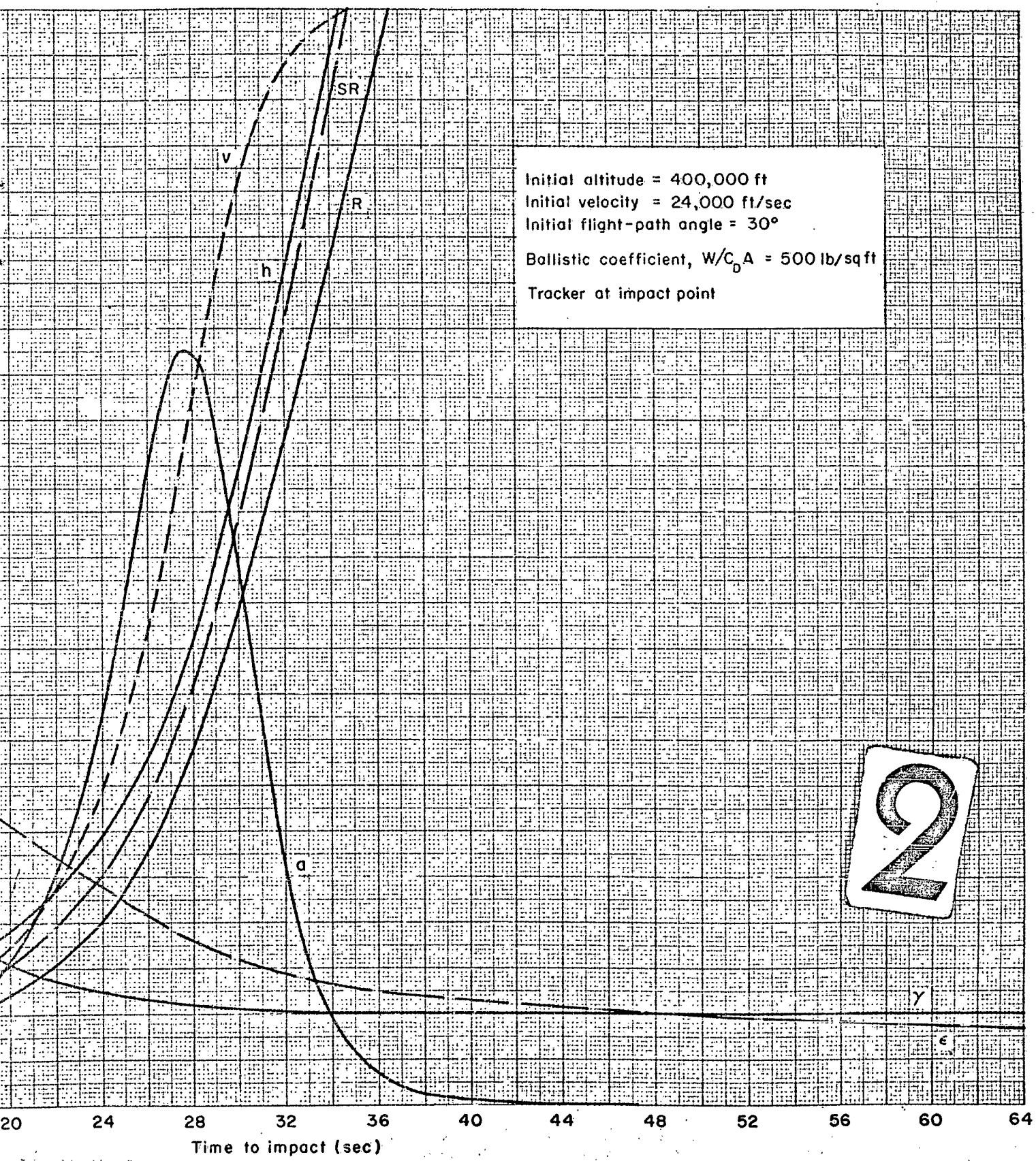
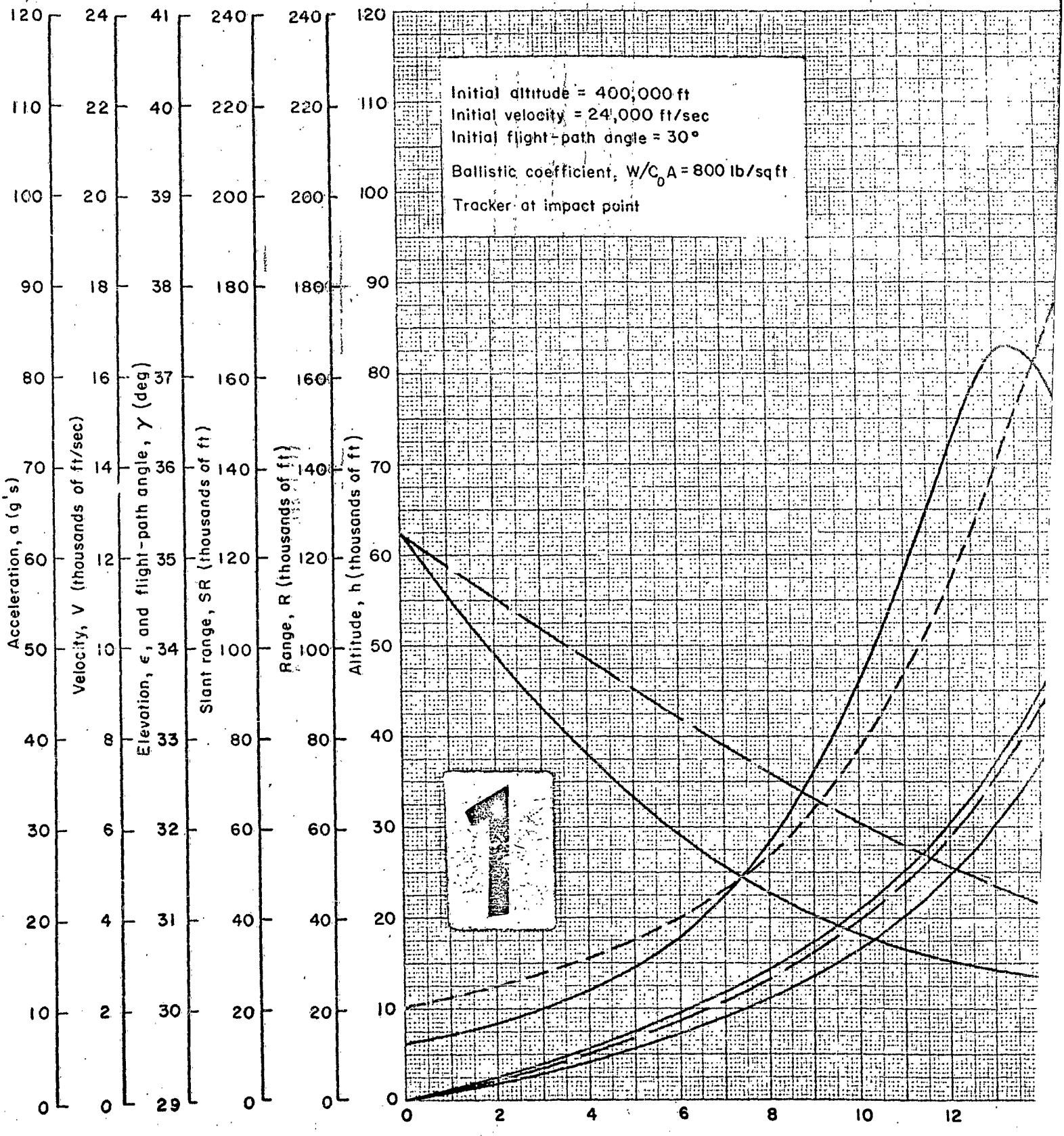

SR
V
R
h
a
γ
ϵ
Initial altitude = 400,000 ft
Initial velocity = 24,000 ft/sec
Initial flight-path angle = 30°
Ballistic coefficient, $W/C_D A$ = 500 lb/sq ft
Tracker at impact point
20
24
28
32
36
40
44
48
52
56
60
64
Time to impact (sec)

Fig. A—18


Initial altitude = 400,000 ft
Initial velocity = 24,000 ft/sec
Initial flight-path angle = 30°
Ballistic coefficient, W/C_0A = 800 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
1

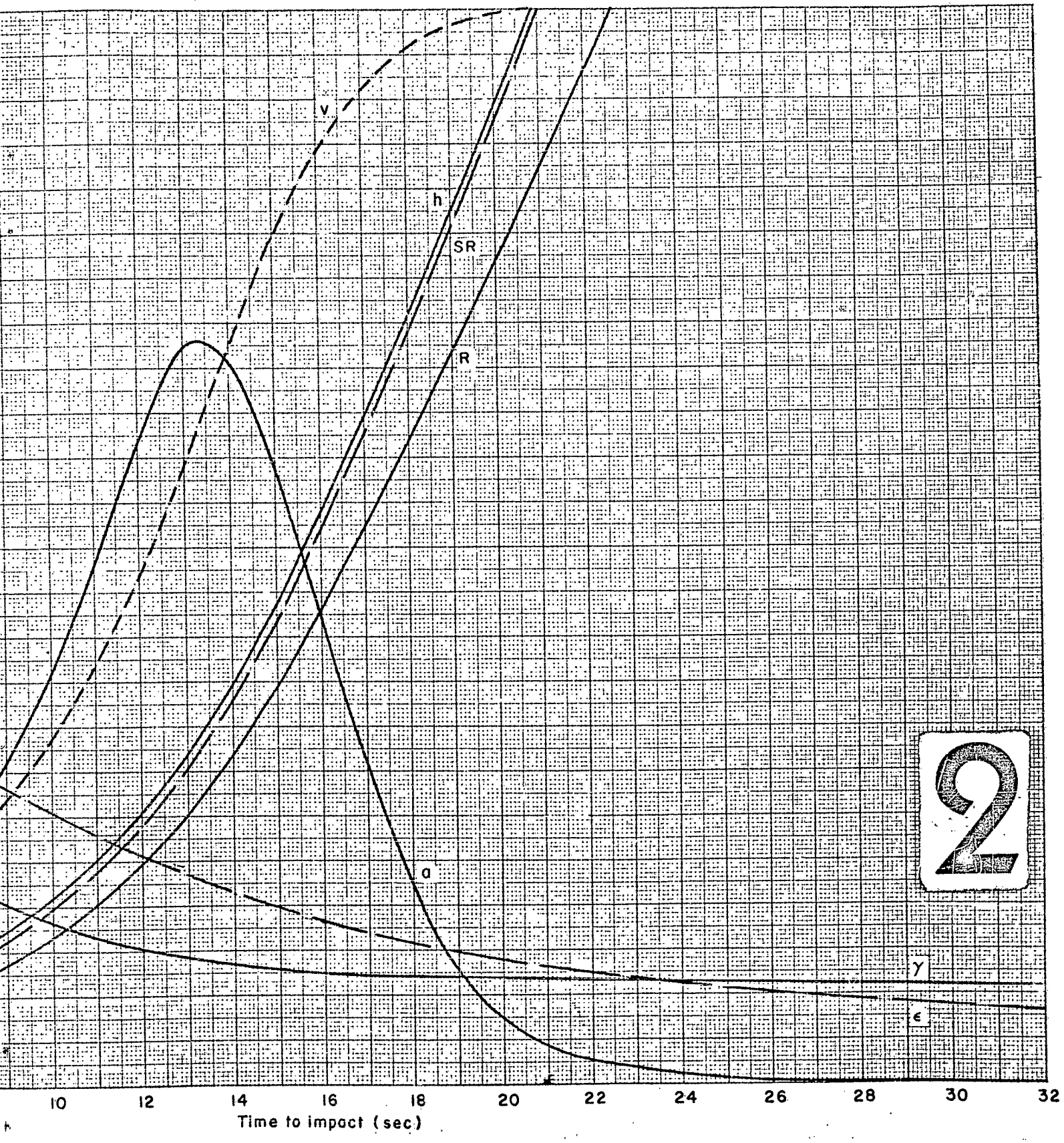
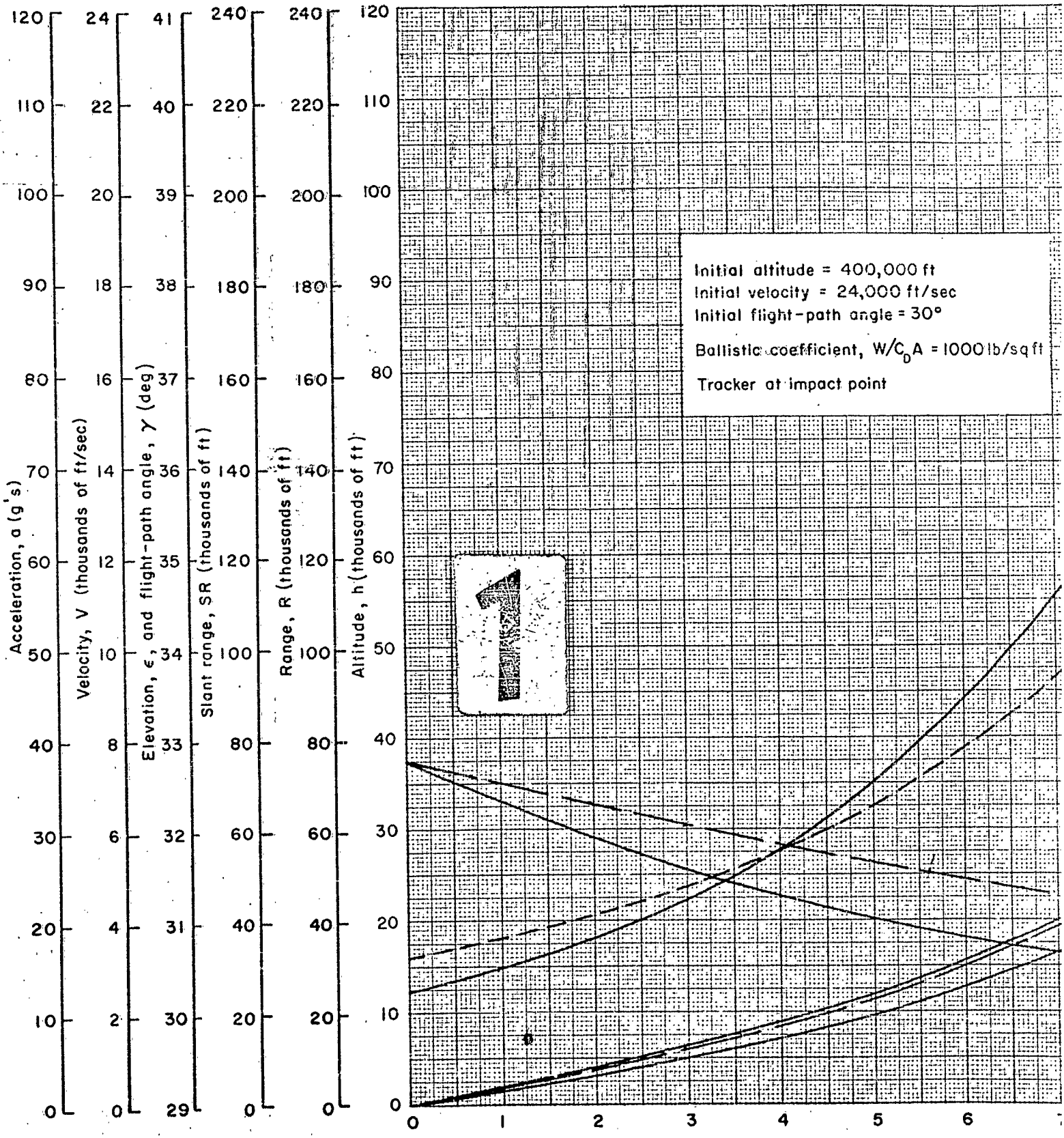


Fig. A—19


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 24,000 ft/sec
Initial flight-path angle = 30°
Ballistic coefficient, W/C_D A = 1000 lb/sq ft
Tracker at impact point

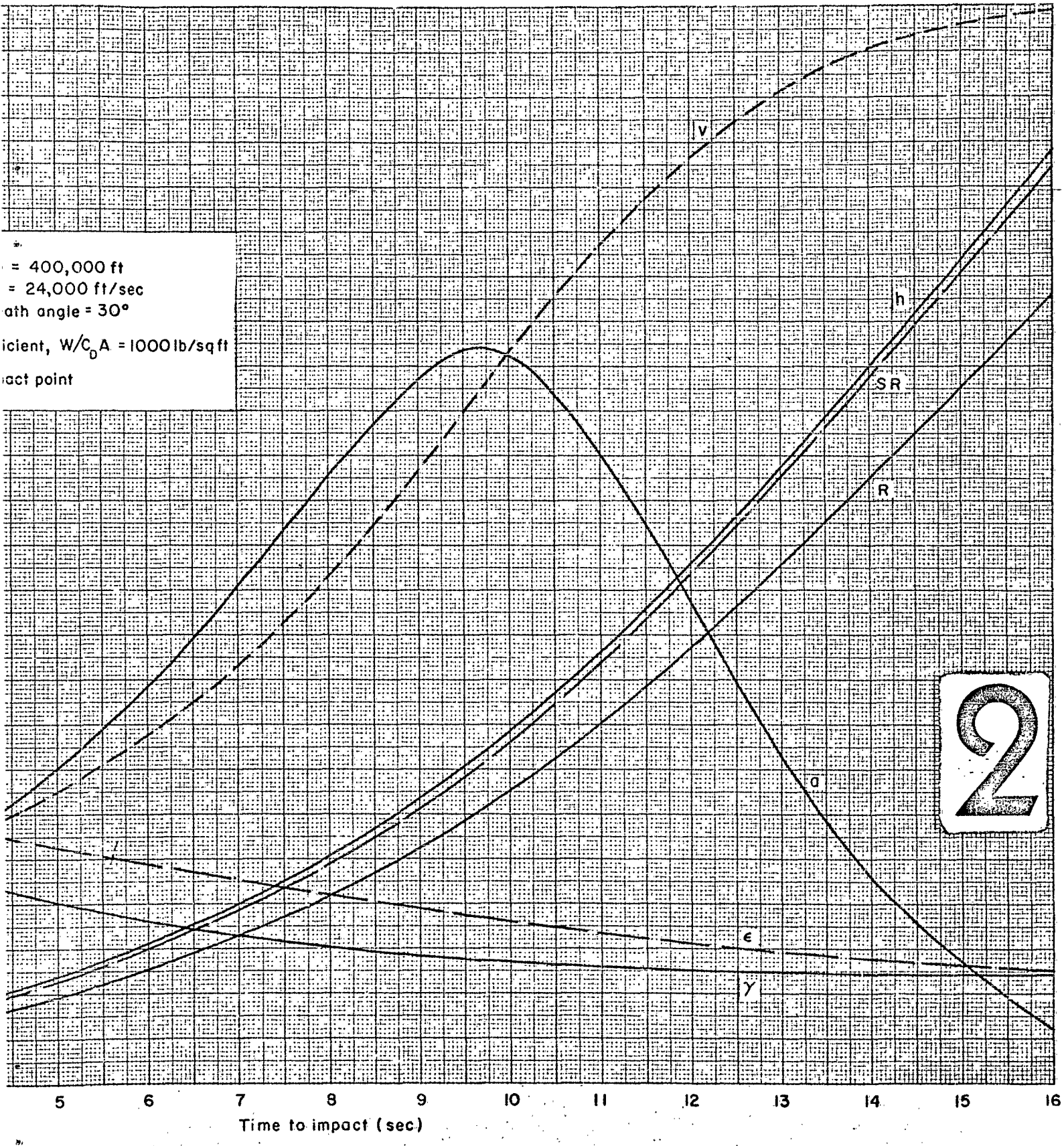
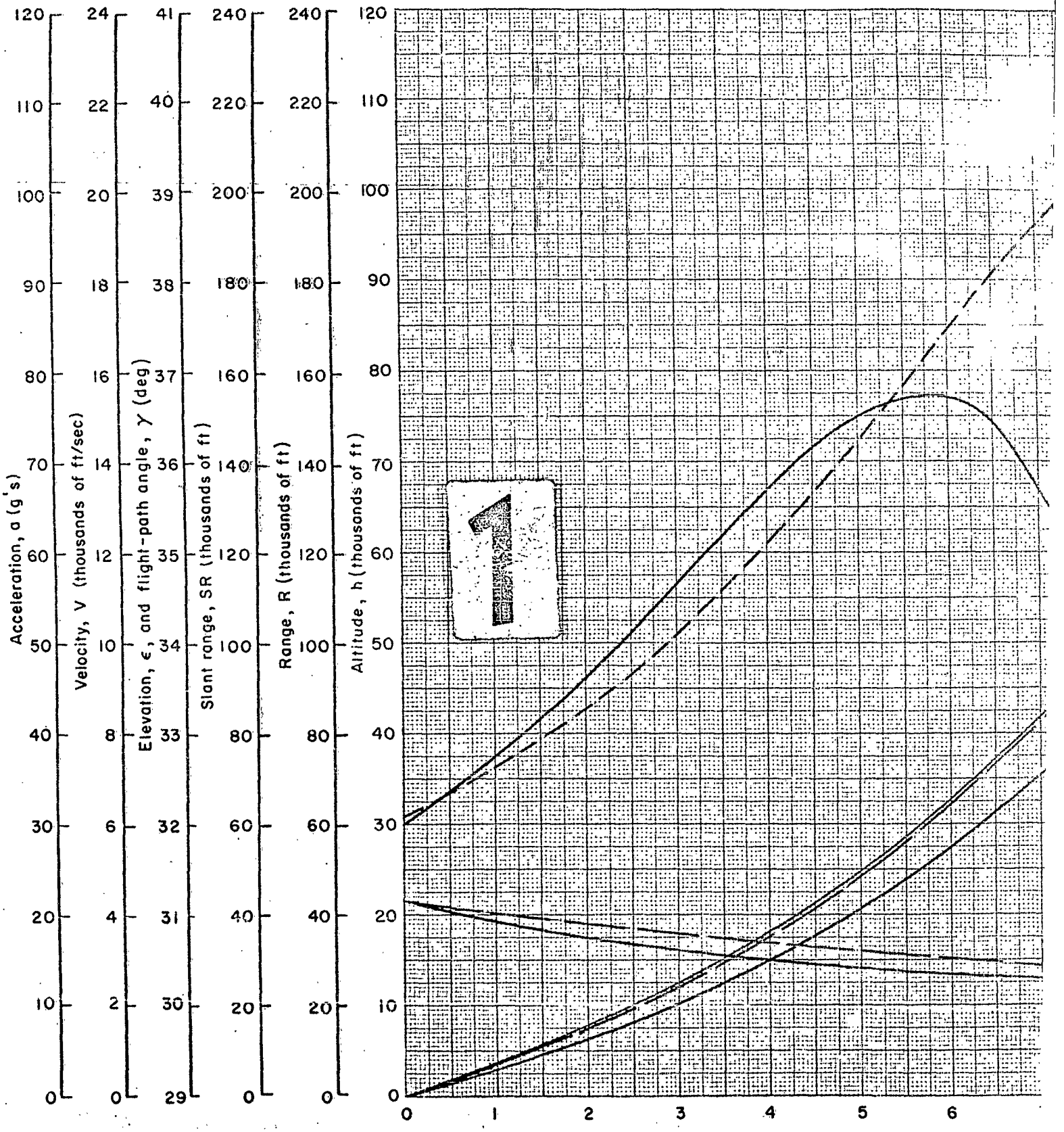

= 400,000 ft
= 24,000 ft/sec
ath angle = 30°
icient, W/C_DA = 1000 lb/sq ft
act point
V
h
SR
R
a
ϵ
γ
5
6
7
8
9
10
11
12
13
14
15
16
Time to impact (sec)

Fig. A—20


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
0
10
20
30
40
50
60
70
80
90
100
110
120
2
4
6
8
10
12
14
16
18
20
22
24
29
30
31
32
33
34
35
36
37
38
39
40
41
20
40
60
80
100
120
140
160
180
200
220
240
1
2
3
4
5
6

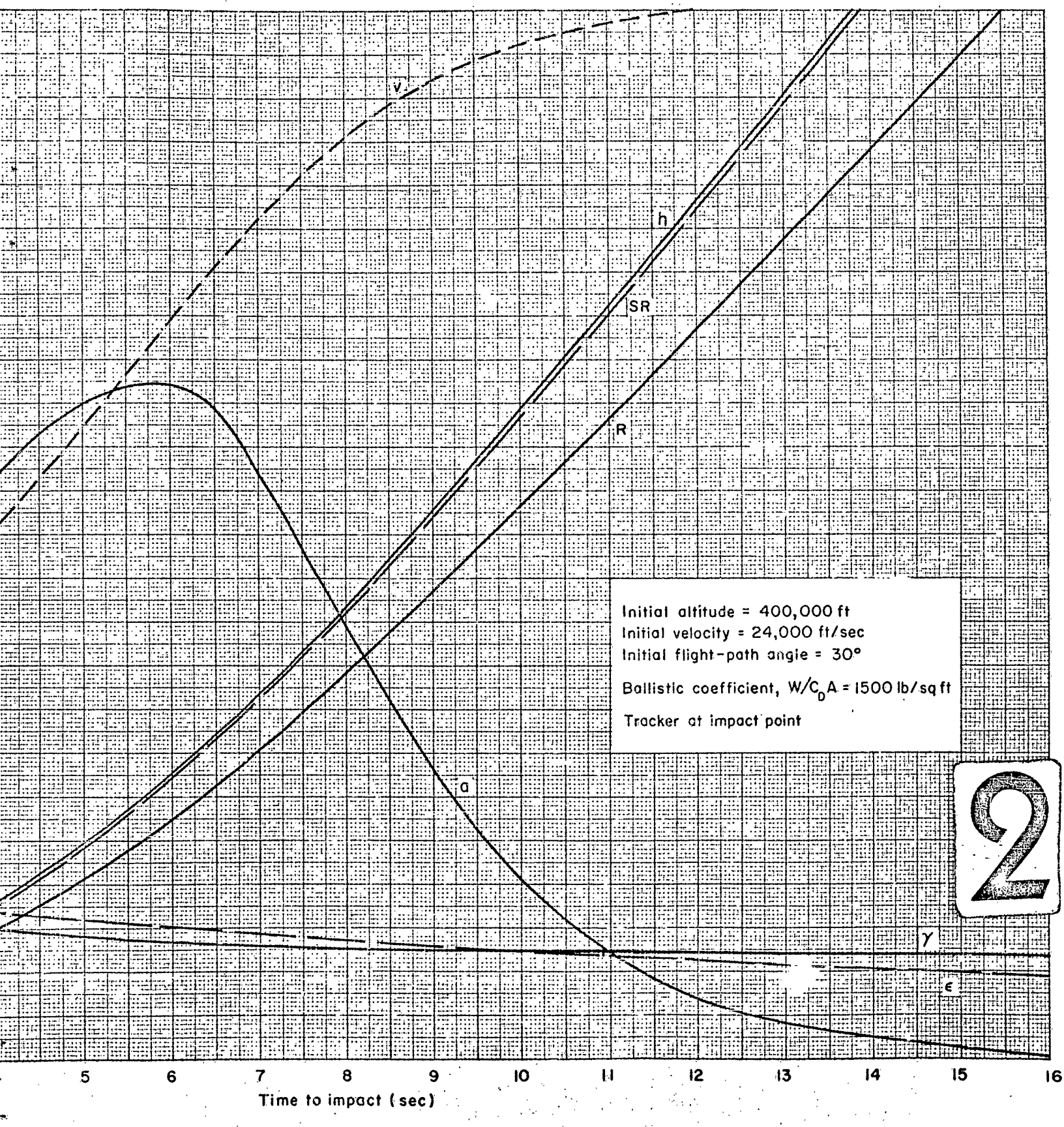
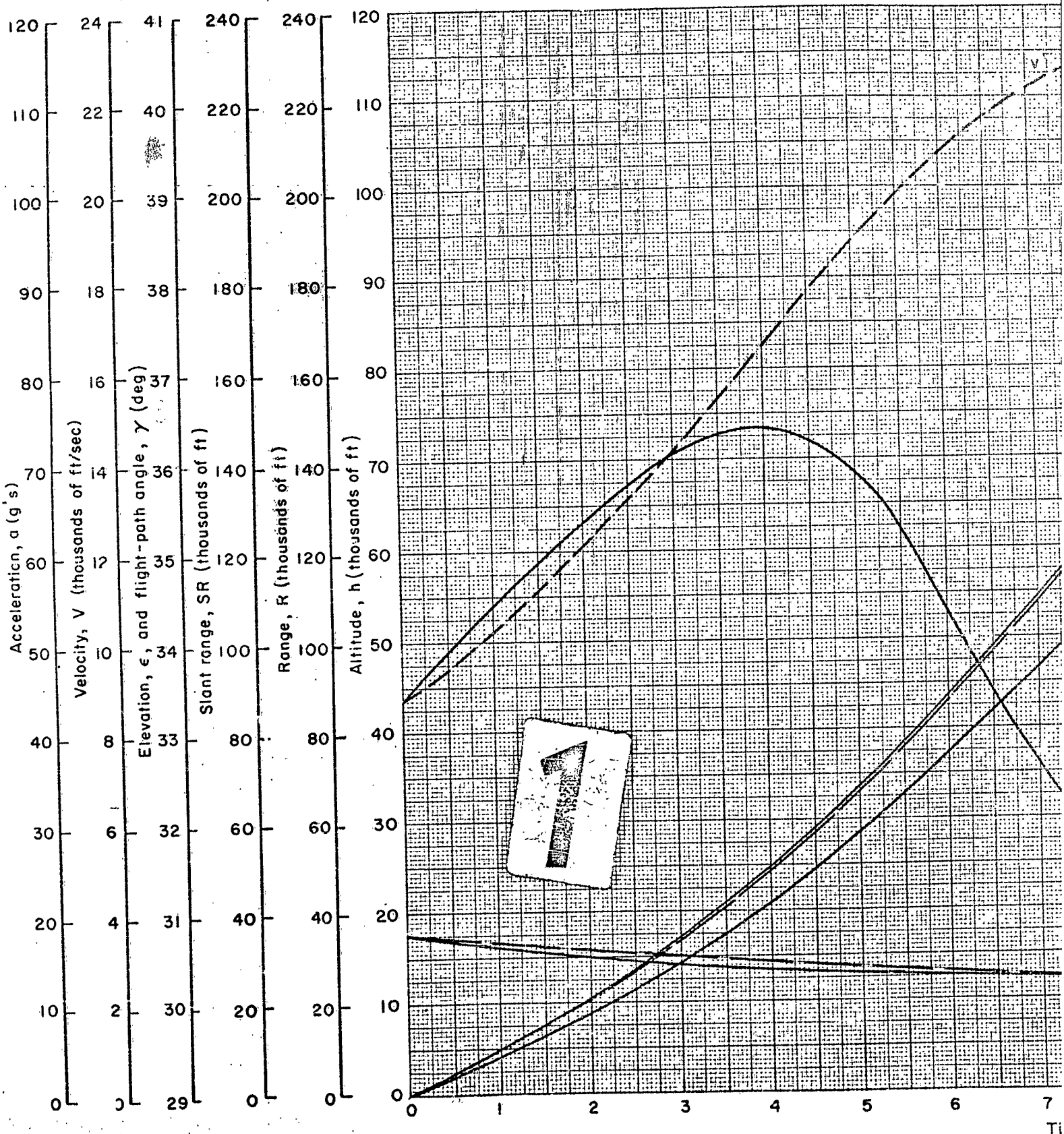

v
h
SR
R
a
γ
ε
Initial altitude = 400,000 ft
Initial velocity = 24,000 ft/sec
Initial flight-path angle = 30°
Ballistic coefficient, W/C_D A = 1500 lb/sq ft
Tracker at impact point
2
5
6
7
8
9
10
11
12
13
14
15
16
Time to impact (sec)

Fig. A—21


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
V
Ti

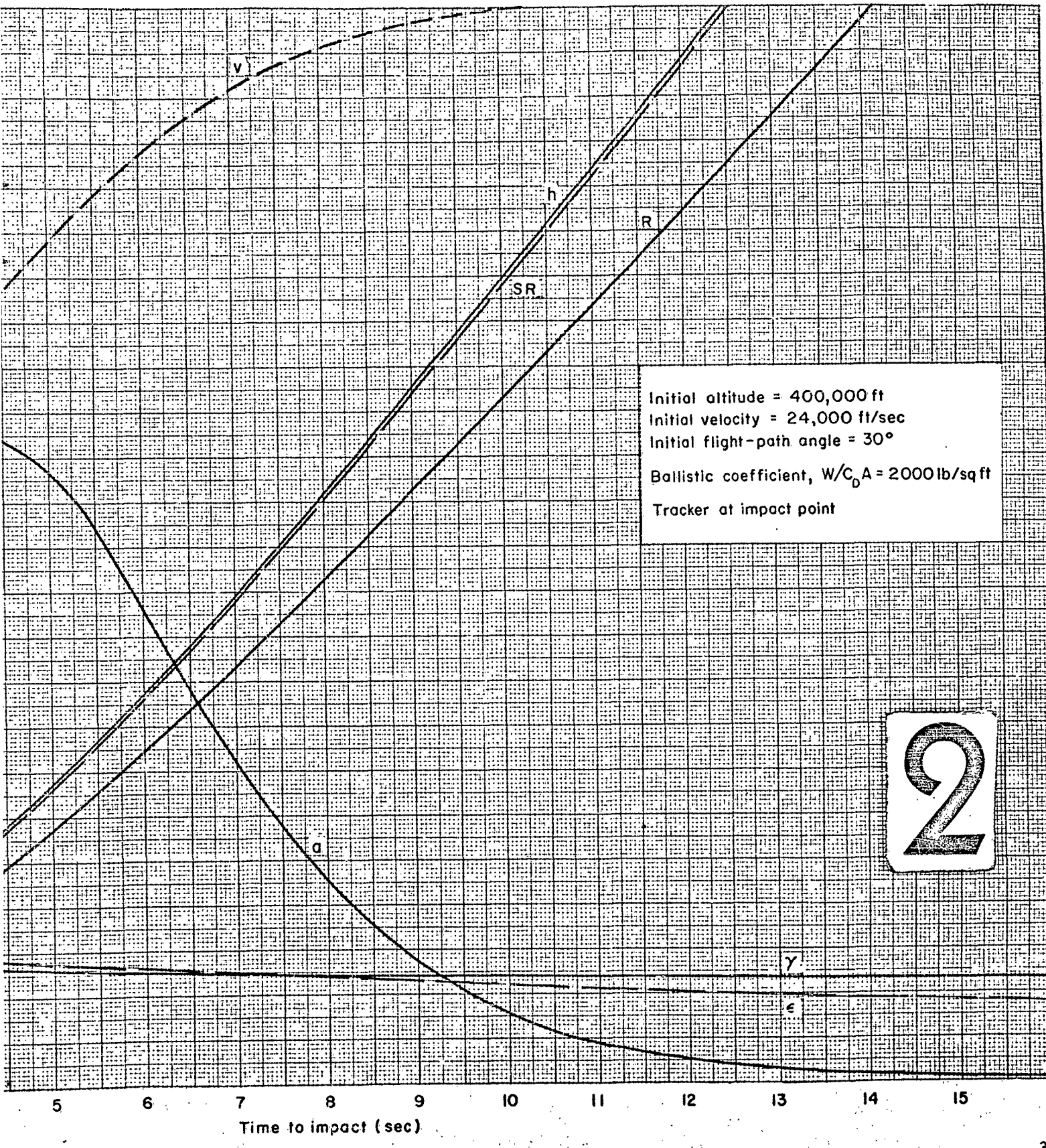
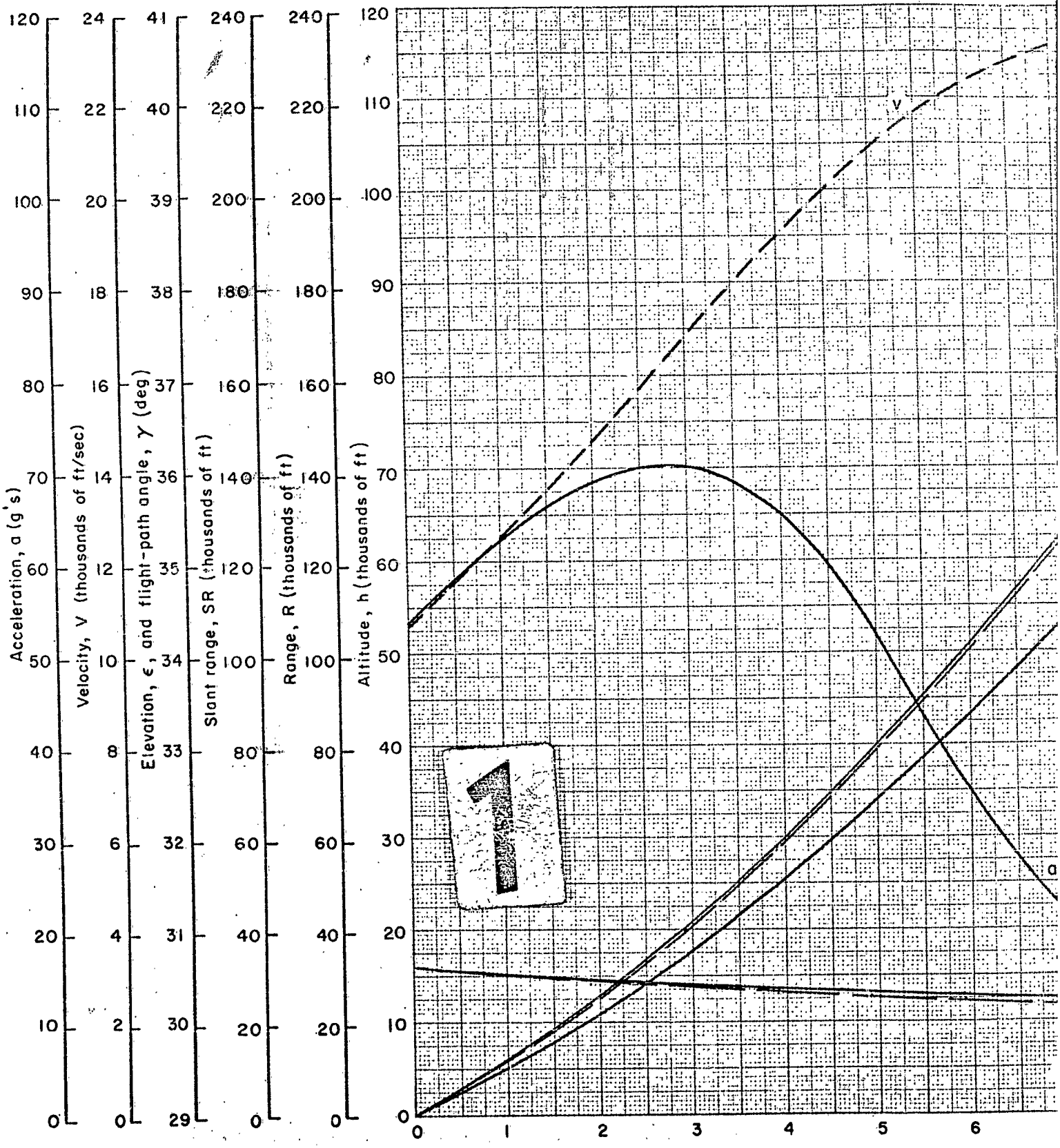

v
h
R
SR
a
γ
ε
Initial altitude = 400,000 ft
Initial velocity = 24,000 ft/sec
Initial flight-path angle = 30°
Ballistic coefficient, W/C_DA = 2000 lb/sq ft
Tracker at impact point
2
5
6
7
8
9
10
11
12
13
14
15
16
Time to impact (sec)

Fig. A—22


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
V
a

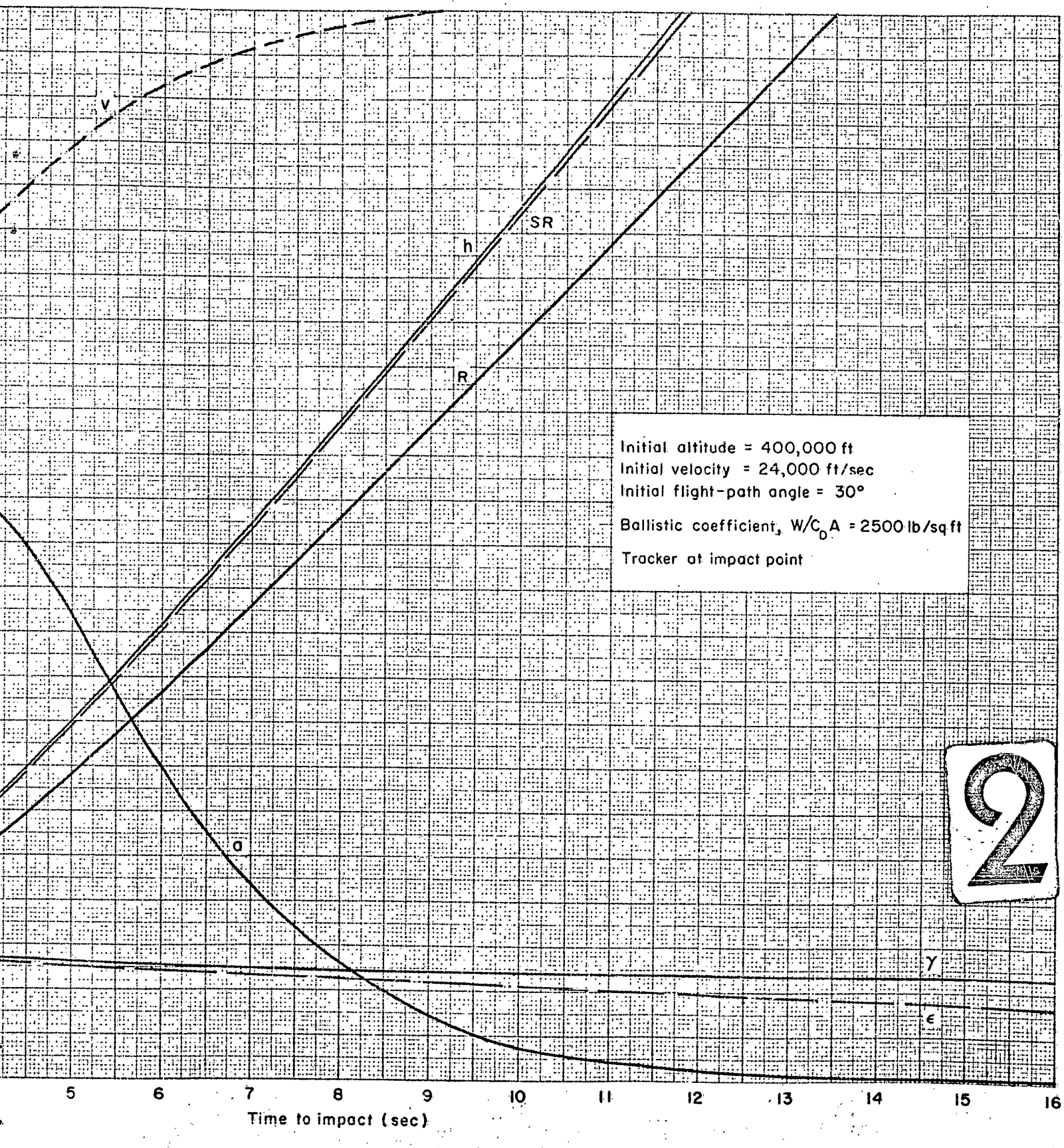
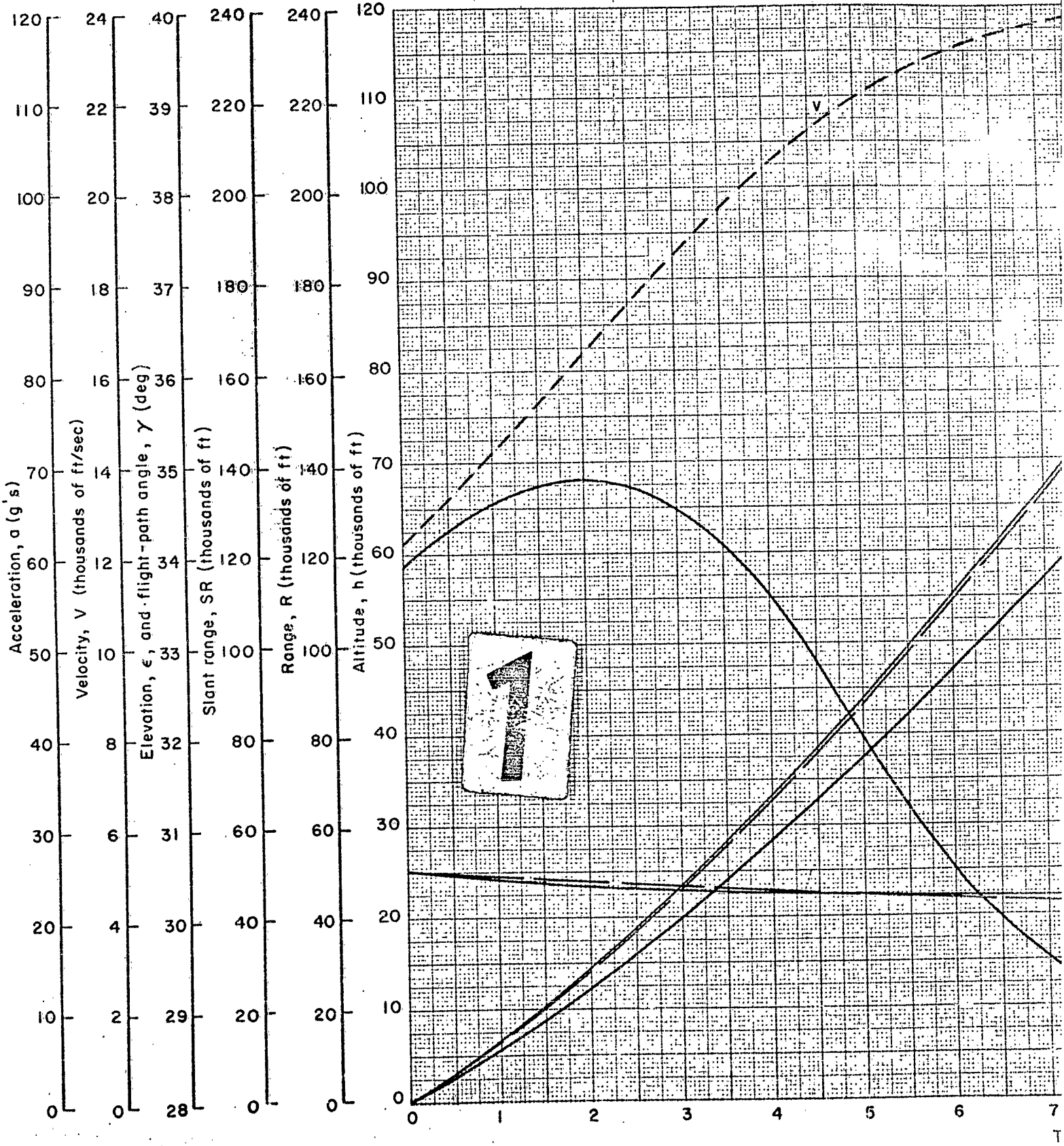

V
SR
h
R
Initial altitude = 400,000 ft
Initial velocity = 24,000 ft/sec
Initial flight-path angle = 30°
Ballistic coefficient, $W/C_D A$ = 2500 lb/sq ft
Tracker at impact point
a
γ
ε
5
6
7
8
9
10
11
12
13
14
15
16
Time to impact (sec)

Fig. A--23


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
V
T

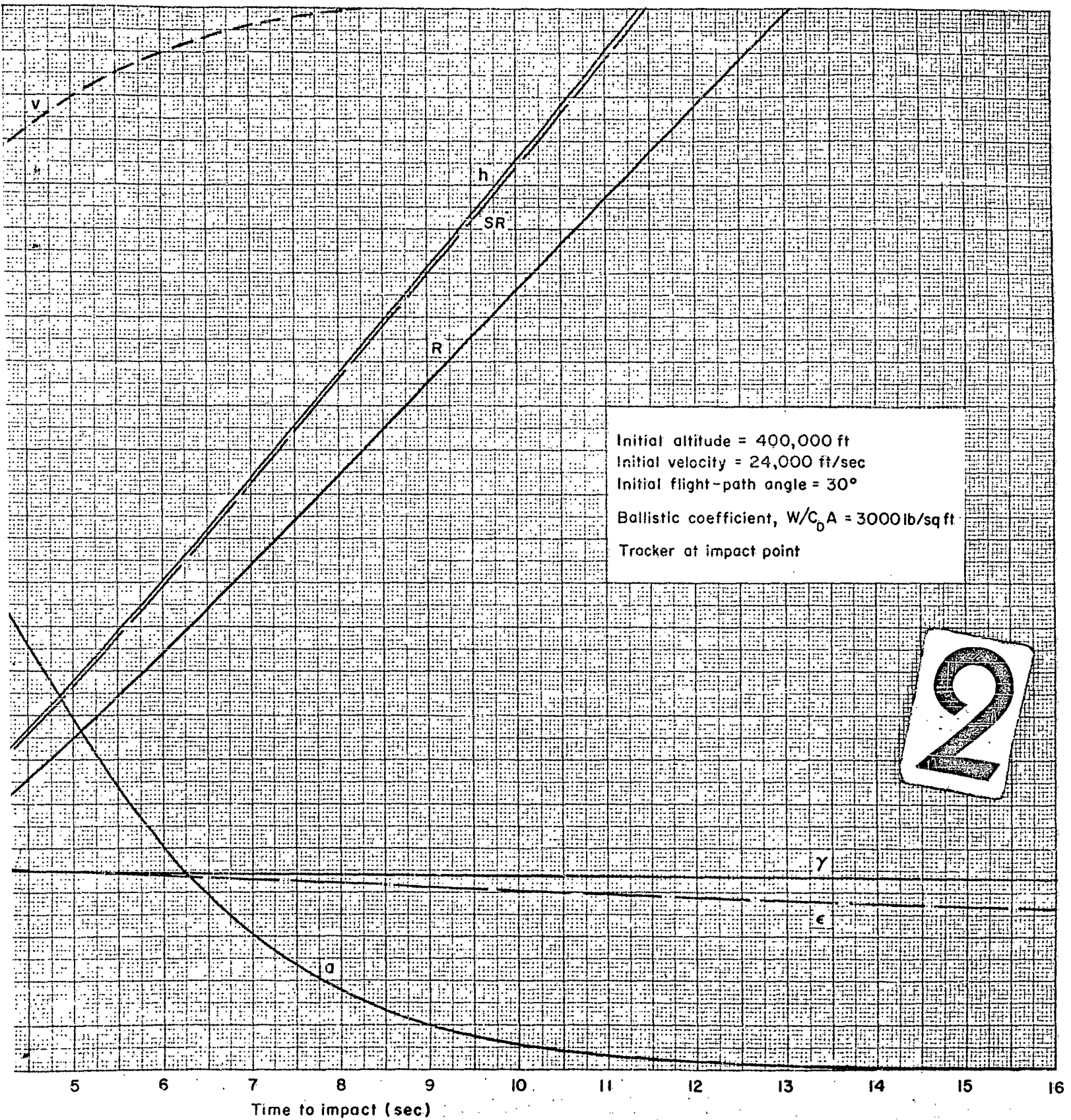
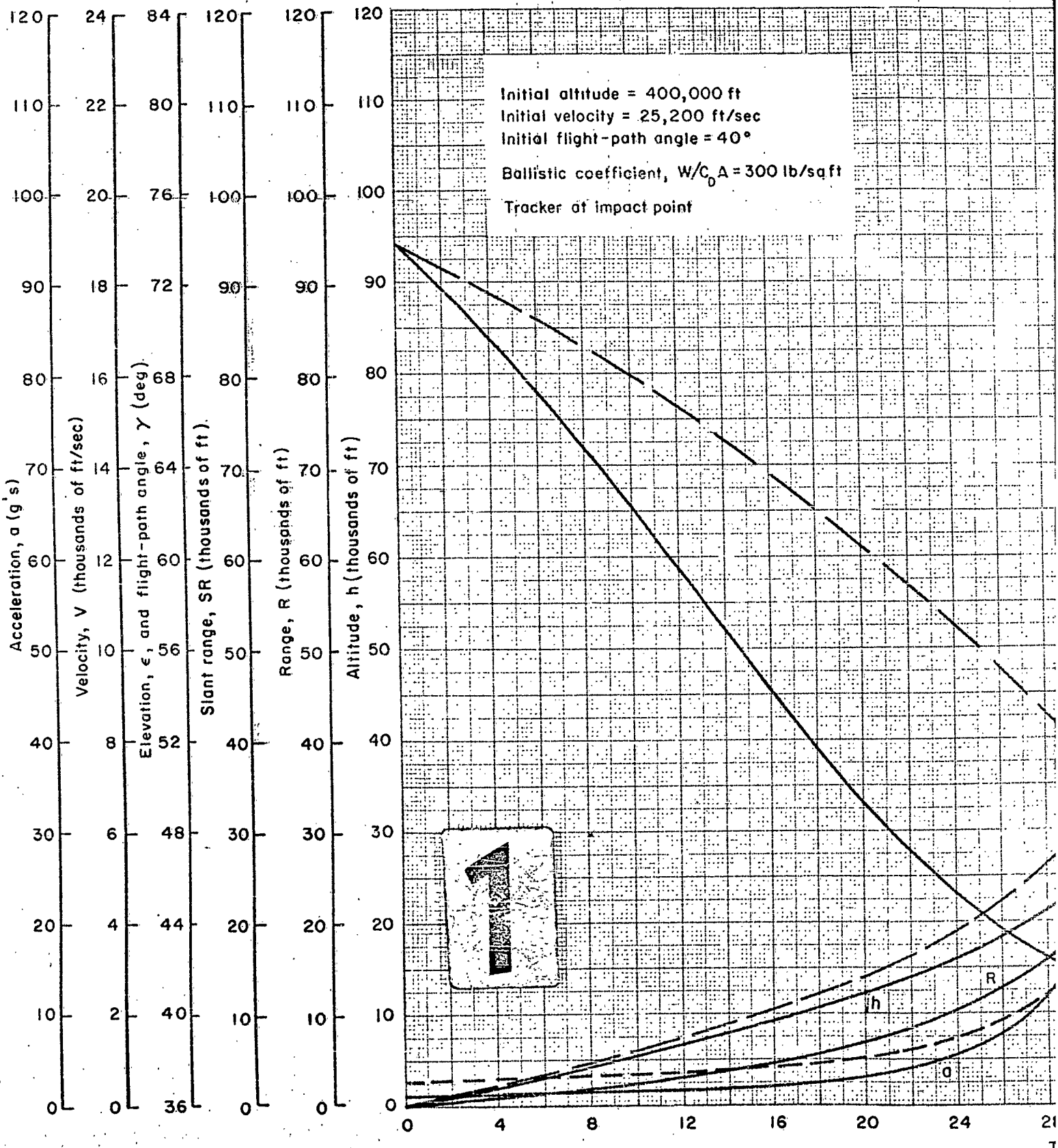
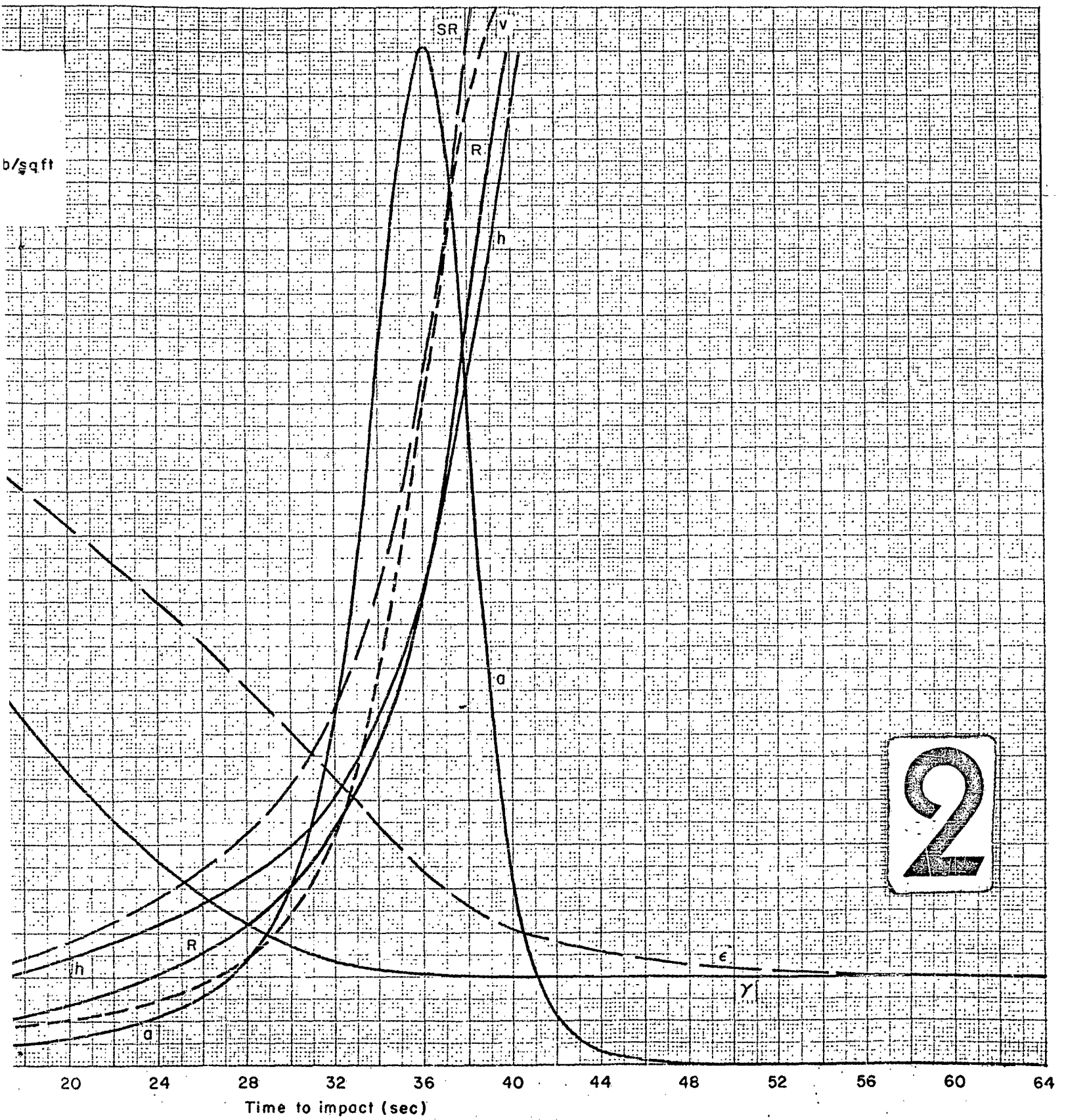

V
h
SR
R
Initial altitude = 400,000 ft
Initial velocity = 24,000 ft/sec
Initial flight-path angle = 30°
Ballistic coefficient, $W/C_D A$ = 3000 lb/sq ft
Tracker at impact point
γ
ε
α
5
6
7
8
9
10
11
12
13
14
15
16
Time to impact (sec)

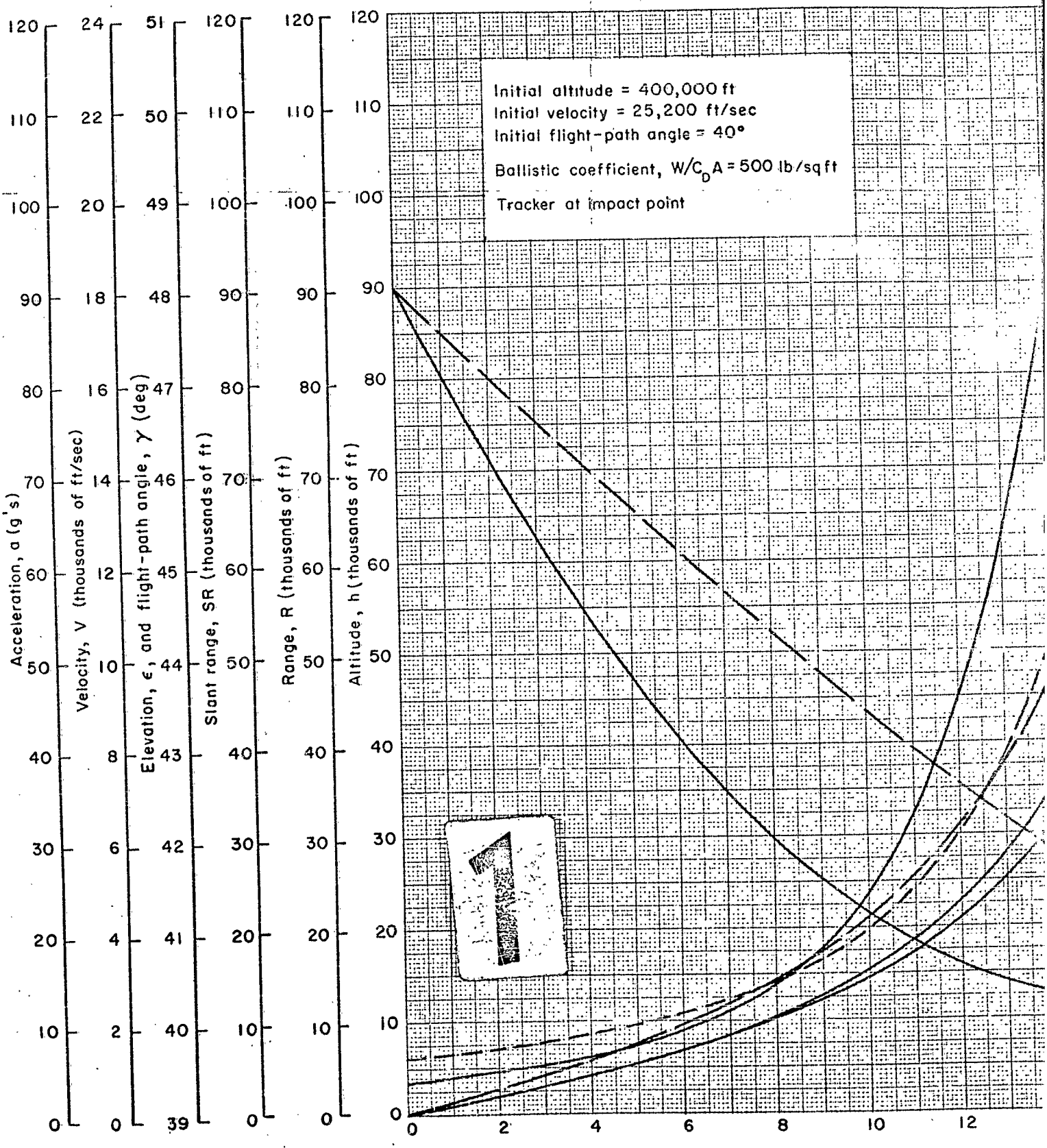
Fig. A—24


Initial altitude = 400,000 ft
Initial velocity = 25,200 ft/sec
Initial flight-path angle = 40°
Ballistic coefficient, $W/C_D A$ = 300 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
h
R
a



b/sqft
SR
v
R
h
a
R
h
a
ε
γ
2
20
24
28
32
36
40
44
48
52
56
60
64
Time to impact (sec)

Fig. A — 25


Initial altitude = 400,000 ft
Initial velocity = 25,200 ft/sec
Initial flight-path angle = 40°
Ballistic coefficient, $W/C_D A$ = 500 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)

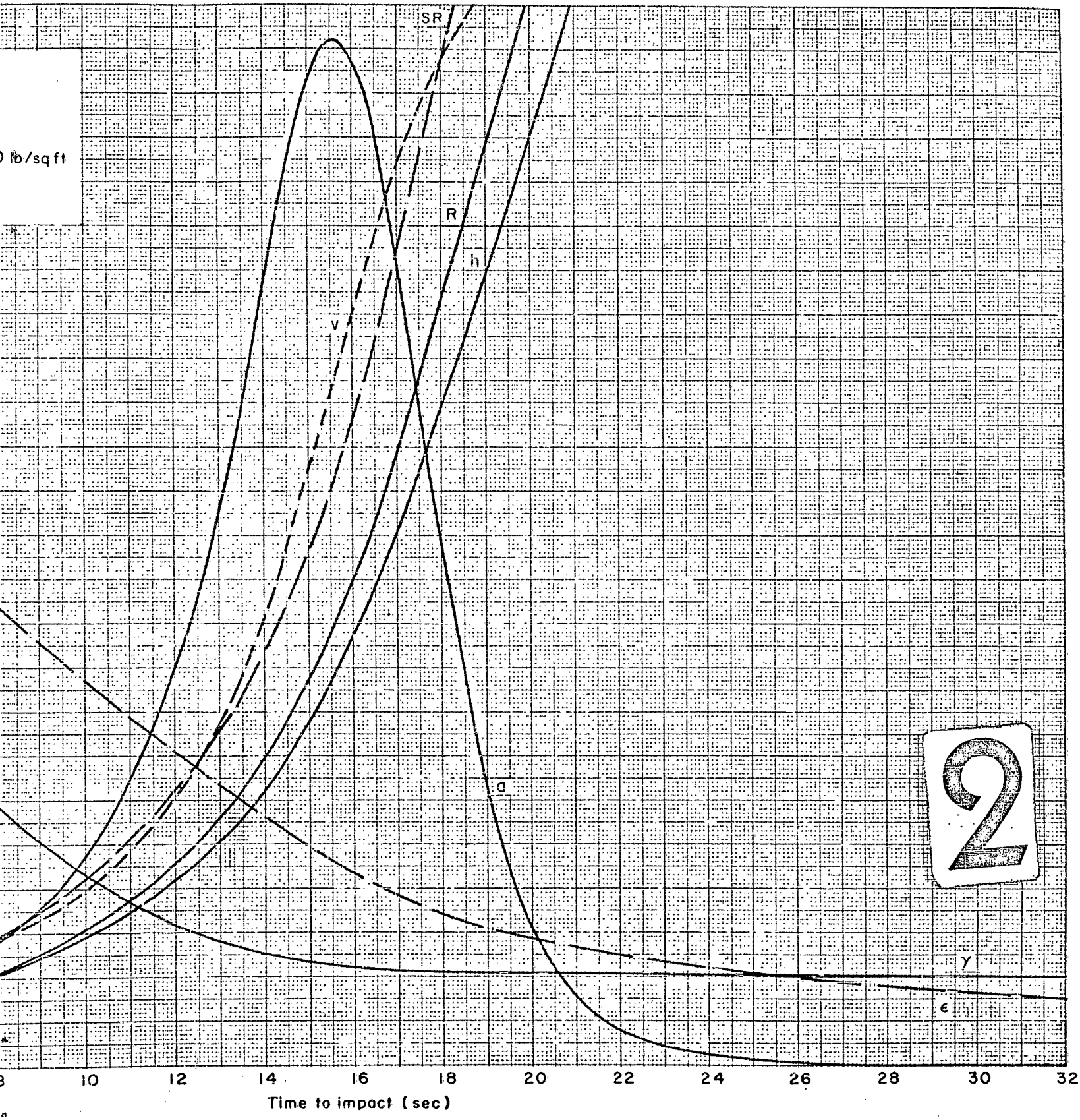
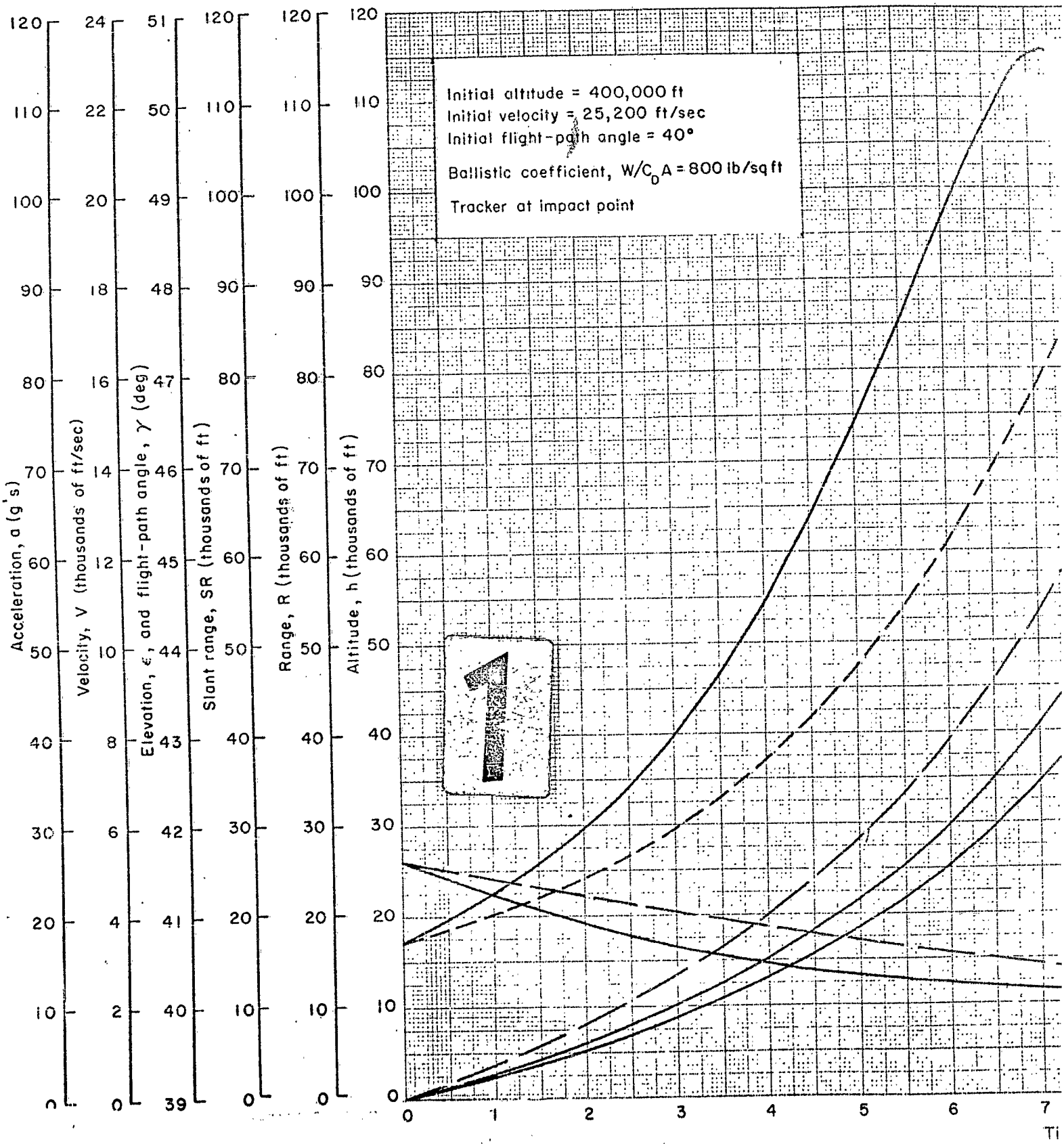

SR
R
h
v
a
γ
ε
2
) lb/sq ft
8
10
12
14
16
18
20
22
24
26
28
30
32
Time to impact (sec)

Fig. A—26


Initial altitude = 400,000 ft
Initial velocity = 25,200 ft/sec
Initial flight-path angle = 40°
Ballistic coefficient, W/C_DA = 800 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ϵ, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Ti

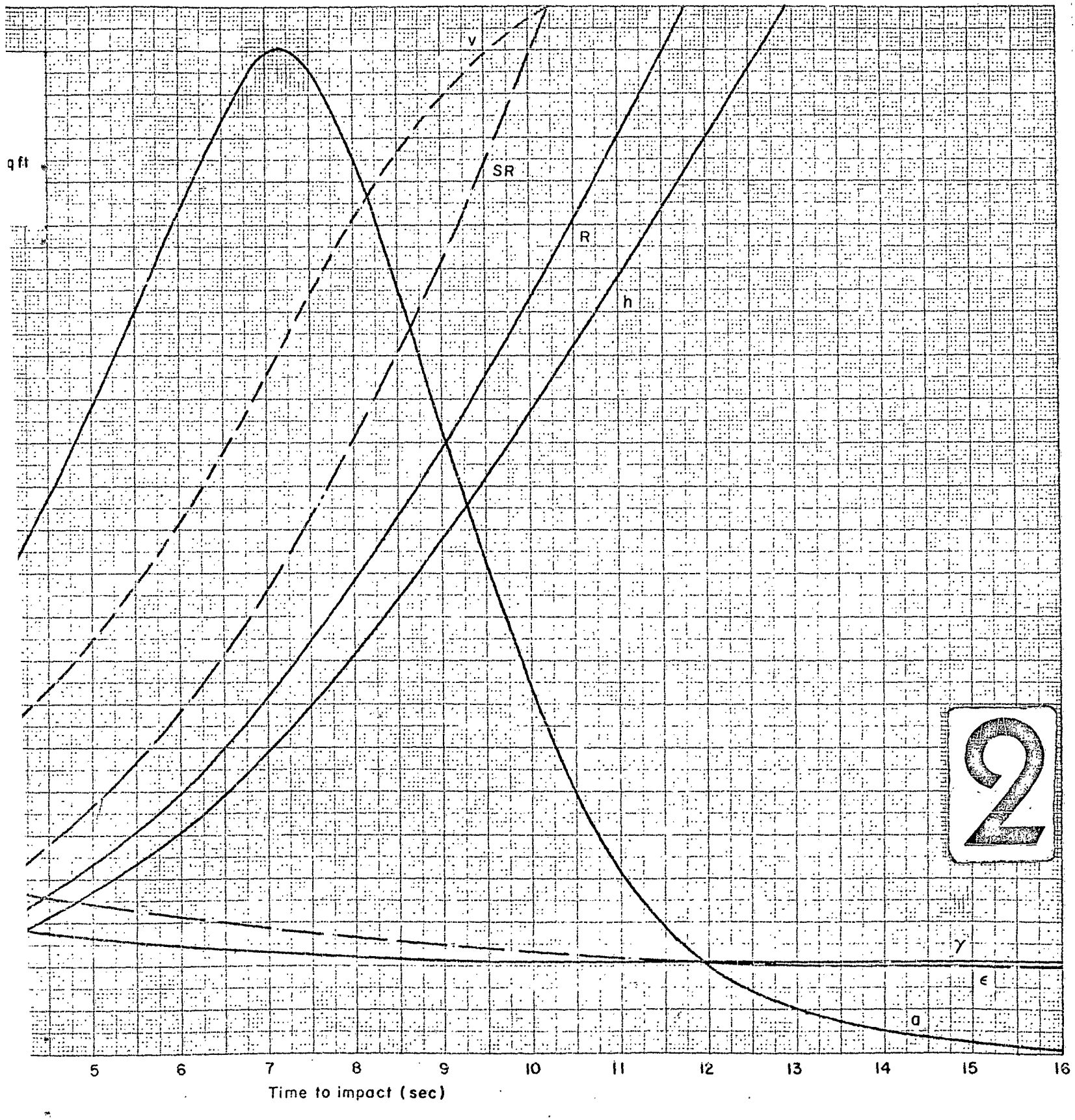
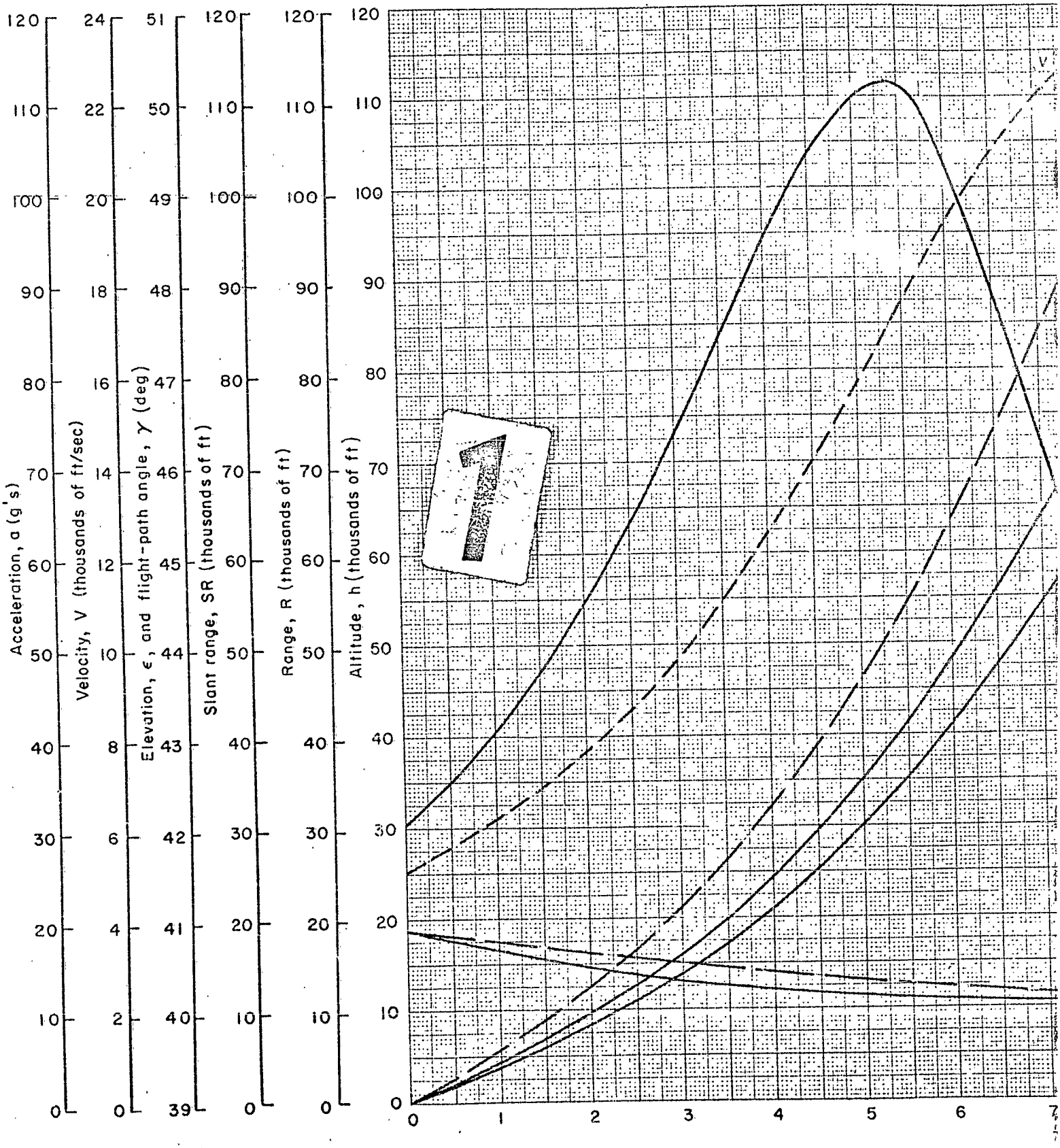


Fig. A — 27


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
V
1

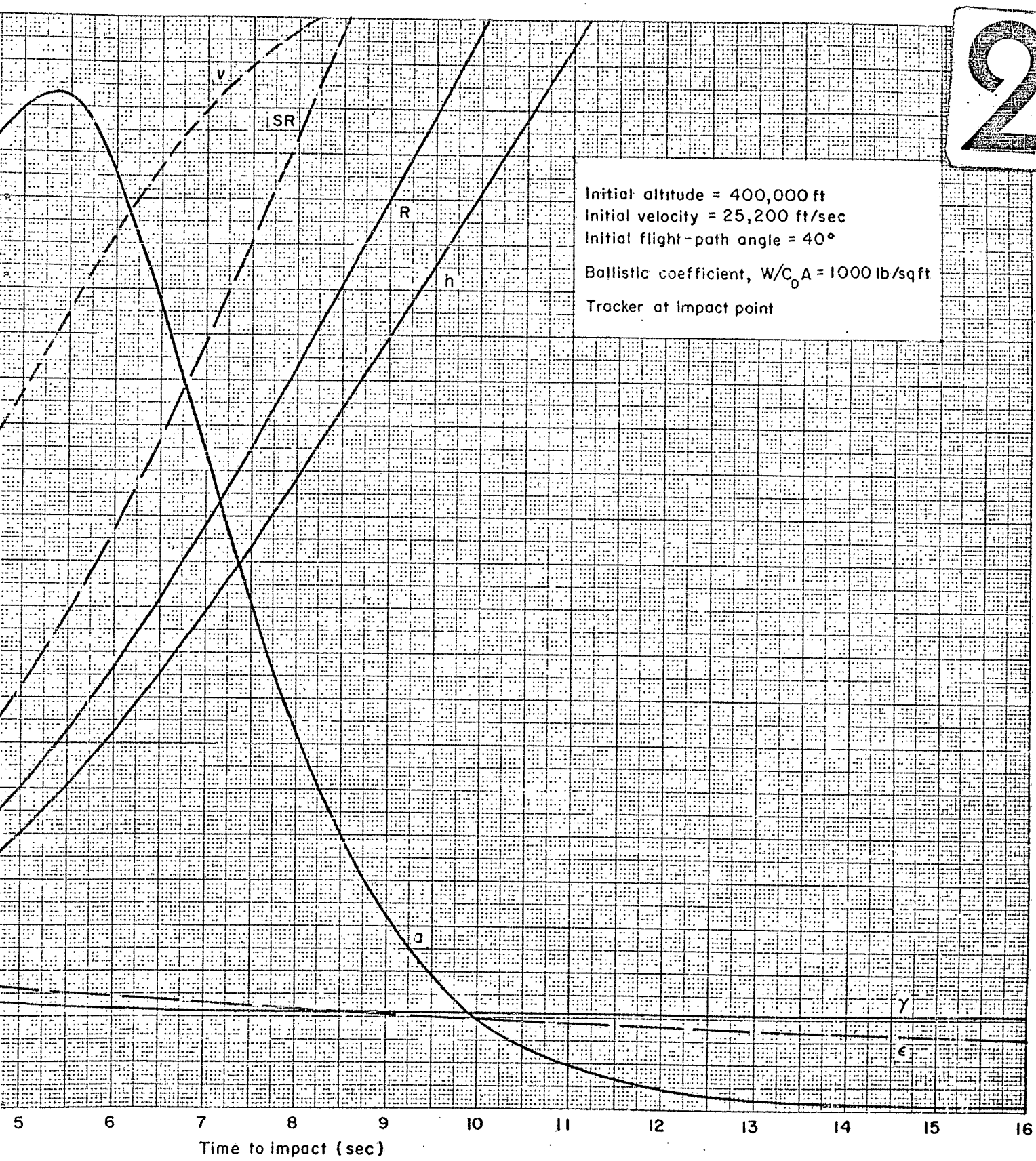

2
Initial altitude = 400,000 ft
Initial velocity = 25,200 ft/sec
Initial flight-path angle = 40°
Ballistic coefficient, $W/C_D A$ = 1000 lb/sq ft
Tracker at impact point
V
SR
R
h
a
γ
ϵ
5
6
7
8
9
10
11
12
13
14
15
16
Time to impact (sec)

Fig. A — 28

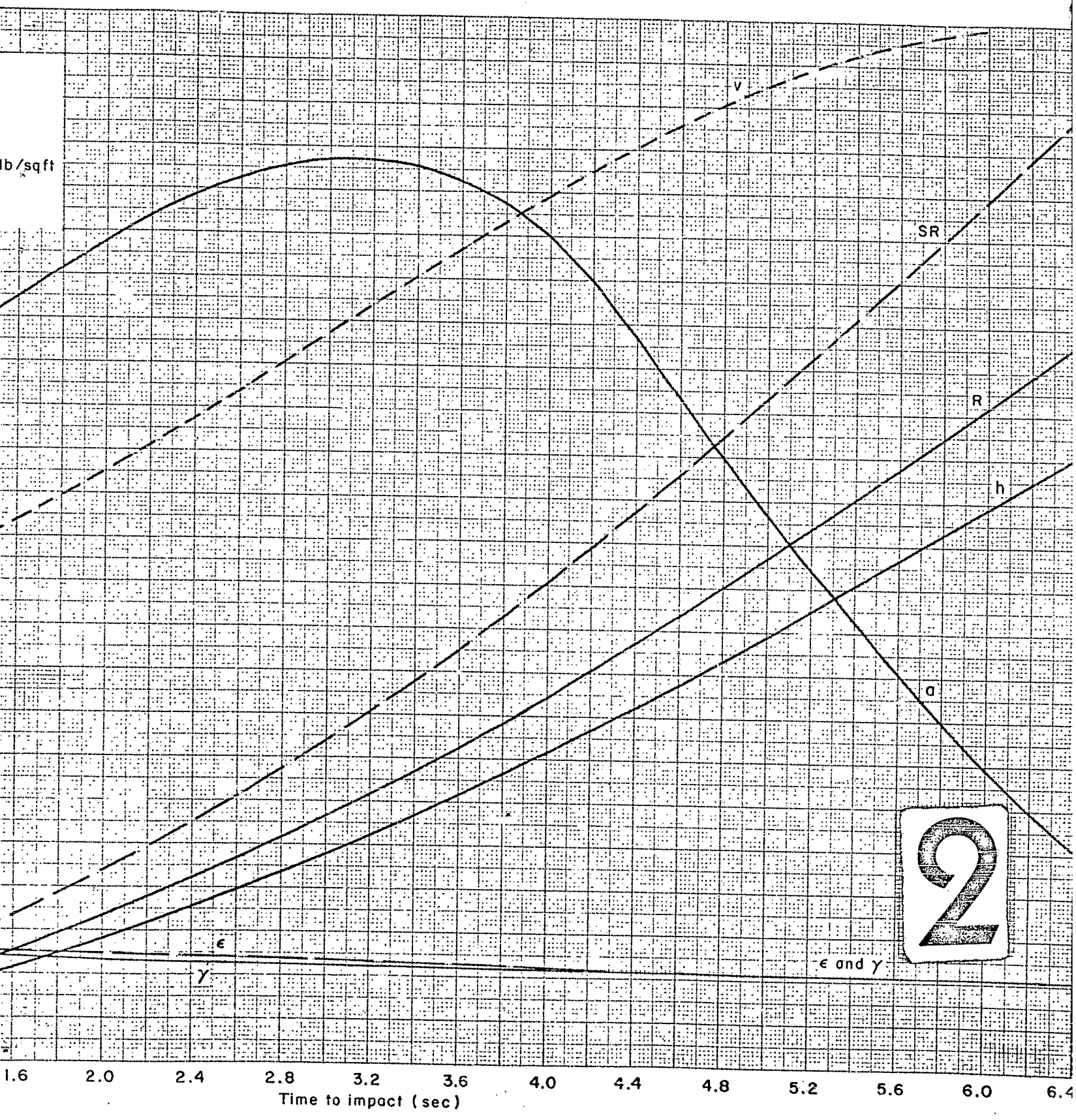
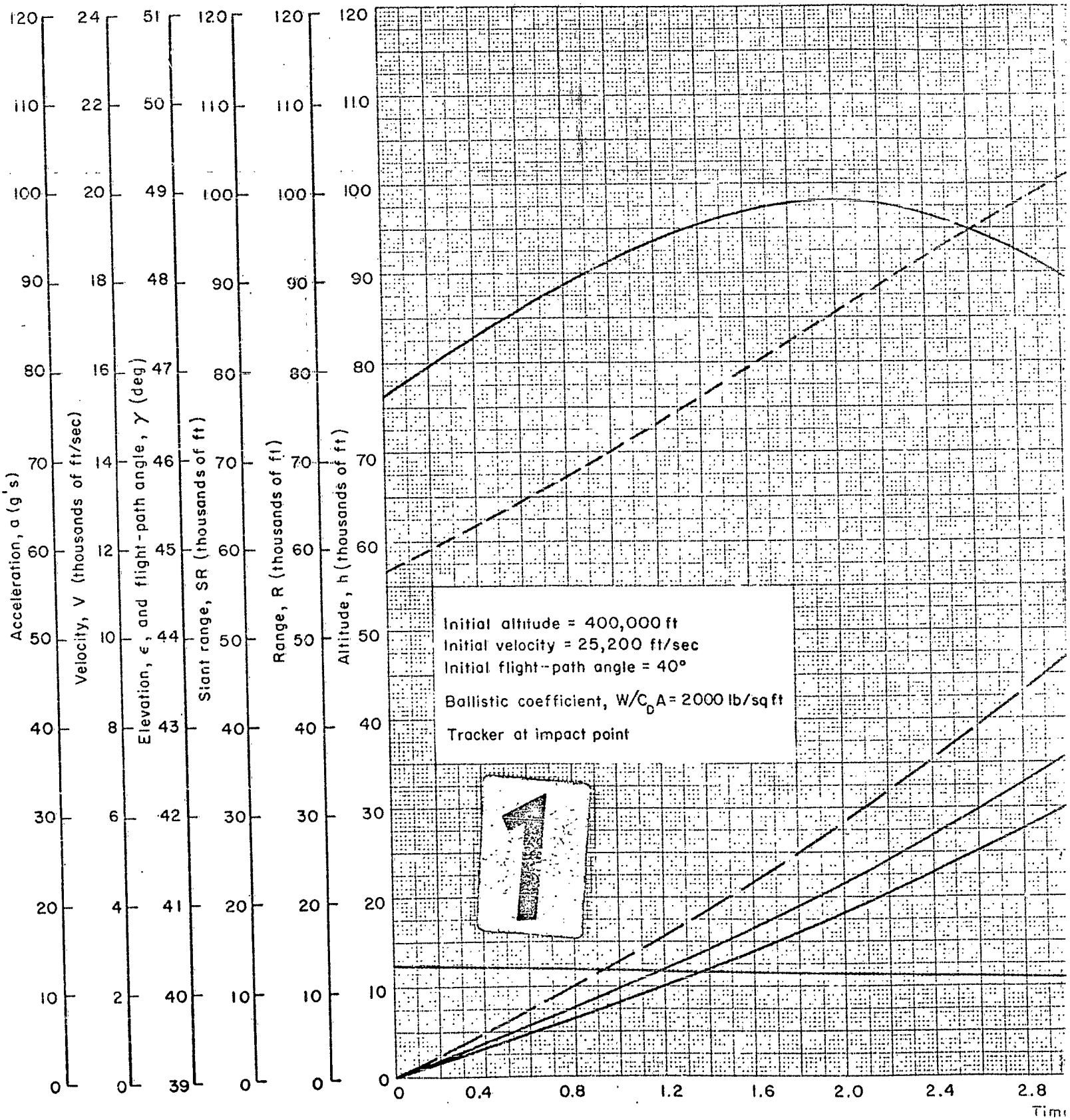

lb/sqft
V
SR
R
h
a
ε
γ
ε and γ
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
Time to impact (sec)

Fig. A—29


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 25,200 ft/sec
Initial flight-path angle = 40°
Ballistic coefficient, W/C_D A = 2000 lb/sq ft
Tracker at impact point
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Time

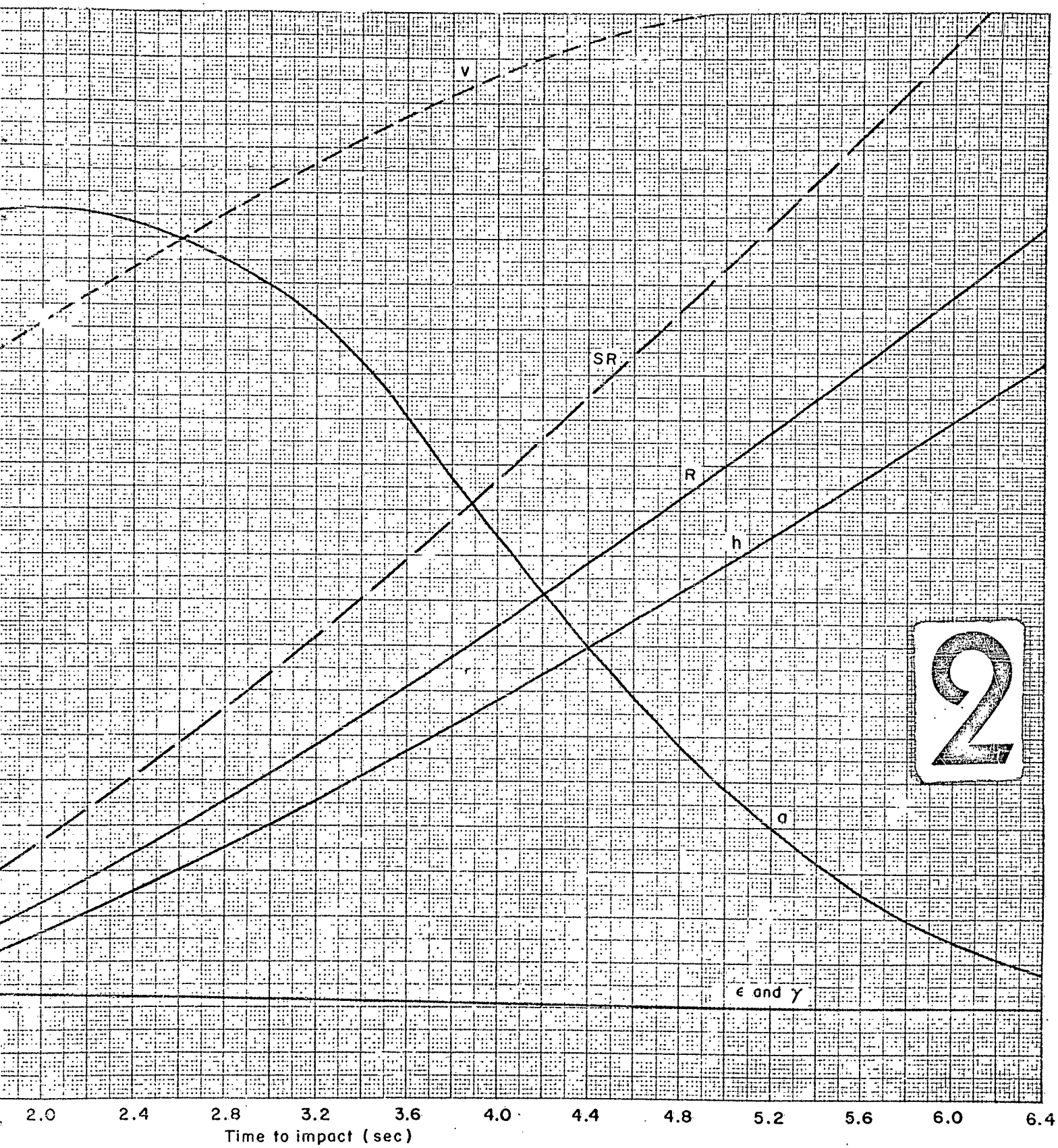
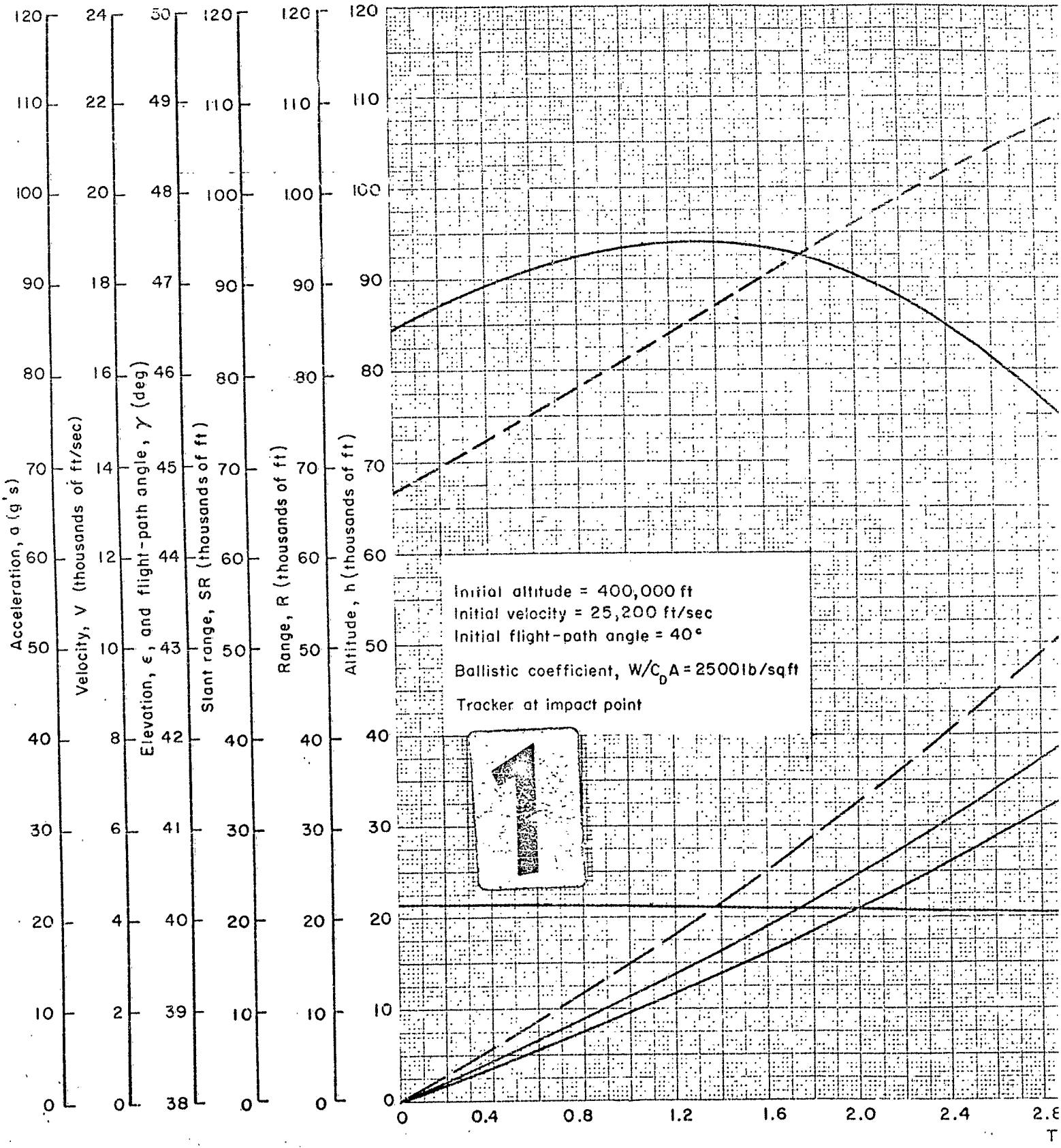

v
SR
R
h
a
ϵ and γ
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A —30


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 25,200 ft/sec
Initial flight-path angle = 40°
Ballistic coefficient, W/C_DA = 2500 lb/sq ft
Tracker at impact point
0
0.4
0.8
1.2
1.6
2.0
2.4
T

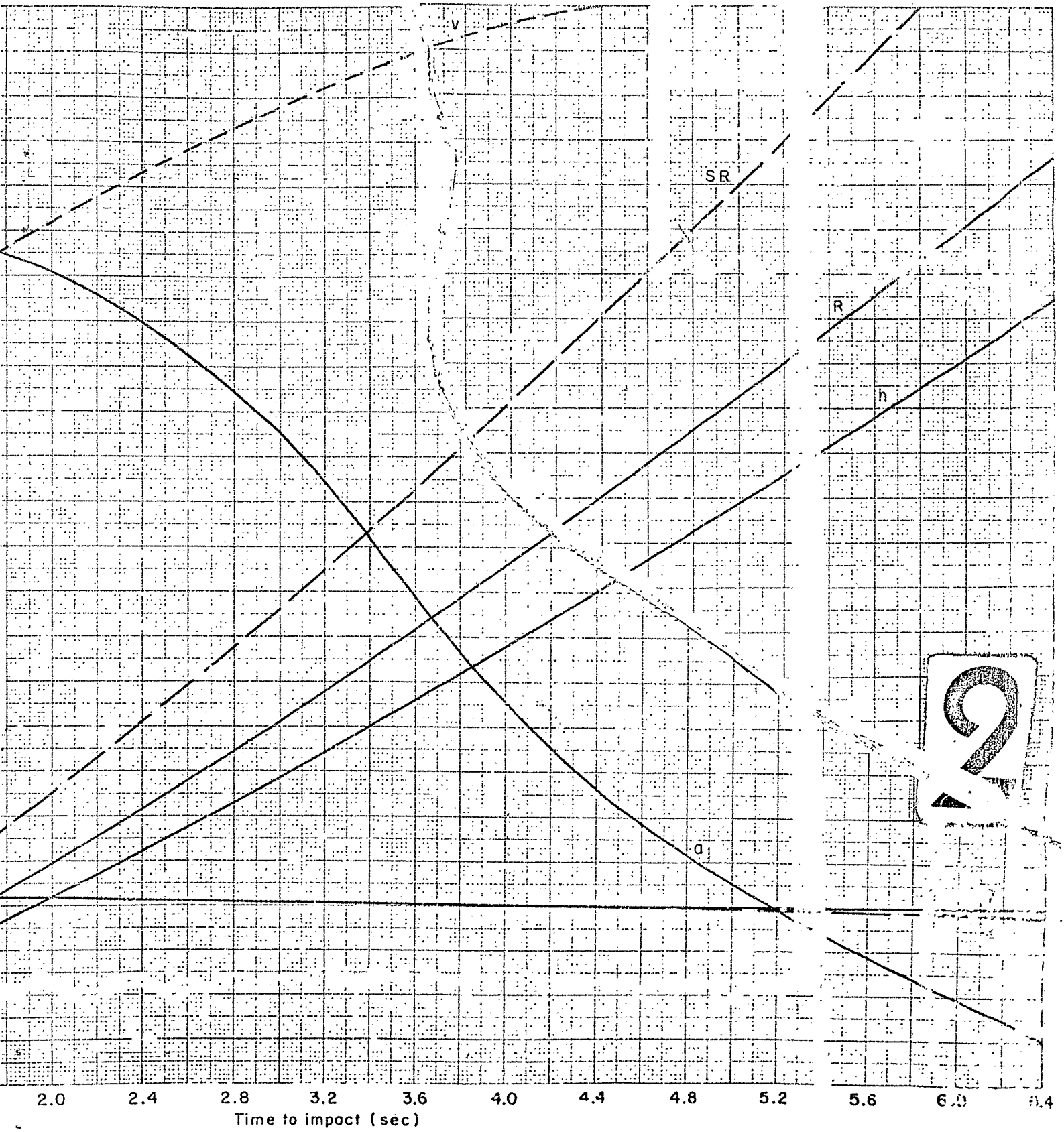
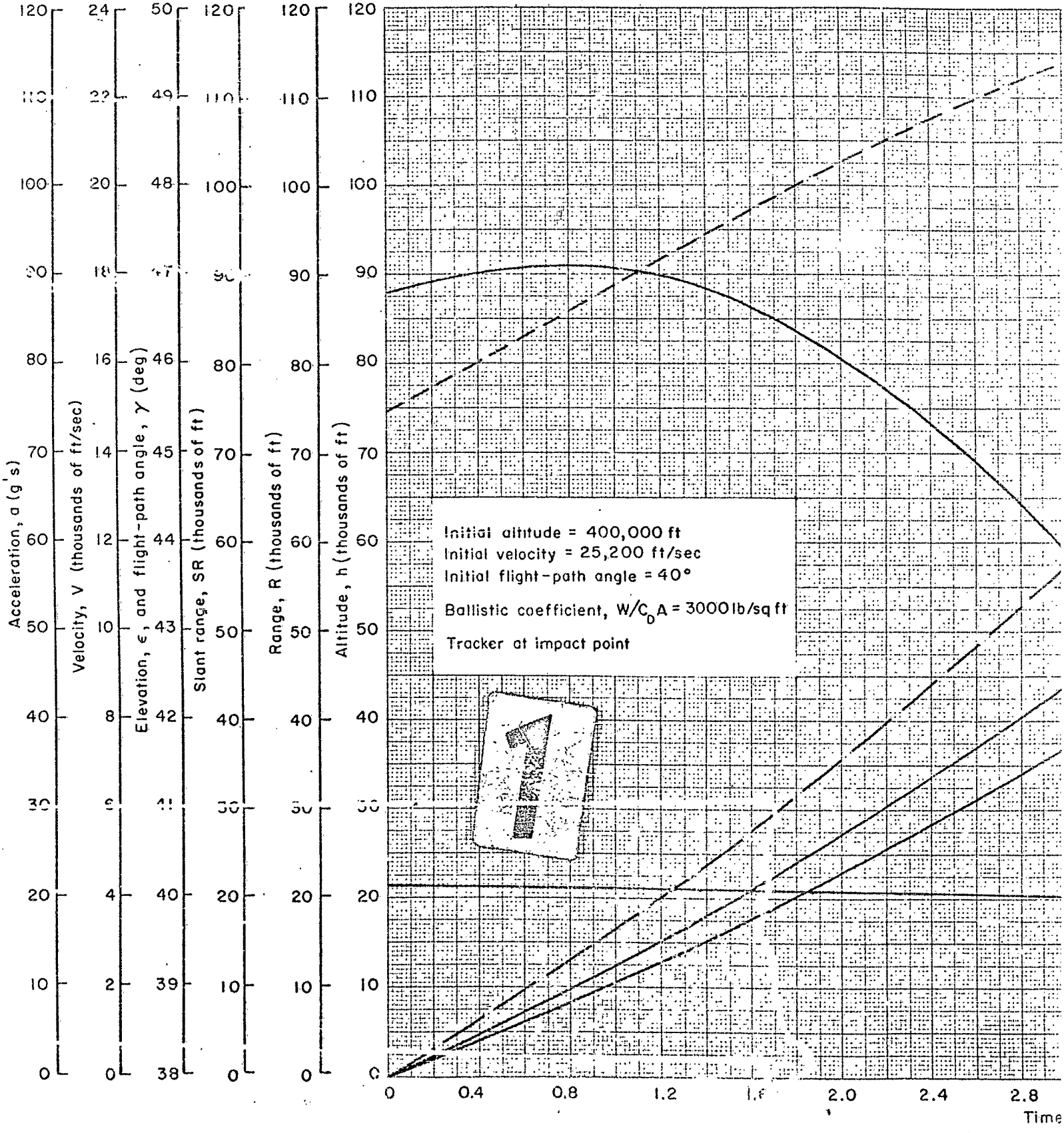


Fig. A — 31


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 25,200 ft/sec
Initial flight-path angle = 40°
Ballistic coefficient, W/C_DA = 3000 lb/sq ft
Tracker at impact point
0
0.4
0.8
1.2
2.0
2.4
2.8
Time

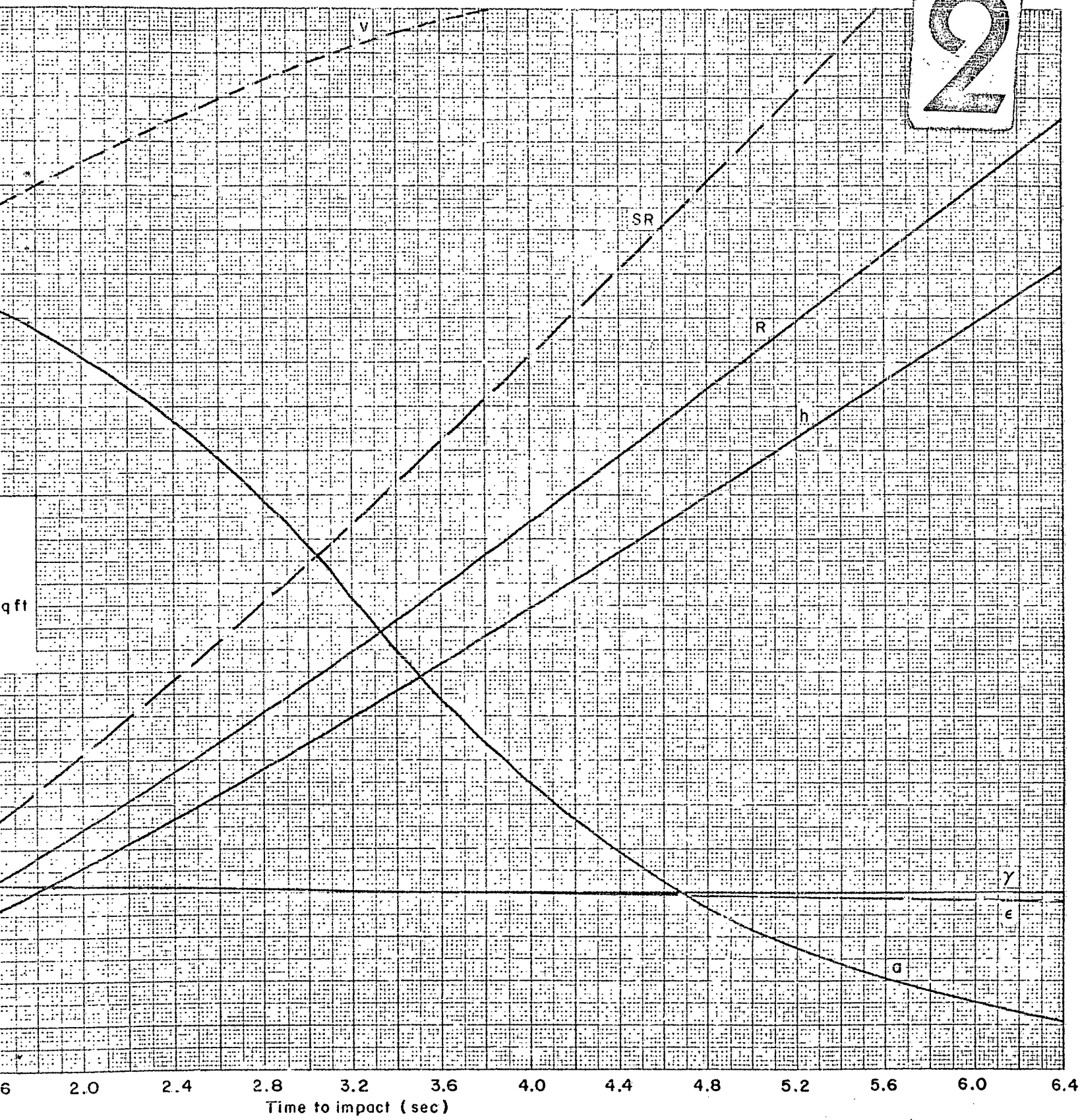
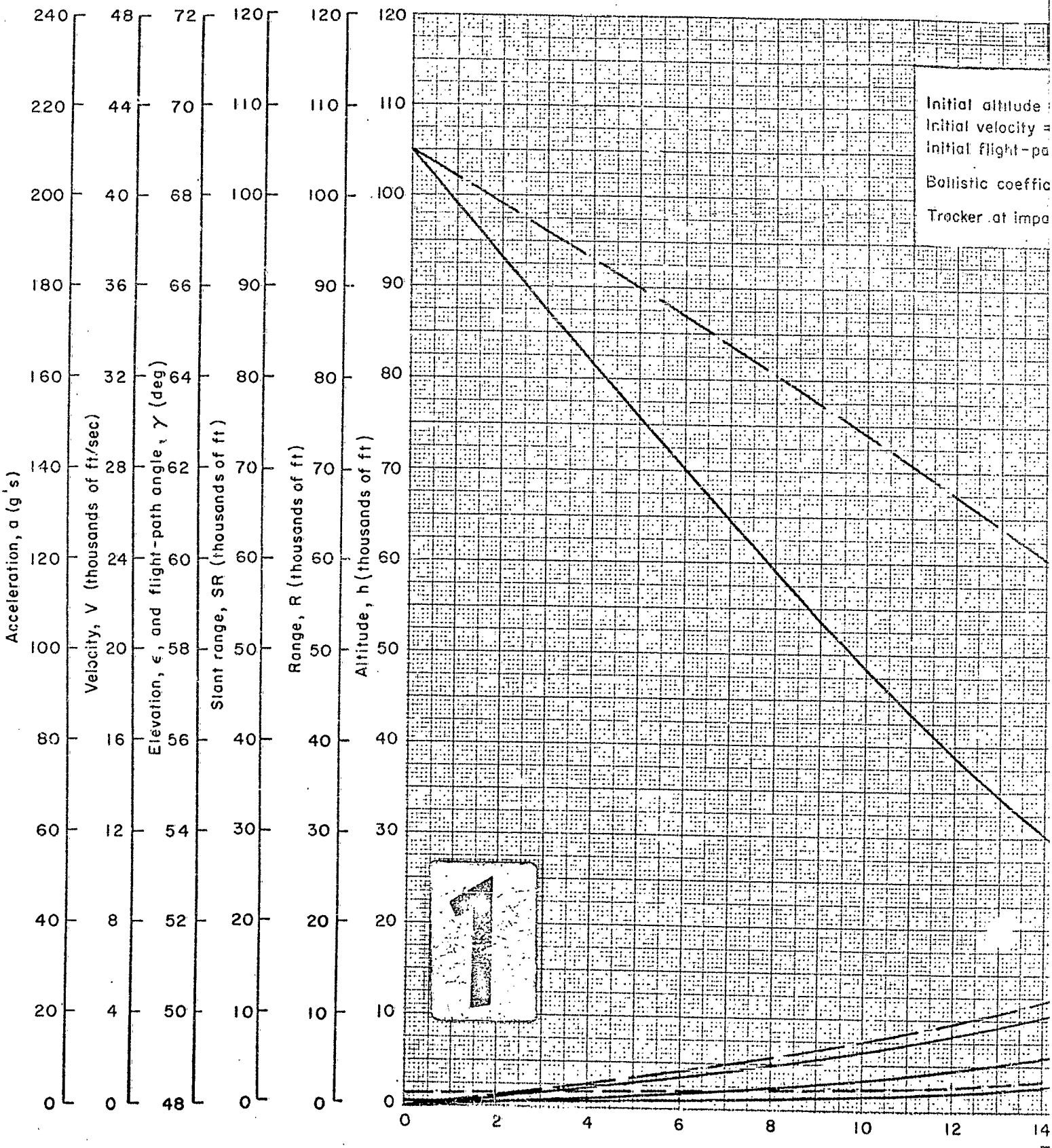

V
SR
R
h
qft
γ
ε
α
6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A—32


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude
Initial velocity =
Initial flight-pa
Ballistic coeffic
Tracker at impa
T

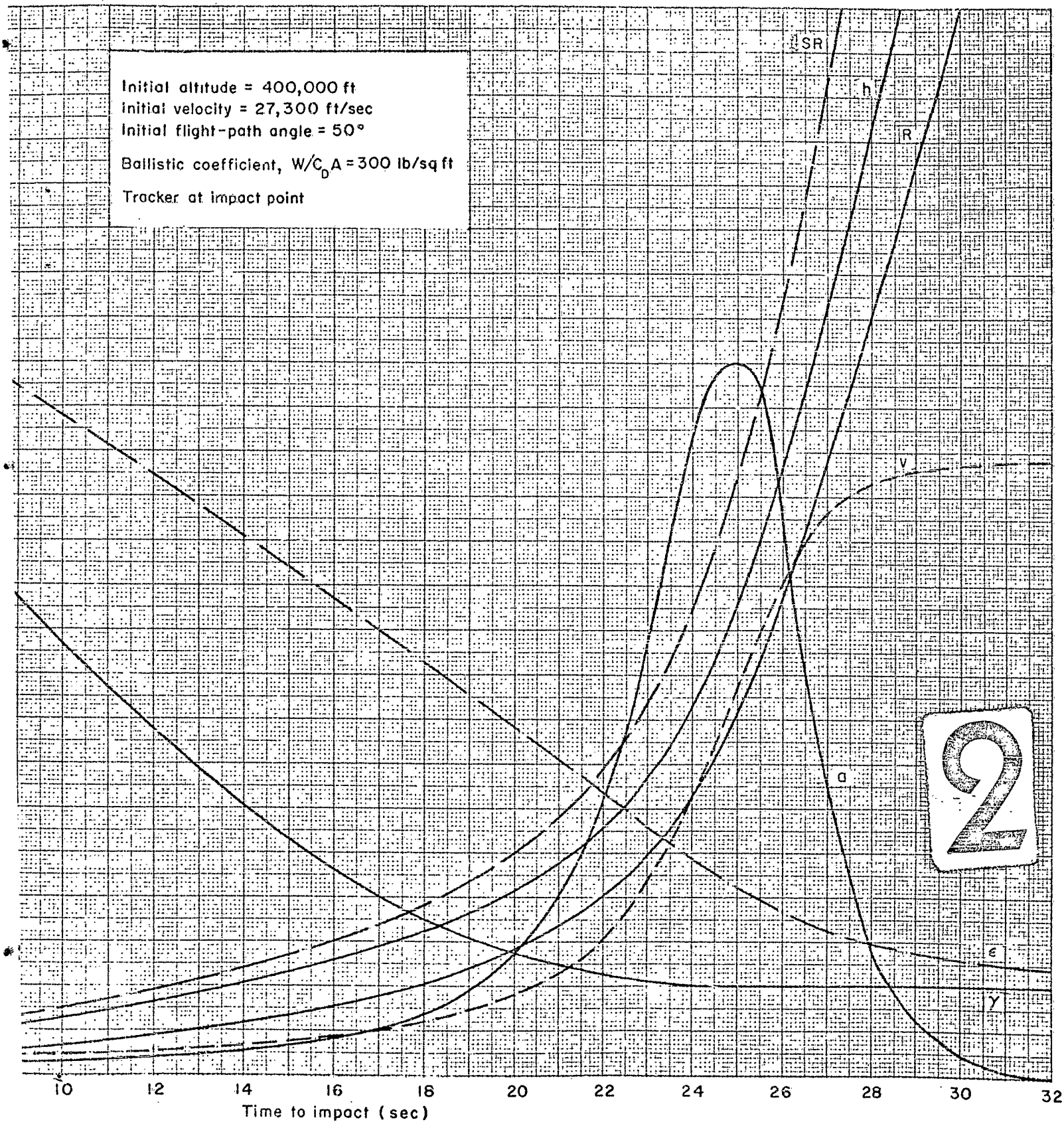
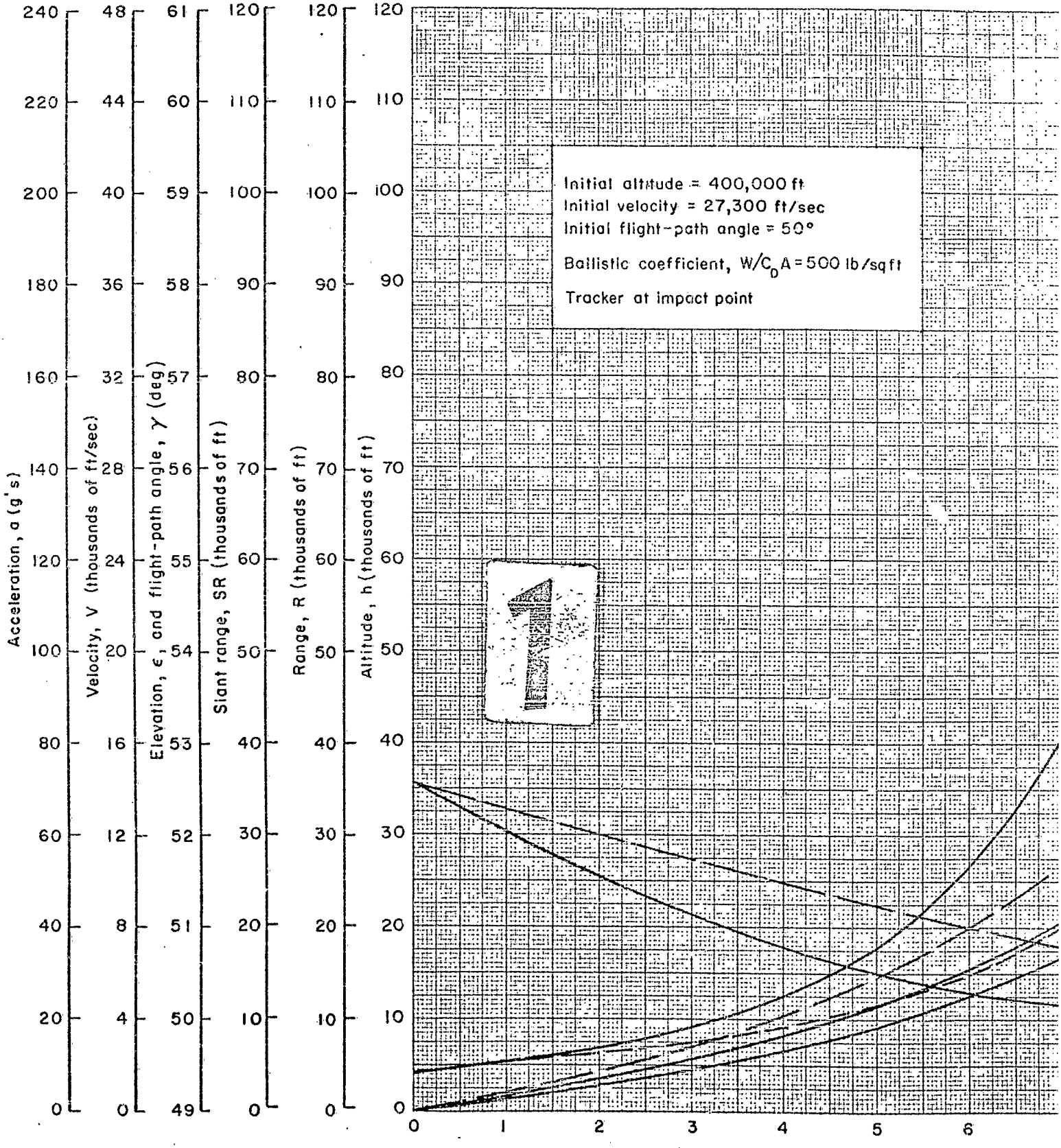

Initial altitude = 400,000 ft
Initial velocity = 27,300 ft/sec
Initial flight-path angle = 50°
Ballistic coefficient, $W/C_D A = 300$ lb/sq ft
Tracker at impact point
SR
h
R
V
a
ε
γ
10
12
14
16
18
20
22
24
26
28
30
32
Time to impact (sec)

Fig. A — 33


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 27,300 ft/sec
Initial flight-path angle = 50°
Ballistic coefficient, W/C_D A = 500 lb/sq ft
Tracker at impact point

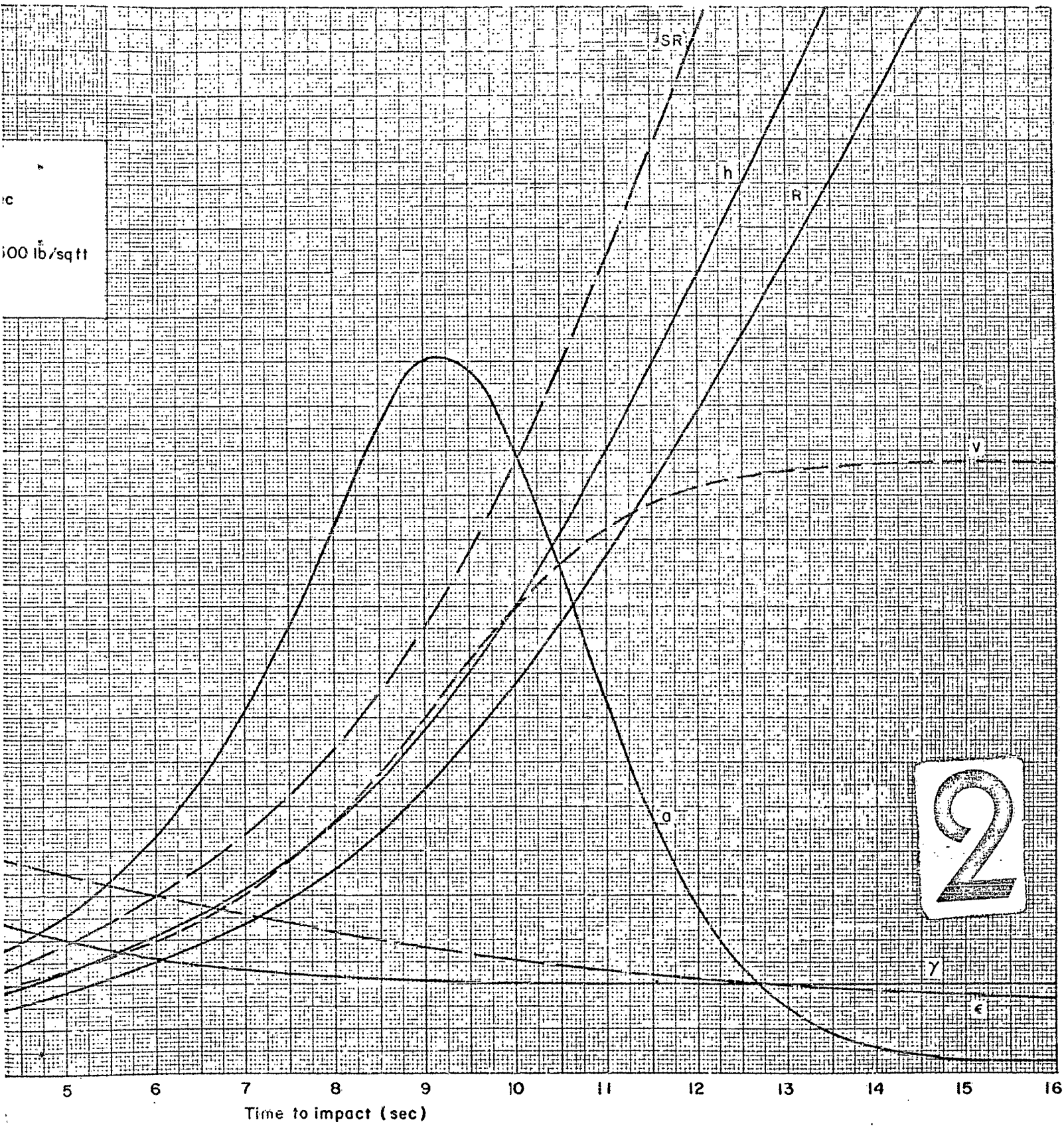
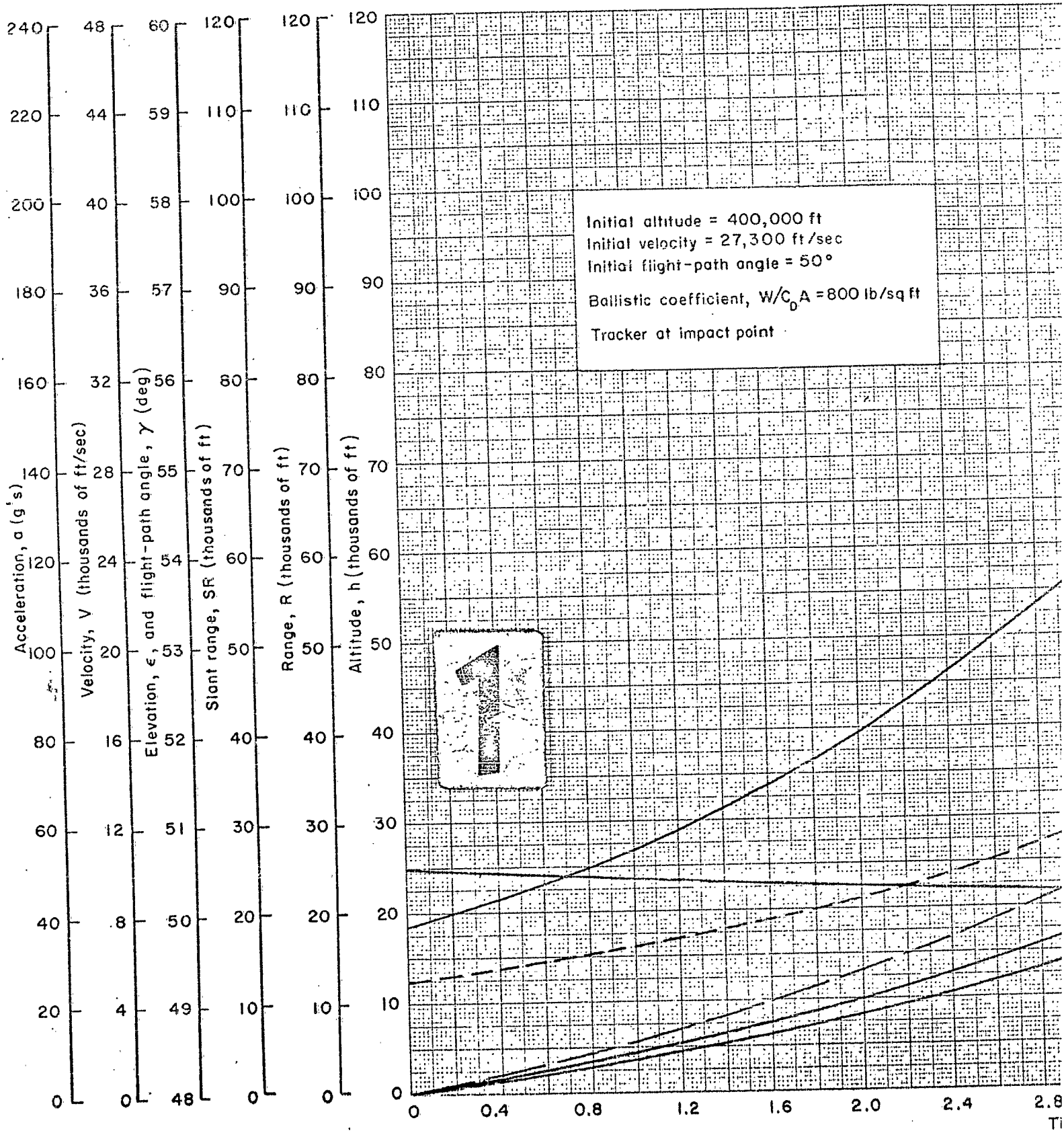


Fig. A — 34


Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Initial altitude = 400,000 ft
Initial velocity = 27,300 ft/sec
Initial flight-path angle = 50°
Ballistic coefficient, W/C_DA = 800 lb/sq ft
Tracker at impact point
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Ti

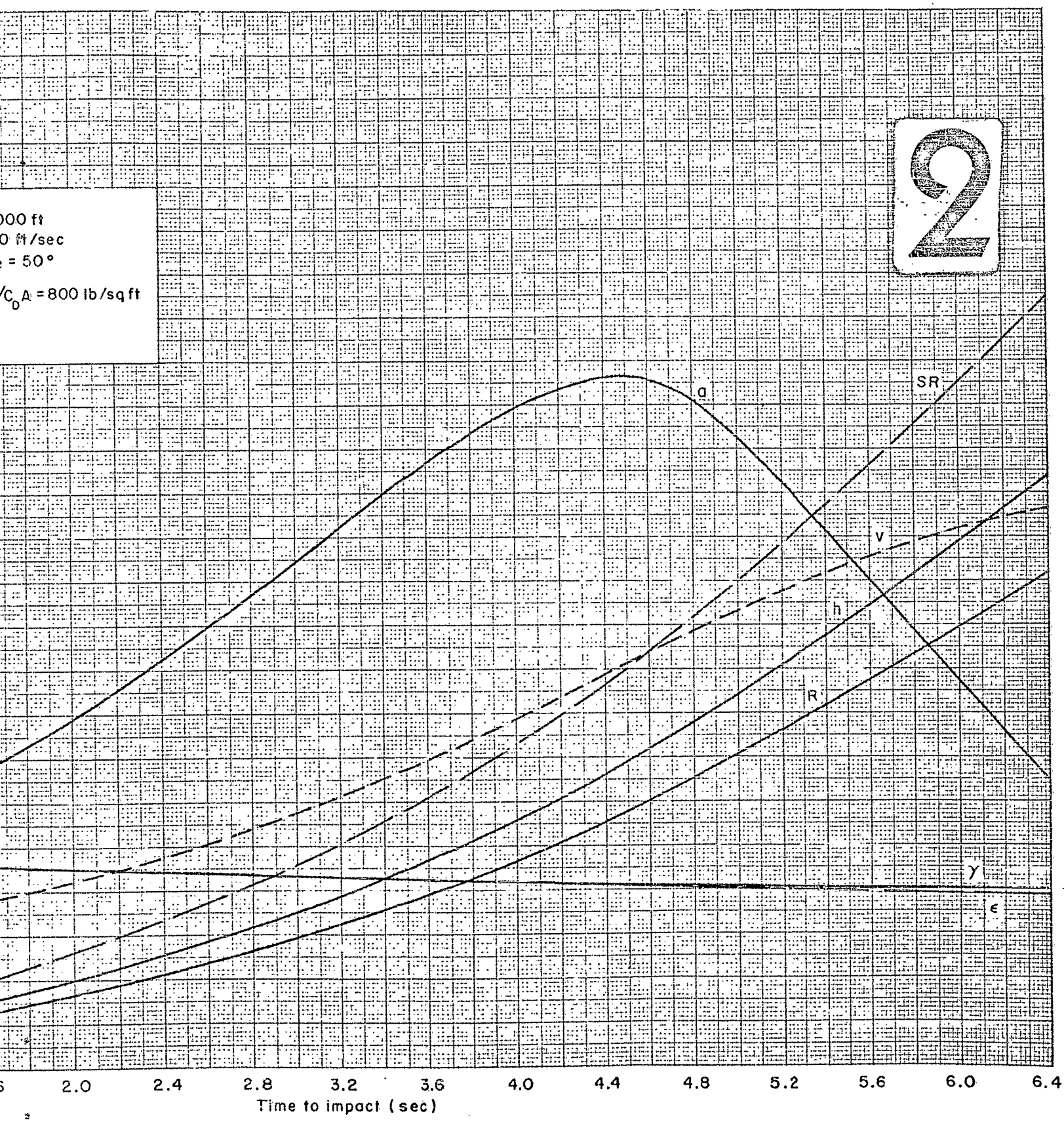
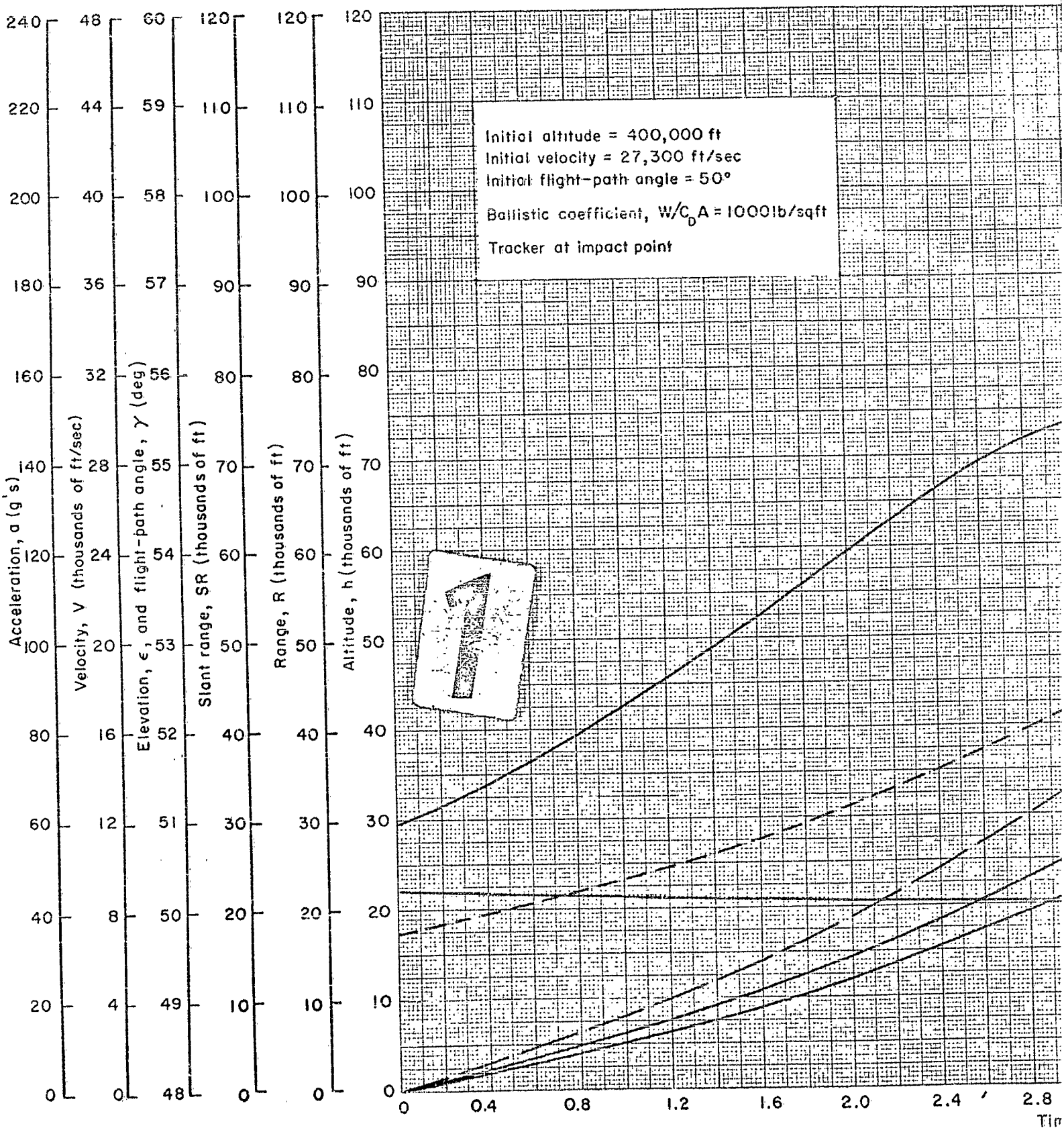

000 ft
0 ft/sec
= 50°
$/C_D A$ = 800 lb/sq ft
2
a
SR
v
h
R
γ
ϵ
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A — 35


Initial altitude = 400,000 ft
Initial velocity = 27,300 ft/sec
Initial flight-path angle = 50°
Ballistic coefficient, $W/C_D A$ = 1000 lb/sqft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Time

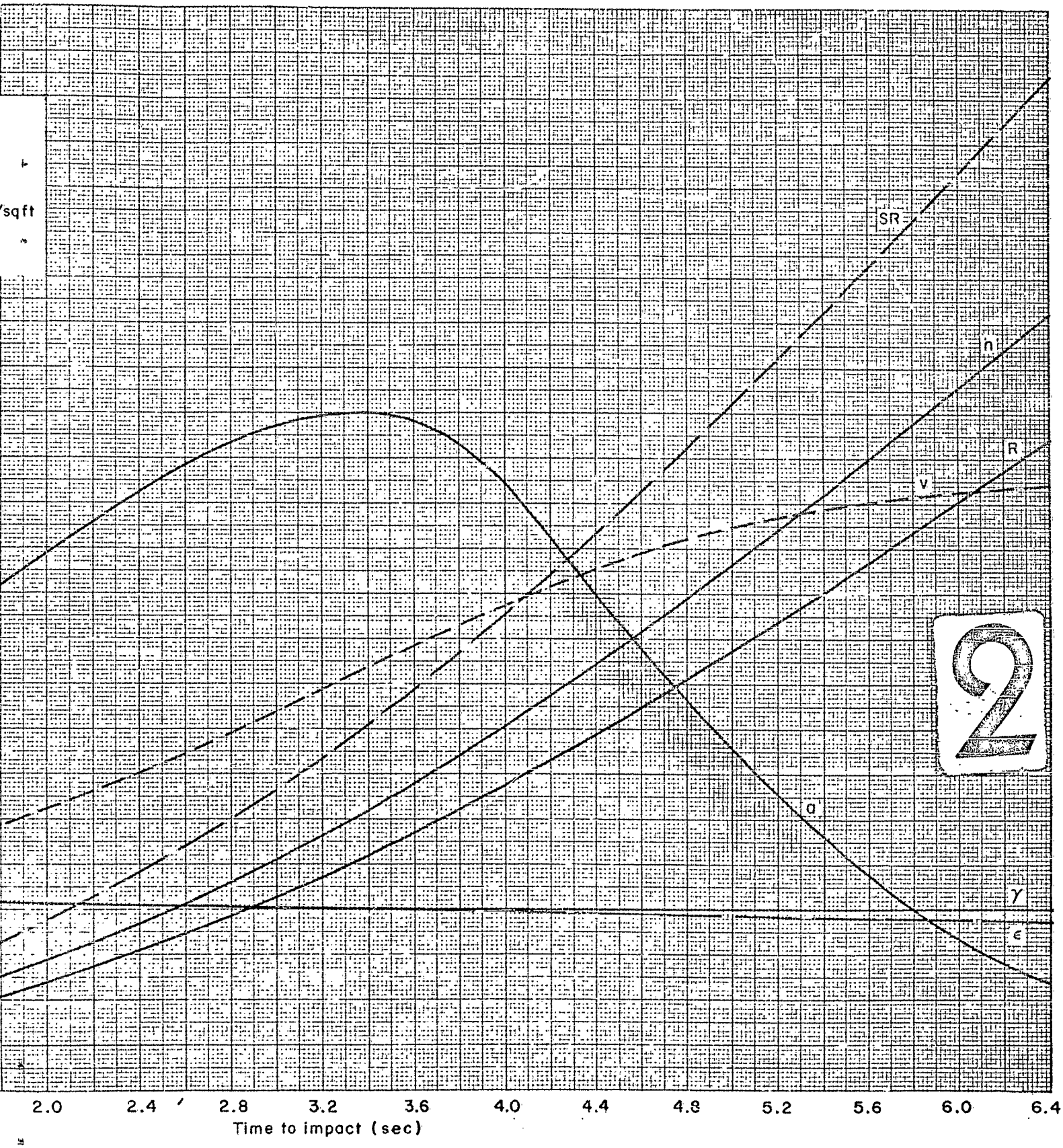
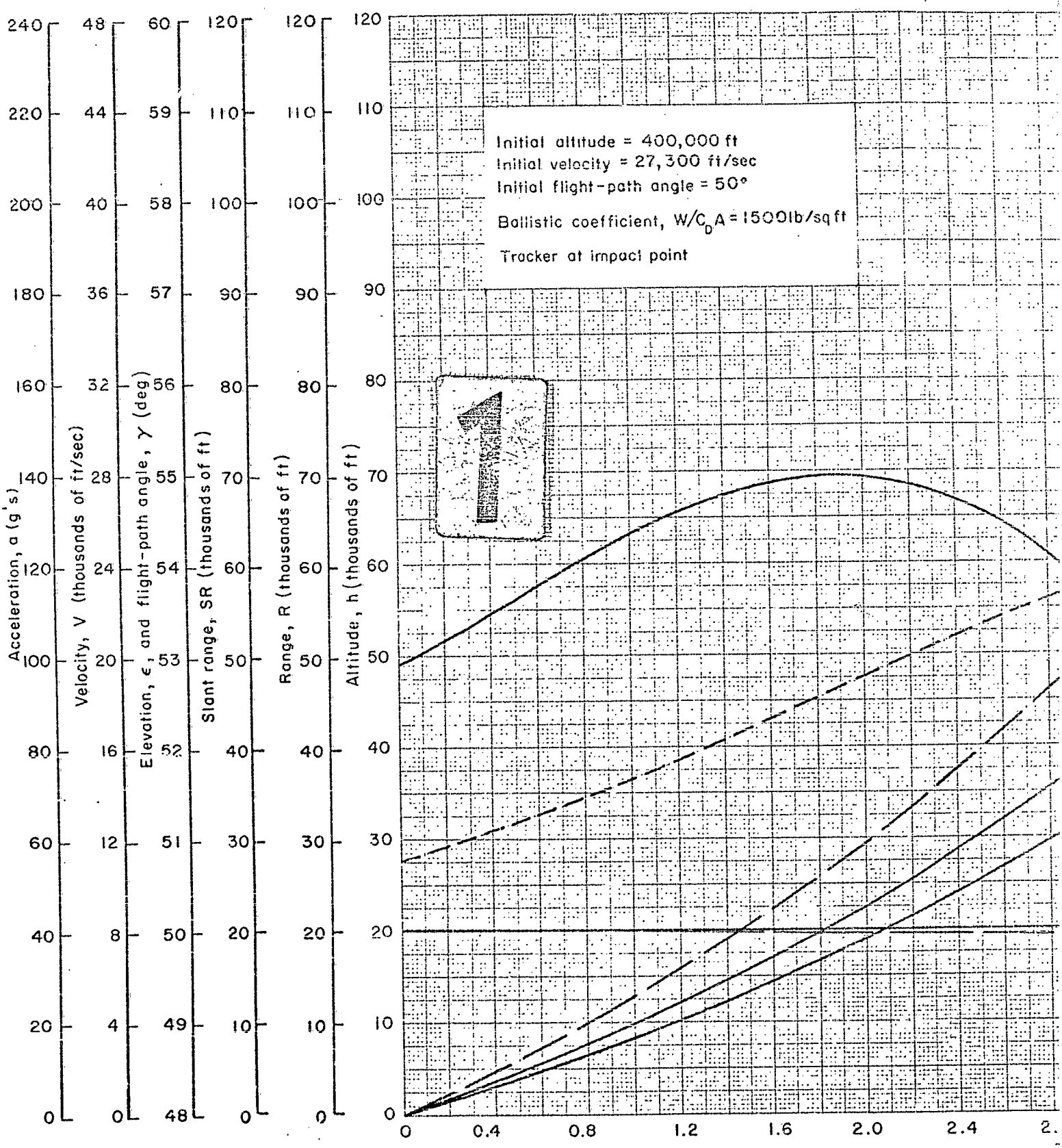

'sqft
SR
h
R
V
a
γ
ε
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A—36


Initial altitude = 400,000 ft
Initial velocity = 27,300 ft/sec
Initial flight-path angle = 50°
Ballistic coefficient, W/C_D A = 1500 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
240
220
200
180
160
140
120
100
80
60
40
20
0
48
44
40
36
32
28
24
20
16
12
8
4
0
60
59
58
57
56
55
54
53
52
51
50
49
48
120
110
100
90
80
70
60
50
40
30
20
10
0
120
110
100
90
80
70
60
50
40
30
20
10
0
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
2.0
2.4
2.

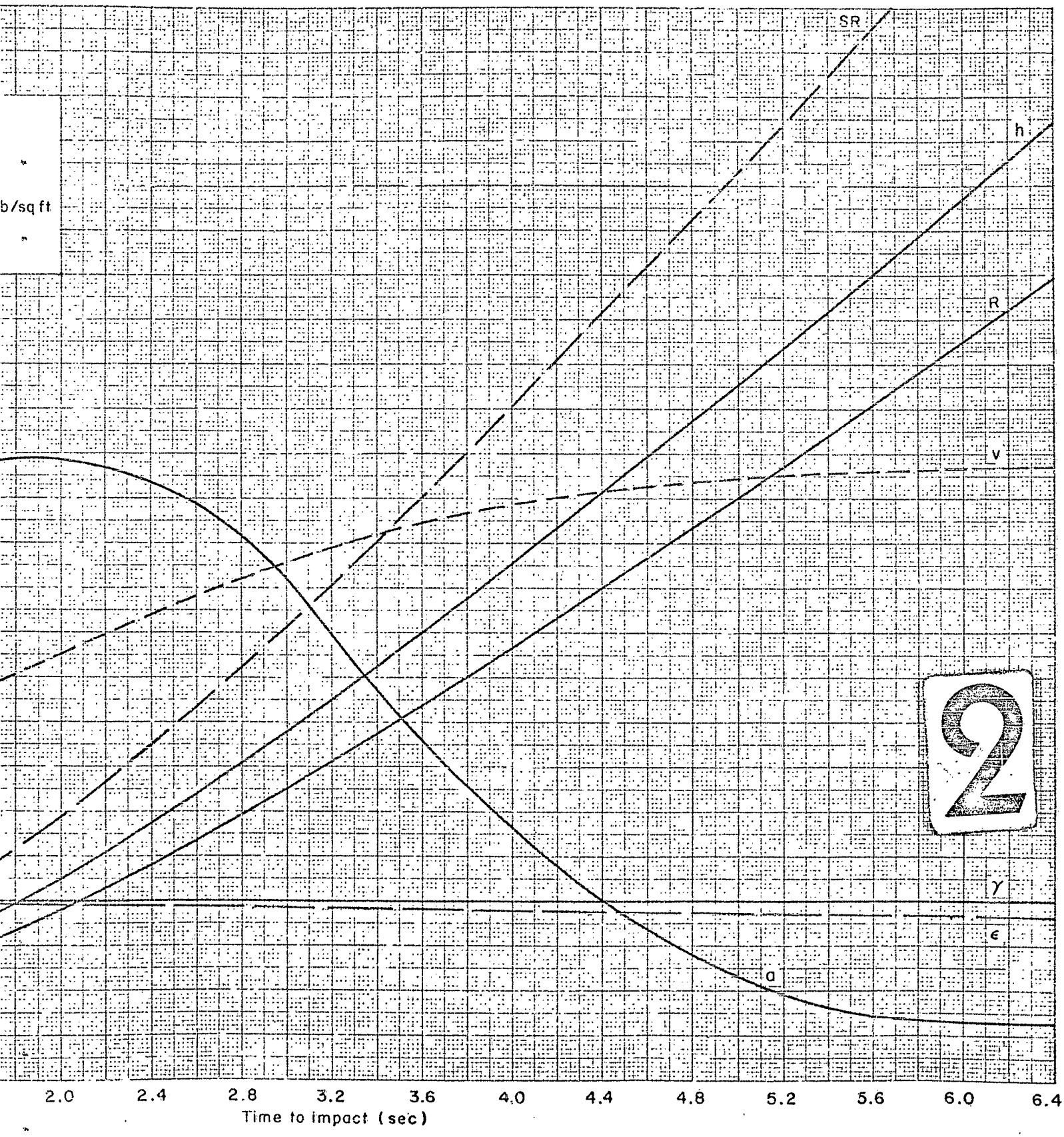
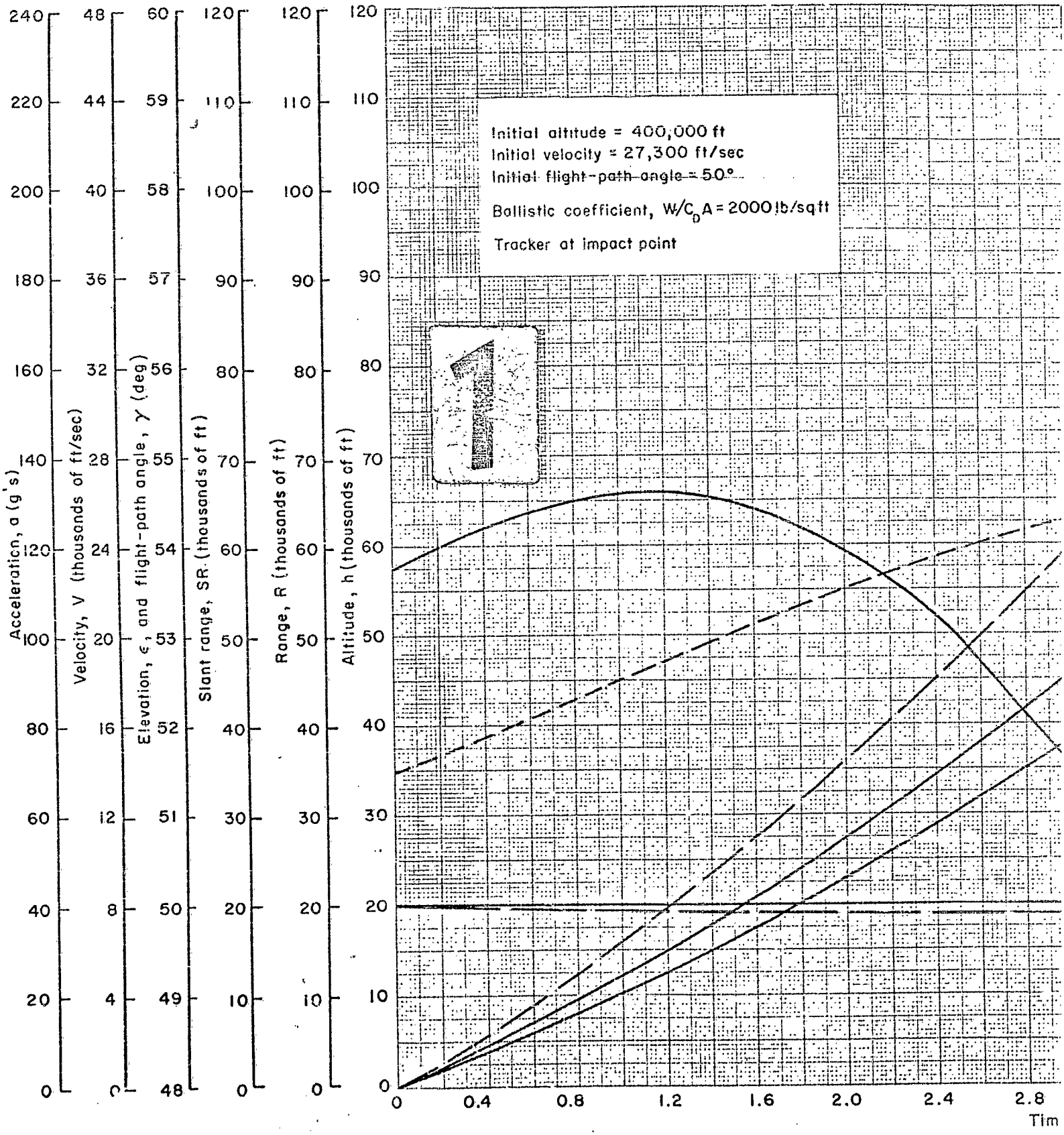

SR
h
R
V
γ
ϵ
a
2
b/sq ft
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A—37


Initial altitude = 400,000 ft
Initial velocity = 27,300 ft/sec
Initial flight-path angle = 50°
Ballistic coefficient, $W/C_D A$ = 2000 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ϵ, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Tim

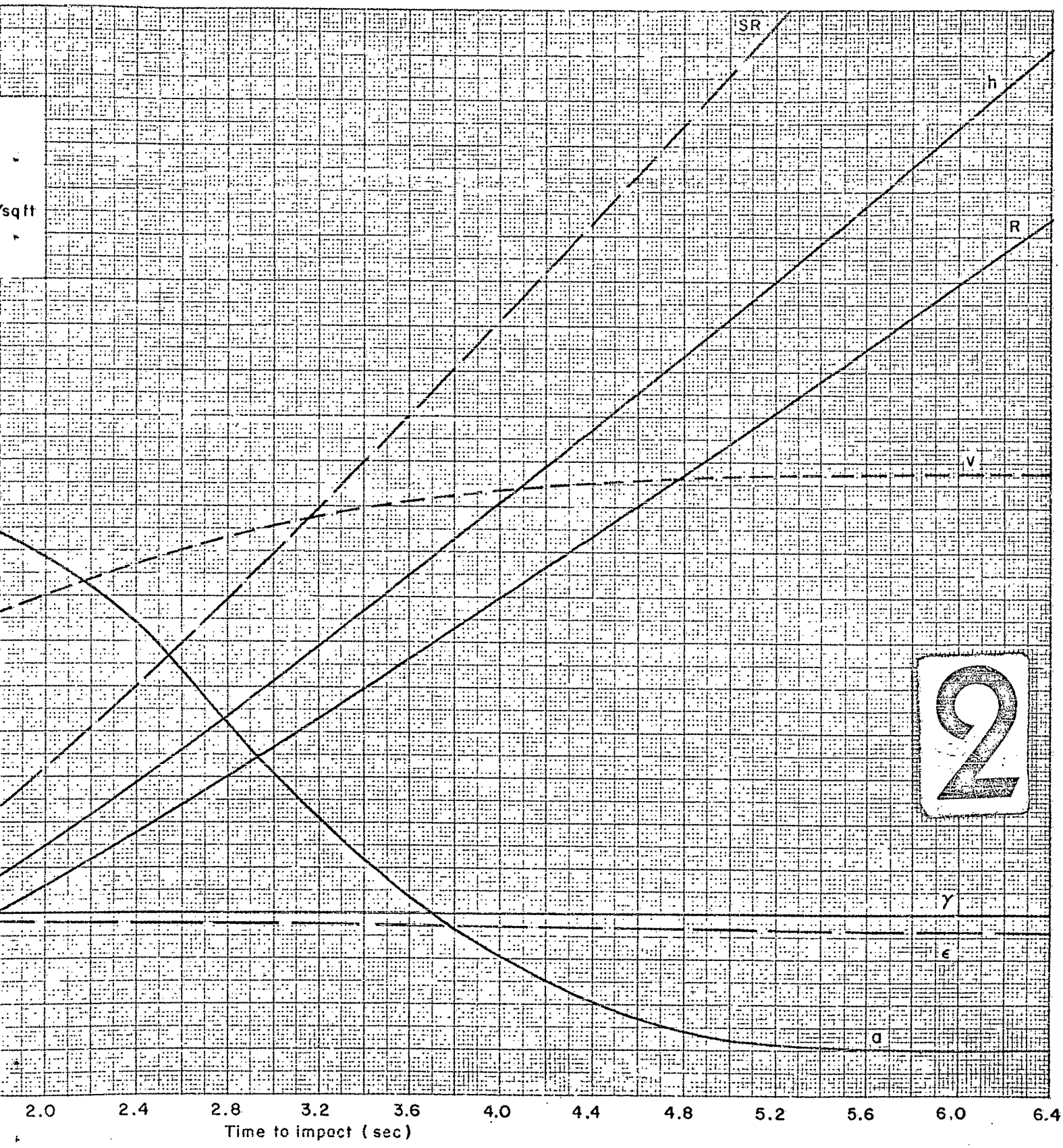
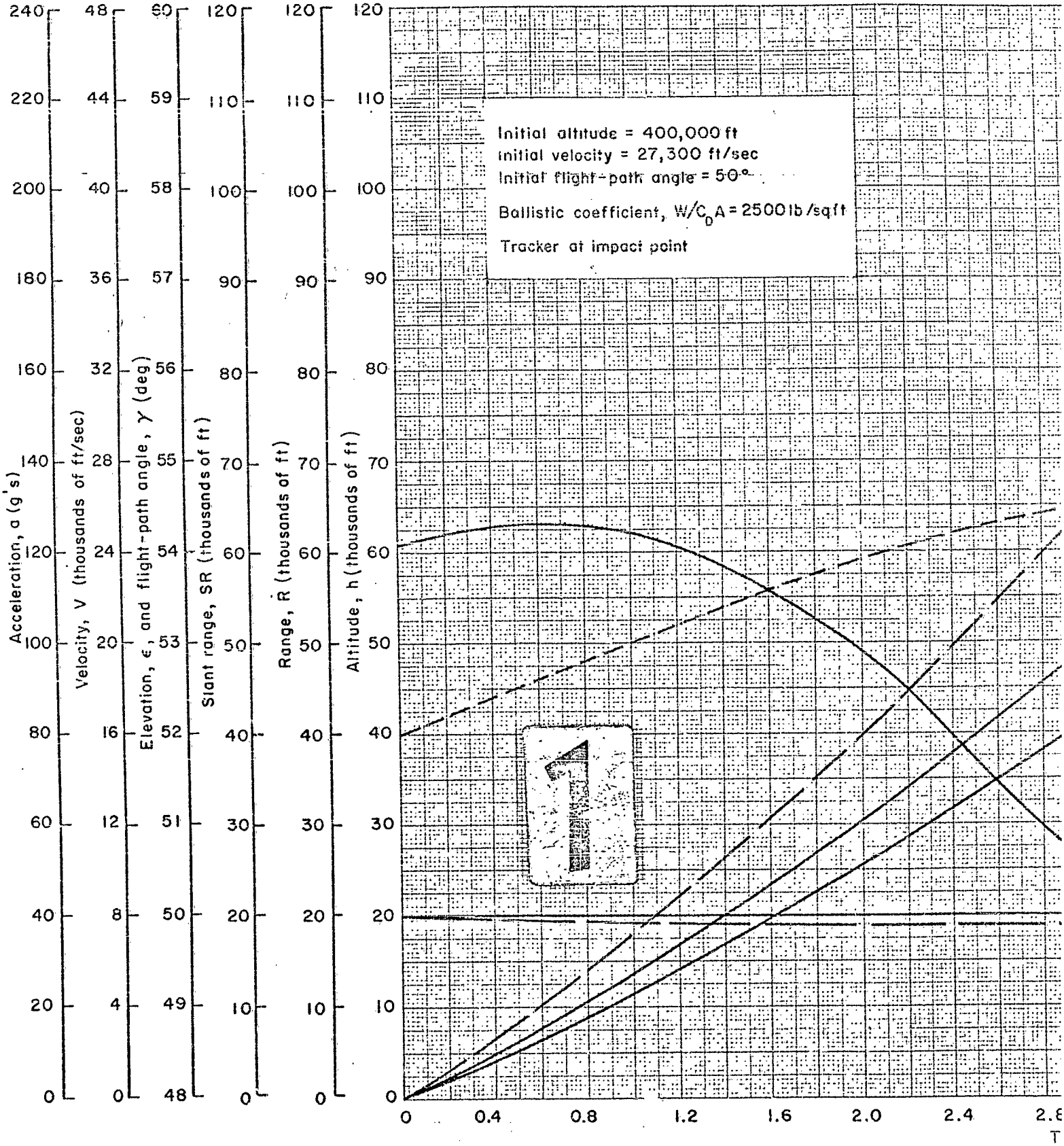

SR
h
R
V
γ
ϵ
a
'sqft
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A — 38


Initial altitude = 400,000 ft
Initial velocity = 27,300 ft/sec
Initial flight-path angle = 5.0°
Ballistic coefficient, W/C_DA = 2500 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
T

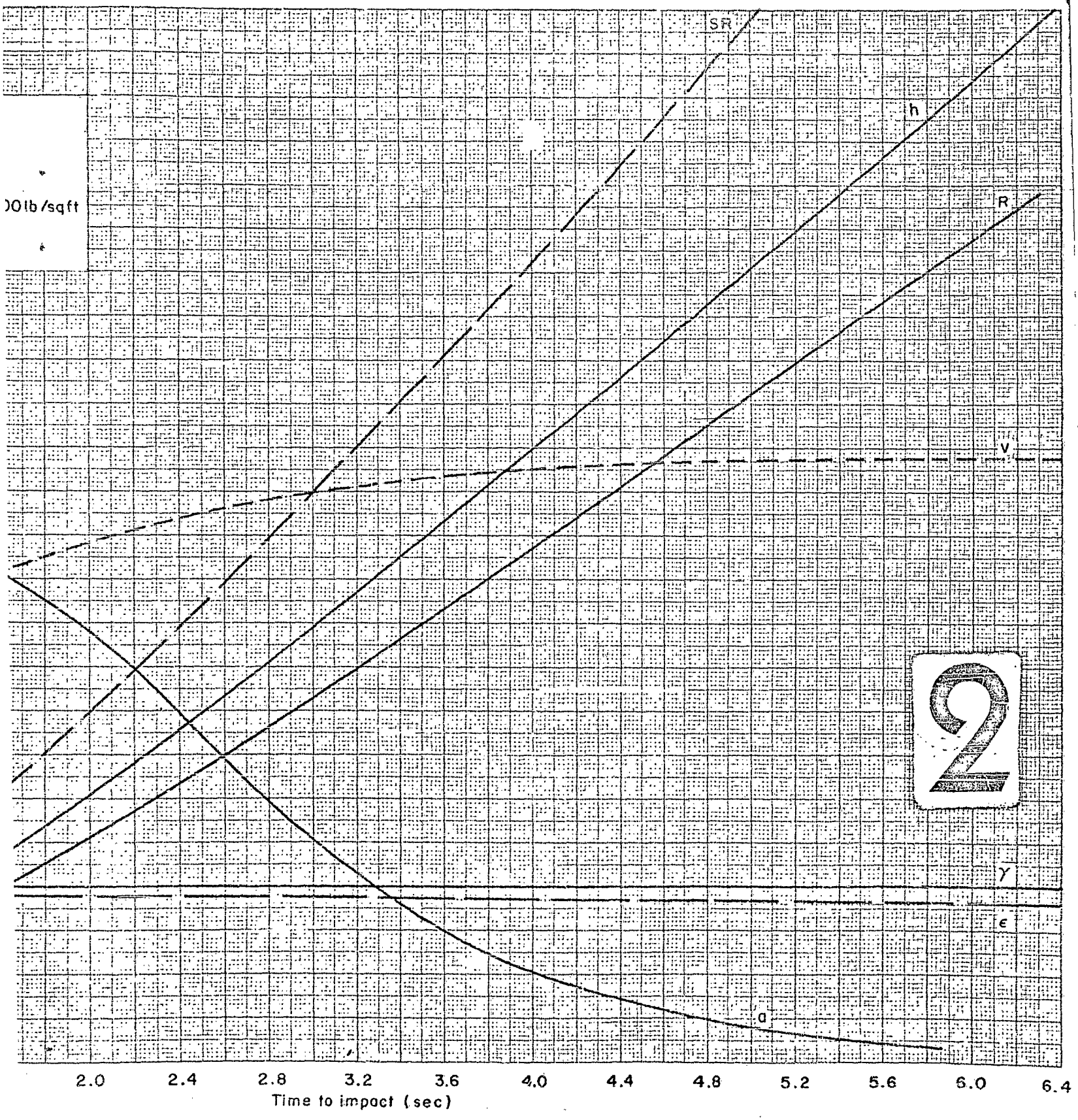
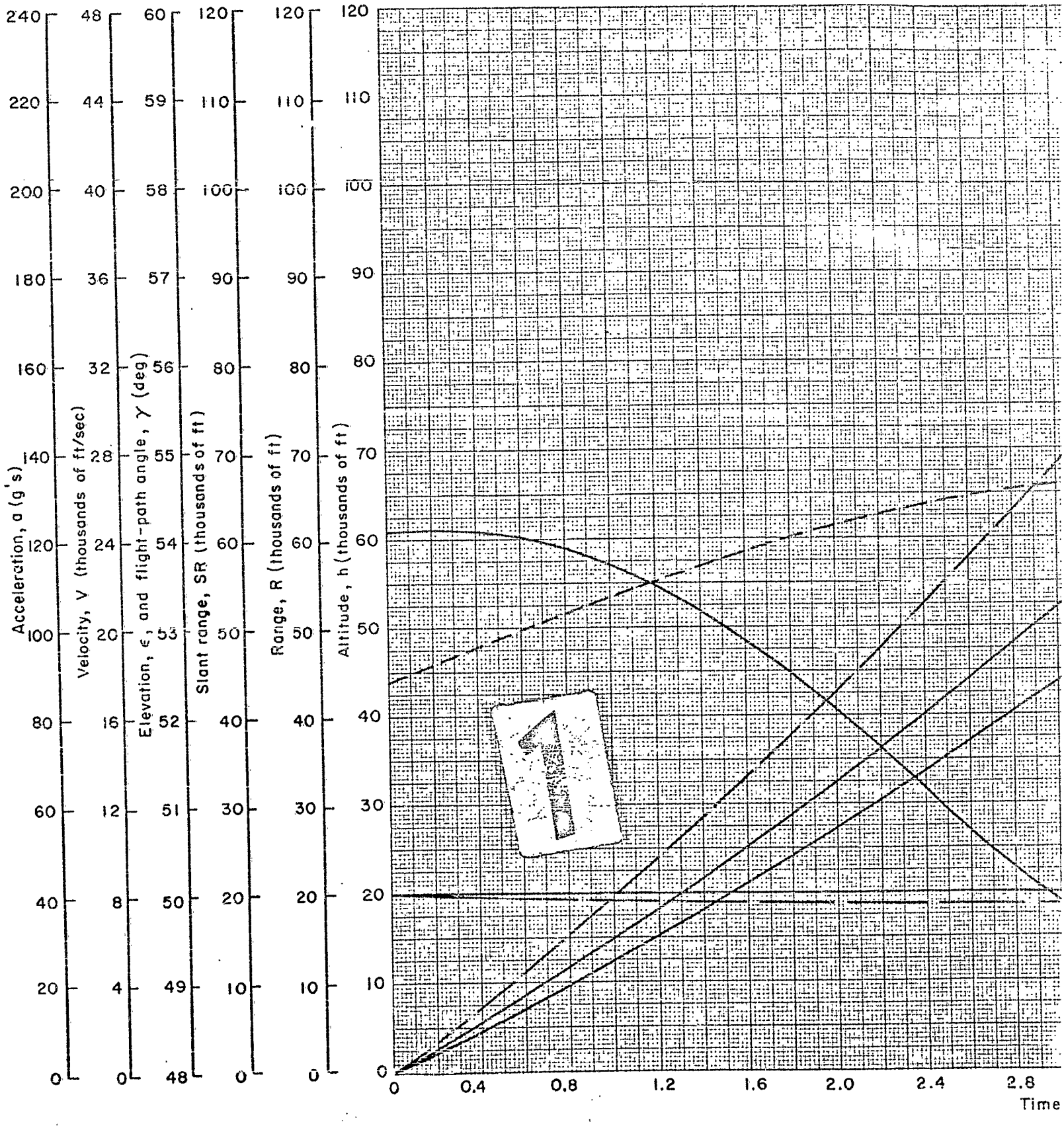

SR
h
R
V
γ
ε
a
)01b/sqft
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A—39


Acceleration, a (g's)
240
220
200
180
160
140
120
100
80
60
40
20
0
Velocity, V (thousands of ft/sec)
48
44
40
36
32
28
24
20
16
12
8
4
0
Elevation, ε, and flight-path angle, γ (deg)
60
59
58
57
56
55
54
53
52
51
50
49
48
Slant range, SR (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Range, R (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Altitude, h (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Time

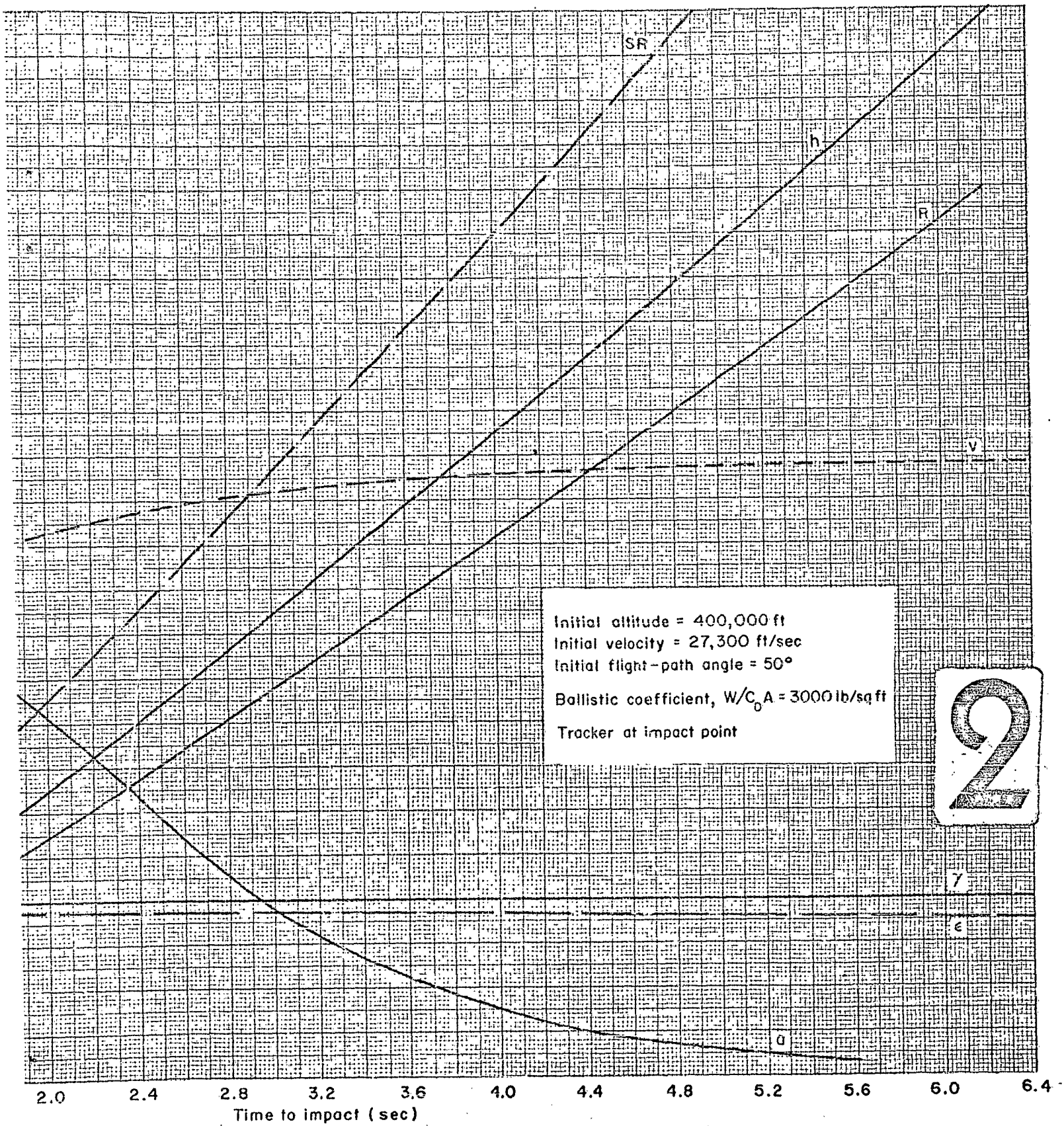
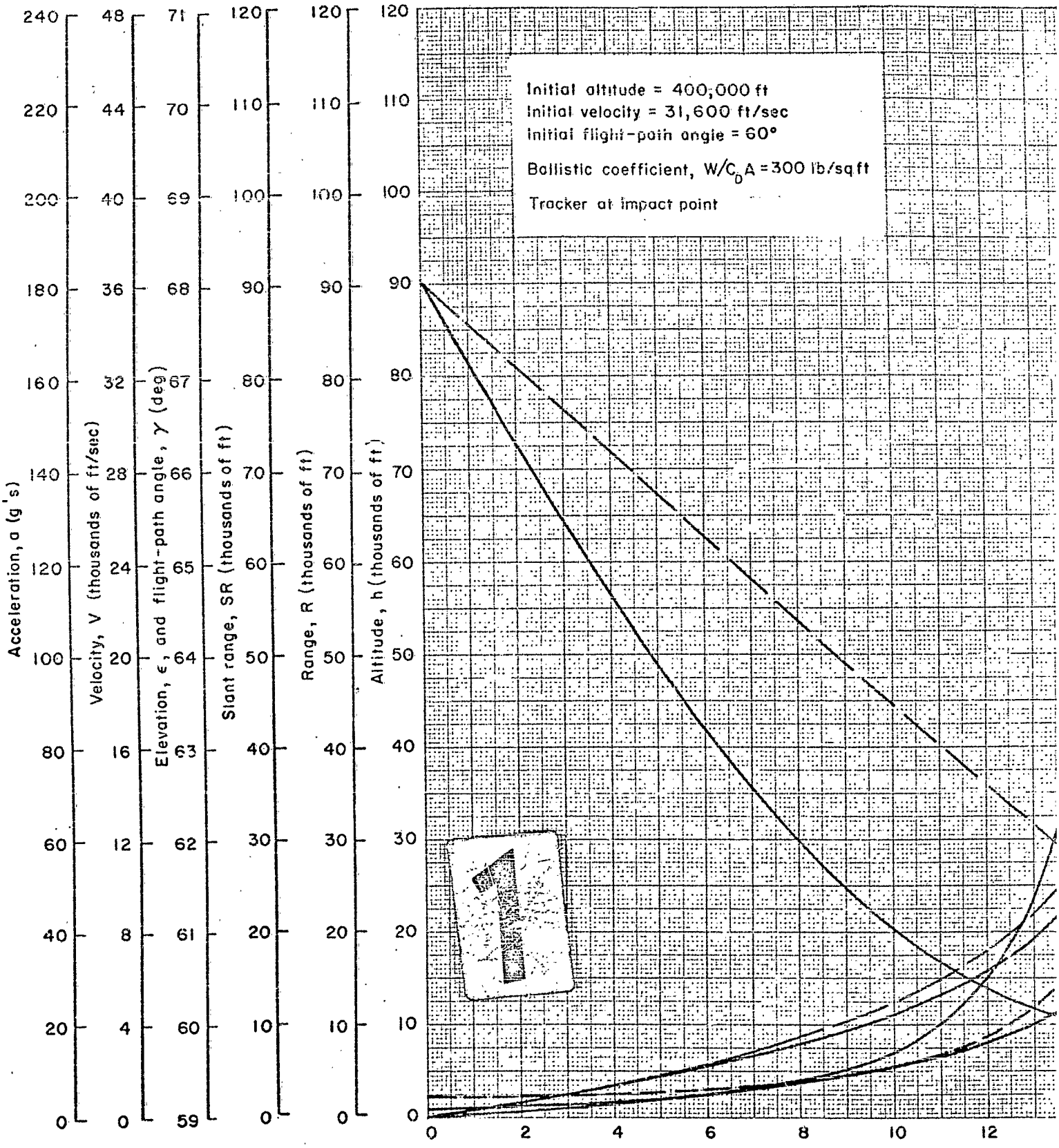

SR
h
R
V
Initial altitude = 400,000 ft
Initial velocity = 27,300 ft/sec
Initial flight-path angle = 50°
Ballistic coefficient, W/C_0A = 3000 lb/sq ft
Tracker at impact point
2
γ
ϵ
a
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A—40


Initial altitude = 400,000 ft
Initial velocity = 31,600 ft/sec
Initial flight-path angle = 60°
Ballistic coefficient, W/C_DA = 300 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)

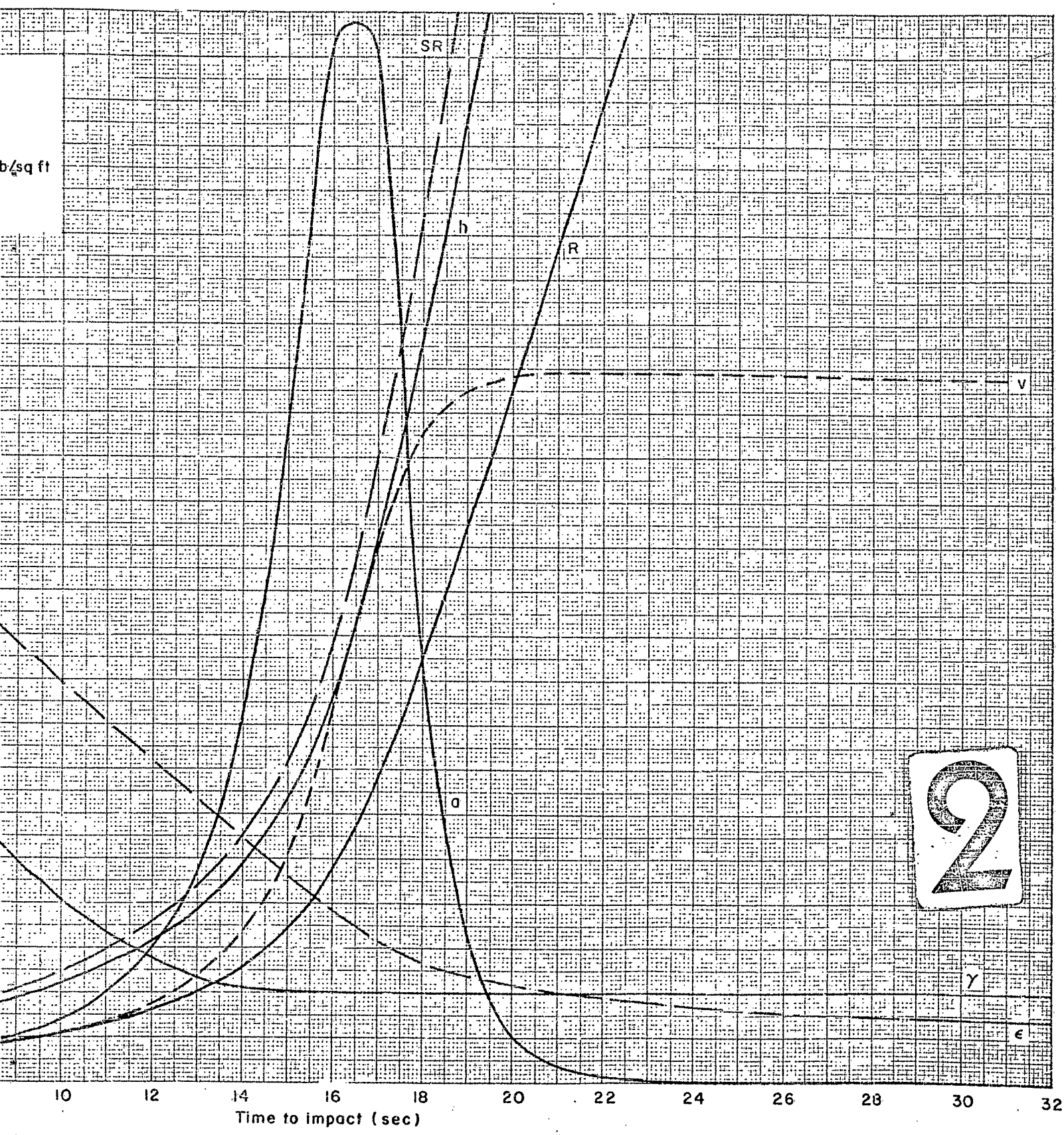
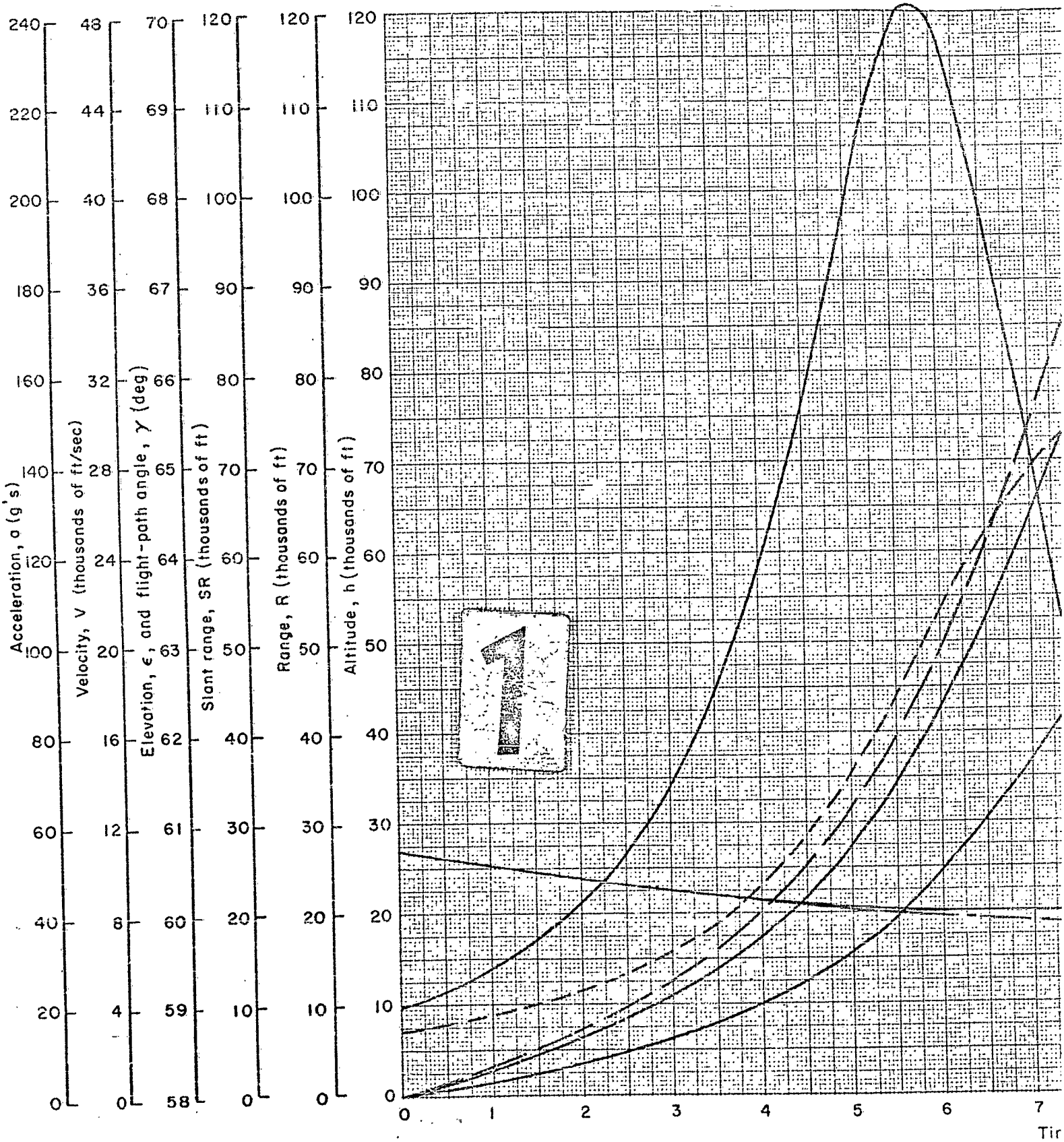

lb/sq ft
SR
h
R
V
a
γ
ε
10
12
14
16
18
20
22
24
26
28
30
32
Time to impact (sec)

Fig. A — 41


Acceleration, a (g's)
240
220
200
180
160
140
120
100
80
60
40
20
0
Velocity, V (thousands of ft/sec)
48
44
40
36
32
28
24
20
16
12
8
4
0
Elevation, ϵ, and flight-path angle, γ (deg)
70
69
68
67
66
65
64
63
62
61
60
59
58
Slant range, SR (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Range, R (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Altitude, h (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
Tir

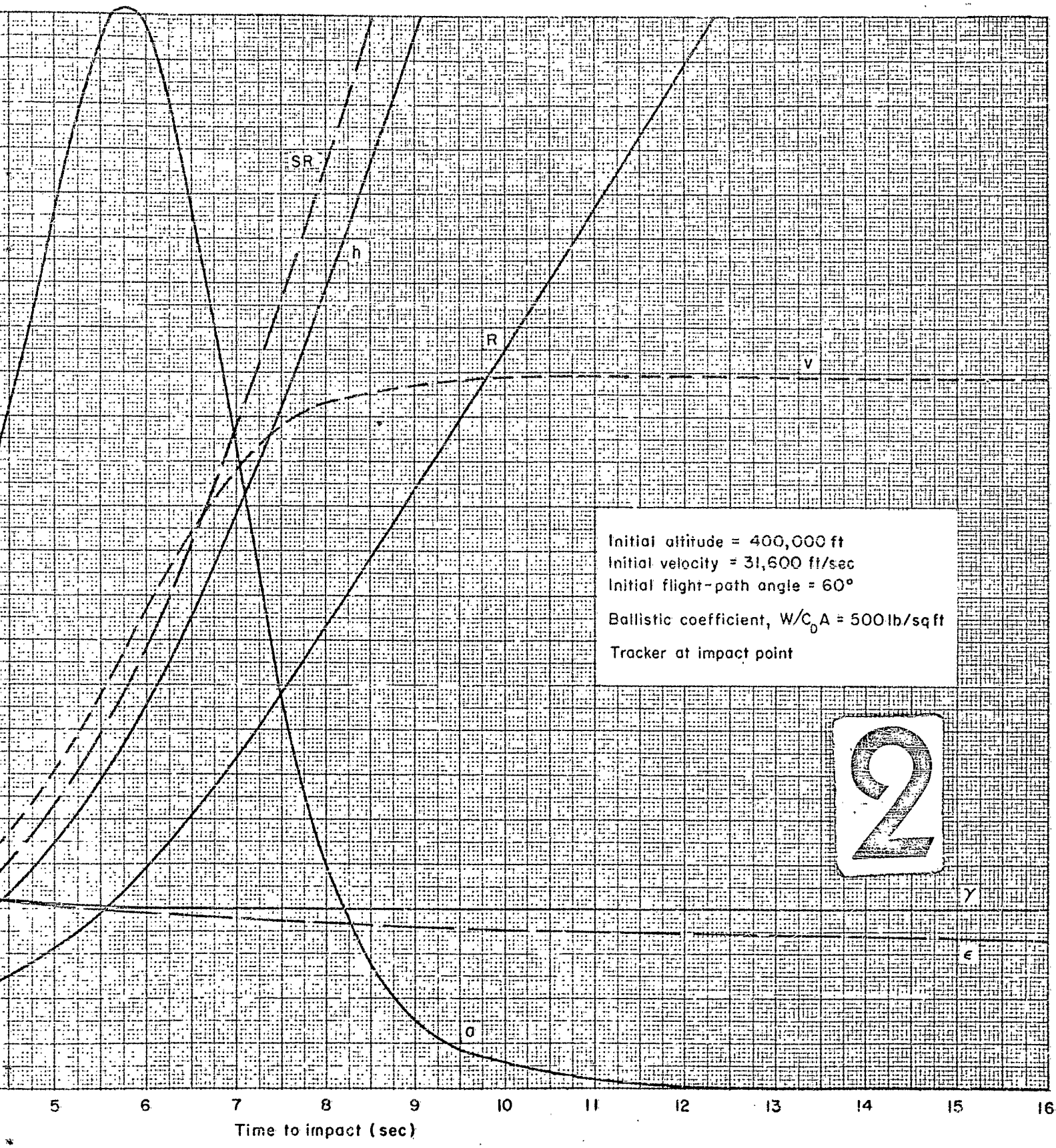
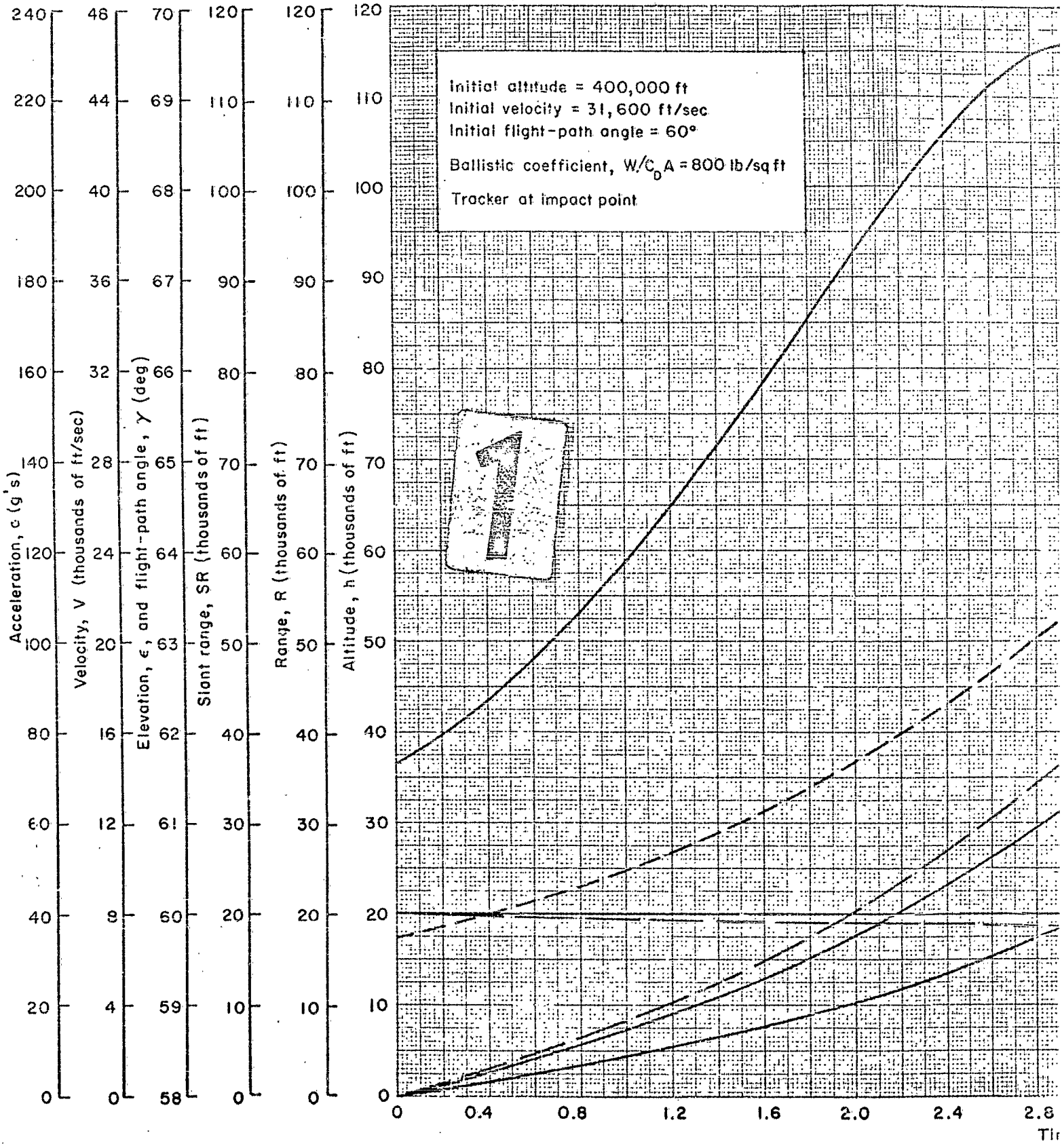

SR
h
R
V
γ
ε
α
Initial altitude = 400,000 ft
Initial velocity = 31,600 ft/sec
Initial flight-path angle = 60°
Ballistic coefficient, $W/C_D A$ = 500 lb/sq ft
Tracker at impact point
2
5
6
7
8
9
10
11
12
13
14
15
16
Time to impact (sec)

Fig. A—42


Initial altitude = 400,000 ft
Initial velocity = 31,600 ft/sec
Initial flight-path angle = 60°
Ballistic coefficient, $W/C_D A$ = 800 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Time

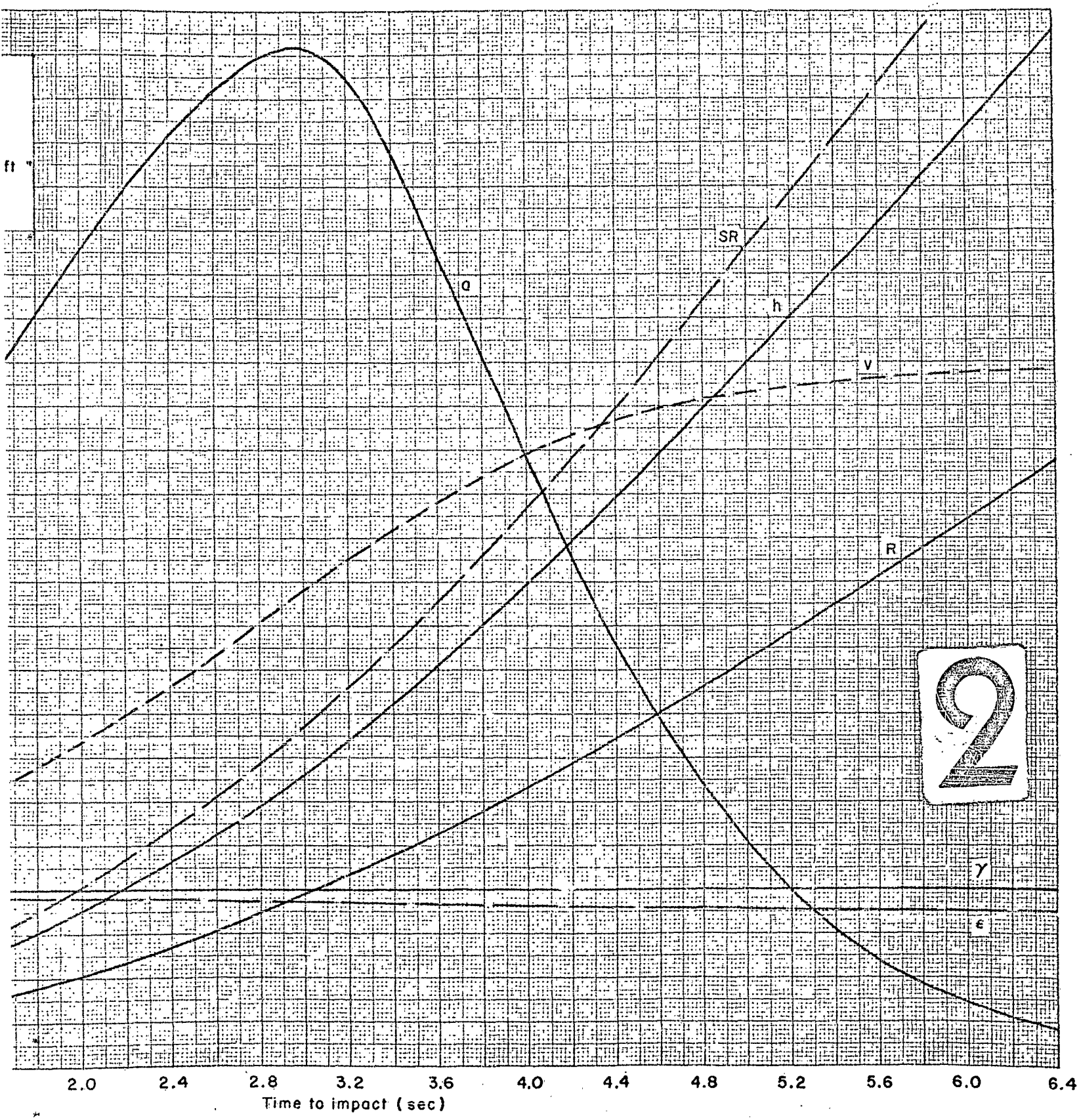
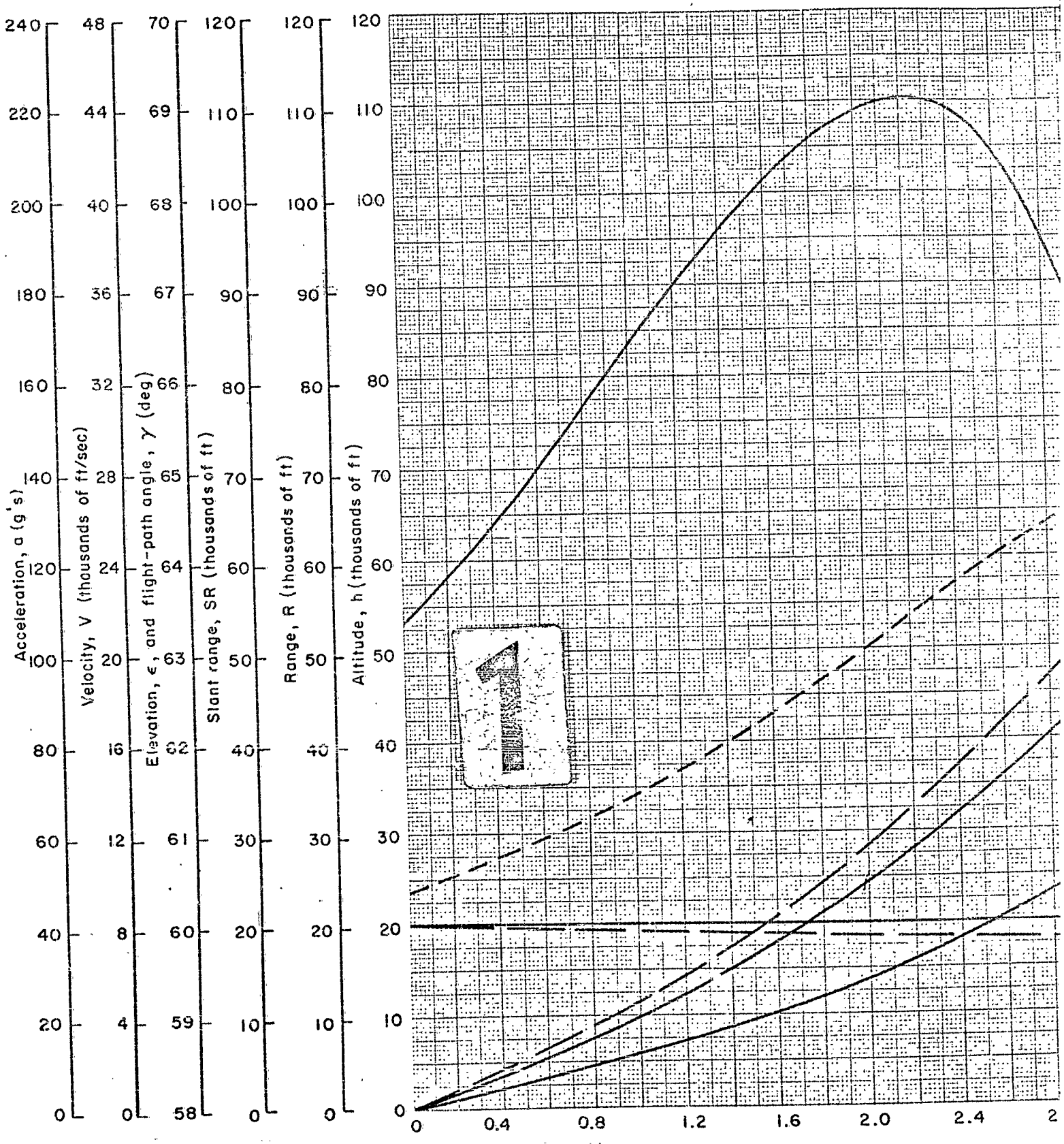


Fig. A—43


Acceleration, a (g's)
240
220
200
180
160
140
120
100
80
60
40
20
0
Velocity, V (thousands of ft/sec)
48
44
40
36
32
28
24
20
16
12
8
4
0
Elevation, ε, and flight-path angle, γ (deg)
70
69
68
67
66
65
64
63
62
61
60
59
58
Slant range, SR (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Range, R (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Altitude, h (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
2.0
2.4
2

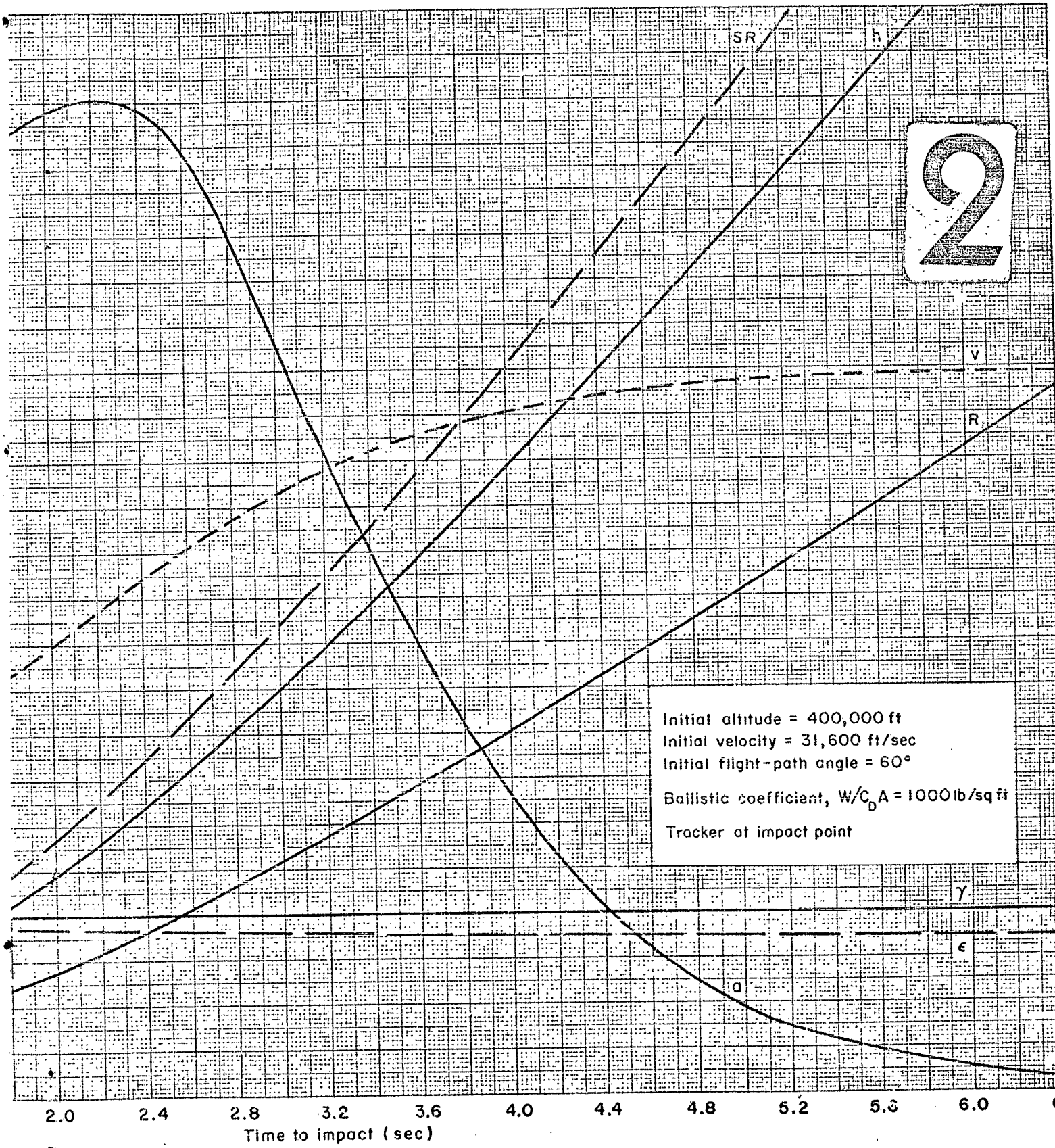
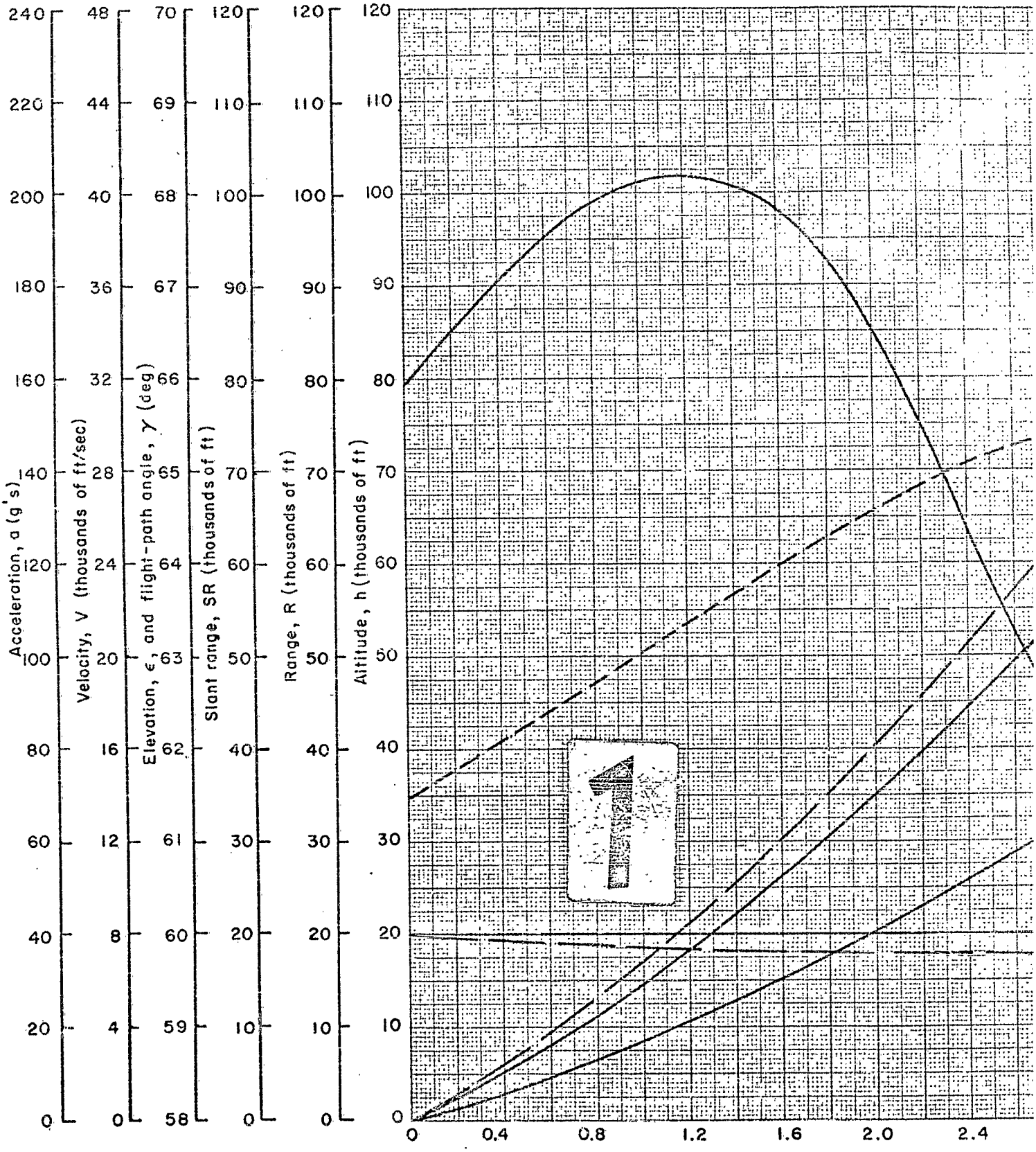

SR
h
V
R
γ
ε
a
Initial altitude = 400,000 ft
Initial velocity = 31,600 ft/sec
Initial flight-path angle = 60°
Ballistic coefficient, W/C_DA = 1000 lb/sq ft
Tracker at impact point
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A—44


Acceleration, a (g's)
240
220
200
180
160
140
120
100
80
60
40
20
0
Velocity, V (thousands of ft/sec)
48
44
40
36
32
28
24
20
16
12
8
4
0
Elevation, ε, and flight-path angle, γ (deg)
70
69
68
67
66
65
64
63
62
61
60
59
58
Slant range, SR (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Range, R (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Altitude, h (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
2.0
2.4

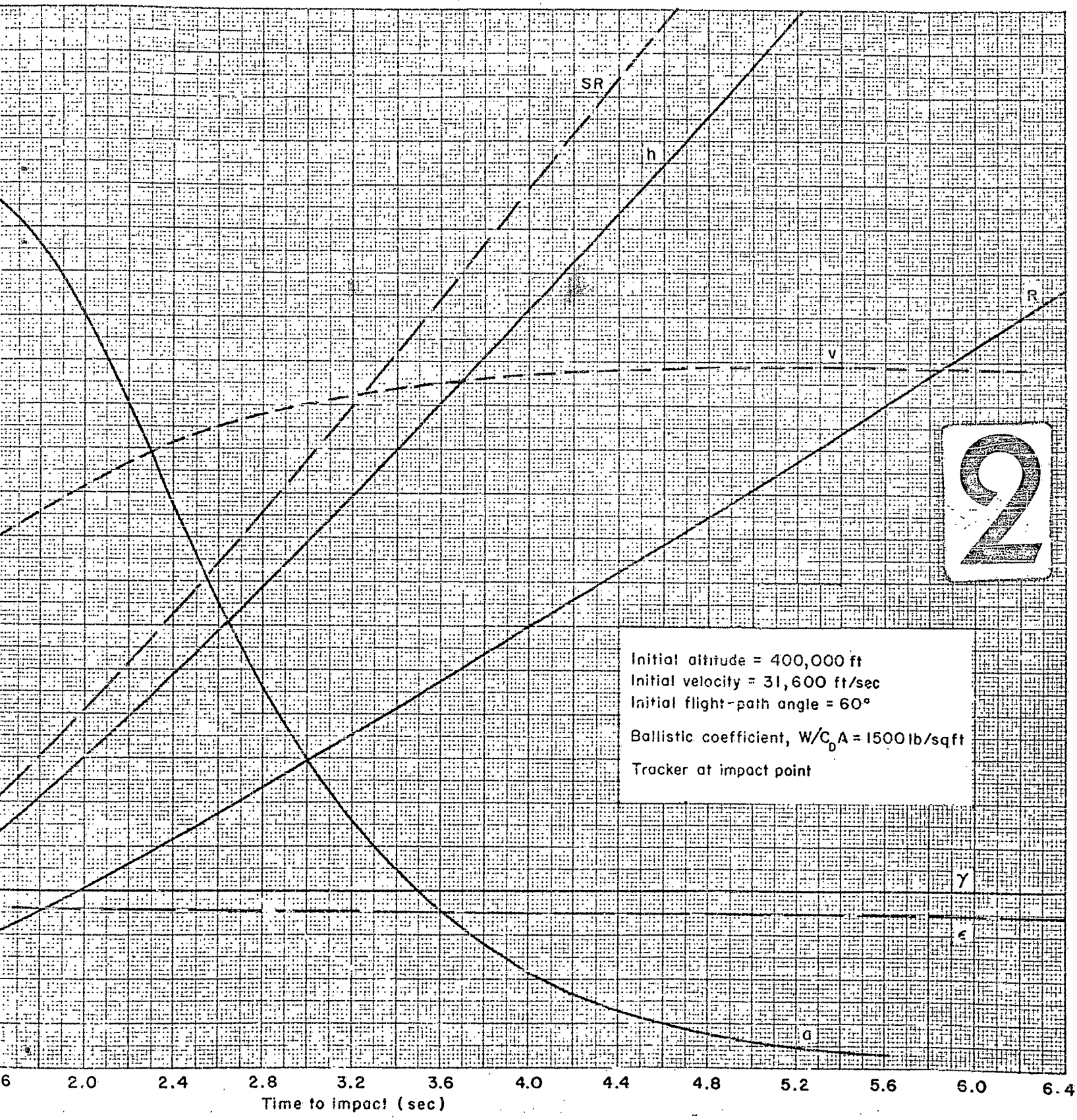
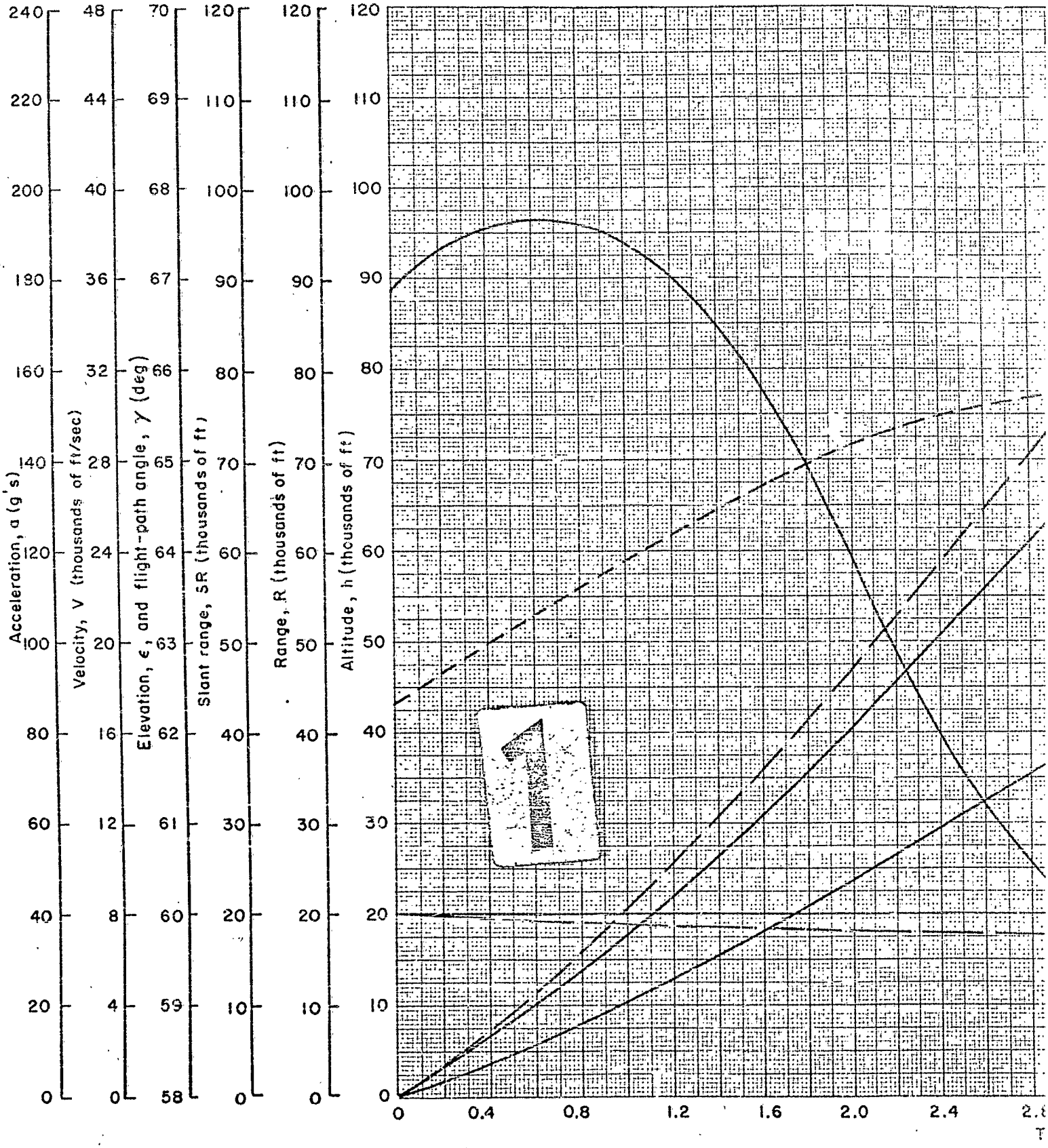

SR
h
R
V
γ
ε
α
Initial altitude = 400,000 ft
Initial velocity = 31,600 ft/sec
Initial flight-path angle = 60°
Ballistic coefficient, W/C_D A = 1500 lb/sqft
Tracker at impact point
6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A—45


Acceleration, a (g's)
240
220
200
180
160
140
120
100
80
60
40
20
0
Velocity, V (thousands of ft/sec)
48
44
40
36
32
28
24
20
16
12
8
4
0
Elevation, ε, and flight-path angle, γ (deg)
70
69
68
67
66
65
64
63
62
61
60
59
58
Slant range, SR (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Range, R (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Altitude, h (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
2.0
2.4

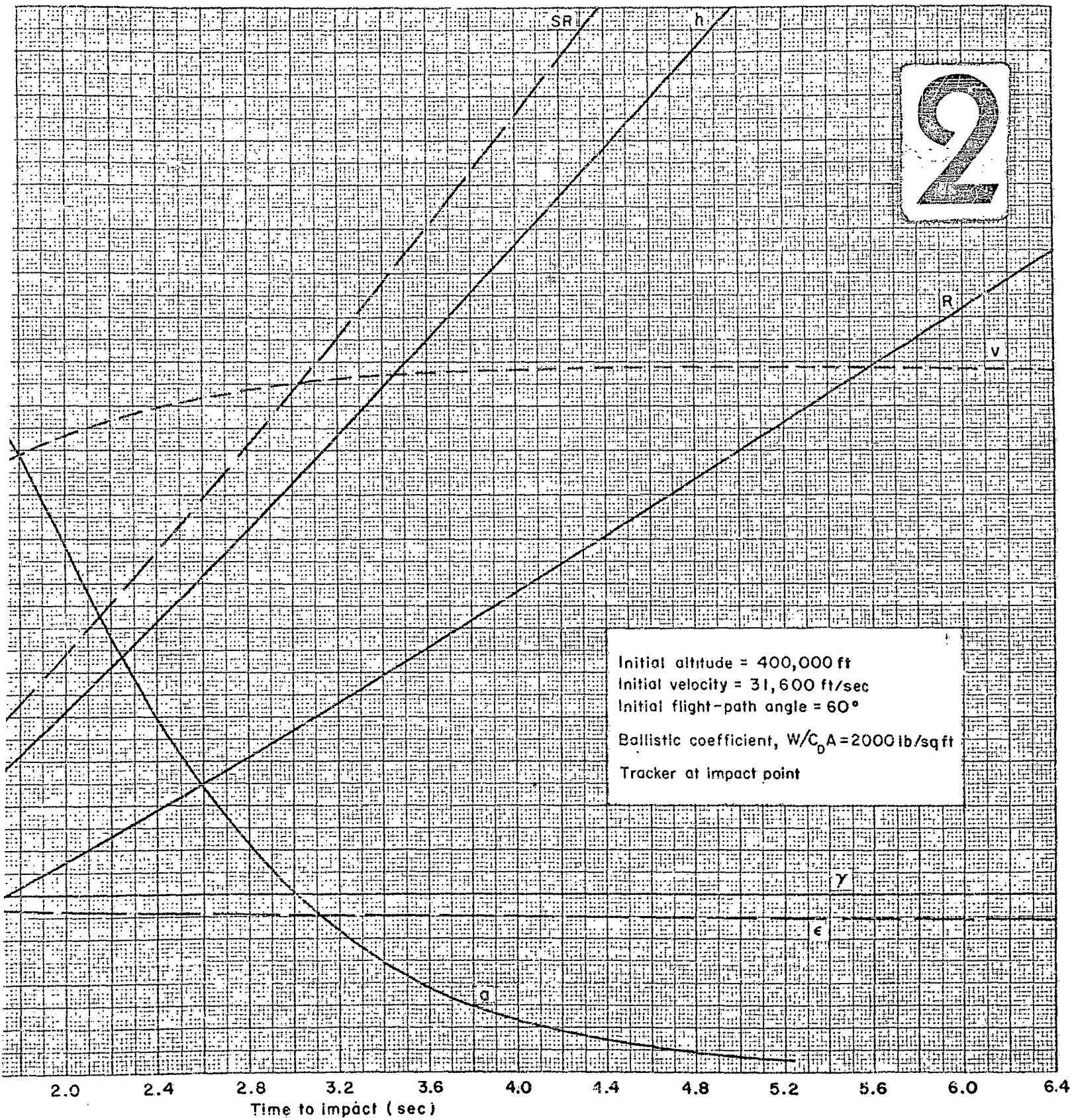
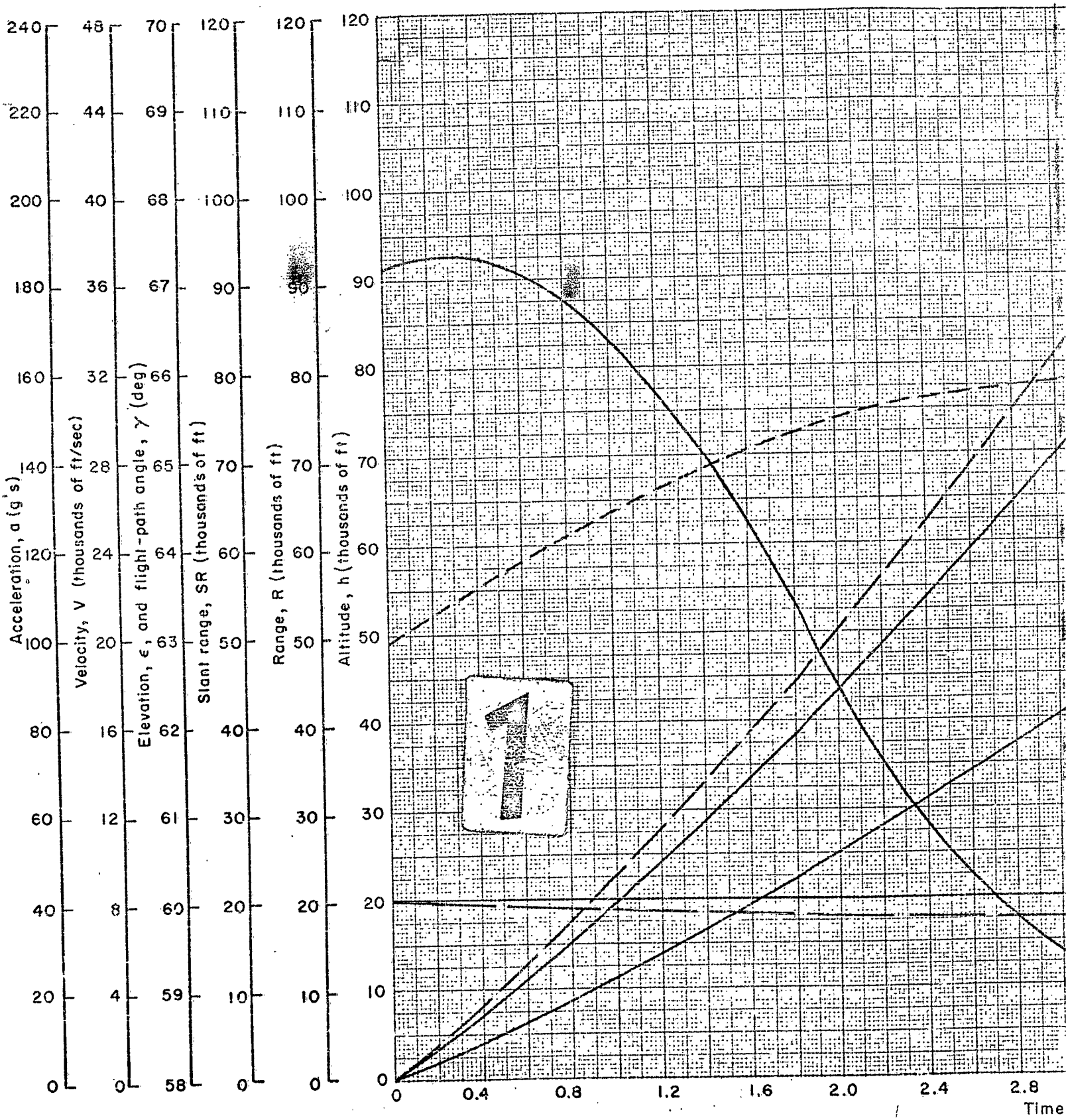

SR
h
R
V
γ
ϵ
α
Initial altitude = 400,000 ft
Initial velocity = 31,600 ft/sec
Initial flight-path angle = 60°
Ballistic coefficient, $W/C_D A = 2000$ lb/sq ft
Tracker at impact point
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A—46


Acceleration, a (g's)
240
220
200
180
160
140
120
100
80
60
40
20
0
Velocity, V (thousands of ft/sec)
48
44
40
36
32
28
24
20
16
12
8
4
0
Elevation, ε, and flight-path angle, γ (deg)
70
69
68
67
66
65
64
63
62
61
60
59
58
Slant range, SR (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Range, R (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
Altitude, h (thousands of ft)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Time

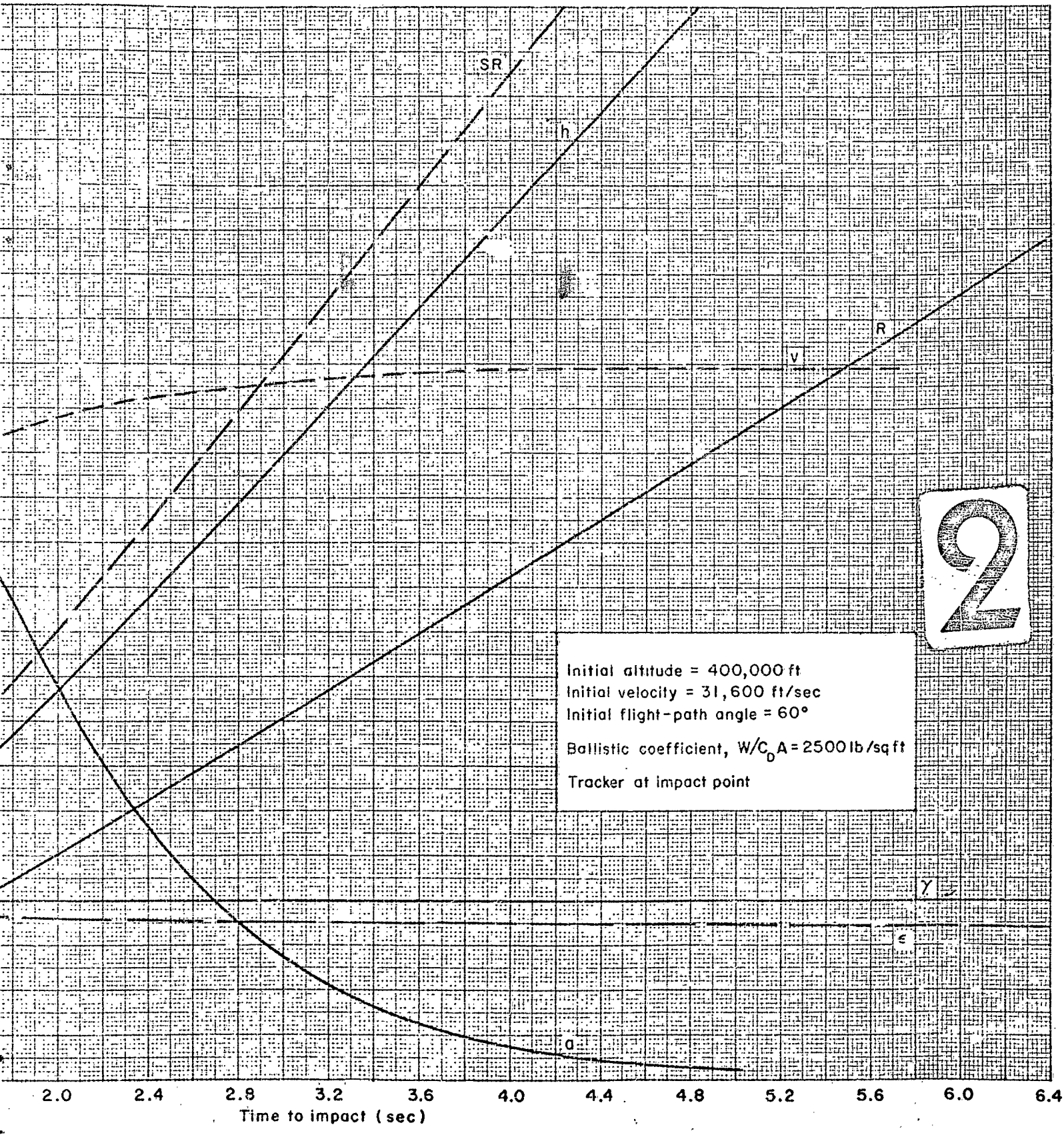
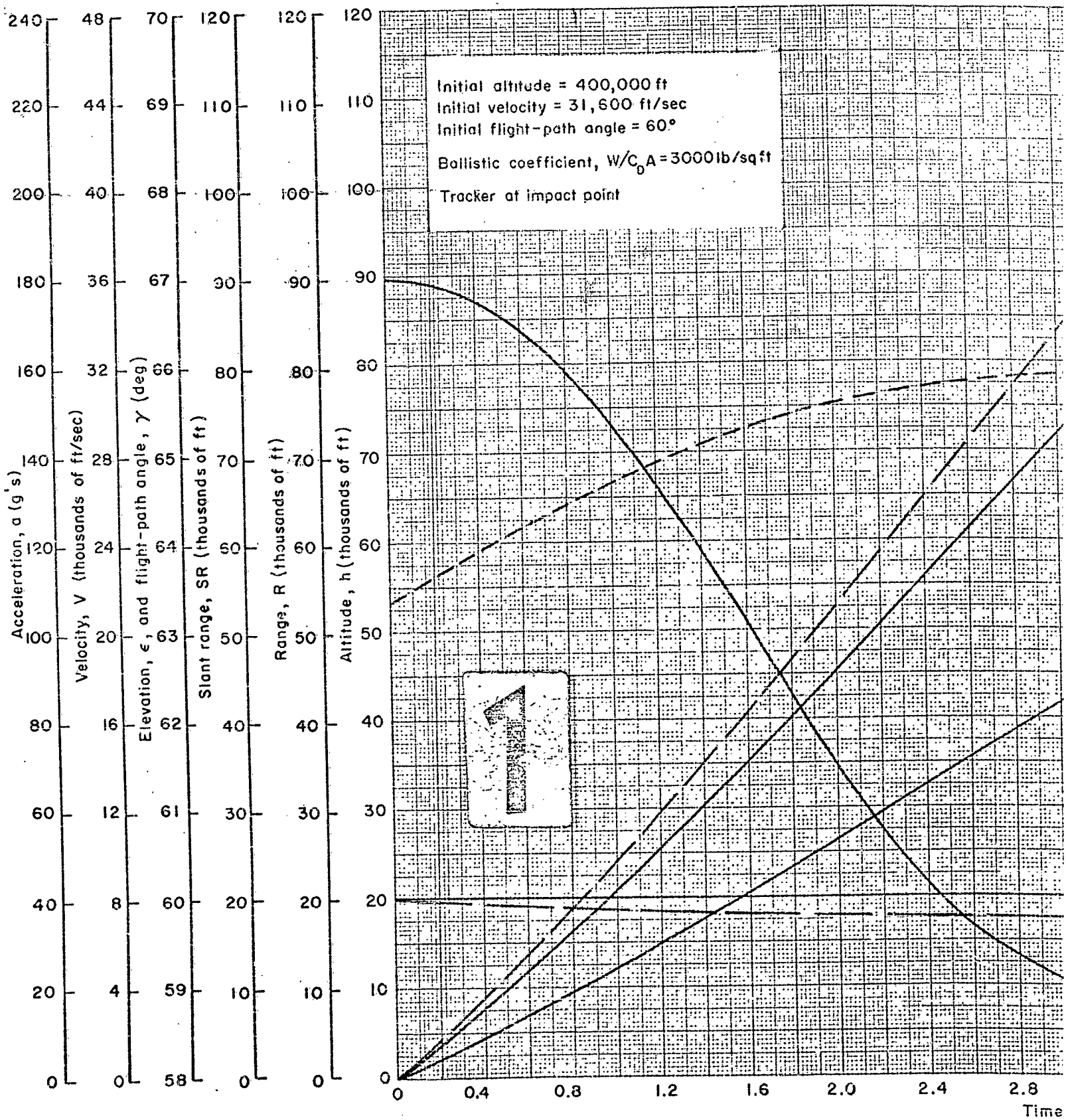

SR
h
R
V
γ
ε
a
Initial altitude = 400,000 ft
Initial velocity = 31,600 ft/sec
Initial flight-path angle = 60°
Ballistic coefficient, W/C_D A = 2500 lb/sq ft
Tracker at impact point
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
5.6
6.0
6.4
Time to impact (sec)

Fig. A—47


Initial altitude = 400,000 ft
Initial velocity = 31,600 ft/sec
Initial flight-path angle = 60°
Ballistic coefficient, W/C_DA = 3000 lb/sq ft
Tracker at impact point
Acceleration, a (g's)
Velocity, V (thousands of ft/sec)
Elevation, ε, and flight-path angle, γ (deg)
Slant range, SR (thousands of ft)
Range, R (thousands of ft)
Altitude, h (thousands of ft)
Time

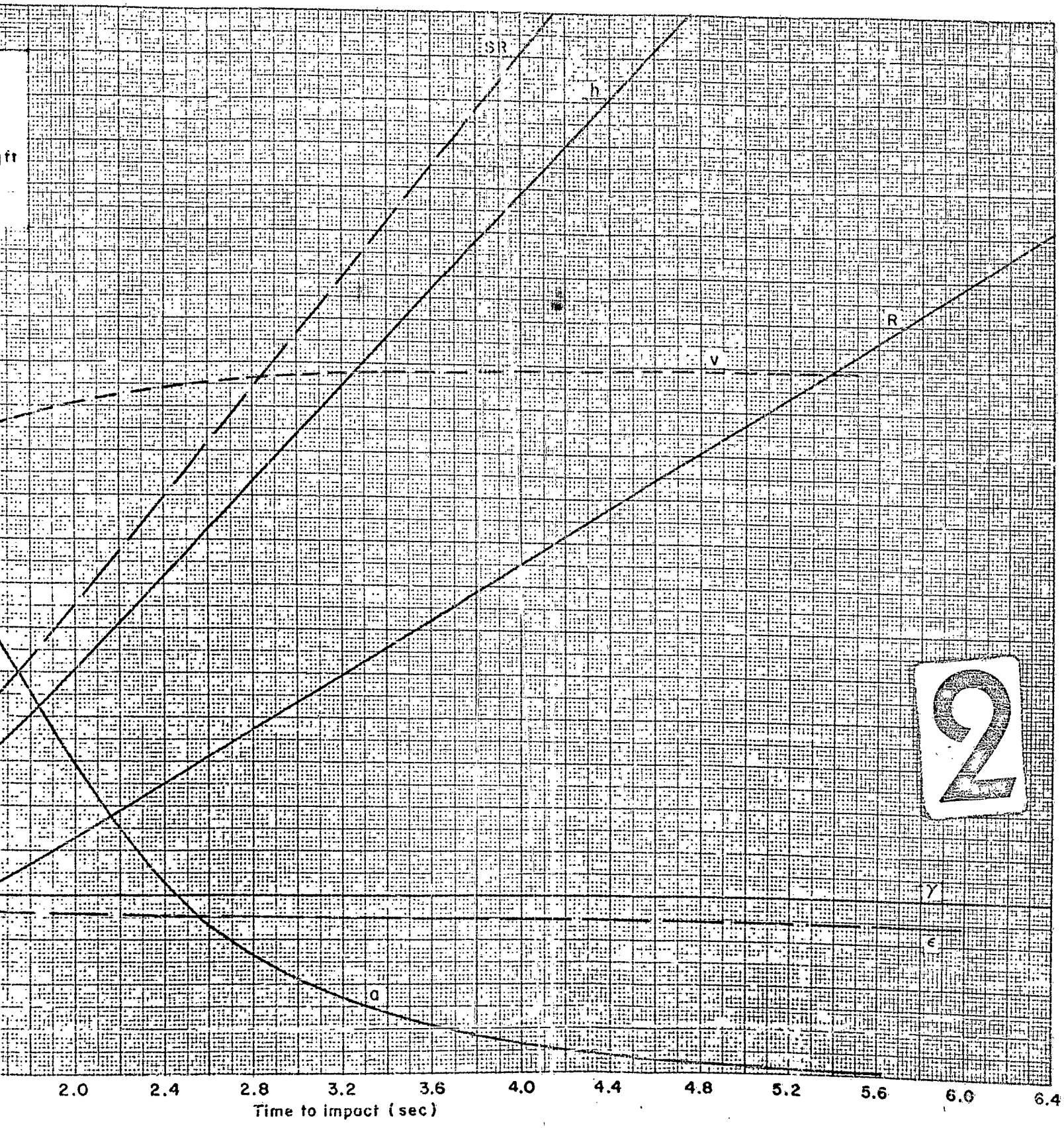


Fig. A—48