AEROSPACE REPORT NO.
ATR-2005(5138)-2

Reentry Hazard Analysis Handbook

28 January 2005

Prepared by

J. TOOLEY, T. M. HABIGER, and K. R. BOHMAN
Flight Mechanics Department
Vehicle Systems Division

Prepared for

VOLPE NATIONAL TRANSPORTATION SYSTEMS CENTER
U.S. DEPARTMENT OF TRANSPORTATION
Cambridge, MA 02142

Contract No. DTRS57-99-D-00062
Task 9.0

Space Launch Operations

PUBLIC RELEASE IS AUTHORIZED

THE AEROSPACE CORPORATION
EL SEGUNDO, CALIFORNIA

Technical Report Documentation Page

<table>
<tr><td>1. Report No.

DOT-VNTSC-RITA-05-01</td><td>2. Government Accession No.</td><td>3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Reentry Hazard Analysis Handbook</td><td>5. Report Date
January 28, 2005</td></tr>
<tr><td>6. Performing Organization Code
DOT-RITA-VNTSC-DTS-67</td></tr>
<tr><td colspan="2">7. Author(s)*
J. Tooley, T. M. Habiger, and K. R. Bohman</td><td>8. Performing Organization Report No.</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
U.S. Department of Transportation
Research and Innovative Technology Administration
Volpe National Transportation Systems Center
Aviation Safety Division
Cambridge, MA 02142-1093</td><td>10. Work Units No. (TRAIS)
FA-42R; BL411</td></tr>
<tr><td>11. Contract or Grant No.
DTRS57-99-D-00062, Task 9.0</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Aviation Administration
Office of the Assoc. Administrator for Commercial Space Transportation
Washington, DC 20591</td><td>13. Type of Report and Period Covered
Contractor Final Report:
April – December 2004</td></tr>
<tr><td>14. Sponsoring Agency Code
FAA/AST-300</td></tr>
<tr><td colspan="3">15. Supplementary Notes
*The Aerospace Corporation, El Segundo, CA 90245-4691, under contract to the Volpe National Transportation Systems Center -- DTRS57-99-D-00062, Task 9.0

Aerospace Corporation Report No. ATR-2005(5138)-2</td></tr>
</table>

16. Abstract

The Aerospace Corporation was tasked by the Volpe National Transportation Systems Center to provide technical support to the Federal Aviation Administration, Office of Commercial Space Transportation (FAA/AST), in developing acceptable methods of evaluating risk posed by reentering space hardware during conduct of FAA-licensed operations. The objective of the task is to enhance the reentry hazard handbook, spreadsheet, and survivability tables developed at Aerospace under Task 4.0.

The updated handbook provides step-by-step instructions for calculating casualty expectation using a simplified, conservative methodology during planned reentry over populated areas with the use of the reentry_casualty_expectation_v2.0.xls spreadsheet and the survivability tables contained in the handbook. Features of the new spreadsheet includes computation of casualty area from debris inputs, a world population database, a trajectory integrator to compute impact points, and debris impact probability distribution calculations. The survivability tables in the handbook contain reentry survivability data for sphere, cylinder, and flat plate shaped debris made of aluminum, titanium, or stainless steel. The handbook used in combination with these tools allows AST and its customers to estimate casualty expectation for a given reentry mission.

<table>
<tr><td colspan="2">17. Key Words
reusable launch vehicle, human safety, flight licensing, reentry debris</td><td colspan="2">18. Distribution Statement
PUBLIC RELEASE IS AUTHORIZED</td></tr>
<tr><td>19. Security Classification. (of this report)
None</td><td>20. Security Classification. (of this page)
None</td><td>21. No. of Pages
181</td><td>22. Price</td></tr>
</table>

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

AEROSPACE REPORT NO.
ATR-2005(5138)-2

REENTRY HAZARD ANALYSIS HANDBOOK

Prepared by

J. TOOLEY, T. M. HABIGER, and K. R. BOHMAN
Flight Mechanics Department
Vehicle Systems Division

28 January 2005

Space Launch Operations
THE AEROSPACE CORPORATION
El Segundo, CA 90245

Prepared for

VOLPE NATIONAL TRANSPORTATION SYSTEMS CENTER
U.S. DEPARTMENT OF TRANPORTATION
Cambridge, MA 02142

Contract No. DTRS57-99-D-00062
Task 9.0

PUBLIC RELEASE IS AUTHORIZED

AEROSPACE REPORT NO.
ATR-2005(5138)-2

REENTRY HAZARD ANALYSIS HANDBOOK

Prepared by:

J. TOOLEY
Flight Mechanics Department
Vehicle Systems Division

T. M. HABIGER
Flight Mechanics Department
Vehicle Systems Division

K. R. BOHMAN
Flight Mechanics Department
Vehicle Systems Division

Approved by:

W. P. HALLMAN, Director
Flight Mechanics Department
Space Launch Support Division

E. K. RUTH, Systems Director
Space Launch Projects Directorate
Space Launch Support Division

Abstract

The Aerospace Corporation was tasked by the Volpe National Transportation Systems Center to provide technical support to the Federal Aviation Administration, Office of Commercial Space Transportation (FAA/AST), in developing acceptable methods of evaluating risk posed by reentering space hardware during conduct of FAA-licensed operations. The objective of the task is to enhance the reentry hazard handbook, spreadsheet, and survivability tables developed at Aerospace under Task 4.0.

The updated handbook gives step-by-step instructions for calculating casualty expectation using a simplified, conservative methodology during planned reentry over populated areas with the use of the *reentry_casualty_expectation_v2.0.xls* spreadsheet and the survivability tables contained in the handbook. Features of the new spreadsheet includes computation of casualty area from debris inputs, a world population database, a trajectory integrator to compute impact points, and debris impact probability distribution calculations. The survivability tables in the handbook contain reentry survivability data for sphere, cylinder, and flat plate shaped debris made of aluminum, titanium, or stainless steel. The handbook used in combination with these tools allows AST and its customers to estimate casualty expectation for a given reentry mission.

Acknowledgements

The authors would like to thank Mr. Robert W. Seibold who served as the Program Manager for this task. The authors are also grateful for the valuable contributions provided by the following Aerospace personnel: Dr. Douglas M. Moody, Dr. William H. Ailor, and Dr. Michael A. Weaver. Gratitude is extended to Gregory Yetman and Dr. Christopher Lenhardt at the Center for International Earth Science Information Network at Columbia University. Gratitude is also extended to Mr. Lyndon Bonaparte, Office of the Associate Administrator for Commercial Space Transportation, Federal Aviation Administration, for valuable guidance on FAA/AST regulatory and licensing needs relevant to casualty expectation computations. The authors also wish to thank Mr. John J. Sigona, who served as the Contracting Officer's Technical Representative (COTR) for the Volpe National Transportation Systems Center and provided valuable insight on government needs and regulations.

Contents

Figures

Tables

1 INTRODUCTION AND SUMMARY

The objective of this task is to enhance the reentry hazard handbook, spreadsheet, and survivability tables developed at Aerospace under Task 4.0, with the goal of enabling AST and its customers to obtain a conservative estimation of casualty expectation for given reentry missions. This document contains seven sections, five appendices, and is supplemented by the *reentry_casualty_expectation_v2.0* spreadsheet and *Population_Data_2.xla* Add-In. Section 2 describes the steps for acquiring and entering inputs for the reentry hazard spreadsheet. Section 3 provides details on how to calculate debris survivability based on the tabular data in the Appendices. Sections 4-7 contain the conclusions, list of acronyms, references, and bibliography. Appendix A is a viewgraph presentation, with facing page text, describing the theory behind the casualty expectation calculation used in the spreadsheet. Appendix B presents an example calculation. Sections C, D, and E contain tabular data for debris survivability for a hollow tumbling sphere, hollowing tumbling cylinder, and a tumbling flat plate.

2 CASUALTY EXPECTATION HANDBOOK

The steps delineated in this section describe how a launch vehicle license applicant can acquire and enter inputs into the accompanying *reentry_casualty_expectation_v2.0* spreadsheet to calculate casualty expectation (E_c) for a specific vehicle and mission. A full description of the theory behind the methodology is given in Appendix A. A summary of the assumptions used to develop the methodology and inputs are given below.

- An aggregate casualty area for all debris is used to calculate casualty expectation.
- At the time the breakup point is reached, all major components separate from the main structure.
- A spacing of 2 nmi is used between consecutive discretized breakup points.
- All debris is represented by a single impact probability density function.
- The impact probability density function is Gaussian in the crossrange direction.
- The impact probability density function is uniform in the downrange direction and is based on high and low ballistic coefficient impact points.
- A failure probability of one is used for each breakup point.
- The largest reasonable number of pieces is used for the breakup model.
- A splatter factor of 2 is used to calculate the debris casualty area.
- A simplified sheltering model is used to calculate the debris sheltered casualty area.

Step 1 <u>Open Spreadsheet</u>

The spreadsheet consists of two pieces: an Excel Workbook (*reentry_casualty_expectation_v2.0.xls*) and an Excel Add-In (*Population_Data_2.xla*). The first time the spreadsheet is opened on a particular computer the Add-In must be connected to the spreadsheet by going to *Tools -> Add-Ins* on the menu bar. This will bring up the Add-Ins box similar to Figure 2-1.

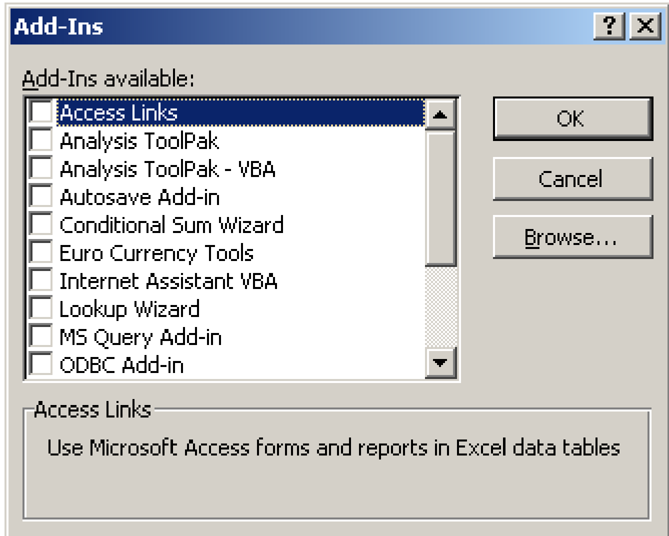


Figure 2-1. Add-Ins Box

From the Add-Ins box the *Browse* button should be selected, and the file called *population_data_2.xla* should be found by browsing the directory listing. Check the box next to the *Population_Data_2* Add-Ins as is shown in Figure 2-2.

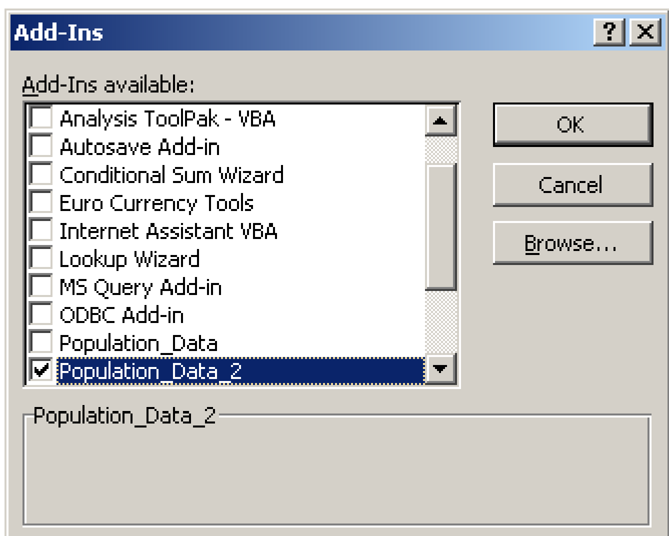


Figure 2-2. *Population_Data_2* Add-In

When opening the Workbook subsequent times it is only necessary to make sure the check box in Figure 2-2 is selected. When closing the spreadsheet the *Population_Data_2* Add-In should be deselected so that it is not activated when running other spreadsheet functions (see Step 14 for a further description of this).

Step 2 Establish trajectory

The casualty expectation calculation is based on the flight trajectory; therefore, it is necessary to have a vehicle nominal trajectory available. For ease of use with other spreadsheet functions it is suggested that the following variables are made available as a function of time: altitude (nmi), Earth relative velocity (ft/s), geocentric Earth relative flight path angle (deg), geocentric Earth relative flight azimuth (deg), longitude (°E), and geodetic latitude (°N).

Step 3 Establish discrete breakup points

A reentry failure can occur at any time in the trajectory due to aero-thermal failure, structural failure, explosion, range destruct, or other vehicle failure modes. A discretized trajectory is used to represent possible vehicle breakup points. It is suggested that discrete breakup points are chosen based on altitude within the trajectory. A good spacing is trajectory dependent, however, 2 nmi should be adequate for a first-order approximation. The trajectory can be discretized based on other parameters such as time or velocity. If there is overflight of a particularly high population or order-of-magnitude changes in casualty expectation between breakup points, finer spacing should be used for these periods. Steps 4 through 12 are repeated for each breakup point.

Step 4 Establish and enter a failure probability for breakup points

For each discrete breakup point, a failure probability is assigned. The most conservative approach is to assign a failure probability of one to each breakup point. The maximum casualty expectation is selected from the resulting array to represent a breakup occurring at approximately the worst point in the trajectory. This methodology requires the user to have no knowledge of the failure probability of the vehicle and is the most conservative methodology available.

A less conservative representation of the failure probability is to assign a failure probability based on flight history and reliability numbers and combine this with a time dependent failure probability. An example of this is shown in Appendix B.

Once the failure probability is computed it is input into the first cell in Figure 2-3.

inputs for calculation		impact points – must be different			
failure probability	crossrange standard deviation (nmi)	longitude of low beta impact point (deg E)	latitude of low beta impact point (deg N)	longitude of high beta impact point (deg E)	latitude of high beta impact point (deg N)
1	10	-124.2433	50.8816	-107.0463	42.8021

Figure 2-3. Failure Probability Input

Step 5 Compute casualty area

The spreadsheet has two methods available for computing the casualty area. The first involves computing the casualty area outside of the spreadsheet and using the total aggregate casualty area as an input. The second involves the input of a debris inventory list and using the spreadsheet to calculate casualty area. The user should select the type of input desired from the option box in Figure 2-4.

○ INPUT TOTAL CASUALTY AREA ● USE DEBRIS INVENTORY

Figure 2-4. Choose Casualty Area Input Type

If *INPUT TOTAL CASUALTY AREA* is selected the aggregate casualty area is calculated by the user and input into the cell in Figure 2-5. If this methodology is employed the user can skip to Step 8.

total sheltered casualty area	units
0	feet^2

Figure 2-5. Total Sheltered Casualty Area Input

If *USE DEBRIS INVENTORY* is selected from Figure 2-4, the debris model and debris survivability must be input. Steps 6 and 7 describe how this is done.

Step 6 Establish a breakup model

The breakup model represents the pieces of debris immediately after breakup and before debris survivability has been determined. It is comprised of a list of debris fragments that are defined by weight, material, shape, and dimensions. Creating a debris model generally involves a significant amount of engineering analysis and judgment; below are some guidelines intended to simplify the development of this breakup model.

It is assumed that at the breakup point all major components connected by structure that can be broken apart by aerodynamic or aero-thermal forces separate from the main vehicle. Because multiple breakup points are being analyzed, the assumption that all components break apart is a reasonable one. Typically, the main components are tanks, engines, boxes, batteries, pieces of structure, solar panels, etc. If more refined debris is desired, analysis can be done based on heating and aerodynamic moment calculations to determine if components will break apart. Within reason the more pieces a vehicle breaks into the larger the casualty area, so the conservative solution is to assume a larger number of pieces. Breakups that occur at lower velocities will result in a lower number of pieces.

Once the debris model has been established it should be entered into the spreadsheet inputs in Table 2-6. There are four pre-defined shapes: tumbling flat plate debris, tumbling hollow box debris, tumbling hollow sphere debris, and tumbling hollow cylinder debris. The word tumbling is used to describe how the aerodynamic properties were determined (tumbling rather than trimmed). The word hollow is used to describe how the geometric properties were determined; all of the debris mass is assumed to be distributed along the walls of the debris. If the debris cannot be approximated by any of these shapes, there is a fifth input type called other debris shape. For each of the four shape types there are inputs of debris notes, number of pieces, liquid fraction, debris material density, weight, and shape dimensions. From these inputs the aerodynamic properties and casualty area of the debris are calculated by the spreadsheet and listed to the right of the debris input (see Appendix A for a detailed description of these equations). The liquid fraction for each piece of debris is determined in Step 7. The other debris shape has inputs of debris notes, number of pieces, liquid fraction, weight, aerodynamic reference area, hypersonic continuum drag coefficient, and subsonic drag coefficient. To add a new piece of debris the *add [shape] debris* button is used. To delete debris the pull-down box for each shape is used to delete specific or all rows.

tumbling flat plate debris — add plate debris

debris notes	number of pieces	debris material density (lbs/ ft^3)	liquid fraction	weight (lbs)	length (ft)	width (ft)
aluminum skin	10	175	0	100	5	5

tumbling hollow box debris — add box debris

debris notes	number of pieces	debris material density (lbs/ ft^3)	liquid fraction	weight (lbs)	length (ft)	width (ft)	height (ft)
batteries	6	200	0	125	1	1	1

tumbling hollow sphere debris — add sphere debris

debris notes	number of pieces	debris material density (lbs/ ft^3)	liquid fraction	weight (lbs)	radius (ft)
aluminum tank	4	175	1	300	2

tumbling hollow cylinder debris — add cylinder debris

debris notes	number of pieces	debris material density (lbs/ ft^3)	liquid fraction	weight (lbs)	radius (ft)	length (ft)
titanium tank	1	277	0	250	2	5

other debris shape — add other debris

debris notes	number of pieces	liquid fraction	original weight (lbs)	aerodynamic reference area (ft^2)	hypersonic continuum drag coefficient	subsonic drag coefficient
aluminum structure	1	0	100	25	1.6	0.8

Figure 2-6. Debris Model Inputs

Step 7 Determine and enter liquid fraction

The liquid fraction used for each piece of debris in Table 2-6 is computed using the survivability tables in Appendices C though E. For instructions on how to extract the data from the tables see Section 3. If it is desired to assume all debris survives, which is the most conservative assumption, a liquid fraction of 0 should be entered for each piece of debris in Table 2-6.

Step 8 Enter sheltering and casualty area multiplication factor

Figure 2-7 shows the inputs for sheltering and the casualty area multiplication factor.

casualty area sheltering effect – percentages should total 100			**casualty area multiplication factor** (debris bounce, skip, and splatter effect)
population unsheltered (%)	population protected by light sheltering (%)	population protected by heavy sheltering (%)	
10	70	20	2

Figure 2-7. Sheltering and Casualty Area Multiplication Factor

The sheltering model used is based on Reference 3. A summary of this model is given in Appendix A. The three inputs in Table 2-7 are the percentage of population under certain sheltering. The user can change these percentages, but must supply reasoning for the change. When these numbers are changed, the three percentages should still total 100%. To represent an unsheltered population *population unsheltered (%)* should be changed to 100% and the other two percentages should be changed to 0%.

The casualty area multiplication factor is based on Reference 4. This factor is used to account for debris that slides, skids, bounces, ricochets, splatters, or craters on impact. Because most high altitude breakups hit the ground as inert debris falling vertically, this value is conservatively estimated as two. For inert debris that hits the ground with any horizontal velocity this number should be reevaluated using Reference 4. Currently the same multiplication factor is applied to all debris and cannot be added to individual debris.

Step 9 Compute trajectory impact points

Two methods in the spreadsheet exist for entering the high and low ballistic coefficient impact points. One method accepts the impact points as inputs based on computations done by the user, and the other method uses the spreadsheet to compute impact points based on the breakup point state.

If the user wishes to input the impact points, the check box shown in Figure 2-8 should be deselected as is shown.

☐ COMPUTE IMPACT POINTS

Figure 2-8. Compute Impact Point Check Box

The user can then input the longitude and geodetic latitude of the low and high ballistic coefficient impacts shown in Figure 2-9. These values should be determined by integrating a low and high ballistic coefficient trajectory to the ground using the vehicle breakup point as the initial state.

inputs for calculation		impact points – must be different			
failure probability	crossrange standard deviation (nmi)	longitude of low beta impact point (deg E)	latitude of low beta impact point (deg N)	longitude of high beta impact point (deg E)	latitude of high beta impact point (deg N)
1	10	-127.6037	51.9034	40.	0

Figure 2-9. Low and High Ballistic Coefficient Impact Inputs

To use the spreadsheet to compute the impact points the check box shown in Figure 2-8 should be selected. The user then inputs the vehicle breakup point state into the input cells in Figure 2-10.

vehicle state					
breakup altitude (nmi)	longitude of vehicle (deg E)	geodetic latitude of vehicle (deg N)	geocentric relative flight path angle (deg)	geocentric relative azimuth (deg)	magnitude of relative velocity (ft/ sec)
46	228.5	52.9	-0.614	111	24865

Figure 2-10. Vehicle Breakup Point State Input for Computing Impact Points

The ballistic coefficient used to compute the impact points is taken from the lowest and highest hypersonic continuum ballistic coefficient in the debris model. There must be at least two pieces of debris with different ballistic coefficients to use this function. If an aggregate casualty area is input (no debris model) the low and high ballistic coefficient must be input in the cells show in Figure 2-11.

ballistic coefficients – must be different	
Maximum (lb/ ft^2)	Minimum (lb/ ft^2)
100	1

Figure 2-11. Maximum and Minimum Ballistic Coefficient for Impact Point

Once this data is entered, the *COMPUTE IMPACT POINTS* button in Figure 2-12 is pressed. This will update the impact point locations in Figure 2-9.

COMPUTE
IMPACT POINTS

Figure 2-12. Compute Impact Points Button

To compute the impact points a simple trajectory propagator that uses a 1962 U.S. standard atmosphere along with the gravity and Earth constants shown in Table 2-1 is executed.

Table 2-1. Gravity and Earth Constants in Trajectory Propagator

Polar radius of Earth (ft)	20855486.60
Equatorial radius of Earth (ft)	20925646.33
Earth gravitational constant (ft^3/s^2)	$1.407644176 \times 10^{16}$
Rotation rate of the Earth (rad/s)	0.7292115×10^{-4}
Zonal Harmonic J2	1082.62×10^{-6}
Note: These constants are slightly different than constants used for the heating calculation trajectory integration	

Step 10 Determine and enter crossrange distribution to Gaussian input

It is assumed that the crossrange impact probability density function is Gaussian. The crossrange standard deviation should be based on the type of flight termination system, the maximum vehicle crossrange capability, debris crossrange due to winds, debris lift-to-drag ratio, and other trajectory effects. Once crossrange standard deviation is determined it is input into the cell in Figure 2-13.

inputs for calculation		impact points – must be different			
failure probability	crossrange standard deviation (nmi)	longitude of low beta impact point (deg E)	latitude of low beta impact point (deg N)	longitude of high beta impact point (deg E)	latitude of high beta impact point (deg N)
1	10	-124.2433	50.8816	-107.0463	42.8021

Figure 2-13. Crossrange Standard Deviation Input

Step 11 Compute casualty expectation

To compute the casualty expectation, the button in Figure 2-14 is pressed.

RUN CASUALTY EXPECTATION

Figure 2-14. Run Casualty Expectation Button

The resulting casualty expectation is output in the cell shown in Figure 2-15.

casualty expectation (people in a million)
0

Figure 2-15. Total Casualty Expectation

The user should save this run as a new version of the spreadsheet.

Step 12 <u>Observing output</u>

A more detailed output is contained on the *calculations* Worksheet. This sheet gives a summary of the casualty expectation for each population center. This output can be used for post-processing and plotting the results. A short summary of the inputs and results is also saved to the *output storage* Worksheet.

Step 13 <u>Repeat</u>

Steps 4 through 12 are repeated for each discretized breakup point in the trajectory. Once all of the discretized breakup points have been run, the method used to determine the total casualty expectation depends on the type of failure probability used in Step 4. If a failure probability of one for each breakup is chosen, the maximum casualty expectation from all of the breakup points is used as the total. If a portion of the failure probability is assigned to each breakup point, then the total casualty expectation is computed by summing the results from all breakup points.

Step 14 <u>Closing Worksheet</u>

When closing the spreadsheet the *Population_Data_2* Add-In, seen in Figure 2-15, should be deselected. The Add-Ins box is found by going to *Tools-> Add-Ins* on the menu bar. If this Add-In is not deselected, the population data will be loaded every time Excel is opened.

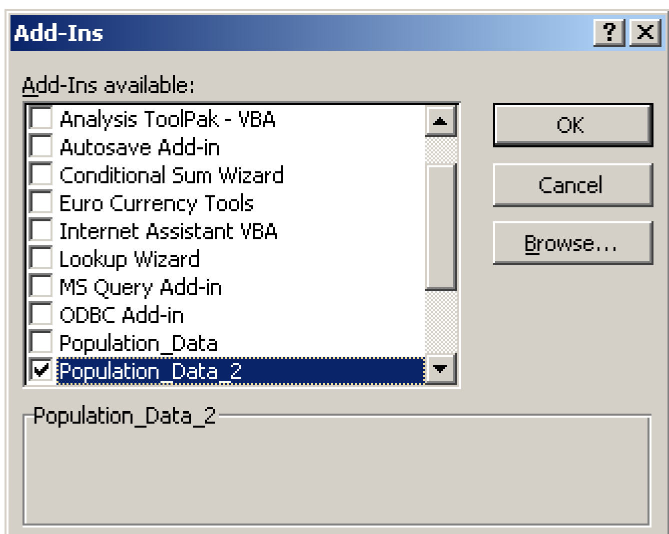


Figure 2-16. *Population_Data_2* Add-In

3 SURVIVABILITY TABLES

This section describes the assumptions that were used in the creation of the survivability tables and the steps that are used to extract data from the tables in Appendix C through E.

3.1 Survivability Assumptions and Table Legend

The following is a list of the assumptions used to generate the survivability tables. More detail on the heating calculations and how these assumptions were derived are outlined in the presentation in Appendix A.

- A limited number of reentry states have been run.
- A limited number of initial temperatures have been run.
- Because not every case has been run, some variables are rounded; this rounding technique is described in Section 3.2.
- The Area averaging factor in the stagnation heat equation is set at 0.12.
- There are no secondary breakups; the debris begins falling on its individual trajectory from the moment the breakup altitude is reached.
- The heating calculations treat the spacecraft as a lump mass, and no spatial gridding is done; the temperature of the lump changes in time with the total heat content.
- The heating model described in the *Backup* Section of Appendix A is used for the survivability analysis.
- All mass is distributed to the outside wall of the debris (shell shape).
- Shape and mass properties are assumed to be constant throughout melting.
- Atmosphere used for reentry is the 1962 United States Standard Atmosphere.
- Gravity and Earth constants used in trajectory propagation are outlined in Table 3-1.

Table 3-1. Gravity and Earth Constants

Polar radius of Earth (ft)	20855588.21
Equatorial radius of Earth (ft)	20925738.19
Earth gravitational constant (ft^3/s^2)	$1.407653916 \times 10^{16}$
Rotation rate of the Earth (rad/s)	$0.729211585 \times 10^{-4}$
Zonal Harmonic J2	1082.3×10^{-6}
Zonal Harmonic J3	-2.3×10^{-6}
Zonal Harmonic J4	-1.8×10^{-6}

Other shape specific assumptions such as the melt direction, drag coefficients, and heating radius are given in Appendix A.

3.2 Using the Survivability Tables (Step 7 in Section 2)

The following steps describe how to determine survivability from the tables in Appendices C through E. Anywhere the tables do not apply the user can either chose to run independent analysis for survivability or assume the debris survives. In Determining survivability from the tables the variables in Table 3-2 are required.

Table 3-2. Required Variables for Determining Survivability

Breakup altitude (nmi)
Breakup Earth relative velocity (ft/s)
Breakup geocentric Earth relative flight path angle (deg)
Debris material
Debris shape
Debris geometry at breakup (ft)
Debris temperature at breakup (°R)

Survivability in the tables is given in terms of a liquid fraction (LF). This number is a measure of the melting of debris. A zero indicates that the debris has not melted; a one indicates that the debris has melted; a number in between these indicates the fraction of debris that has melted. A legend for the survivability tables is seen in Table 3-2.

Table 3-3. Survivability Table Legend

s	Trajectory skips out of atmosphere
	Violates geometry constraints (see shape specific Appendices C through E for constraints)

LF values

0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1

Survivability tables are generated based on specific debris shapes.

Step a Determine material

Survivability tables are developed for three materials listed in Table 3-4. The debris material is selected from one of the materials in the list. If the debris is not one of these materials, then the tables do not apply. Data for this table was taken from Reference 2.

Table 3-4. Materials Analyzed for Survivability

Material	Melt temperature (°R)	Specific heat capacity (BTU/lb/°R)	Heat of fusion (BTU/lb)	Material density (lb/ft^3)
Aluminum 2024-T8xx	1541	0.232	166	175
Titanium (6 Al-4 V)	3497	0.192	169	277
Stainless Steel 21-6-9	3110	0.105	123	489

Step b Determine shape

The tables are developed for four shapes: tumbling hollow sphere, tumbling hollow cylinder, tumbling flat plate, and tumbling hollow box. The word tumbling is used to describe how the aerodynamic properties were determined (tumbling rather than trimmed). The word hollow is used to describe that the debris mass is distributed along wall of the debris (shell shape). The appropriate shape should be selected from one of these four shapes. The equations for the shapes are show in Appendix A. If an appropriate shape is not found for a particular piece of debris, then the tables do not apply.

Step c Determine breakup altitude

There reentry breakup altitude is chosen from the finite list in Table 3-5. If the breakup altitude is outside of the 30-46 nmi bounds the tables do not apply. If the breakup altitude is inside these bounds, the closest available altitude should be used.

Table 3-5. Breakup Altitudes

46 nmi	44 nmi	42 nmi	40 nmi	38 nmi	36 nmi	34 nmi	32 nmi	30 nmi

Step d Determine breakup Earth relative velocity and geocentric Earth relative flight path angle

Based on the altitude from Step c Table 3-6 is used to determine the discrete Earth relative velocity and geocentric Earth relative flight path angles that are available. If the velocity or flight path angle is outside of the bounds of the table for a given altitude, then the tables do not apply. If they are inside these bounds, then the closest available value should be used.

Table 3-6. Available Breakup States

Altitude (nmi)	Earth relative velocity (ft/sec)			Geocentric Earth relative flight path angle (deg)		
46	27000	25000	23000	-0.5	-3.0	-5.5
44	26000	24000	22000	-0.5	-3.0	-5.5
42	25000	23000	21000	-0.5	-3.0	-5.5
40	23000	21000	19000	-0.5	-3.0	-5.5
38	21000	19000	17000	-0.5	-3.0	-5.5
36	19000	17000	15000	-0.5	-3.0	-5.5
34	17000	15000	13000	-0.5	-3.0	-5.5
32	14000	12000	10000	-0.5	-3.0	-5.5
30	12000	10000	8000	-0.5	-3.0	-5.5

Step e <u>Determine initial temperature</u>

The user must select from only two initial debris temperatures that are available in the tables, 540°R and 1541°R. Assuming 540°R is the conservative assumption and should be used unless a particular piece of debris will be exposed to heating in a failure that leads to a breakup. The 1541°R is the melt temperature of aluminum and represents debris exposed to the freestream air in the time leading to breakup. If the temperature of debris at breakup is known to be below 540°R, then the tables do not apply.

Step f <u>Find appropriate table</u>

Based on material, shape, breakup state, and breakup temperature determined from the previous steps the appropriate table to use from the Appendices should be determined using Tables 3-7 through 3-15. For cases where all debris survives *all survive* is written. For some of the cases where *all survive* is written a table is not available. When determining survivability for a tumbling hollow box the tumbling hollow cylinder tables are used.

Table 3-7. Table Numbers for Aluminum 2024-T8xx Tumbling Hollow Spheres

Altitude at breakup (nmi)	Temperature at breakup	
	1541°R	540°R
46	Table C-2	Table C-3
44	Table C-4	Table C-5
42	Table C-6	Table C-7
40	Table C-8	Table C-9
38	Table C-10	Table C-11 (all survive)
36	Table C-12	Table C-13 (all survive)
34	Table C-14	Table C-15 (all survive)
32	Table C-16	Table C-17 (all survive)
30	Table C-18	Table C-19 (all survive)

Table 3-8. Table Numbers for Stainless Steel 21-6-9 Tumbling Hollow Spheres

Altitude at breakup (nmi)	Temperature at breakup	
	1541°R	540°R
46	Table C-20 (all survive)	all survive
44	all survive	all survive
42	all survive	all survive
40	all survive	all survive
38	all survive	all survive
36	all survive	all survive
34	all survive	all survive
32	all survive	all survive
30	all survive	all survive

Table 3-9. Table Numbers for Titanium (6 Al-4 V) Tumbling Hollow Spheres

Altitude at breakup (nmi)	Breakup temperature	
	1541°R	540°R
46	Table C-21 (all survive)	all survive
44	all survive	all survive
42	all survive	all survive
40	all survive	all survive
38	all survive	all survive
36	all survive	all survive
34	all survive	all survive
32	all survive	all survive
30	all survive	all survive

Table 3-10. Table Numbers for Aluminum 2024-T8xx Tumbling Hollow Cylinders

Altitude at breakup (nmi)	Earth relative velocity at breakup (ft/s)	Temperature at breakup	
		1541°R	540°R
46	23000	Table D-2	Table D-5
	25000	Table D-3	Table D-6
	27000	Table D-4	Table D-7
44	22000	Table D-8	Table D-11
	24000	Table D-9	Table D-12
	26000	Table D-10	Table D-13
42	21000	Table D-14	Table D-17
	23000	Table D-15	Table D-18
	25000	Table D-16	Table D-19
40	19000	Table D-20	Table D-23
	21000	Table D-21	Table D-24
	23000	Table D-22	Table D-25
38	17000	Table D-26	Table D-29
	19000	Table D-27	Table D-30
	21000	Table D-28	Table D-31
36	15000	Table D-32	Table D-35 (all survive)
	17000	Table D-33	Table D-36
	19000	Table D-34	Table D-37
34	13000	Table D-38	Table D-41 (all survive)
	15000	Table D-39	Table D-42 (all survive)
	17000	Table D-40	Table D-43 (all survive)
32	10000	Table D-44	Table D-47 (all survive)
	12000	Table D-45	Table D-48 (all survive)
	14000	Table D-46	Table D-49 (all survive)
30	8000	Table D-50 (all survive)	Table D-53 (all survive)
	10000	Table D-51	Table D-54 (all survive)
	12000	Table D-52	Table D-55 (all survive)

Table 3-11. Table Numbers for Stainless Steel 21-6-9 Tumbling Hollow Cylinders

Altitude at breakup (nmi)	Earth relative velocity at breakup (ft/s)	Temperature at breakup	
		1541°R	540°R
46	23000	Table D-56	all survive
	25000	Table D-57	all survive
	27000	Table D-58	all survive
44	22000	Table D-59	all survive
	24000	Table D-60	all survive
	26000	Table D-61	all survive
42	21000	Table D-62	all survive
	23000	Table D-63	all survive
	25000	Table D-64	all survive
40	19000	Table D-65 (all survive)	all survive
	21000	Table D-66 (all survive)	all survive
	23000	Table D-67 (all survive)	all survive
38	17000	all survive	all survive
	19000	all survive	all survive
	21000	all survive	all survive
36	15000	all survive	all survive
	17000	all survive	all survive
	19000	all survive	all survive
34	13000	all survive	all survive
	15000	all survive	all survive
	17000	all survive	all survive
32	10000	all survive	all survive
	12000	all survive	all survive
	14000	all survive	all survive
30	8000	all survive	all survive
	10000	all survive	all survive
	12000	all survive	all survive

Table 3-12. Table Numbers for Titanium (6 Al-4 V) Tumbling Hollow Cylinders

Altitude at breakup (nmi)	Earth relative velocity at breakup (ft/s)	Temperature at breakup	
		1541°R	540°R
46	23000	Table D-68 (all survive)	all survive
	25000	Table D-69 (all survive)	all survive
	27000	Table D-70 (all survive)	all survive
44	22000	all survive	all survive
	24000	all survive	all survive
	26000	all survive	all survive
42	21000	all survive	all survive
	23000	all survive	all survive
	25000	all survive	all survive
40	19000	all survive	all survive
	21000	all survive	all survive
	23000	all survive	all survive
38	17000	all survive	all survive
	19000	all survive	all survive
	21000	all survive	all survive
36	15000	all survive	all survive
	17000	all survive	all survive
	19000	all survive	all survive
34	13000	all survive	all survive
	15000	all survive	all survive
	17000	all survive	all survive
32	10000	all survive	all survive
	12000	all survive	all survive
	14000	all survive	all survive
30	8000	all survive	all survive
	10000	all survive	all survive
	12000	all survive	all survive

Table 3-13. Table Numbers for Aluminum 2024-T8xx Tumbling Flat Plates

Altitude at breakup (nmi)	Earth relative velocity at breakup (ft/s)	Temperature at breakup	
		1541°R	540°R
46	23000	Table E-2	Table E-5 (all survive)
	25000	Table E-3	Table E-6 (all survive)
	27000	Table E-4	Table E-7
44	22000	Table E-8	Table E-11 (all survive)
	24000	Table E-9	Table E-12 (all survive)
	26000	Table E-10	Table E-13 (all survive)
42	21000	Table E-14	Table E-17 (all survive)
	23000	Table E-15	Table E-18 (all survive)
	25000	Table E-16	Table E-19 (all survive)
40	19000	Table E-20	Table E-23 (all survive)
	21000	Table E-21	Table E-24 (all survive)
	23000	Table E-22	Table E-25 (all survive)
38	17000	Table E-26	Table E-29 (all survive)
	19000	Table E-27	Table E-30 (all survive)
	21000	Table E-28	Table E-31 (all survive)
36	15000	Table E-32	Table E-35 (all survive)
	17000	Table E-33	Table E-36 (all survive)
	19000	Table E-34	Table E-37 (all survive)
34	13000	Table E-38 (all survive)	Table E-41 (all survive)
	15000	Table E-39	Table E-42 (all survive)
	17000	Table E-40	Table E-43 (all survive)
32	10000	Table E-44 (all survive)	Table E-47 (all survive)
	12000	Table E-45 (all survive)	Table E-48 (all survive)
	14000	Table E-46 (all survive)	Table E-49 (all survive)
30	8000	Table E-50 (all survive)	Table E-53 (all survive)
	10000	Table E-51 (all survive)	Table E-54 (all survive)
	12000	Table E-52 (all survive)	Table E-55 (all survive)

Table 3-14. Table Numbers for Stainless Steel 21-6-9 Tumbling Flat Plates

Altitude at breakup (nmi)	Earth relative velocity at breakup (ft/s)	Temperature at breakup	
		1541°R	540°R
46	23000	Table E-56 (all survive)	all survive
	25000	Table E-57	all survive
	27000	Table E-58	all survive
44	22000	all survive	all survive
	24000	all survive	all survive
	26000	all survive	all survive
42	21000	all survive	all survive
	23000	all survive	all survive
	25000	all survive	all survive
40	19000	all survive	all survive
	21000	all survive	all survive
	23000	all survive	all survive
38	17000	all survive	all survive
	19000	all survive	all survive
	21000	all survive	all survive
36	15000	all survive	all survive
	17000	all survive	all survive
	19000	all survive	all survive
34	13000	all survive	all survive
	15000	all survive	all survive
	17000	all survive	all survive
32	10000	all survive	all survive
	12000	all survive	all survive
	14000	all survive	all survive
30	8000	all survive	all survive
	10000	all survive	all survive
	12000	all survive	all survive

Table 3-15. Table Numbers for Titanium (6 Al-4 V) Tumbling Flat Plates

Altitude at breakup (nmi)	Earth relative velocity at breakup (ft/s)	Temperature at breakup	
		1541°R	540°R
46	23000	Table E-59 (all survive)	all survive
	25000	Table E-60 (all survive)	all survive
	27000	Table E-61 (all survive)	all survive
44	22000	all survive	all survive
	24000	all survive	all survive
	26000	all survive	all survive
42	21000	all survive	all survive
	23000	all survive	all survive
	25000	all survive	all survive
40	19000	all survive	all survive
	21000	all survive	all survive
	23000	all survive	all survive
38	17000	all survive	all survive
	19000	all survive	all survive
	21000	all survive	all survive
36	15000	all survive	all survive
	17000	all survive	all survive
	19000	all survive	all survive
34	13000	all survive	all survive
	15000	all survive	all survive
	17000	all survive	all survive
32	10000	all survive	all survive
	12000	all survive	all survive
	14000	all survive	all survive
30	8000	all survive	all survive
	10000	all survive	all survive
	12000	all survive	all survive

Step g <u>Determine geometric properties</u>

Once the table number has been determined the geometric and mass properties are determined. For each shape different geometric properties are required. A discrete number of geometric properties are available from the tables. Tables 3-16 through 3-19 should be used to round the parameters off to values that are available. For a tumbling hollow box the equivalent cylinder parameters are determined using the equations in Table 3-19. If any of the parameters are outside of the bounds of the table for a given altitude, then the tables do not apply.

Table 3-16. Tumbling Hollow Sphere Geometry and Weight Values Available

weight (lb): 5, 10, 25, 50, 75, 100, 250, 750, 1000, 2500, 5000
radius (ft): 0.5, 1.0, 1.5, 2, 3, 4, 5, 6, 8, 10

Table 3-17. Tumbling Hollow Cylinder Geometry and Weight Values Available

weight (lb): 5, 10, 25, 50, 75, 100, 250, 750, 1000, 2500, 5000
radius (ft): 0.1, 0.5, 1, 1.5, 2, 3, 4, 5
length (ft): 1, 2.5, 5, 10, 20, 30

Table 3-18. Tumbling Flat Plate Geometry and Weight Values Available

weight (lb): 5, 10, 25, 50, 75, 100, 250, 750, 1000, 2500, 5000
length (ft): 1, 1.5, 2, 3, 5, 7.5, 10
width (ft): 1, 1.5, 2, 3, 5, 7.5, 10

Table 3-19. Tumbling Hollow Box Equations to Determine Equivalent Cylinder

$l_c = l$
$r_c = \mathrm{sqrt}((wh)/\pi)$
l_c – equivalent cylinder length
r_c – equivalent cylinder radius
length (l) > width (w) > height (h)

Step h <u>Lookup liquid fraction</u>

Based on the table number and variables determined in the previous step, the LF is looked up in Appendices C through E.

4 CONCLUSIONS

A description of a simplified, conservative, spreadsheet methodology for calculating casualty expectation during planned reentry over populated areas has been introduced. The step-by-step instructions show how a user can combine the *reentry_casualty_expectation_v2.0* spreadsheet, *Population_Data_2.xla* Add-In, and survivability tables to compute casualty expectation.

5 ACRONYMS AND ABBREVIATIONS

A_c	casualty area
A_p	projected area
AST	Office of Commercial Space Transportation
A_w	wetted area
BTU	British Thermal Unit
β_{hc}	hypersonic continuum ballistic coefficient
β_{sub}	subsonic ballistic coefficient
$\overline{c}$	mean specific heat
C_{Dhc}	hypersonic continuum drag coefficient
C_{Dsub}	subsonic drag coefficient
COTR	Contracting Officer's Technical Representative
C_p	specific heat
deg	degree
E	east
E_c	casualty expectation
E_{ci}	casualty expectation for i_{th} area
FAA	Federal Aviation Administration
ft	foot
h	altitude at breakup
h_f	heat of fusion
k_2	stagnation heating area averaging factor
KE	kinetic energy
l	length
L/D	lift-to-drag ratio
lb	pound
lb/ft^2	pounds per square foot
l_c	equivalent cylinder length
LF	liquid fraction
l_m	length of debris after melting
m	mass
N	north
N/A_i	population density for i^{th} area
nmi	nautical mile
ºR	degrees Rankine
pdf	probability density function
P_F	probability of failure
PI_i	probability of impact for i^{th} area
psf	pounds per square foot
Q	net heat flow
Q_0	heat content at t_0
Q_1	total heat imparted to debris after breakup

Q_a	total heat required to melt entire body
q_s	stagnation heat flux
ρ_{ref}	reference density of air
ρ_{sl}	density of air at sea level
ρ_{mat}	material density
°R	degrees Rankine
ρ_∞	density at altitude
r	radius
r_c	equivalent cylinder radius
r_h	heating radius
r_m	radius of debris after melting
r_p	radius of a person
R_{ref}	reference radius of debris
σ	Stefen-Boltzmann constant
ε	surface emissivity
S	aerodynamic reference area
sec	second
S_m	melted aerodynamic reference area
SS	stainless steel
T	temperature at breakup
T_b	body temperature
$T_{breakup}$	material temperature at breakup
T_{eq}	equilibrium temperature
Ti	titanium
T_m	melt temperature
T_o	initial temperature
T_{ref}	reference temperature
T_s	stagnation temperature
v	Earth relative velocity
V_∞	freestream air velocity
V_{ref}	reference velocity of vehicle
W	weight
w	width
W_m	weight of debris remaining after melting
w_m	width of debris after melting
γ	geocentric Earth relative flight path angle

6 REFERENCES

1. Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI); and World Resources Institute (WRI). 2000. Gridded Population of the World (GPW), Version 3. Palisades, NY: CIESIN, Columbia University. Available at **http://sedac.ciesin.columbia.edu/plue/gpw**.

2. *NASA Safety Standard: Guidelines and Assessment Procedures for Limiting Orbital Debris*, NASA Document NSS 1740. 14, August 1995.

3. Refling, O., Stern, R. & Potz, C., *Review of Orbital Reentry Risk Prediction*, The Aerospace Corporation ATR-92(2835)-1, July 15, 1992.

4. Research Triangle Institute, *Casualty Areas from Impacting Inert Debris for People in the Open*, RTI Report No. RTI/5180/60-31F, April 13, 1995.

7 BIBLIOGRAPHY

1. Cropp, L. O. Analytical Methods Used in Predicting the Re-Entry Ablation of Spherical and Cylindrical Bodies, Sandia Corporation, September 1965.

2. Detra, R.W., Kemp, N.H. and Riddell, F.R., *Addendum to Heat Transfer to Satellite Vehicle Re-entering the Atmosphere*, Jet Propulsion Laboratory, December 1957.

APPENDIX A
CASUALTY EXPECTATION METHODOLOGY

This Appendix is a presentation that details the methodology, assumptions, and equations that are used for the development of the reentry handbook, spreadsheet, and survivability tables.

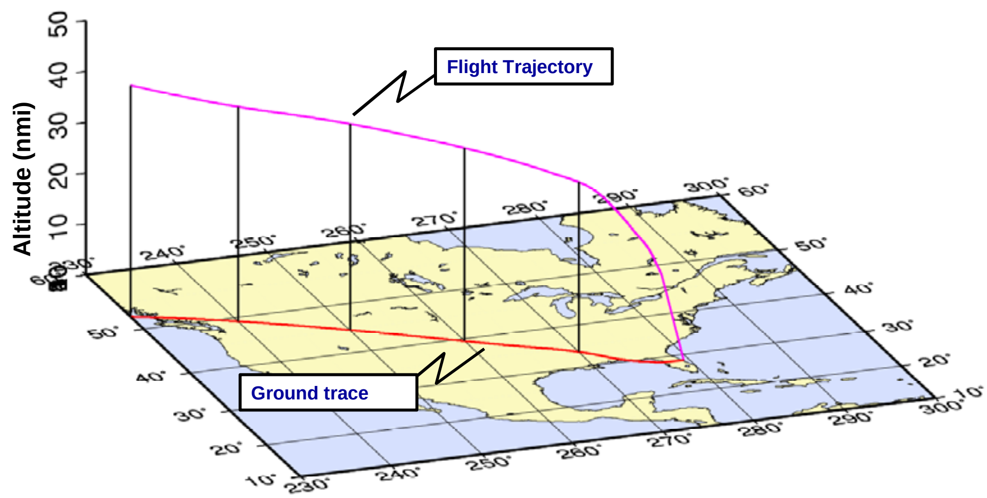
Outline

Introduce simplified, conservative methodology for calculating casualty expectation during planned reentry over populated areas. This methodology is basis of spreadsheet tool, handbook, and survivability lookup tables.

- **Initialize trajectory**
- **Discretize trajectory**
- **Assign failure probability**
- **Initialize debris model**
- **Determine survivability**
- **Determine casualty area**
- **Determine impact area**
- **Combine with population data**
- **Compute casualty expectation**
- **Example**

This presentation outlines a simplified, conservative methodology for the calculation of casualty expectation for the breakup of a planned reentry over populated areas. The methodology outlined is used for the development of a handbook, spreadsheet, and survivability tables to perform the casualty expectation calculation.

Establish Nominal Trajectory

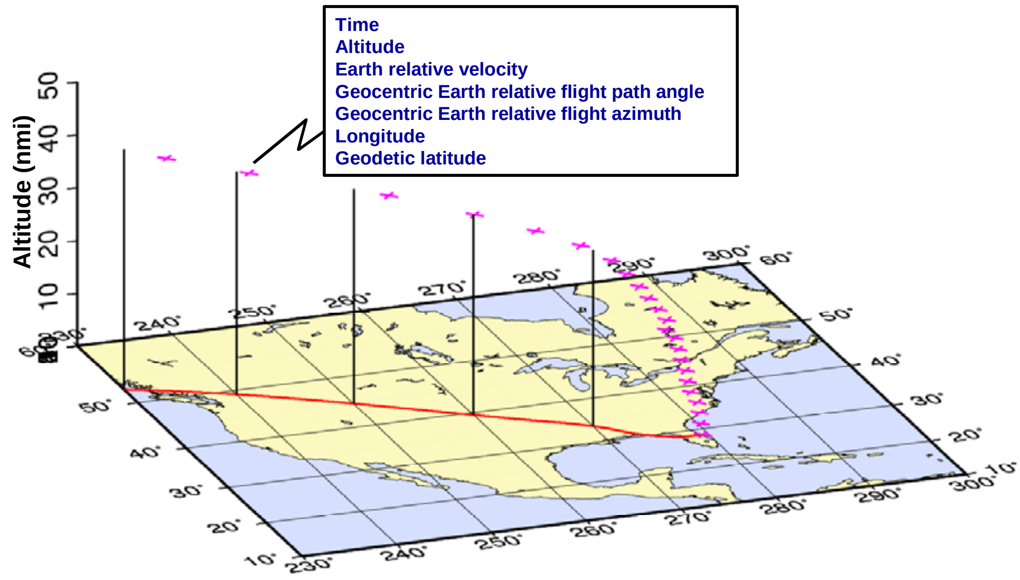


Nominal Trajectory

- **Trajectory data required as function of time**
  - **Altitude**
  - **Earth Relative velocity**
  - **Geocentric Earth relative flight path angle**
  - **Geocentric Earth relative flight azimuth**
  - **Longitude**
  - **Geodetic latitude**

The nominal trajectory is established based on a specific mission. The data that is required as a function of time is altitude, Earth relative velocity, geocentric Earth relative flight path angle, geocentric Earth relative flight, azimuth, longitude, and geodetic latitude.

Discretize Trajectory

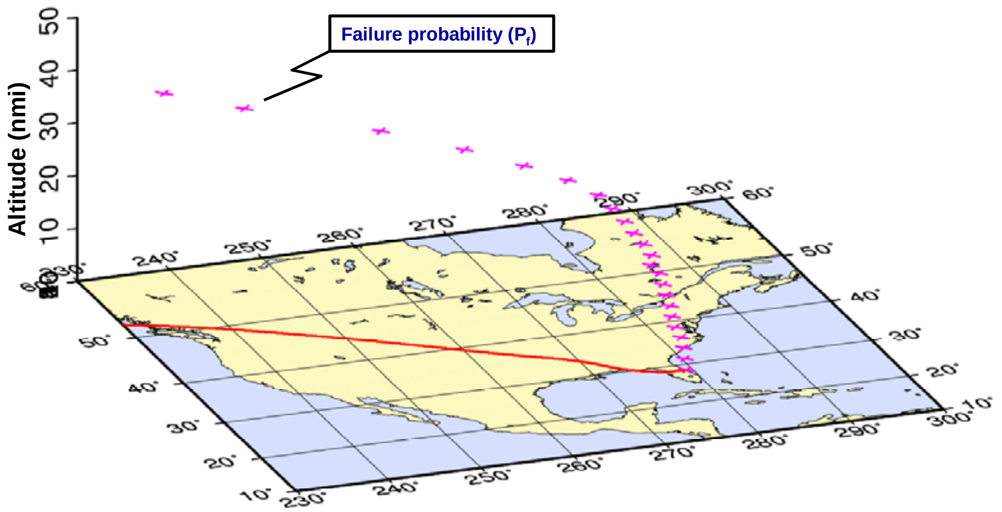


Discretize Trajectory

- Trajectory is discretized to represent possible breakup points
- Trajectory is discretized based on altitude, time, or velocity
  – The finer the spacing the more time the calculation takes
  – The finer the spacing the more accurate the calculation
- We suggest that the trajectory be discretized using altitude every 2 nmi
  – Order of magnitude changes between the casualty expectation results for adjacent breakup points should be examined at a finer spacing
  – A finer spacing should be used around heavily populated areas

The trajectory is discretized to represent possible breakup points in the trajectory. A casualty expectation value will be computed for each of these breakup points. It is suggested that discrete breakup points are chosen based on altitude within the trajectory. A good spacing is trajectory dependent, however, 2 nmi should be adequate for a first-order approximation. Other parameters the trajectory can be discretized on are time or velocity. If there is overflight of a particularly high population or order-of-magnitude changes in casualty expectation between breakup points, finer spacing should be used for these periods.

Failure Probability



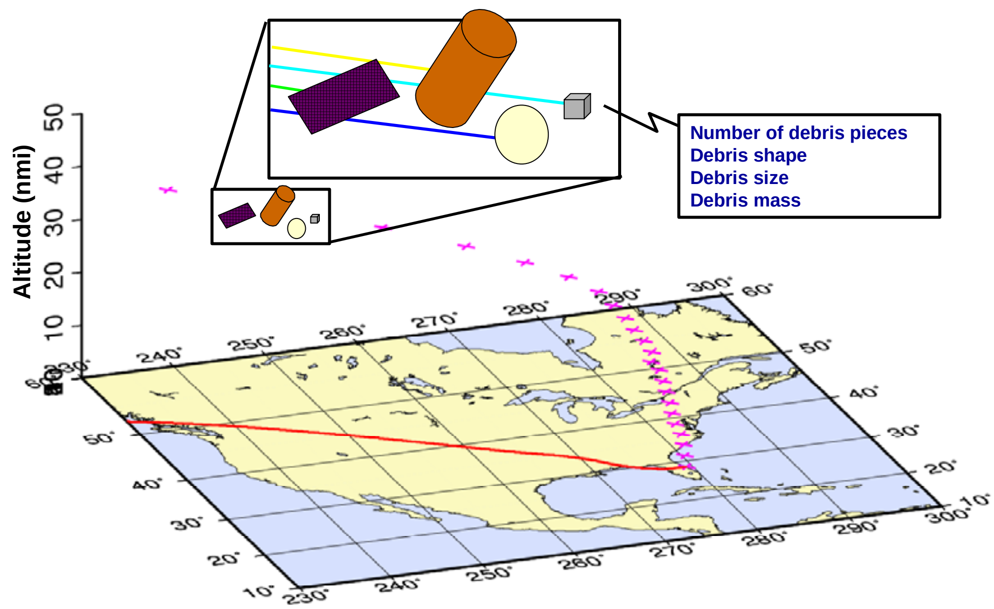
Determining Failure Probability

- Two methods for determining failure probability are described
- First method assumes failure probability of one at each discretized breakup point
  - Each altitude will have an associated casualty expectation; the maximum casualty expectation is chosen as the most conservative value
    - Conservative method for analyzing casualty expectation
    - Assumes failure will occur and will happen at or close to worst possible point
  - Method requires no knowledge of failure probability
- Second method assigns a failure probability to each phase of flight and distributes this probability as a function of time over the discretized breakup points
  - Summation of casualty expectations at each breakup point yields total casualty expectation
  - Method less conservative but generally more realistic
  - Requires knowledge about vehicle failure probability
  - Example of this method given in Example section

Two methods are described for computing failure probability. The first assumes a failure probability of one at each discrete breakup point. The highest casualty expectation from each of these breakup points will be taken from the resulting array of casualty expectations. This method is conservative because it assumes that a failure will occur and that it will occur at the worst possible discretized breakup point.

The second, less conservative method assigns a failure probability to each phase of flight and distributes this probability as a function of time over the discretized breakup points. This approach is used in the example shown in Appendix B.

Initialize Debris Model

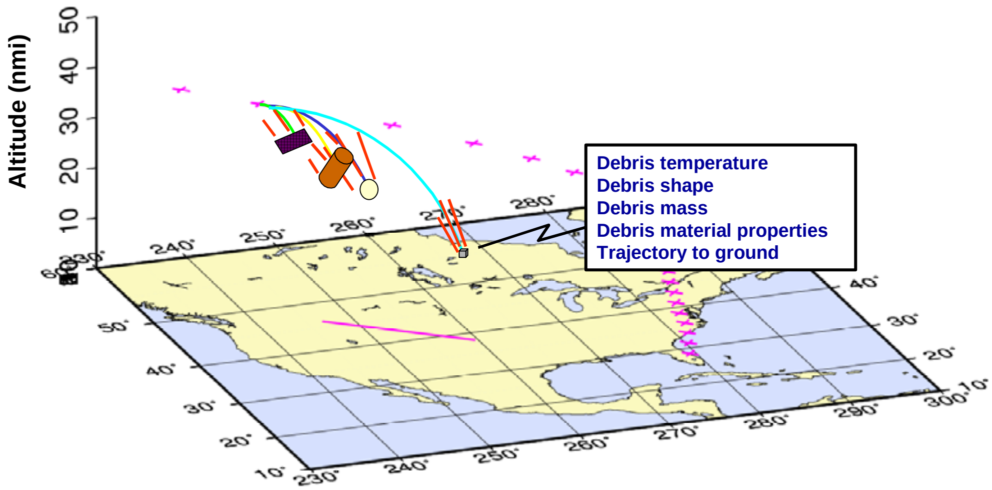


Breakup Model

- **Breakup can occur at any altitude**
- **As a simplification, all major components connected by structure that can be broken by aerodynamic forces, thermal failure, explosion, range destruct, or other failure modes are assumed to instantaneously separate (no secondary breakups considered)**
  - **Most conservative debris model**
    - **Uses engineering judgment and analysis to determine the largest number of pieces vehicle can break into**
    - **The larger the number of pieces in the model the higher the casualty area**
    - **Assumes all debris survives to the ground**
  - **Less conservative accounts for survivability of debris**
    - **Survivability discussed in “Determine Survivability” Section**
  - **Least conservative with altitude-varying breakup model can also be used**
    - **Requires more detailed modeling of breakup**
    - **Can result in smaller casualty areas for breakup at lower velocities due to smaller number of debris pieces**

The breakup can be due to aerothermal heating, aerodynamic forces, explosion, range destruct, or other failure modes. All major components connected by structure that can be broken apart by these destruct modes are assumed to instantaneously separate (no secondary breakups considered). This is a simplification because most breakups involve secondary and primary breakups. In general, the more pieces the larger the casualty area, so the conservative assumption is to assume a larger number of pieces. Secondary breakups can affect survivability; this effect is discussed in the *Determine Survivability* Section.

Determine Survivability



Measuring Survivability (Liquid Fraction)

- Tables are developed to represent survivability of debris in terms of liquid fraction
- Liquid fraction (LF) is measure of weight of material that has melted
  - Zero indicates that the debris has not melted (RED).
  - One indicates that the debris has melted (GREEN).
  - A number in between indicates fraction of debris mass that has melted (SHADES OF RED, YELLOW, OR GREEN).
  - Grey box with an s denotes that trajectory has skipped out of the atmosphere
  - Grey box means a geometry constraint has been violated; geometry constraints are listed in section for each shape.
- Legend for survivability tables

Liquid Fraction Legend

0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1

s — Trajectory skips (a flight path angle of greater than zero is reached)

Violates geometry constraints

Survivability will be represented in tables. The parameter used to represent survivability in these tables is the liquid fraction (LF). The LF is a number from 0 to 1 that measures the fraction of mass of a piece of debris that has melted. A grey box in the tables denotes either a trajectory or shape constraint has been violated.

List of Variables

- **From the heating equations outlined in the backup charts, the survivability of a debris piece is a function of 14 variables:**
    1. **Wetted area**
    2. **Drag coefficient**
    3. **Aerodynamic reference area**
    4. **Reference radius for heating calculations**
    5. **Weight at breakup**
    6. **Flight azimuth at breakup**
    7. **Longitude at breakup**
    8. **Latitude at breakup**
    9. **Altitude at breakup**
    10. **Velocity at breakup**
    11. **Flight path angle at breakup**
    12. **Material type**
    13. **Temperature at breakup**
    14. **Area averaging factor (fixed to 0.12)**
- **Multiple steps are taking to reduce the number of variables**
    - **Shape assumptions**
    - **Material assumptions**
    - **State assumptions**
    - **Breakup temperature assumptions**

From the heating equations outlined in the *Backup* Section the survivability is a function of 14 variables. Four assumptions are made to reduce the number of variables; shape assumptions, material assumptions, state assumptions, and breakup temperature assumptions.

Shape Assumptions

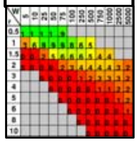
Shape and shape variables with ranges	<u>Tumbling hollow sphere</u> weight (W) (5 to 5000 lb) radius (r) (0.5 to 10 ft)	<u>Tumbling hollow cylinder</u> weight (W) (5 t0 5000 lb) radius (r) (0.5 to 5 ft) length (l) (1 to 30 ft)	<u>Tumbling flat plate</u> weight (W) (5 to 500 lb) length (l) (1 to 10 ft) width (w) (1 to 10 ft)	<u>Tumbling hollow box (represented as equivalent cylinder)</u> weight (W) length (l) width (w) height (h)
Wetted area (A_w)	$4\pi r^2$	$2\pi r(r+l)$	2lw + 2lt + 2wt	$2\pi r_c(r_c+l_c)$
Hypersonic continuum drag coefficient (C_{Dhc})	0.92	0.720 + 0.326(2r/l)	1.84	$0.720 + 0.326(2r_c/l_c)$
Aerodynamic reference area (S)	πr^2	2rl	lw	$2r_cl_c$
Hypersonic continuum ballistic coefficient (β_{hc})	$W/S/C_{Dhc}$	$W/S/\ C_{Dhc}$	$W/S/\ C_{Dhc}$	$W/S/\ C_{Dhc}$
Heating radius (r_h)	r	r	w/2	r_c
Other equations	N/A	N/A	$t = W/\rho_{mat}/l/w$ Flat plate thickness (t) Material density (ρ_{mat})	l > w > h $l_c = l$ r_c= sqrt((wh)/π) Equivalent cylinder weight (W_c) Equivalent cylinder length (l_c) Equivalent cylinder radius (r_c)

To reduce the number of variables in the calculation of LF a shape is assumed. This chart shows the equations used to compute wetted area, drag coefficient, aerodynamic reference area, heating radius, and weight based on shape, geometry, and weight. The four shapes analyzed are a tumbling hollow sphere, tumbling hollow cylinder, tumbling flat plate, and a tumbling hollow box.

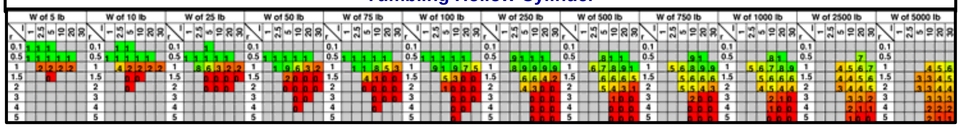
Shape Tables

Example shape tables are shown based on shape geometry variables and weight

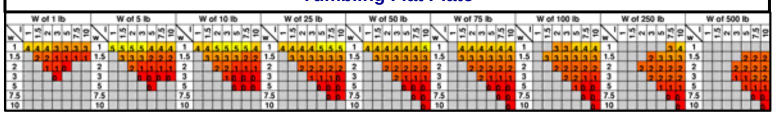
Tumbling Hollow Sphere



Tumbling Hollow Cylinder



Tumbling Flat Plate



Example shape tables are shown in this chart. Spheres are represented by a two dimensional table of weight (W) and radius (r). Flat plates are represented by a three dimensional table of weight (W), length (l), and width (w). Cylinders are represented by a three dimensional table of weight (W), length (l), and radius (r).

Materials Analyzed

- **Three materials are analyzed for debris survivability**

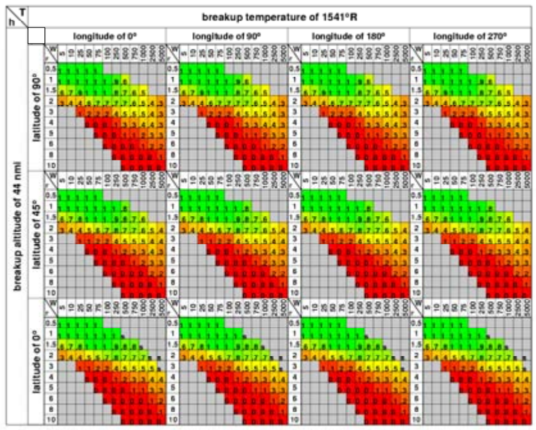
	Melt temperature (°R)	Specific heat (btu/lb-°R)	Heat of fusion (btu/lb)	material density (lb/ft^3)
Aluminum 2024-T8xx	1541	0.232	165.87	175
Titanium (6 Al-4 V)	3497	0.192	169.07	277
Stainless Steel 21-6-9	3110	0.105	122.91	489

Reference: NASA Safety Standard - Guidelines and Assessment Procedures for Limiting Orbital Debris

The properties listed here are for common materials used in space vehicle applications. These are the only three materials analyzed in the survivability tables. This data was taken from the NASA Safety Standard document, *Guidelines and Assessment Procedures for Limiting Orbital Debris*.

Longitude and Geodetic Latitude

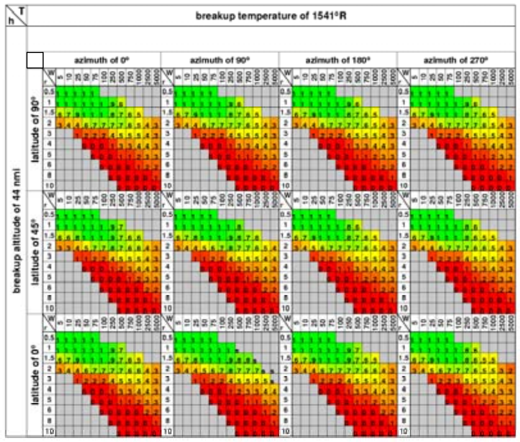
- **Example plot generated for aluminum sphere shows effect of breakup longitude and latitude**
  - **Differences for changing latitude and longitude are small**
  - **Small differences are due to oblate Earth effects and Earth rotation effects**
  - **Plot uses a breakup velocity of 25000 ft/s and flight path angle of –0.5°**
- **Because of this insensitivity a value of zero is used for latitude and longitude to initialize the state of the debris in the final tables generated**



The plot in this figure shows that for the entire range of longitude (0°E to 360°E) and latitude (-90°N to 90°N); these two parameters have a small effect on survivability. These small differences are due to trajectory changes caused by oblate Earth effects and Earth rotation. Because these variables have a small effect they are set to 0° for all cases in the survivability tables to reduce the number of variables.

Geocentric Earth Relative Flight Azimuth and Geodetic Latitude

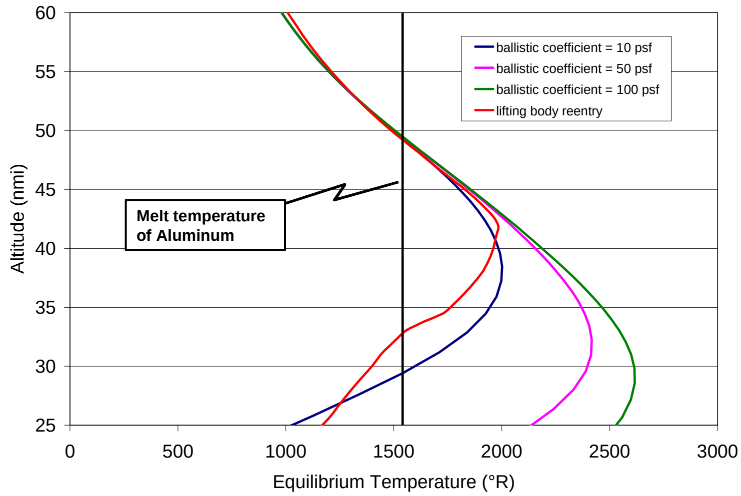
- Example plot generated for aluminum sphere shows effect of breakup flight azimuth and latitude
  - Differences for changing azimuth and latitude are small (<0.3 for liquid fraction)
  - Small differences are due to oblate Earth effects and Earth rotation effects
  - Plot uses a breakup velocity of 25000 ft/s and flight path angle of –0.5°
- Flight azimuth has a larger affect than longitude or latitude
- A value of 90° is used for the flight azimuth for all cases in the final tables generated



Azimuth also has a small effect on survivability across the entire range of possible values (0° to 360°). Its effect on survivability is larger than both longitude and latitude. In order to reduce the number of variables in the survivability tables the azimuth is set to 90°.

Ranges for Altitude

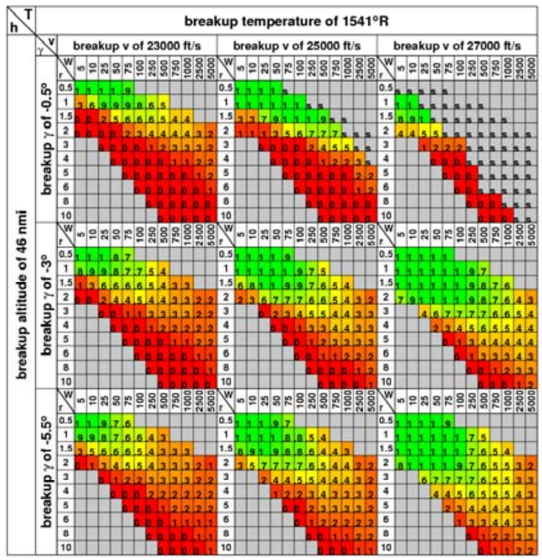
- Plot shows equilibrium heating for 1 ft radius sphere
- Based on this plot a range of 30 to 46 nmi is used for altitude ranges in survivability tables
  - The upper altitude bound is obtained by observing where the curves cross the melt temperature of aluminum
  - The lower altitude bound is obtained by observing where the temperature begins to decrease



This plot shows equilibrium temperature on a 1 ft radius sphere for typical reentries. The melt temperature of aluminum is also displayed on this chart. For the survivability tables only altitudes where temperatures can reach near the melt temperature of aluminum are investigated (30 to 46 nmi). Establishing this range helps reduce the number of cases that are run for the survivability tables.

Earth Relative Velocity (v) and Geocentric Earth Relative Flight Path Angle (γ)

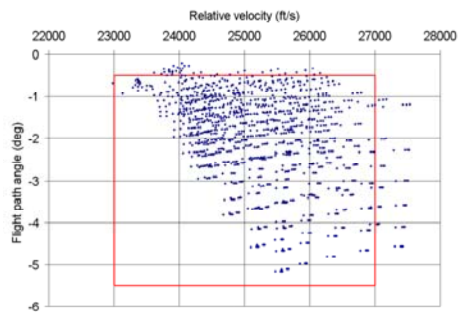
- **Relative velocity and flight path angle have a large affect on survivability**



Earth relative velocity and geocentric Earth relative flight path angle have a large effect on survivability, therefore they are included as variables in the survivability tables.

Ranges for Geocentric Earth Relative Flight Path Angle and Earth Relative Velocity at Breakup

- Parameter study is setup to obtain typical ranges for velocity and flight path angle
- Initialize simple trajectory with typical reentry conditions
  - Apogee (100 to 1000 nmi)
  - Perigee (-60 to 60 nmi)
  - Inclination (0 – 100 deg)
  - 1963 Patrick Atmosphere
  - Ballistic coefficient (10 – 100 psf)
- Example results shown for 46 nmi
  - Blue dots represent cases
  - Red Square represents ranges used for tables
  - From results relative velocity of 23000, 25000, and 27000 ft/s are used for tables
  - From results geocentric relative flight path angles of –0.5°, 3.0°, and –5.5° are used for tables



Ranges for Earth relative velocity and geocentric Earth relative flight path angle are established based on running a range of low earth orbit reentry trajectories. The plot shows the flight path angle and velocity at 46 nmi for all of the reentry cases shown. Establishing ranges for these parameters at each altitude helps reduce the number of cases that are run for the survivability tables.

States Used for Reentry

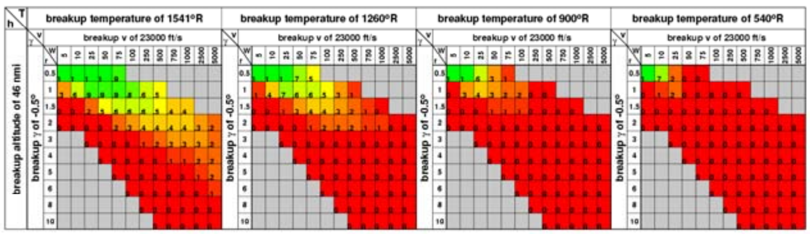
- Geocentric Earth relative flight azimuth of 90°, geodetic latitude of 0°, and longitude of 0° are used
- The ranges used for altitude, Earth relative velocity, and geocentric Earth relative flight path angle are shown in the table
- A total of 81 states are used

Altitude (nmi)	Earth Relative velocity (ft/sec)	Geocentric Earth relative flight path angle (deg)
46	27000, 25000, 23000	-0.5, -3.0, -5.5
44	26000, 24000, 22000	-0.5, -3.0, -5.5
42	25000, 23000, 21000	-0.5, -3.0, -5.5
40	23000, 21000, 19000	-0.5, -3.0, -5.5
38	21000, 19000, 17000	-0.5, -3.0, -5.5
36	19000, 17000, 15000	-0.5, -3.0, -5.5
34	17000, 15000, 13000	-0.5, -3.0, -5.5
32	14000, 12000, 10000	-0.5, -3.0, -5.5
30	12000, 10000, 8000	-0.5, -3.0, -5.5

From the state assumptions and ranges established in the previous charts this table shows a list of the states that are used for the survivability tables.

Temperature at Breakup

- Initial temperature at breakup has large effect on survivability
- For the tables, two breakup temperatures are used (1541°R and 540°R)
  - 1541°R (melt temperature of aluminum) is used to represent debris that is not shielded from heat before breakup
  - 540°R represents reentry debris shielded before breakup
    - This assumption gives a conservative solution
    - This temperature should be used in determining survivability unless it's known debris is exposed to the heating environment during a failure



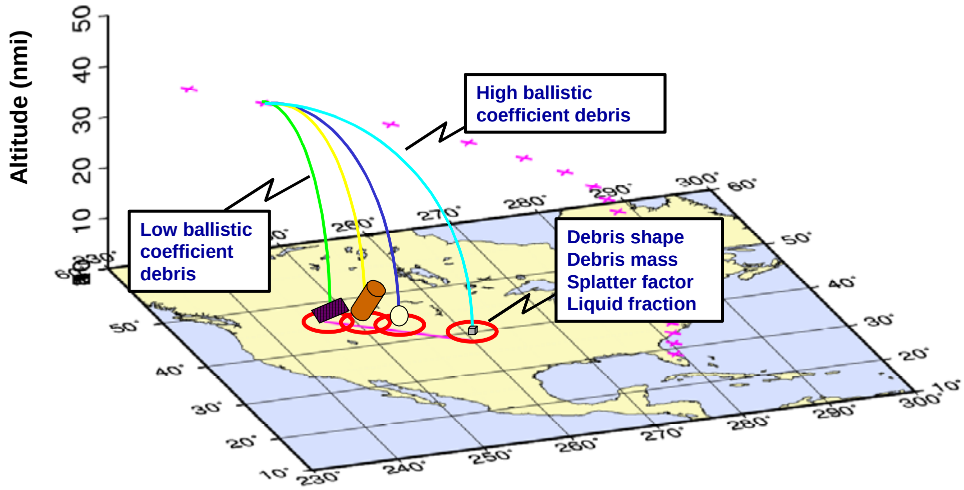
This plot shows initial temperature has a large effect on survivability. For the final tables two initial temperatures are used. The high temperature (1541°R) represents debris that has reached the melt temperature of aluminum at the time of breakup, the lower temperature (540°R) represents debris that has been shielded from reentry until breakup.

Tables Generated

- **Tumbling hollow Sphere (Total of 58320 cases)**
  - 12 weight values
  - 10 radius values
  - 3 velocity values for each altitude
  - 3 flight path angle values
  - 9 altitudes
  - 2 breakup temperatures
  - 3 materials
- **Tumbling hollow cylinder (Total of 279963 cases)**
  - 12 weight values
  - 6 radius values
  - 8 height values
  - 3 velocity values for each altitude
  - 3 flight path angle values
  - 9 altitudes
  - 2 breakup temperatures
  - 3 materials
- **Tumbling flat plate (Total of 214326 cases)**
  - 9 weight values
  - 7 width values
  - 7 length values
  - 3 velocity values for each altitude
  - 3 flight path angle values
  - 9 altitudes
  - 2 breakup temperatures
  - 3 materials
- **Tumbling hollow box (Uses cylinder equivalent)**

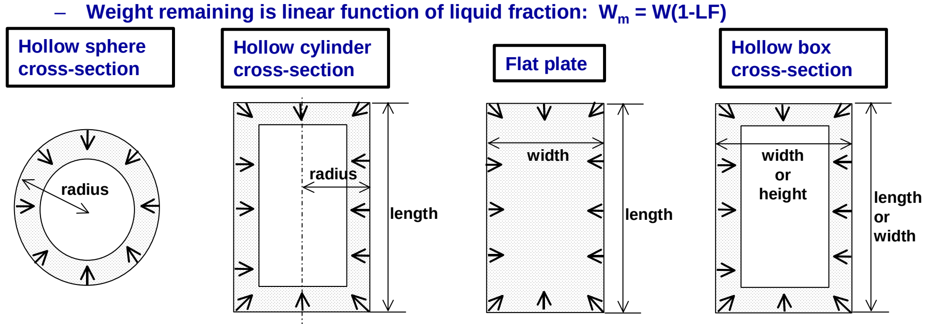
From the assumptions outlined over 500,000 cases are analyzed for survivability.

Determine Casualty Area



Melted Shape Parameters

- Based on the liquid fraction, the melted shape parameters can be calculated; the calculation is based on melt direction
  - Tumbling hollow sphere – melt direction along thickness
  - Tumbling hollow cylinder – melt direction along thickness
  - Tumbling flat plate – melt direction along length and width of plate
  - Tumbling hollow box – melt direction along thickness
  - Black arrows in graphics denote melt direction
  - Equation for final or melted shape parameters are not a linear function of liquid fraction
    - Eqautions are cubics; melted parameters are solved using a Newtonian search method
    - Melted parameters are not tracked in trajectory; are analyzed only in spreadsheet
  - Weight remaining is linear function of liquid fraction: $W_m = W(1\text{-}LF)$



Based on the LF, shape, and melt direction the size and weight of debris after it has melted can be calculated.

Parameters for Casualty Area

Shape and shape variables along with typical ranges	Tumbling hollow sphere melted weight (W_m) melted radius (r_m)	Tumbling hollow Cylinder melted weight (W_m) melted radius (r_m) melted length (l_m)	Tumbling flat plate melted weight (W_m) melted length (l_m) melted width (w_m)	Tumbling hollow box (represented as equivalent cylinder) melted weight (W_{mc}) melted radius (l_{mc}) melted length (w_{mc}) melted height (h_{mc})	Other shapes
Projected Area (A_p)	πr_m^2	$2r_m l_m$ or πr_m^2 (whichever is greater)	$l_m w_m$	$2r_m l_m$ or πr_m^2 (whichever is greater)	user input
Unsheltered casualty area (A_p) with 1 ft man border (r_p)	$\pi(r_m+r_p)^2$	$2(r_p+r_m)(l+2r_p)$ $\pi(r_m+r_p)^2$ (whichever is greater)	$(l_m+2r_p)(w_m+2r_p)$	$2(r_p+r_{mc})(l+2r_p)$ $\pi(r_{mc}+r_p)^2$ (whichever is greater)	r_e = squareroot(A_p/π) $A_p = \pi(r_e+r_p)^2$
Aerodynamic reference area (S_m)	πr_m^2	$2r_m l_m$	$l_m w_m$	$2r_{mc} l_{mc}$	user input
Subsonic drag coeficient (C_{Dsub})	0.48	$0.360 + 0.326(r_m/l_m)$	0.92	$0.360 + 0.326(r_{mc}/l_{mc})$	user input
Subsonic ballistic coefficient at impact (β_{sub})	$W_m/S_m/ C_{Dsub}$	$W_m/S_m/ C_{Dsub}$	$W_m/S_m/ C_{Dsub}$	$W_{mc}/S_{mc}/ C_{Dsub}$	$W_m/S_m/ C_{Dsub}$
Other equations				$l_m > w_m > h_m$ $l_{mc} = l_m$ r_{mc}= sqrt($(w_m h_m)/\pi$) Equivalent melted cylinder weight (W_{mc}) Equivalent melted cylinder length (l_{mc}) Equivalent melted cylinder radius (r_{mc})	

Note: If material has not melted initial debris parameters are used as melted parameters in equations

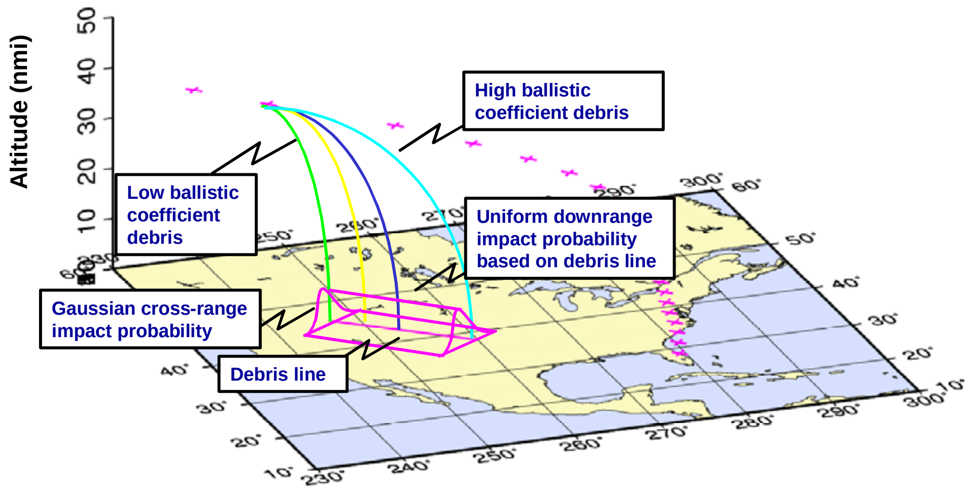
Based on the debris inputs the above equations are used to determine the casualty area for each shape.

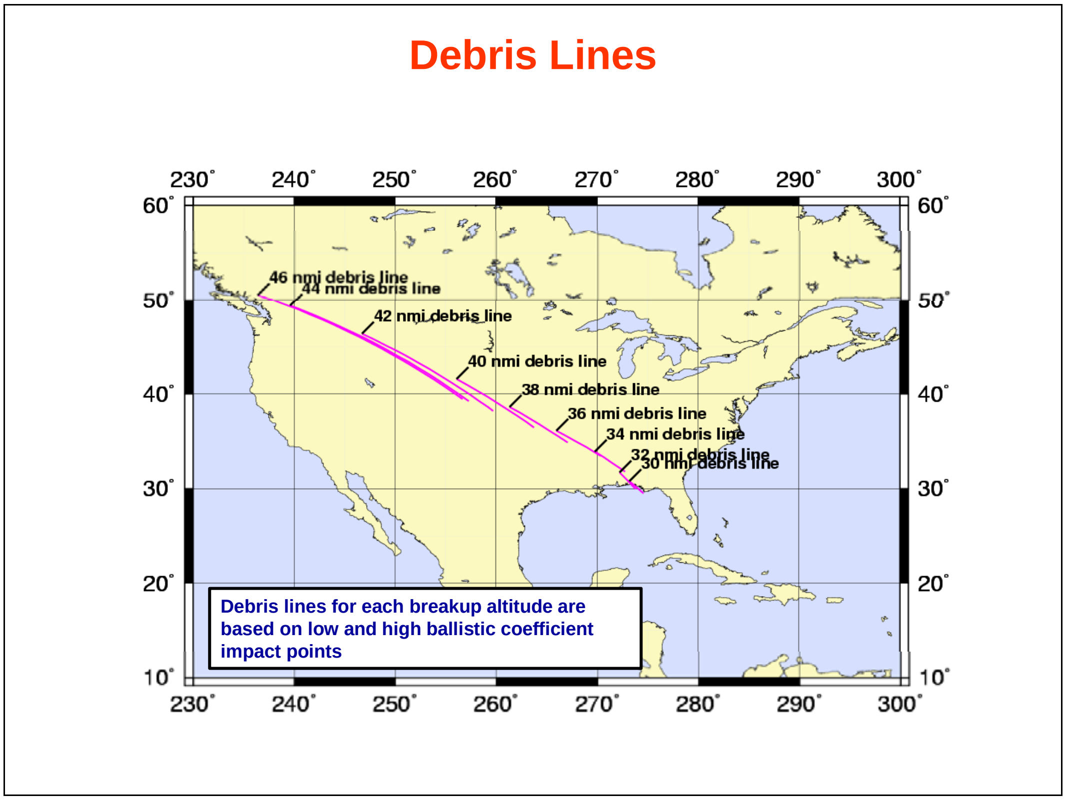
Sheltering and Other Effects

- Splatter, skid, bounce, ricochet, splattering, and cratering effects are modeled with a multiplication factor applied to the unsheltered casualty area
  - Because most reentry debris is inert and will be falling vertically by the time it hits the ground this affect is small
  - A default conservative value of 2 is used for this number
  - If the debris has a horizontal velocity component the user is referred to to RTI Report No. RTI/5180 60-31F April 13, 1995
- A “Weighted Effective Casualty Area” approach (*O. Refling, R. Stern, & C. Potz, “Review of Orbital Reentry Risk Predictions,” The Aerospace Corp., Report No. ATR-92(2835)-1, 15 July 1992.)
  - Kinetic energy (KE) = $W_m\beta_{sub}\rho_{sl}$
  - Three levels of protection considered:
  - Type 1: Buildings with concrete or reinforced roofs
    - Minimum KE (for onset of risk) = 6200 ft-lb
    - Maximum KE (for which the probability of casualty is unity) = 74,000 ft-lb
  - Type 2: Single story buildings such as houses or trailers
    - Minimum KE (for onset of risk) = 100 ft-lb
    - Maximum KE (for which the probability of casualty is unity) = 3200 ft-lb
  - Type 3: Unsheltered (no protection)
    - KE for lethality > 35 ft-lb
  - Type 1 Protection: 20%
  - Type 2 Protection: 70%
  - Type 3 Protection: 10%

This chart shows the simplified methodology used for sheltering and the casualty area multiplication factor.

Determine Impact Area





The debris lines show the downrange areas where debris of varying ballistic coefficients can land given a specific breakup altitude. The lines represent the downrange distribution of the debris for each breakup altitude. The end points of each breakup altitude's debris lines are determined by the impact of the lowest and highest ballistic coefficient pieces in the debris model.

Apply Crossrange Distribution to Each Debris Line

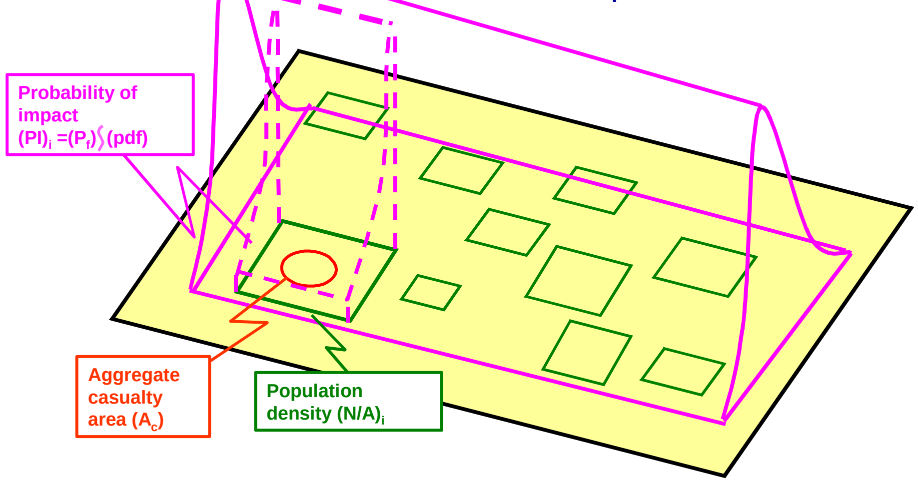
- No conservative solution exists for crossrange distribution; depends on population centers relative to debris line
- Distribution is function of vehicle type
  - In particular the safing or destruct options
  - Aerodynamic stability and vehicle L/D
- Other uncertainties
  - Vehicle
    - Deorbit burn dispersions (mainly affects downrange)
    - Wind and atmospheric conditions
    - Aerodynamic modeling
    - Guidance and control
  - Debris
    - Velocity imparted to debris due to explosion
    - L/D
    - Wind and atmospheric conditions

A crossrange Gaussian distribution is applied to the downrange distribution shown on the previous chart. The standard deviation of this distribution is a function of the vehicle characteristics. Of particular importance are the destruct options and vehicle lift-to-drag ratio. Other uncertainties associated with the debris impact area include de-orbit burn dispersions, wind and atmospheric conditions, aerodynamic modeling uncertainty, and guidance & control. Uncertainties associated with debris include velocity imparted to debris due to explosion, aspect ratio, and atmospheric conditions.

Combine Population, Casualty Area, and Impact Probability

Casualty expectation for i^{th} population center area simplified to

$$E_{ci} = (N/A)_i \, (A_c) \, (P_f) \int_i (pdf)$$

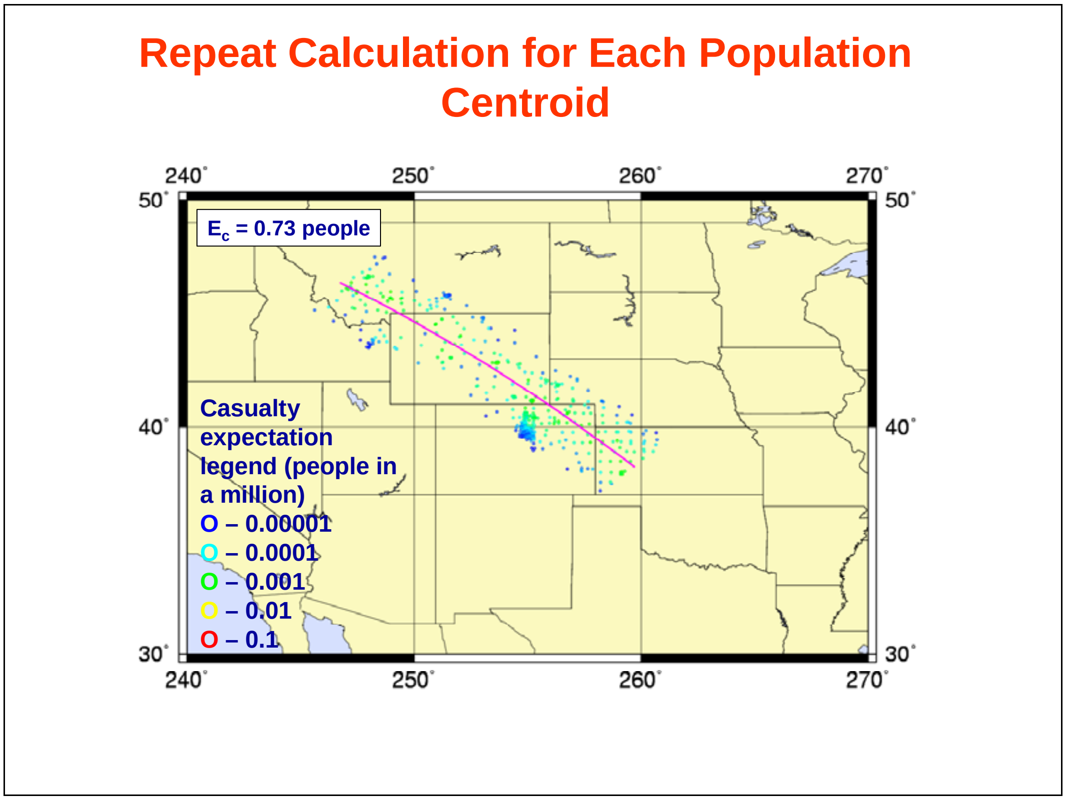


The casualty expectation is calculated for a population cell by multiplying the casualty area, population density, failure probability, and the integral of the impact probability density function (pdf).

Population Data

- Population data obtained from Center for International Earth Science Information Network (CIESIN) at Columbia University, http://www.ciesin.org
- Latest population data from 2004
- Population provided as number of people, area (usually cities), and location

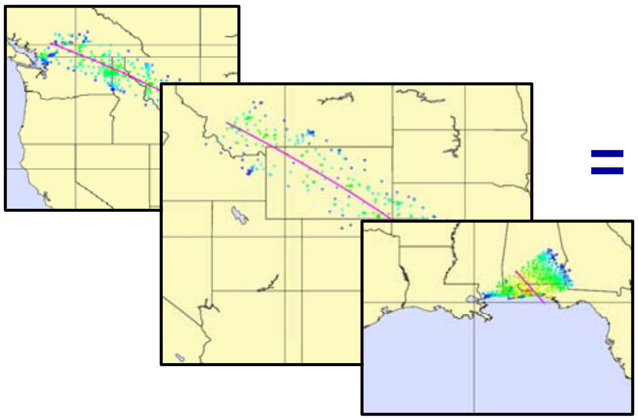
The population data is obtained from the Center for International Earth Science Information Network at Columbia University.



The calculation is repeated for each population cell in the database. This chart is a graphical representation of the risk to each population cell. Different colors represent different risk.

Repeat Calculation for Each Breakup Point

- Calculation is repeated for each breakup point
- To obtain total casualty expectation a maximum or summation of results for each breakup point is done
  - If a failure probability of one is used for each breakup point the maximum value is taken as the total casualty expectation
  - If the failure probability is divided over each breakup point a summation is done to compute the total casualty expectation



= Total casualty expectation

The calculation is repeated for each discretized breakup point. Depending on the failure probability methodology used, a summation or maximum value is calculated for the array of casualty expectations to compute the total casualty expectation.

Model Validation

Validating Models

- Two model validations are completed
- The first validates the calculation of casualty expectation based on inputs from the CAIB investigation report
- The second validates survivability tables using an Aerospace higher fidelity survivability model called AHaB (Atmospheric Heating and Breakup tool)

Two validations are done. One is done to determine the validity of the casualty expectation calculation; the other is done to establish the validity of the survivability analysis in the tables.

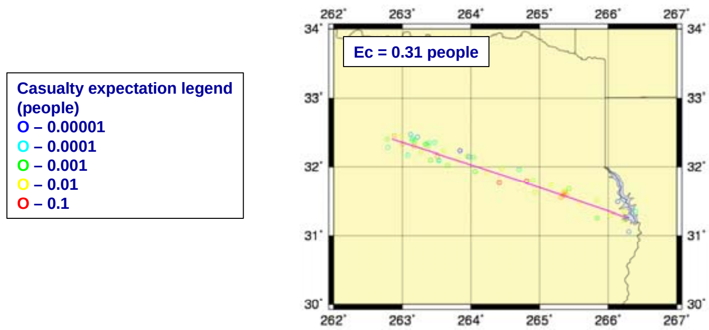
CAIB Report

- NOTE: The following input data represents only one of many cases in the CAIB Report
- Inputs are taken from Volume II Appendix D.16 Determination of Debris Risk to the Public Due to the Columbia Breakup During Reentry
- The following data is taken from the report
  - This data is used as inputs for comparison
  - The data is not always exact because in some cases it was approximated from graphical representations
- Casualty expectation
  - 0.14 people
  - Volume II Appendix D.16 page 476
- Casualty area
  - 191760 ft^2
  - Volume II Appendix D.16 page 489
- Longitude and latitude of low ballistic coefficient (uprange) impacts
  - 262.85°E, 32.4°N
  - Volume II Appendix D.16 page 477
- Longitude and latitude of high ballistic coefficient (downrange) impacts
  - 266.30°E, 31.25°N
  - Volume II Appendix D.16 page 477
- Crossrange standard deviation
  - 1.7 nmi
  - Volume II Appendix D.16 page 487

The inputs displayed here are culled from the *Columbia* Accident Investigation Board Report.

Aerospace Results

- Aerospace E_c results are twice that of Columbia Accident Investigation Board (CAIB) report
  - This is a good agreement considering model differences
  - CAIB reports E_c of 0.14 people
  - Aerospace results show E_c of 0.31 people
- Differences are due to the Aerospace model being a simpler model
  - Different population data
  - Different impact probability density function
    - Aerospace model uses a simplified uniform downrange distribution and crossrange distribution
    - CAIB report uses a more accurate probability density function



The comparison of the results shows Aerospace results that are over twice the CAIB results. This is due to the CAIB performing a more detailed analysis.

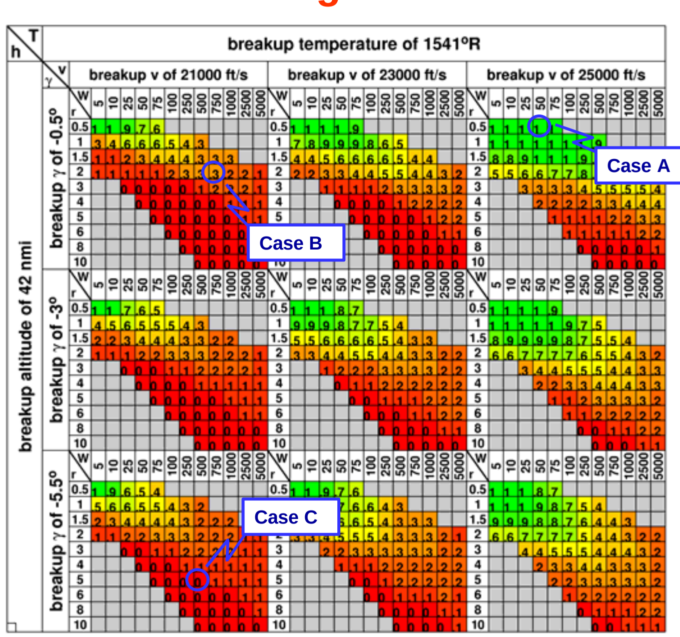
Comparing Survivability Tables for Tumbling Hollow Sphere to AHaB

- A comparison is made of 3 selected hollow sphere results
- The initial conditions for the 3 cases are shown below
- The survivability table associated with these three cases is shown on the next slide
- The survivability table results are compared to AHaB results
  - AHaB: Atmospheric Heating and Breakup tool
  - Developed and applied by Dr. Michael A. Weaver at The Aerospace Corporation
  - AHaB is a higher-fidelity model than that used for the survivability tables

Case	Breakup altitude (nmi)	Breakup Earth relative velocity (ft/s)	Breakup Earth relative geocentric flight path angle (deg)	Breakup Earth relative geocentric flight azimuth (deg)	Breakup geodetic latitude (°N)	Breakup longitude (°E)	Breakup initial temperature (°R)	Material	weight (lb)	radius (ft)
A	42	25000	-0.5	90	0	0	1541	Aluminum	50	0.5
B	42	21000	-0.5	90	0	0	1541	Aluminum	750	2
C	42	21000	-5.5	90	0	0	1541	Aluminum	500	5

Three cases are analyzed to determine the survivability of debris. The initialization state for these three cases is shown in this chart. The results from the survivability tables will be compared to a higher fidelity survivability tool called AHaB.

Survivability Table Showing Cases A through C



The survivability table containing the three examples introduced on the previous chart is shown in this chart.

Comparing Survivability Tables and AHaB

- **A comparison of the options and results of the two tools is shown below**
  - **Some of the default input values are changed in AHaB to provide a direct comparison with the survivability tables (see notes)**
- **A good match is obtained for the final liquid fraction for each of the 3 cases**
- **Plots of liquid fraction as a function of time are shown on the next few charts**

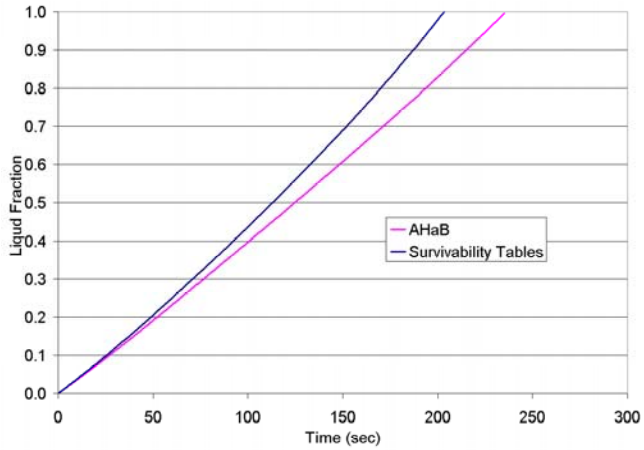
	AHaB	Survivability Tables
Change heating radius and wetted area with melting	Yes	No
Change ballistic coefficient with melting	No[1]	No
Surface emmisivity	1.00[2]	1.00
Area averaging factor for stagnation heating equation (continuum)	0.12[3]	0.12
Stagnation heating equation	Detra-Kemp-Riddell	Detra-Kemp-Riddell
Wall temperature gradient	Yes	No (treats debris as lump mass)
Atmosphere	US Standard 1976	US Standard 1963
Liquid fraction for Case A	1.00	1.00
Liquid fraction for Case B	0.27	0.27
Liquid fraction for Case C	0.04	0.04

[1] Ballistic coefficient can be changed as a function of changing radius and mass in AHaB
[2] For aluminum, AHaB is typically run with an emissivity value of 0.33
[3] For a sphere, AHaB is typically run with a hypersonic continuum area-averaging factor of 0.11

This chart compares options and results for AHaB and the survivability table tools. AHaB is considered a higher fidelity tool because of its ability to track the temperature of the debris along the wall thickness and its ability to track the debris properties as a function of the percentage of debris that has melted. Even though these differences exist, a good match is still obtained for the liquid fraction for the three cases.

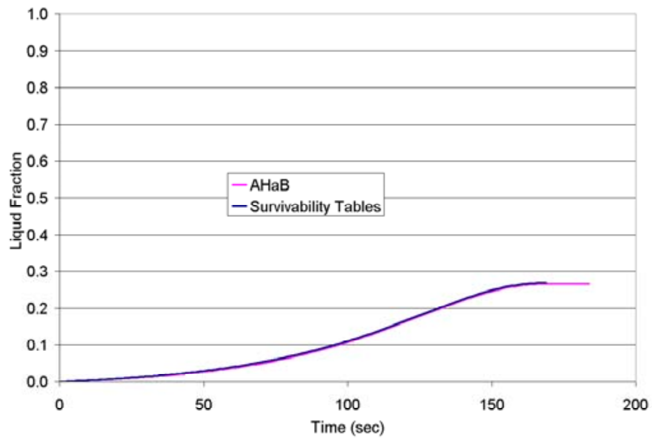
Case A
Liquid Fraction Comparison

- Comparison of liquid fraction shows similar results
- Slight difference in time history of liquid fraction is due to modeling differences between AHaB and the survivability tables
- Simulation ends when debris has melted (liquid fraction of 1.0)



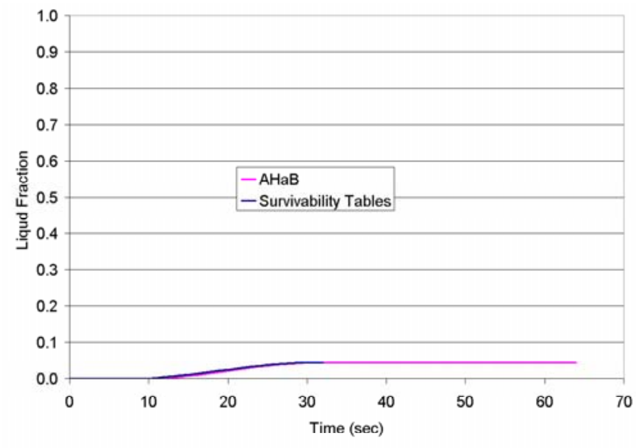
Case B
Liquid Fraction Comparison

- A good match is obtained between these results
- AHaB simulation ends at validity limit of Detra-Kemp-Riddell correlation
- Survivability tables simulation ends when debris begins cooling



Case C
Liquid Fraction Comparison

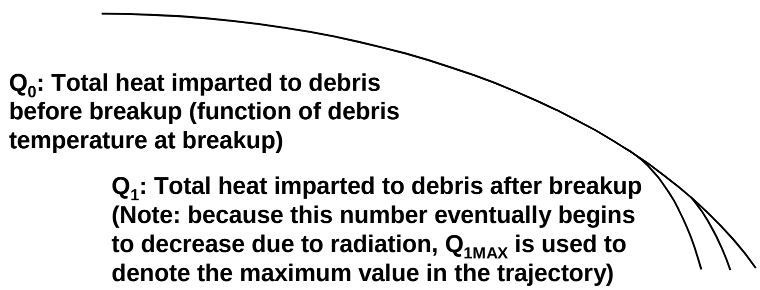
- A good match is obtained between these results
- AHaB simulation ends at Detra-Kemp-Riddell heating equations limit
- Survivability tables simulation ends when debris begins cooling



Backup

Liquid Fraction

- **Liquid fraction is a measure of fraction of debris that has ablated**
- **LF = $(Q_{TMAX} - Q_m)/(Q_a - Q_m)$**
  - **$Q_{TMAX} = Q_0 + Q_{1MAX}$**
  - **Where Q_m is the total heat required to raise a body to the melt temperature**
- **If $Q_{TMAX} > Q_a$, debris does not survive; this is represented by a liquid fraction of 1**
- **If $Q_{TMAX} < Q_a$ and $Q_T > Q_m$ debris partially survives; this is represented by a LF between 0 and 1**
- **If $Q_{TMAX} < Q_m$ debris survives; this is represented by a LF of 0**



This representation shows the heat input to a reentering body. Q_0 is the heat imparted to a particular piece of debris before breakup. Q_{1MAX} is the maximum heat imparted to the debris after breakup. A methodology for calculating Q_0, Q_{1MAX} and Q_a is outlined in the following charts. If Q_0 plus Q_{1MAX} is greater than the heat of ablation (Q_a), the debris will not survive.

Heat Content at Breakup

- **Q_0 is total heat imparted to debris piece before breakup**
  - **Function of debris piece temperature at breakup:**

$$Q_0 = m\bar{c}T_{breakup}$$

    - m – mass
    - $T_{breakup}$ – material temperature at breakup
    - $\bar{c}$ – specific heat of material

To calculate the heat imparted to a vehicle component of known material and size before breakup (Q_0), only the temperature of the component at breakup must be known. Details on how to chose this initial temperature is given in the *Survivabilty* Section.

Stagnation Heat Flux

- **Stagnation heat flux (rate) computed using Detra, Kemp, Riddel expression**
  - **Point on body at which inward heat flux is a maximum**

$$\dot{q}_s(\mathrm{Btu/ft^2/sec}) = 17{,}600\sqrt{\frac{r_h \rho_\infty}{r_{ref}\rho_{ref}}}\left(\frac{V_\infty}{V_{ref}}\right)^{3.15}\left(\frac{T_s - T_b}{T_s - T_{ref}}\right)$$

$$T_s = T_\infty + \frac{V_\infty^{\;2}}{2c_p}$$

- **Where**
  - C_p (6007.56 ft^2/sec/°R) – ideal specific heat of air
  - r_{ref} (ft) – effective radius
  - r_h (1.0 ft) – reference radius of debris
  - $\rho_?$ (slug/ft^3) – density at altitude
  - ρ_{ref} (2.3769 x 10^{-3} slug/ft^3) – reference density of air
  - T_b (°R) – material body temperature
  - T_{ref} (540 °R) – reference temperature
  - T_s (°R) – stagnation temperature
  - $T_?$ (°R) – freestream air temperature
  - V_{ref} (26,000 ft/sec) – reference velocity of vehicle
  - $V_?$ (ft/sec) – freestream air velociy

This equation treats the debris as a lump mass. There is no spatial girding of the debris. The heat rate input is seen to be a function of the trajectory state (altitude and velocity) and the reference radius. The reference radius is calculated based on the size and shape of the debris.

Net Heat Flow into a Body

- **Net heat flow**

$$\dot{Q} = (k_2 \dot{q}_s - \varepsilon \sigma T_b^4) A_w$$

- **Heat content of a body at time (t) in a trajectory (Q_{1MAX} is computed by integrating this equation along the trajectory and observing the maximum value)**

$$Q(t) = Q_0 + \int_0^t \dot{Q} dt$$

- **Body bulk temperature**

$$T_b = \begin{cases} Q/m\bar{c} & \text{for } Q < m\bar{c}T_m \\ T_m & \text{for } Q > m\bar{c}T_m \end{cases}$$

- **Where**
  - A_w – wetted area
  - $\bar{c}$ – mean specific heat of material
  - ε – surface emissivity, approaches unity after quick char build up
  - k_2 – area averaging factor
  - m – mass
  - σ – Stefan-Boltzmann constant
  - T_b – body temperature
  - T_m – melt temperature
  - Q_0 – heat content at t_0

The net heat flow into a body is shown here to be a function of the heating rate and body temperature. The body temperature is a function of the debris mass and material.
The area-averaging factor k_2 is set at 0.12 and the surface emissivity is set to 1. These values provide a good match with past reentries.

Total Heat Required to Melt a Body

- **Total heat required to melt entire body (Q_a) is heat required to raise the body to melt temperature plus heat required to melt it**

$$Q_a = m\bar{c}(T_m - T_0) + mh_f$$

- **Where**
  - $\bar{c}$ – specific heat of material
  - h_f – heat of fusion
  - m – mass
  - T_0 – initial temperature
  - T_m – melt temperature

The total heat required to melt a body is designated the heat of ablation (Q_a). This is a function of the initial temperature of the body, the melt temperature of the body, the heat of fusion for the material, and the mass of the body.

APPENDIX B
EXAMPLE

This Appendix is an example that shows the inputs and results for a winged-body reentry case.

Example

Example Calculation

- Determine casualty expectation for a winged body reentry during Temperature-control phase of flight
- Temperature-control phase is from 46 nmi to 30 nmi
- Spreadsheets are saved with the results from the example
  - reentry_casualty_expectation_example_46nmi_v2.0.xls
  - reentry_casualty_expectation_example_44nmi_v2.0.xls
  - reentry_casualty_expectation_example_42nmi_v2.0.xls
  - reentry_casualty_expectation_example_40nmi_v2.0.xls
  - reentry_casualty_expectation_example_38nmi_v2.0.xls
  - reentry_casualty_expectation_example_36nmi_v2.0.xls
  - reentry_casualty_expectation_example_34nmi_v2.0.xls
  - reentry_casualty_expectation_example_32nmi_v2.0.xls
  - reentry_casualty_expectation_example_30nmi_v2.0.xls

Discretize Trajectory

- The discretized trajectory for the Temperature-control phase portion of the flight is shown below

Time (sec)	Altitude (nmi)	Earth relative velocity (ft/s)	Geocentric Earth relative flight path angle (deg)	Geocentric Earth relative flight azimuth (deg)	Longitude (deg E)	Geodetic latitude (deg N)
5740	46	24865	-0.64	111	228.5	52.9
5790	44	24610	-0.51	115	233.5	51.5
5870	42	23838	-0.53	120	240.7	49.0
6030	40	21576	-0.54	124	252.6	43.5
6160	38	19077	-0.53	124	260.3	39.3
6260	36	16591	-0.57	121	265.3	36.5
6350	34	13863	-0.54	126	269.1	34.4
6430	32	11367	-1.02	134	271.5	32.5
6480	30	9833	-1.52	133	272.5	31.4

Assign Failure Probability and Crossrange

- Failure probability for Temperature Control phase of 0.01
- Failure probability for each breakup altitude is based on dwell time

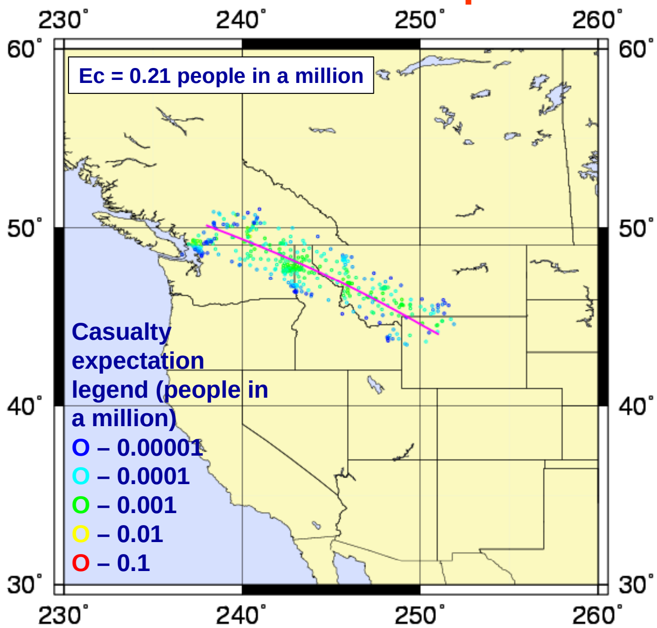
Time (sec)	Altitude (nmi)	Failure probability	Crossrange standard deviation (nmi)
5740	46	0.0005	30
5790	44	0.0006	30
5870	42	0.0010	30
6030	40	0.0021	30
6160	38	0.0017	30
6260	36	0.0013	30
6350	34	0.0012	30
6430	32	0.0010	30
6480	30	0.0006	30

Establish Debris Model

- Debris model shown is a subset of a more complete model
- Value of 1.0 is used for splatter, skid, bounce, ricochet, splattering, and cratering
- Default spreadsheet values are used for sheltering

Description	# of pieces	Shape	Material	Initial Temperature	Weight (lb)	Size
Aluminum skin	10	Flat plate	Aluminum	1541°R	100 lb	5 ft length 5 ft width
Batteries	6	Box	Mixed	540°R	125 lb	1 ft length 1 ft width 1 ft height
Instrument	4	Box	Aluminum	1541°R	50 lb	3 ft length 2 ft width 2 ft height
Aluminum tank	4	Sphere	Aluminum	540°R	300 lb	2 ft radius
Aluminum tank	1	Cylinder	Aluminum	540°R	500 lb	1 ft radius 5 ft length
Titanium tank	1	Clyinder	Titanium	540°R	250 lb	2 ft radius 5 ft length

46 nmi Breakup



Total Casualty Expectation

Breakup altitude	Total casualty expectation (people in a million)
46	0.19
44	0.20
42	0.19
40	0.35
38	3.01
36	2.10
34	1.19
32	1.24
30	1.02
Sum	9.49

APPENDIX C
TUMBLING HOLLOW SPHERE SURVIVABILITY TABLE

Table C-1 shows the survivability legend used for the tumbling hollow sphere survivability tables in Appendix C. Instructions for use of the tables are given in Section 3.

Table C-1. Legend for Survivability Tables in Appendix C

T – temperature at breakup point (°R)
h – altitude at breakup point (nmi)
v – Earth relative velocity at breakup point (ft/s)
γ – geocentric Earth relative flight path angle at breakup point (deg)
W – weight at breakup point (lb)
r – sphere outside wall radius at breakup point (ft)

Liquid fraction values

0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1

s Symbol if trajectory skips out of atmosphere (geocentric Earth relative flight path increases to greater than 0°)

Symbol if total mass is greater than mass that could fit inside the sphere

Symbol if wall thickness (assuming evenly distributed material along wall) is less than 0.01% of diameter

C.1 Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability Tables

Table C-2. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

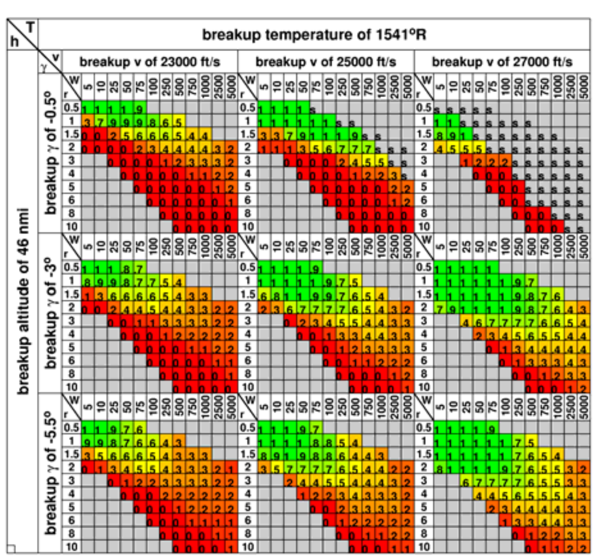


Table C-3. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

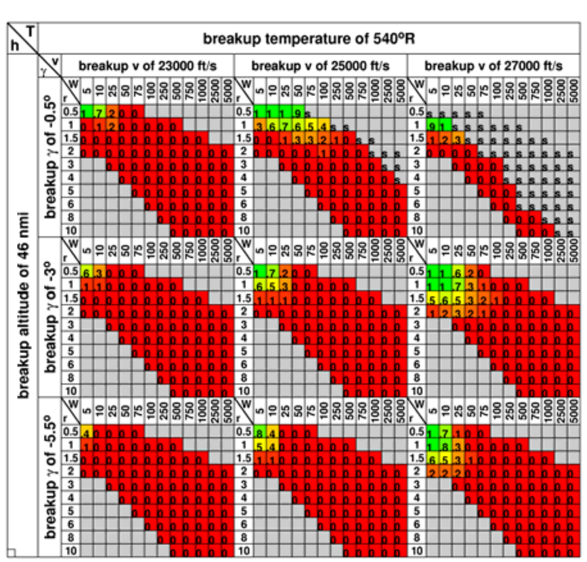


Table C-4. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

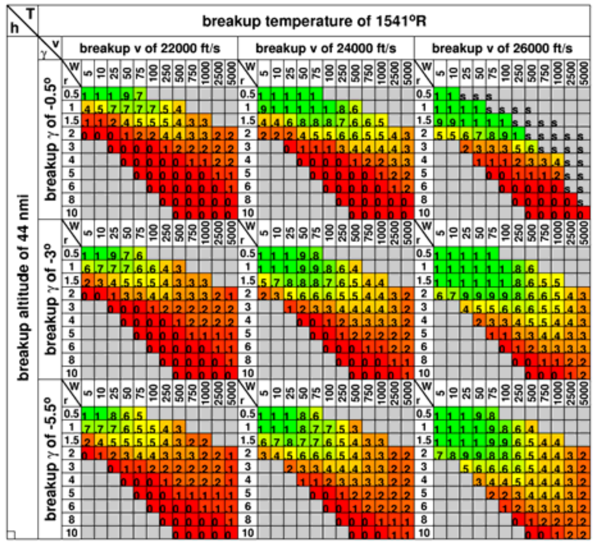


Table C-5. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

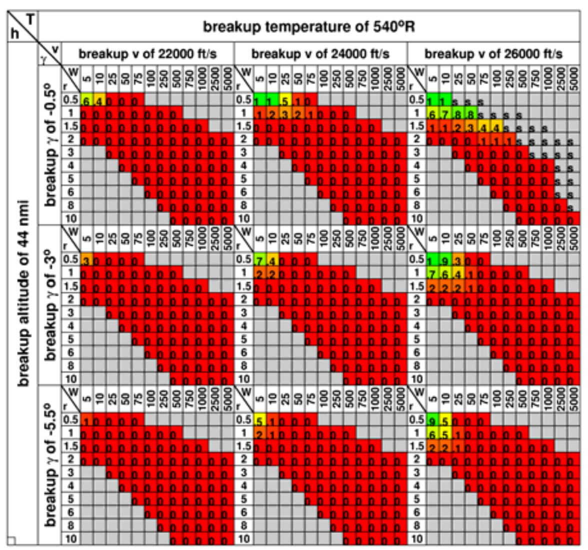


Table C-6. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

breakup altitude of 42 nmi; breakup temperature of 1541°R

breakup γ of -0.5°, breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	.9	.7	.6							
1	.3	.4	.6	.6	.6	.5	.4	.3				
1.5	.1	.1	.2	.3	.4	.4	.4	.3	.3	.3		
2	.1	.1	.1	.1	.1	.2	.3	.3	.3	.2	.2	.1
3			0	0	0	0	0	.1	.2	.2	.2	.1
4				0	0	0	0	0	0	.1	.1	.1
5					0	0	0	0	0	0	.1	.1
6						0	0	0	0	0	0	.1
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5°, breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	1	1	.9							
1	.7	.8	.9	.9	.9	.8	.6	.5				
1.5	.4	.4	.5	.6	.6	.6	.6	.5	.4	.4		
2	.2	.2	.3	.3	.4	.4	.5	.5	.4	.4	.3	.2
3			.1	.1	.1	.1	.2	.3	.3	.3	.3	.2
4				0	0	0	0	.1	.2	.2	.2	.2
5					0	0	0	0	0	.1	.2	.2
6						0	0	0	0	0	.1	.1
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5°, breakup v of 25000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	1	1	1							
1	1	1	1	1	1	1	1	.9				
1.5	.8	.8	.9	1	1	1	.9	.8	.7	.7		
2	.5	.5	.6	.6	.7	.7	.8	.7	.7	.6	.5	s
3			.3	.3	.3	.3	.4	.5	.5	.5	.5	.4
4				.2	.2	.2	.2	.3	.3	.4	.4	.4
5					.1	.1	.1	.1	.2	.2	.3	.3
6						.1	.1	.1	.1	.1	.2	.2
8							0	0	0	0	0	.1
10								0	0	0	0	0

breakup γ of -3°, breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	.7	.6	.5							
1	.4	.5	.6	.5	.5	.5	.4	.3				
1.5	.2	.2	.3	.4	.4	.4	.3	.3	.2	.2		
2	.1	.1	.1	.2	.2	.3	.3	.3	.2	.2	.2	.1
3			0	0	0	.1	.1	.2	.2	.2	.2	.1
4				0	0	0	0	.1	.1	.1	.1	.1
5					0	0	0	0	0	.1	.1	.1
6						0	0	0	0	0	.1	.1
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3°, breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	1	.8	.7							
1	.9	.9	.9	.8	.7	.7	.5	.4				
1.5	.5	.5	.6	.6	.6	.6	.5	.4	.3	.3		
2	.3	.3	.4	.4	.5	.5	.4	.4	.3	.3	.2	.2
3			.1	.2	.2	.2	.3	.3	.3	.3	.2	.2
4				0	.1	.1	.2	.2	.2	.2	.2	.2
5					0	0	.1	.1	.1	.2	.2	.2
6						0	0	0	.1	.1	.2	.2
8							0	0	0	0	.1	.1
10								0	0	0	0	0

breakup γ of -3°, breakup v of 25000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	1	1	.9							
1	1	1	1	1	1	.9	.7	.5				
1.5	.8	.9	.9	.9	.9	.8	.7	.5	.5	.4		
2	.6	.6	.7	.7	.7	.7	.6	.5	.5	.4	.3	.2
3			.3	.4	.4	.5	.5	.5	.4	.4	.3	.3
4				.2	.2	.3	.3	.4	.4	.4	.3	.3
5					.1	.1	.2	.3	.3	.3	.3	.2
6						.1	.1	.2	.2	.2	.2	.2
8							0	0	.1	.1	.2	.2
10								0	0	0	.1	.1

breakup γ of -5.5°, breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	.9	.6	.5	.4							
1	.5	.6	.6	.5	.5	.4	.3	.2				
1.5	.2	.3	.4	.4	.4	.4	.3	.2	.2	.2		
2	.1	.1	.2	.2	.3	.3	.3	.2	.2	.2	.1	.1
3			0	0	.1	.1	.2	.2	.2	.2	.1	.1
4				0	0	0	.1	.1	.1	.1	.1	.1
5					0	0	0	0	.1	.1	.1	.1
6						0	0	0	0	0	.1	.1
8							0	0	0	0	0	.1
10								0	0	0	0	0

breakup γ of -5.5°, breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	.9	.7	.6							
1	.9	.9	.8	.7	.6	.6	.4	.3				
1.5	.5	.6	.6	.6	.6	.5	.4	.3	.3	.3		
2	.3	.3	.4	.5	.5	.5	.4	.3	.3	.3	.2	.1
3			.2	.2	.3	.3	.3	.3	.3	.3	.2	.2
4				.1	.1	.1	.2	.2	.2	.2	.2	.2
5					0	0	.1	.2	.2	.2	.2	.2
6						0	0	.1	.1	.1	.2	.1
8							0	0	0	0	.1	.1
10								0	0	0	0	.1

breakup γ of -5.5°, breakup v of 25000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	1	.8	.7							
1	1	1	1	.9	.8	.7	.5	.4				
1.5	.9	.9	.9	.8	.8	.7	.6	.4	.4	.3		
2	.6	.6	.7	.7	.7	.7	.5	.4	.4	.3	.2	.2
3			.4	.4	.5	.5	.5	.4	.4	.4	.3	.2
4				.2	.3	.3	.4	.4	.3	.3	.3	.2
5					.2	.2	.3	.3	.3	.3	.3	.2
6						.1	.2	.2	.2	.2	.2	.2
8							0	.1	.1	.1	.2	.2
10								0	0	.1	.1	.1

Table C-7. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

breakup altitude of 42 nmi; breakup temperature of 540°R

breakup γ of -0.5°, breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.2	.1	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5°, breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.7	.5	.2	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5°, breakup v of 25000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	.8	.4	.3							
1	.3	.3	.4	.3	.2	.1	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	s
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3°, breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3°, breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.4	.2	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3°, breakup v of 25000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.9	.5	.1	0	0							
1	.3	.3	.1	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5°, breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5°, breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.2	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5°, breakup v of 25000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.6	.2	0	0	0							
1	.3	.2	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

Table C-8. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

breakup altitude of 40 nmi; breakup temperature of 1541ºR

breakup γ of -0.5º — breakup v of 19000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.6	.7	.6	.5	.4							
1	.2	.2	.3	.3	.3	.3	.3	.2				
1.5	.1	.1	.1	.1	.2	.2	.2	.2	.2	.2		
2	0	0	0	0	0	0	.1	.2	.2	.2	.1	.1
3			0	0	0	0	0	0	.1	.1	.1	.1
4				0	0	0	0	0	0	0	.1	.1
5					0	0	0	0	0	0	0	.1
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5º — breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	.9	.7	.6							
1	.4	.5	.6	.6	.6	.5	.4	.3				
1.5	.2	.2	.3	.3	.4	.4	.4	.3	.3	.3		
2	.1	.1	.1	.2	.2	.2	.3	.3	.3	.3	.2	.1
3			.1	.1	.1	.1	.1	.2	.2	.2	.2	.1
4				0	0	0	0	0	.1	.1	.1	.1
5					0	0	0	0	0	0	.1	.1
6						0	0	0	0	0	0	.1
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5º — breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	1	1	.9							
1	.8	.8	.9	.9	.8	.8	.6	.5				
1.5	.5	.5	.5	.6	.6	.6	.6	.5	.4	.4		
2	.3	.3	.3	.4	.4	.4	.5	.5	.4	.4	.3	.2
3			.2	.2	.2	.2	.2	.3	.3	.3	.3	.2
4				.1	.1	.1	.1	.2	.2	.2	.2	.2
5					.1	.1	.1	.1	.1	.1	.2	.2
6						0	0	0	0	0	.1	.2
8							0	0	0	0	0	.1
10								0	0	0	0	0

breakup γ of -3º — breakup v of 19000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.6	.6	.5	.4	.4							
1	.2	.3	.3	.3	.3	.3	.2	.2				
1.5	.1	.1	.1	.2	.2	.2	.2	.2	.2	.2		
2	0	0	0	.1	.1	.1	.2	.2	.2	.1	.1	.1
3			0	0	0	0	0	.1	.1	.1	.1	.1
4				0	0	0	0	0	0	.1	.1	.1
5					0	0	0	0	0	0	0	.1
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3º — breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	.9	.7	.6	.5							
1	.5	.5	.6	.5	.5	.5	.3	.3				
1.5	.3	.3	.3	.4	.4	.4	.3	.3	.2	.2		
2	.1	.2	.2	.2	.3	.3	.3	.3	.2	.2	.2	.1
3			.1	.1	.1	.1	.2	.2	.2	.2	.2	.1
4				0	0	0	.1	.1	.1	.1	.1	.1
5					0	0	0	0	.1	.1	.1	.1
6						0	0	0	0	0	.1	.1
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3º — breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	1	.8	.7							
1	.8	.9	.8	.8	.7	.6	.5	.4				
1.5	.5	.5	.6	.6	.6	.6	.5	.4	.3	.3		
2	.3	.4	.4	.4	.5	.5	.4	.4	.3	.3	.2	.2
3			.2	.2	.2	.3	.3	.3	.3	.3	.2	.2
4				.1	.1	.1	.2	.2	.2	.2	.2	.2
5					.1	.1	.1	.1	.2	.2	.2	.2
6						0	.1	.1	.1	.1	.2	.2
8							0	0	0	0	.1	.1
10								0	0	0	0	.1

breakup γ of -5.5º — breakup v of 19000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.6	.6	.5	.4	.3							
1	.2	.3	.3	.3	.3	.3	.2	.2				
1.5	.1	.1	.2	.2	.2	.2	.2	.2	.1	.1		
2	0	0	.1	.1	.1	.1	.2	.2	.1	.1	.1	.1
3			0	0	0	0	.1	.1	.1	.1	.1	.1
4				0	0	0	0	0	.1	.1	.1	.1
5					0	0	0	0	0	0	.1	.1
6						0	0	0	0	0	0	.1
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5º — breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.9	.8	.6	.5	.4							
1	.5	.5	.5	.5	.4	.4	.3	.2				
1.5	.3	.3	.4	.4	.4	.4	.3	.2	.2	.2		
2	.2	.2	.2	.3	.3	.3	.3	.2	.2	.2	.1	.1
3			.1	.1	.1	.1	.2	.2	.2	.2	.1	.1
4				0	0	0	.1	.1	.1	.1	.1	.1
5					0	0	0	.1	.1	.1	.1	.1
6						0	0	0	0	.1	.1	.1
8							0	0	0	0	0	.1
10								0	0	0	0	0

breakup γ of -5.5º — breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	1	1	.8	.6	.5							
1	.9	.8	.8	.7	.6	.6	.4	.3				
1.5	.5	.6	.6	.6	.5	.5	.4	.3	.3	.2		
2	.4	.4	.4	.5	.5	.5	.4	.3	.3	.3	.2	.1
3			.2	.3	.3	.3	.3	.3	.3	.3	.2	.2
4				.1	.2	.2	.2	.2	.2	.2	.2	.2
5					.1	.1	.1	.2	.2	.2	.2	.2
6						0	.1	.1	.1	.1	.2	.1
8							0	0	0	.1	.1	.1
10								0	0	0	.1	.1

Table C-9. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

breakup altitude of 40 nmi; breakup temperature of 540ºR

breakup γ of -0.5º — breakup v of 19000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5º — breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.1	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5º — breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.5	.4	.1	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3º — breakup v of 19000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3º — breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3º — breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.3	.1	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5º — breakup v of 19000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5º — breakup v of 21000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5º — breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.1	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

Table C-10. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

Breakup altitude (h) of 38 nmi; breakup temperature (T) of 1541°R

Breakup v of 17000 ft/s

γ	r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
breakup γ of -0.5°	0.5	.3	.4	.4	.3	.3							
	1	.1	.1	.1	.2	.2	.2	.2	.1				
	1.5	0	0	0	0	0	.1	.1	.1	.1	.1		
	2	0	0	0	0	0	0	0	.1	.1	.1	.1	.1
	3			0	0	0	0	0	0	0	0	.1	.1
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -3°	0.5	.3	.4	.3	.3	.2							
	1	.1	.1	.1	.2	.2	.2	.2	.1				
	1.5	0	0	0	.1	.1	.1	.1	.1	.1	.1		
	2	0	0	0	0	0	0	.1	.1	.1	.1	.1	.1
	3			0	0	0	0	0	0	0	0	.1	.1
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -5.5°	0.5	.4	.3	.3	.2	.2							
	1	.1	.1	.2	.2	.2	.2	.1	.1				
	1.5	0	0	0	.1	.1	.1	.1	.1	.1	.1		
	2	0	0	0	0	0	0	.1	.1	.1	.1	.1	.1
	3			0	0	0	0	0	0	0	.1	.1	.1
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0

Breakup v of 19000 ft/s

γ	r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
breakup γ of -0.5°	0.5	.6	.6	.6	.5	.4							
	1	.2	.2	.3	.3	.3	.3	.3	.2				
	1.5	.1	.1	.1	.1	.2	.2	.2	.2	.2	.2		
	2	.1	.1	.1	.1	.1	.1	.1	.2	.2	.2	.1	.1
	3			0	0	0	0	0	.1	.1	.1	.1	.1
	4				0	0	0	0	0	0	0	.1	.1
	5					0	0	0	0	0	0	0	.1
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -3°	0.5	.6	.6	.5	.4	.3							
	1	.3	.3	.3	.3	.3	.3	.2	.2				
	1.5	.1	.1	.2	.2	.2	.2	.2	.2	.2	.2		
	2	.1	.1	.1	.1	.1	.1	.2	.2	.2	.1	.1	.1
	3			0	0	0	0	.1	.1	.1	.1	.1	.1
	4				0	0	0	0	0	0	.1	.1	.1
	5					0	0	0	0	0	0	.1	.1
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -5.5°	0.5	.6	.6	.4	.4	.3							
	1	.3	.3	.3	.3	.3	.3	.2	.2				
	1.5	.1	.1	.2	.2	.2	.2	.2	.2	.1	.1		
	2	.1	.1	.1	.1	.1	.2	.2	.2	.1	.1	.1	.1
	3			0	0	0	0	.1	.1	.1	.1	.1	.1
	4				0	0	0	0	.1	.1	.1	.1	.1
	5					0	0	0	0	0	0	.1	.1
	6						0	0	0	0	0	0	.1
	8							0	0	0	0	0	0
	10								0	0	0	0	0

Breakup v of 21000 ft/s

γ	r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
breakup γ of -0.5°	0.5	1	1	.8	.7	.6							
	1	.5	.5	.5	.6	.5	.5	.4	.3				
	1.5	.3	.3	.3	.3	.4	.4	.4	.3	.3	.3		
	2	.2	.2	.2	.2	.2	.2	.3	.3	.3	.3	.2	.1
	3			.1	.1	.1	.1	.1	.2	.2	.2	.2	.2
	4				.1	.1	.1	.1	.1	.1	.1	.1	.1
	5					0	0	0	0	0	0	.1	.1
	6						0	0	0	0	0	0	.1
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -3°	0.5	.9	.9	.7	.6	.5							
	1	.5	.5	.5	.5	.5	.4	.3	.3				
	1.5	.3	.3	.3	.4	.4	.4	.3	.3	.2	.2		
	2	.2	.2	.2	.2	.3	.3	.3	.3	.2	.2	.2	.1
	3			.1	.1	.1	.1	.2	.2	.2	.2	.2	.1
	4				.1	.1	.1	.1	.1	.1	.1	.1	.1
	5					0	0	0	.1	.1	.1	.1	.1
	6						0	0	0	0	0	.1	.1
	8							0	0	0	0	0	.1
	10								0	0	0	0	0
breakup γ of -5.5°	0.5	.9	.8	.6	.5	.4							
	1	.5	.5	.5	.5	.4	.4	.3	.2				
	1.5	.3	.3	.4	.4	.4	.4	.3	.2	.2	.2		
	2	.2	.2	.2	.3	.3	.3	.3	.2	.2	.2	.1	.1
	3			.1	.1	.1	.2	.2	.2	.2	.2	.1	.1
	4				.1	.1	.1	.1	.1	.1	.1	.1	.1
	5					0	0	.1	.1	.1	.1	.1	.1
	6						0	0	0	.1	.1	.1	.1
	8							0	0	0	0	0	.1
	10								0	0	0	0	0

Table C-11. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

Breakup altitude (h) of 38 nmi; breakup temperature (T) of 540°R

Breakup v of 17000 ft/s

γ	r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
breakup γ of -0.5°	0.5	0	0	0	0	0							
	1	0	0	0	0	0	0	0	0				
	1.5	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3			0	0	0	0	0	0	0	0	0	0
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -3°	0.5	0	0	0	0	0							
	1	0	0	0	0	0	0	0	0				
	1.5	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3			0	0	0	0	0	0	0	0	0	0
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -5.5°	0.5	0	0	0	0	0							
	1	0	0	0	0	0	0	0	0				
	1.5	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3			0	0	0	0	0	0	0	0	0	0
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0

Breakup v of 19000 ft/s

γ	r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
breakup γ of -0.5°	0.5	0	0	0	0	0							
	1	0	0	0	0	0	0	0	0				
	1.5	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3			0	0	0	0	0	0	0	0	0	0
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -3°	0.5	0	0	0	0	0							
	1	0	0	0	0	0	0	0	0				
	1.5	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3			0	0	0	0	0	0	0	0	0	0
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -5.5°	0.5	0	0	0	0	0							
	1	0	0	0	0	0	0	0	0				
	1.5	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3			0	0	0	0	0	0	0	0	0	0
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0

Breakup v of 21000 ft/s

γ	r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
breakup γ of -0.5°	0.5	0	0	0	0	0							
	1	0	0	0	0	0	0	0	0				
	1.5	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3			0	0	0	0	0	0	0	0	0	0
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -3°	0.5	0	0	0	0	0							
	1	0	0	0	0	0	0	0	0				
	1.5	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3			0	0	0	0	0	0	0	0	0	0
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0
breakup γ of -5.5°	0.5	0	0	0	0	0							
	1	0	0	0	0	0	0	0	0				
	1.5	0	0	0	0	0	0	0	0	0	0		
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3			0	0	0	0	0	0	0	0	0	0
	4				0	0	0	0	0	0	0	0	0
	5					0	0	0	0	0	0	0	0
	6						0	0	0	0	0	0	0
	8							0	0	0	0	0	0
	10								0	0	0	0	0

Table C-12. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

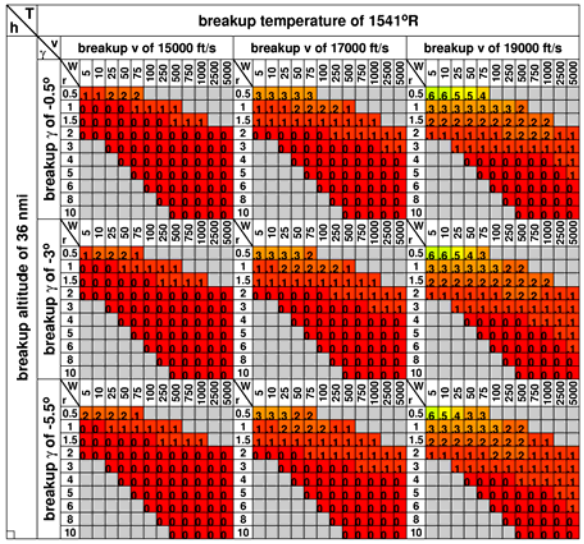


Table C-13. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

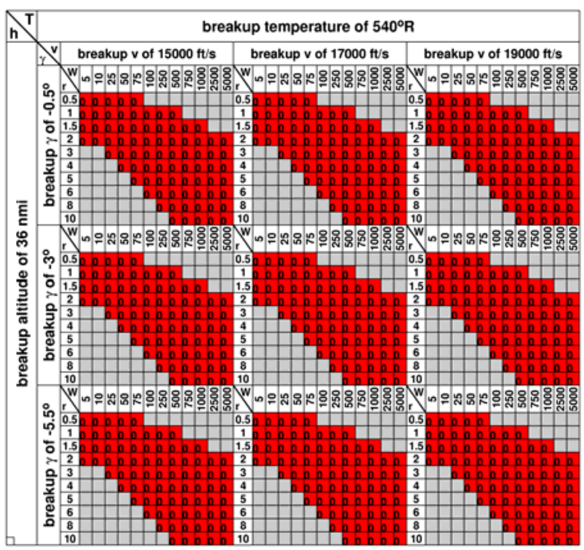


Table C-14. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

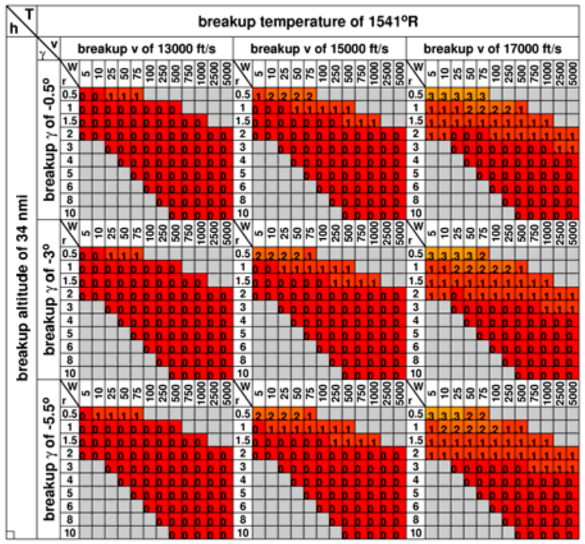


Table C-15. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

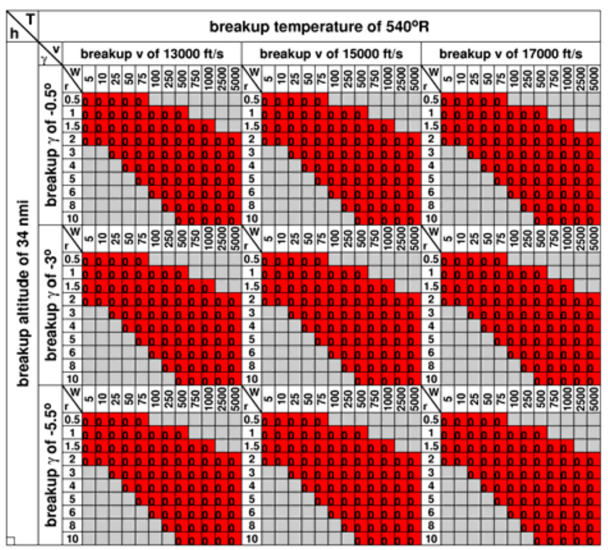


Table C-16. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

breakup temperature of 1541°R; breakup altitude of 32 nmi

breakup γ of -0.5°, breakup v of 10000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	.1							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5°, breakup v of 12000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.1	.1	.1	.1	.1							
1	0	0	0	0	0	0	.1	.1				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5°, breakup v of 14000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.1	.1	.1	.1	.1							
1	0	0	0	0	0	0	.1	.1				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3°, breakup v of 10000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	.1	.1							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3°, breakup v of 12000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.1	.1	.1	.1	.1							
1	0	0	0	0	0	.1	.1	.1				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3°, breakup v of 14000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.1	.1	.1	.1	.1							
1	0	0	0	0	0	.1	.1	.1				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5°, breakup v of 10000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	.1	.1							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5°, breakup v of 12000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.1	.1	.1	.1	.1							
1	0	0	0	0	.1	.1	.1	.1				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5°, breakup v of 14000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	.1	.1	.1	.1	.1							
1	0	0	0	0	.1	.1	.1	.1				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

Table C-17. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

breakup temperature of 540°R; breakup altitude of 32 nmi

breakup γ of -0.5°, breakup v of 10000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5°, breakup v of 12000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -0.5°, breakup v of 14000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3°, breakup v of 10000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3°, breakup v of 12000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -3°, breakup v of 14000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5°, breakup v of 10000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5°, breakup v of 12000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

breakup γ of -5.5°, breakup v of 14000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	0	0	0	0	0							
1	0	0	0	0	0	0	0	0				
1.5	0	0	0	0	0	0	0	0	0	0		
2	0	0	0	0	0	0	0	0	0	0	0	0
3			0	0	0	0	0	0	0	0	0	0
4				0	0	0	0	0	0	0	0	0
5					0	0	0	0	0	0	0	0
6						0	0	0	0	0	0	0
8							0	0	0	0	0	0
10								0	0	0	0	0

Table C-18. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability

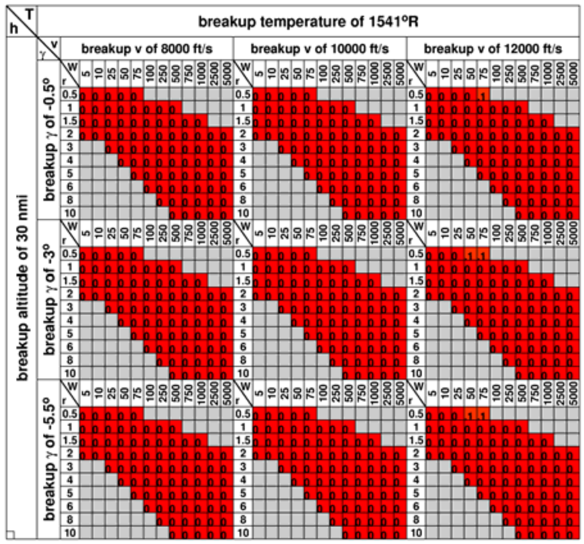
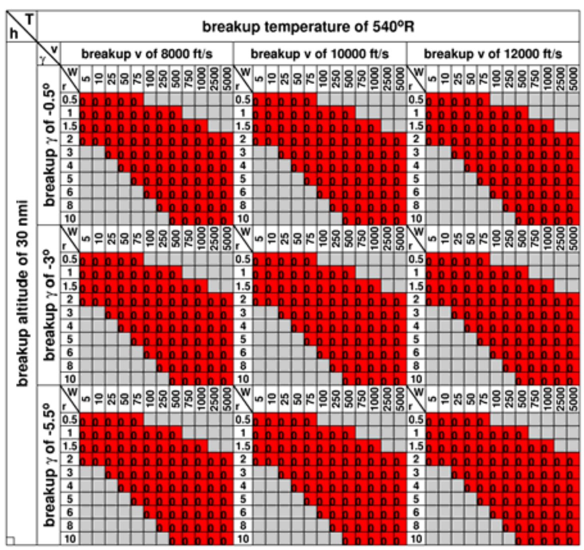


Table C-19. Aluminum 2024-T8xx Tumbling Hollow Sphere Survivability



C.2 Stainless Steel 21-6-9 Tumbling Hollow Sphere Survivability Table

Table C-20. Stainless Steel 21-6-9 Tumbling Hollow Sphere Survivability

breakup altitude (h) of 46 nmi; breakup temperature (T) of 1541°R

breakup v of 23000 ft/s

breakup γ	r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
-0.5°	0.5	D	D	D	D	D	D	D					
	1	D	D	D	D	D	D	D	D	D	D		
	1.5	D	D	D	D	D	D	D	D	D	D	D	D
	2		D	D	D	D	D	D	D	D	D	D	D
	3				D	D	D	D	D	D	D	D	D
	4						D	D	D	D	D	D	D
	5							D	D	D	D	D	D
	6								D	D	D	D	D
	8									D	D	D	D
	10											D	D
-3°	0.5	D	D	D	D	D	D	D					
	1	D	D	D	D	D	D	D	D	D	D		
	1.5	D	D	D	D	D	D	D	D	D	D	D	D
	2		D	D	D	D	D	D	D	D	D	D	D
	3				D	D	D	D	D	D	D	D	D
	4						D	D	D	D	D	D	D
	5							D	D	D	D	D	D
	6								D	D	D	D	D
	8									D	D	D	D
	10											D	D
-5.5°	0.5	D	D	D	D	D	D	D					
	1	D	D	D	D	D	D	D	D	D	D		
	1.5	D	D	D	D	D	D	D	D	D	D	D	D
	2		D	D	D	D	D	D	D	D	D	D	D
	3				D	D	D	D	D	D	D	D	D
	4						D	D	D	D	D	D	D
	5							D	D	D	D	D	D
	6								D	D	D	D	D
	8									D	D	D	D
	10											D	D

breakup v of 25000 ft/s

breakup γ	r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
-0.5°	0.5	D	D	D	D	s	s	s					
	1	D	D	D	D	D	D	s	s	s	s		
	1.5	D	D	D	D	D	D	D	D	s	s	s	s
	2		D	D	D	D	D	D	D	D	s	s	s
	3				D	D	D	D	D	D	D	s	s
	4						D	D	D	D	D	D	s
	5							D	D	D	D	D	D
	6								D	D	D	D	D
	8									D	D	D	D
	10											D	D
-3°	0.5	D	D	D	D	D	D	D					
	1	D	D	D	D	D	D	D	D	D	D		
	1.5	D	D	D	D	D	D	D	D	D	D	D	D
	2		D	D	D	D	D	D	D	D	D	D	D
	3				D	D	D	D	D	D	D	D	D
	4						D	D	D	D	D	D	D
	5							D	D	D	D	D	D
	6								D	D	D	D	D
	8									D	D	D	D
	10											D	D
-5.5°	0.5	D	D	D	D	D	D	D					
	1	D	D	D	D	D	D	D	D	D	D		
	1.5	D	D	D	D	D	D	D	D	D	D	D	D
	2		D	D	D	D	D	D	D	D	D	D	D
	3				D	D	D	D	D	D	D	D	D
	4						D	D	D	D	D	D	D
	5							D	D	D	D	D	D
	6								D	D	D	D	D
	8									D	D	D	D
	10											D	D

breakup v of 27000 ft/s

breakup γ	r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
-0.5°	0.5	s	s	s	s	s	s	s					
	1	D	D	s	s	s	s	s	s	s	s		
	1.5	D	D	D	s	s	s	s	s	s	s	s	s
	2		D	D	D	s	s	s	s	s	s	s	s
	3				D	D	D	s	s	s	s	s	s
	4						D	s	s	s	s	s	s
	5							D	s	s	s	s	s
	6								s	s	s	s	s
	8									D	s	s	s
	10											s	s
-3°	0.5	D	D	D	D	D	D	D					
	1	D	D	D	D	D	D	D	D	D	D		
	1.5	D	D	D	D	D	D	D	D	D	D	D	D
	2		D	D	D	D	D	D	D	D	D	D	D
	3				D	D	D	D	D	D	D	D	D
	4						D	D	D	D	D	D	D
	5							D	D	D	D	D	D
	6								D	D	D	D	D
	8									D	D	D	D
	10											D	D
-5.5°	0.5	D	D	D	D	D	D	D					
	1	D	D	D	D	D	D	D	D	D	D		
	1.5	D	D	D	D	D	D	D	D	D	D	D	D
	2		D	D	D	D	D	D	D	D	D	D	D
	3				D	D	D	D	D	D	D	D	D
	4						D	D	D	D	D	D	D
	5							D	D	D	D	D	D
	6								D	D	D	D	D
	8									D	D	D	D
	10											D	D

C.3 Titanium (6 Al-4 V) Tumbling Hollow Sphere Survivability Tables

Table C-21. Titanium (6 Al-4 V) Tumbling Hollow Sphere Survivability

breakup altitude of 46 nmi (h); breakup temperature of 1541°R (T)

breakup γ of -0.5° — breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	p	p	p	p	p	p						
1	p	p	p	p	p	p	p	p	p	p		
1.5	p	p	p	p	p	p	p	p	p	p	p	
2		p	p	p	p	p	p	p	p	p	p	p
3			p	p	p	p	p	p	p	p	p	p
4				p	p	p	p	p	p	p	p	p
5						p	p	p	p	p	p	p
6							p	p	p	p	p	p
8								p	p	p	p	p
10									p	p	p	p

breakup γ of -0.5° — breakup v of 25000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	p	p	p	p	s	s						
1	p	p	p	p	p	p	s	s	s	s		
1.5	p	p	p	p	p	p	p	p	s	s	s	
2		p	p	p	p	p	p	p	p	s	s	s
3			p	p	p	p	p	p	p	p	s	s
4				p	p	p	p	p	p	p	p	s
5						p	p	p	p	p	p	p
6							p	p	p	p	p	p
8								p	p	p	p	p
10									p	p	p	p

breakup γ of -0.5° — breakup v of 27000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	s	s	s	s	s	s						
1	p	p	s	s	s	s	s	s	s	s		
1.5	p	p	p	s	s	s	s	s	s	s	s	
2		p	p	p	s	s	s	s	s	s	s	s
3			p	p	p	p	s	s	s	s	s	s
4				p	p	p	s	s	s	s	s	s
5						p	p	s	s	s	s	s
6							p	s	s	s	s	s
8								p	p	s	s	s
10									p	p	s	s

breakup γ of -3° — breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	p	p	p	p	p	p						
1	p	p	p	p	p	p	p	p	p	p		
1.5	p	p	p	p	p	p	p	p	p	p	p	
2		p	p	p	p	p	p	p	p	p	p	p
3			p	p	p	p	p	p	p	p	p	p
4				p	p	p	p	p	p	p	p	p
5						p	p	p	p	p	p	p
6							p	p	p	p	p	p
8								p	p	p	p	p
10									p	p	p	p

breakup γ of -3° — breakup v of 25000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	p	p	p	p	p	p						
1	p	p	p	p	p	p	p	p	p	p		
1.5	p	p	p	p	p	p	p	p	p	p	p	
2		p	p	p	p	p	p	p	p	p	p	p
3			p	p	p	p	p	p	p	p	p	p
4				p	p	p	p	p	p	p	p	p
5						p	p	p	p	p	p	p
6							p	p	p	p	p	p
8								p	p	p	p	p
10									p	p	p	p

breakup γ of -3° — breakup v of 27000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	p	p	p	p	p	p						
1	p	p	p	p	p	p	p	p	p	p		
1.5	p	p	p	p	p	p	p	p	p	p	p	
2		p	p	p	p	p	p	p	p	p	p	p
3			p	p	p	p	p	p	p	p	p	p
4				p	p	p	p	p	p	p	p	p
5						p	p	p	p	p	p	p
6							p	p	p	p	p	p
8								p	p	p	p	p
10									p	p	p	p

breakup γ of -5.5° — breakup v of 23000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	p	p	p	p	p	p						
1	p	p	p	p	p	p	p	p	p	p		
1.5	p	p	p	p	p	p	p	p	p	p	p	
2		p	p	p	p	p	p	p	p	p	p	p
3			p	p	p	p	p	p	p	p	p	p
4				p	p	p	p	p	p	p	p	p
5						p	p	p	p	p	p	p
6							p	p	p	p	p	p
8								p	p	p	p	p
10									p	p	p	p

breakup γ of -5.5° — breakup v of 25000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	p	p	p	p	p	p						
1	p	p	p	p	p	p	p	p	p	p		
1.5	p	p	p	p	p	p	p	p	p	p	p	
2		p	p	p	p	p	p	p	p	p	p	p
3			p	p	p	p	p	p	p	p	p	p
4				p	p	p	p	p	p	p	p	p
5						p	p	p	p	p	p	p
6							p	p	p	p	p	p
8								p	p	p	p	p
10									p	p	p	p

breakup γ of -5.5° — breakup v of 27000 ft/s

r \ W	5	10	25	50	75	100	250	500	750	1000	2500	5000
0.5	p	p	p	p	p	p						
1	p	p	p	p	p	p	p	p	p	p		
1.5	p	p	p	p	p	p	p	p	p	p	p	
2		p	p	p	p	p	p	p	p	p	p	p
3			p	p	p	p	p	p	p	p	p	p
4				p	p	p	p	p	p	p	p	p
5						p	p	p	p	p	p	p
6							p	p	p	p	p	p
8								p	p	p	p	p
10									p	p	p	p

APPENDIX D
TUMBLING HOLLOW CYLINDER SURVIVABILITY TABLES

Table D-1 shows the survivability legend used for the tumbling hollow cylinder survivability tables in Appendix D. Instructions for use of the tables are given in Section 3.

Table D-1. Legend for Survivability Tables in Appendix D

T – debris temperature at breakup point (°R)
h – altitude at breakup point (nmi)
v – Earth relative velocity at breakup point (ft/s)
γ – geocentric Earth relative flight path angle at breakup point (deg)
W – weight at breakup point (lb)
r – cylinder radius at breakup point (ft)
l – length of cylinder at breakup point (ft)

Liquid fraction values

0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1

s Symbol if trajectory skips out of atmosphere (geocentric Earth relative flight path increases to greater than 0°)

Symbol if total mass is greater than mass that could fit inside the cylinder

Symbol if wall thickness (assuming evenly distributed material along wall) is less than 0.01% of diameter

Symbol if diameter is greater than length

Symbol if length is more than 26 times greater than diameter

D.1 Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability Tables

Table D-2. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h \ T: breakup temperature of 1541ºR; γ \ v: breakup v of 23000 ft/s; breakup altitude of 46 nmi

breakup γ of -0.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	1	1	1			
	0.5	1	1	1	1	1	
	1		.2	.2	.2	.2	
	1.5			0			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		1	1			
	0.5	1	1	1	1	1	
	1		.4	.2	.2	.2	.2
	1.5			0	0		
	2			0			
	3						
	4						
	5						
W of 25 lb	0.1			1			
	0.5	1	1	1	1	1	
	1		.8	.6	.3	.2	.2
	1.5			0	0	0	0
	2			0	0	0	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	1	1	1	1	1	
	1		1	.9	.6	.3	.2
	1.5			.2	0	0	0
	2			0	0	0	0
	3				0	0	
	4				0		
	5						
W of 75 lb	0.1						
	0.5	1	1	1	1	1	
	1		1	1	.8	.5	.3
	1.5			.4	.1	0	0
	2			0	0	0	0
	3				0	0	0
	4				0		
	5						
W of 100 lb	0.1						
	0.5	1	1	1	1	1	
	1		.9	1	.9	.7	.5
	1.5			.5	.3	0	0
	2			.1	0	0	0
	3				0	0	0
	4				0	0	
	5				0		
W of 250 lb	0.1						
	0.5		.9	1	1	1	
	1		.8	.9	.9	.9	.9
	1.5			.6	.6	.4	.2
	2			.4	.3	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 500 lb	0.1						
	0.5			.8	1	1	
	1		.6	.7	.8	.9	1
	1.5			.6	.6	.6	.5
	2			.5	.4	.3	.1
	3				.1	0	0
	4				0	0	0
	5				0	0	0
W of 750 lb	0.1						
	0.5				.9	1	
	1		.5	.6	.8	.9	.9
	1.5			.5	.6	.6	.6
	2			.5	.5	.4	.3
	3				.2	0	0
	4				0	0	0
	5				0	0	0
W of 1000 lb	0.1						
	0.5				.8	1	
	1		.5	.6	.7	.8	.9
	1.5			.5	.6	.6	.6
	2			.4	.5	.4	.4
	3				.2	.1	0
	4				.1	0	0
	5				0	0	0
W of 2500 lb	0.1						
	0.5					.7	
	1			.4	.5	.6	.7
	1.5			.4	.4	.5	.6
	2			.3	.4	.4	.5
	3				.3	.3	.2
	4				.2	.1	.1
	5				.1	0	0
W of 5000 lb	0.1						
	0.5						
	1				.4	.5	.6
	1.5			.3	.3	.4	.5
	2			.3	.3	.4	.4
	3				.3	.3	.3
	4				.2	.2	.2
	5				.2	.1	.1

breakup γ of -3º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	1	1	1			
	0.5	1	1	1	1	1	
	1		.6	.4	.3	.2	
	1.5			0			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		1	1			
	0.5	1	1	1	1	1	
	1		.8	.7	.5	.3	.2
	1.5			.1	0		
	2			0			
	3						
	4						
	5						
W of 25 lb	0.1			1			
	0.5	1	1	1	1	1	
	1		1	.9	.8	.5	.4
	1.5			.4	.2	0	0
	2			0	0	0	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	1	1	1	1	1	
	1		.9	1	.9	.8	.7
	1.5			.6	.4	.2	.1
	2			.3	.1	0	0
	3				0	0	
	4				0		
	5						
W of 75 lb	0.1						
	0.5	.8	1	1	1	1	
	1		.9	.9	.9	.9	.8
	1.5			.6	.5	.3	.2
	2			.4	.2	0	0
	3				0	0	0
	4				0		
	5						
W of 100 lb	0.1						
	0.5	.7	1	1	1	1	
	1		.8	.9	.9	.9	.9
	1.5			.6	.6	.4	.3
	2			.4	.3	.1	0
	3				0	0	0
	4				0	0	
	5				0		
W of 250 lb	0.1						
	0.5		.7	.9	1	1	
	1		.6	.7	.8	.9	.9
	1.5			.6	.6	.6	.6
	2			.5	.4	.4	.3
	3				.2	0	0
	4				0	0	0
	5				0	0	0
W of 500 lb	0.1						
	0.5			.6	.8	1	
	1		.5	.6	.7	.8	.9
	1.5			.5	.6	.6	.6
	2			.4	.5	.5	.4
	3				.3	.2	.1
	4				.1	0	0
	5				0	0	0
W of 750 lb	0.1						
	0.5				.7	.9	
	1		.4	.5	.6	.7	.8
	1.5			.5	.5	.6	.6
	2			.4	.5	.5	.5
	3				.3	.2	.2
	4				.2	.1	0
	5				.1	0	0
W of 1000 lb	0.1						
	0.5				.6	.8	
	1		.4	.4	.6	.7	.8
	1.5			.4	.5	.6	.6
	2			.4	.4	.5	.5
	3				.3	.3	.2
	4				.2	.1	.1
	5				.1	0	0
W of 2500 lb	0.1						
	0.5					.6	
	1			.3	.4	.5	.6
	1.5			.3	.4	.5	.5
	2			.3	.3	.4	.4
	3				.3	.3	.3
	4				.2	.2	.2
	5				.2	.1	.1
W of 5000 lb	0.1						
	0.5						
	1				.3	.4	.4
	1.5			.2	.3	.4	.4
	2			.2	.3	.3	.4
	3				.2	.3	.3
	4				.2	.2	.2
	5				.2	.2	.2

breakup γ of -5.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	1	1	1			
	0.5	1	1	1	1	1	
	1		.8	.6	.4	.3	
	1.5			.1			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		1	1			
	0.5	1	1	1	1	1	
	1		.9	.8	.7	.4	.3
	1.5			.3	.1		
	2			0			
	3						
	4						
	5						
W of 25 lb	0.1			1			
	0.5	1	1	1	1	1	
	1		.9	.9	.9	.7	.6
	1.5			.5	.4	.2	.1
	2			.2	.1	0	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	.8	1	1	1	1	
	1		.8	.9	.9	.9	.8
	1.5			.6	.5	.4	.3
	2			.4	.3	.1	0
	3				0	0	
	4				0		
	5						
W of 75 lb	0.1						
	0.5	.7	.9	1	1	1	
	1		.8	.9	.9	.9	.9
	1.5			.6	.6	.5	.4
	2			.4	.3	.2	.1
	3				0	0	0
	4				0		
	5						
W of 100 lb	0.1						
	0.5	.6	.8	1	1	1	
	1		.7	.8	.9	.9	.9
	1.5			.6	.6	.6	.5
	2			.5	.4	.3	.2
	3				.1	0	0
	4				0	0	
	5				0		
W of 250 lb	0.1						
	0.5		.5	.7	.9	1	
	1		.5	.6	.7	.9	.9
	1.5			.5	.6	.6	.6
	2			.5	.5	.4	.4
	3				.3	.2	.1
	4				.1	0	0
	5				0	0	0
W of 500 lb	0.1						
	0.5			.5	.7	.9	
	1		.4	.5	.6	.7	.8
	1.5			.4	.5	.6	.6
	2			.4	.4	.5	.5
	3				.3	.3	.2
	4				.2	.1	0
	5				.1	0	0
W of 750 lb	0.1						
	0.5				.6	.8	
	1		.3	.4	.5	.6	.7
	1.5			.4	.5	.5	.6
	2			.4	.4	.5	.5
	3				.3	.3	.3
	4				.2	.2	.1
	5				.1	.1	0
W of 1000 lb	0.1						
	0.5				.5	.7	
	1		.3	.4	.5	.6	.7
	1.5			.4	.4	.5	.6
	2			.3	.4	.4	.5
	3				.3	.3	.3
	4				.2	.2	.2
	5				.2	.1	0
W of 2500 lb	0.1						
	0.5					.5	
	1			.2	.3	.4	.5
	1.5			.2	.3	.4	.4
	2			.2	.3	.4	.4
	3				.3	.3	.3
	4				.2	.2	.2
	5				.2	.2	.2
W of 5000 lb	0.1						
	0.5						
	1				.2	.3	.4
	1.5			.2	.2	.3	.3
	2			.2	.2	.3	.3
	3				.2	.2	.3
	4				.2	.2	.2
	5				.2	.2	.2

Table D-3. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h: breakup altitude of 46 nmi; T: breakup temperature of 1541ºR; v: breakup v of 25000 ft/s

breakup γ of -0.5º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1																					
0.5	1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		s	1	1	1	1	
1		.8	.8	.7	.7			1	.9	.8	.7	.7		1	1	1	.8	.8		1	1	1	1	.9		1	1	1	1	1		1	1	1	1	1
1.5			.3						.3	.3					.4	.3	.3	.3			.7	.4	.3	.3			.8	.6	.4	.3			.9	.7	.4	.4
2									.1						.1	.1	.1				.2	.1	.1	.1			.3	.1	.1	.1			.4	.2	.1	.1
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		s	1	1	1				s	1	1					s	1					s	1						s							
1		1	1	1	1	1		s	1	1	1	1		s	s	1	1	1		s	s	1	1	1			s	s	s	1				s	s	s
1.5			1	1	.8	.7			1	1	1	.9			.9	1	1	1			.9	1	1	1			s	s	.9	1			s	s	s	.9
2			.7	.6	.3	.2			.8	.7	.6	.4			.8	.8	.7	.6			.7	.8	.7	.7			s	.7	.7	.8			s	s	s	.7
3				0	0	0				.2	0	0				.4	.2	0				.4	.3	.1				.5	.5	.4				s	.5	.5
4				0	0	0				0	0	0				0	0	0				.1	0	0				.3	.2	.1				.3	.3	.3
5				0	0	0				0	0	0				0	0	0				0	0	0				.2	0	0				.2	.2	.1

breakup γ of -3º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1																					
0.5	1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1	
1		1	1	1	.8			1	1	1	1	.9		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1
1.5			.4						.6	.4					.9	.7	.5	.4			1	.9	.7	.6			1	1	.9	.7			1	1	.9	.8
2									.2						.5	.3	.2				.7	.5	.3	.2			.7	.6	.4	.3			.7	.7	.5	.4
3																						0	0					.1	0	0				.2	.1	0
4																						0						0						0	0	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		.9	1	1	1				.9	1	1					1	1					.8	1						.8							
1		.8	1	1	1	1		.7	.8	1	1	1		.6	.7	.8	1	1		.5	.6	.8	1	1			.4	.5	.7	.8				.4	.5	.6
1.5			.9	.9	1	1			.7	.8	.9	1			.6	.8	.9	.9			.6	.7	.8	.9			.4	.5	.6	.7			.3	.4	.5	.6
2			.7	.7	.7	.7			.6	.7	.7	.7			.6	.7	.7	.7			.5	.6	.7	.7			.4	.5	.6	.6			.3	.4	.5	.5
3				.4	.3	.2				.5	.4	.4				.5	.5	.4				.5	.5	.5				.4	.5	.5				.3	.4	.4
4				.2	0	0				.3	.2	.1				.4	.3	.2				.4	.3	.3				.4	.4	.4				.3	.3	.4
5				0	0	0				.2	0	0				.2	.1	.1				.3	.2	.1				.3	.3	.3				.3	.3	.3

breakup γ of -5.5º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1																					
0.5	1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		.9	1	1	1	1		.8	1	1	1	1	
1		1	1	1	1			1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		.9	1	1	1	1
1.5			.6						.8	.6					1	.9	.7	.6			1	1	.9	.8			1	1	1	.9			.9	1	1	.9
2									.4						.6	.5	.3				.7	.7	.5	.4			.8	.7	.6	.5			.7	.7	.7	.6
3																						.2	0					.3	.1	0				.4	.2	.1
4																						0						0						.1	0	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		.7	.9	1	1				.7	.9	1					.7	1					.6	.9						.6							
1		.7	.8	1	1	1		.5	.6	.8	1	1		.4	.5	.7	.9	1		.4	.5	.6	.8	.9			.3	.4	.5	.6				.3	.4	.5
1.5			.7	.8	.9	1			.6	.7	.8	.9			.5	.6	.8	.8			.5	.6	.7	.8			.3	.4	.5	.6			.2	.3	.4	.4
2			.7	.7	.7	.7			.6	.6	.7	.7			.5	.6	.7	.7			.4	.5	.6	.7			.3	.4	.5	.5			.2	.3	.4	.4
3				.5	.4	.4				.5	.5	.5				.5	.5	.5				.4	.5	.5				.4	.4	.4				.3	.3	.4
4				.3	.2	.1				.4	.3	.3				.4	.3	.3				.4	.4	.3				.3	.3	.4				.3	.3	.3
5				.1	0	0				.2	.2	.1				.3	.2	.2				.3	.3	.2				.3	.3	.3				.2	.3	.3

Table D-4. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h: breakup altitude of 46 nmi; T: breakup temperature of 1541ºR; v: breakup v of 27000 ft/s

breakup γ of -0.5º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	s	1	1					s	1																											
0.5	1	1	1	1	1		s	1	1	1	1		s	s	1	1	1		s	s	s	s	1		s	s	s	s	1		s	s	s	s	s	
1		1	1	1	1			1	1	1	1	1		s	1	1	1	1		s	s	1	1	1		s	s	s	1	1		s	s	s	s	1
1.5			.8						.8	.8					1	.9	.8	.8			1	.9	.8	.8			1	1	.9	.9			s	s	1	1
2									.4						.5	.5	.4				.6	.5	.5	.4			.6	.5	.5	.5			s	.6	.5	.5
3																						.1	.1					.1	.1	.1				.2	.1	.1
4																						0						0						0	0	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		s	s	s	s				s	s	s					s	s					s	s													
1		s	s	s	s	s		s	s	s	s	s		s	s	s	s	s		s	s	s	s	s			s	s	s	s				s	s	s
1.5			s	s	s	s			s	s	s	s			s	s	s	s			s	s	s	s			s	s	s	s			s	s	s	s
2			s	s	.6	.6			s	s	s	s			s	s	s	s			s	s	s	s			s	s	s	s			s	s	s	s
3				.2	.2	.2				s	s	.2				s	s	s				s	s	s				s	s	s				s	s	s
4				0	0	0				s	0	0				s	s	0				s	s	s				s	s	s				s	s	s
5				0	0	0				s	0	0				s	0	0				s	s	0				s	s	s				s	s	s

breakup γ of -3º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1																					
0.5	1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1	
1		1	1	1	1			1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1
1.5			1						1	1					1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
2									.7						1	.8	.7				1	1	.9	.7			1	1	1	.9			1	1	1	1
3																						.4	.3					.5	.4	.3				.6	.4	.3
4																						.1						.2						.2	.1	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		1	1	1	1				1	1	1					1	1					1	1						1							
1		1	1	1	1	1		.9	1	1	1	1		.8	.9	1	1	1		.7	.8	1	1	1			.6	.7	.9	1				.6	.7	.8
1.5			1	1	1	1			1	1	1	1			.9	1	1	1			.8	.9	1	1			.6	.7	.9	1			.4	.5	.7	.8
2			1	1	1	1			.9	1	1	1			.8	.9	1	1			.7	.8	1	1			.6	.7	.8	.9			.4	.5	.6	.7
3				.7	.7	.6				.8	.7	.7				.7	.8	.7				.7	.7	.7				.6	.7	.7				.5	.6	.6
4				.5	.3	.2				.6	.5	.4				.6	.5	.5				.6	.6	.5				.5	.5	.6				.4	.5	.5
5				.2	.1	0				.4	.3	.2				.4	.4	.3				.4	.4	.3				.4	.5	.4				.4	.4	.4

breakup γ of -5.5º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1																					
0.5	1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1	
1		1	1	1	1			1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1
1.5			1						1	1					1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
2									.9						1	1	.8				1	1	1	1			1	1	1	1			1	1	1	1
3																						.6	.4					.7	.5	.4				.7	.6	.5
4																						.2						.3						.4	.3	
5																																		.2		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		.9	1	1	1				.8	1	1					.9	1					.8	1						.7							
1		.9	1	1	1	1		.6	.8	1	1	1		.5	.7	.9	1	1		.5	.6	.8	1	1			.4	.5	.7	.8				.4	.5	.6
1.5			1	1	1	1			.8	.9	1	1			.7	.8	1	1			.6	.7	.9	1			.4	.5	.6	.7			.3	.4	.5	.6
2			.9	1	1	1			.7	.8	1	1			.6	.7	.9	1			.6	.7	.8	.9			.4	.5	.6	.7			.3	.4	.5	.5
3				.8	.7	.7				.7	.7	.7				.6	.7	.7				.6	.7	.7				.5	.5	.6				.4	.4	.5
4				.6	.5	.4				.6	.6	.5				.5	.6	.6				.5	.6	.6				.4	.5	.5				.3	.4	.4
5				.4	.3	.2				.4	.4	.3				.5	.4	.4				.4	.4	.4				.4	.4	.4				.3	.4	.4

Table D-5. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

breakup altitude h of 46 nmi; breakup temperature T of 540ºR; breakup v of 23000 ft/s

breakup γ of -0.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	1	1	1			
	0.5	1	1	.7	.4	.3	
	1		0	0	0	0	
	1.5			0			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		1	1			
	0.5	1	1	1	.7	.4	
	1		0	0	0	0	0
	1.5			0	0		
	2			0			
	3						
	4						
	5						
W of 25 lb	0.1			1			
	0.5	.5	.9	1	1	.8	
	1		.2	.1	0	0	0
	1.5			0	0	0	0
	2			0	0	0	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	.1	.5	.8	1	1	
	1		.2	.2	.1	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	
	4				0		
	5						
W of 75 lb	0.1						
	0.5	0	.3	.6	.9	1	
	1		.1	.2	.2	.1	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0		
	5						
W of 100 lb	0.1						
	0.5	0	.1	.4	.8	1	
	1		0	.2	.2	.2	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	
	5				0		
W of 250 lb	0.1						
	0.5		0	0	.3	.7	
	1		0	0	.1	.2	.2
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 500 lb	0.1						
	0.5			0	0	.3	
	1		0	0	0	.1	.2
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 750 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	.1
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 1000 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 2500 lb	0.1						
	0.5					0	
	1			0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 5000 lb	0.1						
	0.5						
	1				0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0

breakup γ of -3º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	1	1	1			
	0.5	.8	1	1	.8	.6	
	1		.1	0	0	0	
	1.5			0			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		1	1			
	0.5	.5	.8	.9	1	.9	
	1		.2	.1	0	0	0
	1.5			0	0		
	2			0			
	3						
	4						
	5						
W of 25 lb	0.1			1			
	0.5	.1	.4	.7	.9	1	
	1		.1	.2	.1	0	0
	1.5			0	0	0	0
	2			0	0	0	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	0	.1	.3	.6	.9	
	1		0	.1	.1	.1	.1
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	
	4				0		
	5						
W of 75 lb	0.1						
	0.5	0	0	.1	.5	.7	
	1		0	0	.1	.1	.1
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0		
	5						
W of 100 lb	0.1						
	0.5	0	0	0	.3	.6	
	1		0	0	0	.1	.1
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	
	5				0		
W of 250 lb	0.1						
	0.5		0	0	0	.2	
	1		0	0	0	0	.1
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 500 lb	0.1						
	0.5			0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 750 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 1000 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 2500 lb	0.1						
	0.5					0	
	1			0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 5000 lb	0.1						
	0.5						
	1				0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0

breakup γ of -5.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	1	1	1			
	0.5	.6	.8	1	1	.8	
	1		.1	.1	0	0	
	1.5			0			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		1	1			
	0.5	.3	.6	.8	.9	1	
	1		.1	.1	.1	0	0
	1.5			0	0		
	2			0			
	3						
	4						
	5						
W of 25 lb	0.1			.9			
	0.5	0	.1	.4	.7	.9	
	1		0	.1	.1	.1	.1
	1.5			0	0	0	0
	2			0	0	0	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	0	0	.1	.4	.7	
	1		0	0	.1	.1	.1
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	
	4				0		
	5						
W of 75 lb	0.1						
	0.5	0	0	0	.2	.5	
	1		0	0	0	.1	.1
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0		
	5						
W of 100 lb	0.1						
	0.5	0	0	0	.1	.4	
	1		0	0	0	0	.1
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	
	5				0		
W of 250 lb	0.1						
	0.5		0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 500 lb	0.1						
	0.5			0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 750 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 1000 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 2500 lb	0.1						
	0.5					0	
	1			0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 5000 lb	0.1						
	0.5						
	1				0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0

Table D-6. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

breakup altitude h of 46 nmi; breakup temperature T of 540ºR; breakup v of 25000 ft/s

breakup γ of -0.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	1	1	1			
	0.5	1	1	1	1	1	
	1		.2	.1	.1	.1	
	1.5			0			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		1	1			
	0.5	1	1	1	1	1	
	1		.4	.2	.1	.1	.1
	1.5			0	0		
	2			0			
	3						
	4						
	5						
W of 25 lb	0.1			1			
	0.5	1	1	1	1	1	
	1		.7	.5	.3	.2	.1
	1.5			0	0	0	0
	2			0	0	0	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	1	1	1	1	1	
	1		.8	.7	.6	.3	.2
	1.5			.1	0	0	0
	2			0	0	0	0
	3				0	0	
	4				0		
	5						
W of 75 lb	0.1						
	0.5	.9	1	1	1	1	
	1		.7	.7	.7	.5	.3
	1.5			.2	.1	0	0
	2			0	0	0	0
	3				0	0	0
	4				0		
	5						
W of 100 lb	0.1						
	0.5	s	1	1	1	1	
	1		.6	.7	.7	.6	.4
	1.5			.3	.2	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	
	5				0		
W of 250 lb	0.1						
	0.5		s	.9	1	1	
	1		.3	.5	.7	.7	.7
	1.5			.3	.3	.2	.1
	2			.1	.1	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 500 lb	0.1						
	0.5			s	.9	1	
	1		s	.3	.5	.6	.7
	1.5			.1	.2	.3	.3
	2			0	.1	.1	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 750 lb	0.1						
	0.5				s	1	
	1		s	s	.3	.5	.6
	1.5			0	.1	.3	.3
	2			0	0	.1	.1
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 1000 lb	0.1						
	0.5				s	.9	
	1		s	s	.3	.4	.6
	1.5			0	.1	.2	.3
	2			0	0	.1	.1
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 2500 lb	0.1						
	0.5					s	
	1			s	s	s	.3
	1.5			s	s	0	.1
	2			s	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 5000 lb	0.1						
	0.5						
	1				s	s	s
	1.5			s	s	s	0
	2			s	s	s	0
	3				s	0	0
	4				0	0	0
	5				0	0	0

breakup γ of -3º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	1	1	1			
	0.5	1	1	1	1	1	
	1		.6	.4	.3	.2	
	1.5			0			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		1	1			
	0.5	1	1	1	1	1	
	1		.6	.6	.5	.3	.2
	1.5			.1	0		
	2			0			
	3						
	4						
	5						
W of 25 lb	0.1			1			
	0.5	.5	.9	1	1	1	
	1		.5	.6	.6	.5	.4
	1.5			.2	.1	0	0
	2			0	0	0	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	.1	.4	.8	1	1	
	1		.2	.4	.6	.6	.6
	1.5			.2	.2	.1	.1
	2			0	0	0	0
	3				0	0	
	4				0		
	5						
W of 75 lb	0.1						
	0.5	0	.2	.6	1	1	
	1		.1	.3	.5	.6	.6
	1.5			.1	.2	.2	.1
	2			0	0	0	0
	3				0	0	0
	4				0		
	5						
W of 100 lb	0.1						
	0.5	0	0	.4	.8	1	
	1		0	.2	.4	.5	.6
	1.5			0	.1	.2	.1
	2			0	0	0	0
	3				0	0	0
	4				0	0	
	5				0		
W of 250 lb	0.1						
	0.5		0	0	.2	.6	
	1		0	0	.1	.3	.4
	1.5			0	0	.1	.1
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 500 lb	0.1						
	0.5			0	0	.2	
	1		0	0	0	0	.2
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 750 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 1000 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 2500 lb	0.1						
	0.5					0	
	1			0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 5000 lb	0.1						
	0.5						
	1				0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0

breakup γ of -5.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	1	1	1			
	0.5	1	1	1	1	1	
	1		.6	.6	.4	.3	
	1.5			0			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		1	1			
	0.5	.7	1	1	1	1	
	1		.5	.6	.6	.4	.3
	1.5			.1	.1		
	2			0			
	3						
	4						
	5						
W of 25 lb	0.1			1			
	0.5	.1	.5	.9	1	1	
	1		.3	.4	.6	.6	.5
	1.5			.2	.2	.1	0
	2			0	0	0	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	0	.1	.4	.8	1	
	1		0	.2	.4	.6	.6
	1.5			.1	.1	.2	.1
	2			0	0	0	0
	3				0	0	
	4				0		
	5						
W of 75 lb	0.1						
	0.5	0	0	.2	.6	1	
	1		0	.1	.3	.5	.5
	1.5			0	.1	.2	.2
	2			0	0	0	0
	3				0	0	0
	4				0		
	5						
W of 100 lb	0.1						
	0.5	0	0	0	.4	.8	
	1		0	0	.2	.4	.5
	1.5			0	0	.1	.2
	2			0	0	0	0
	3				0	0	0
	4				0	0	
	5				0		
W of 250 lb	0.1						
	0.5		0	0	0	.3	
	1		0	0	0	.1	.2
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 500 lb	0.1						
	0.5			0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 750 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 1000 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 2500 lb	0.1						
	0.5					0	
	1			0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 5000 lb	0.1						
	0.5						
	1				0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0

Table D-7. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

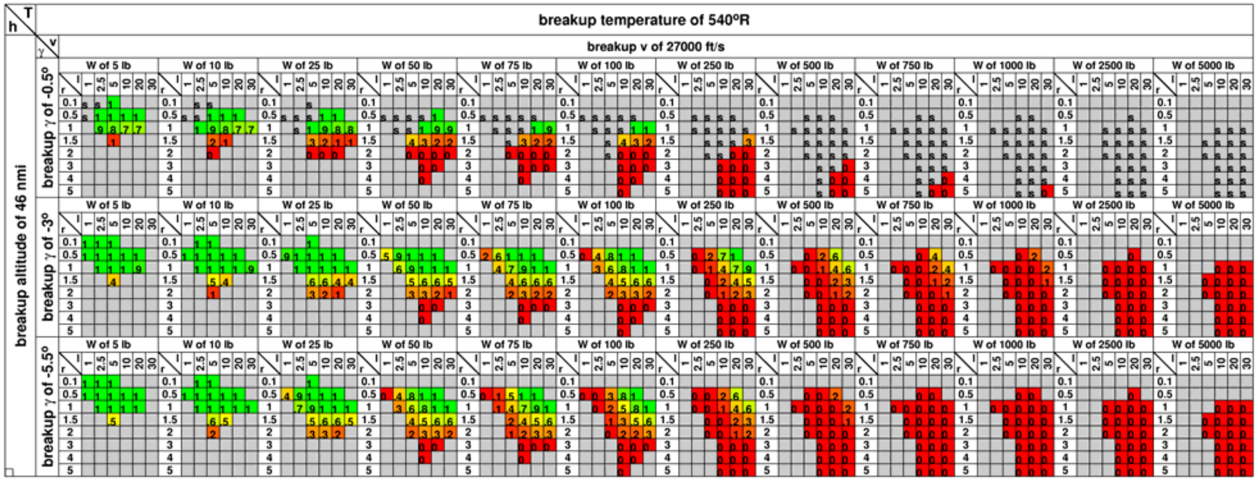


Table D-8. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

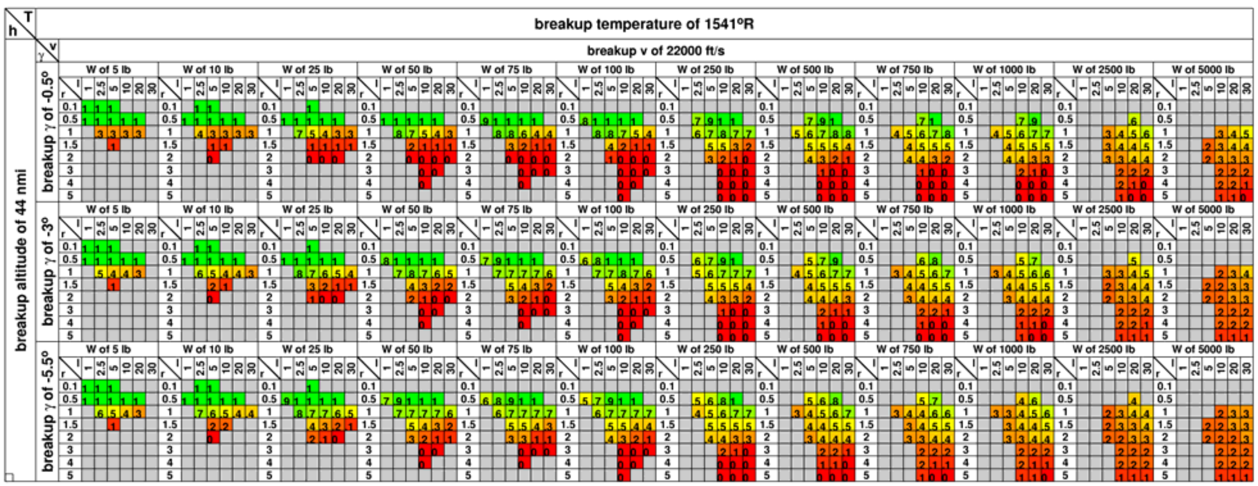


Table D-9. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h: breakup altitude of 44 nmi; T: breakup temperature of 1541°R; v: breakup v of 24000 ft/s

breakup γ of -0.5°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	1	1	1	1	1	
1		.8	.8	.8	.8	
1.5			.4			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	1	1	1	1	1	
1		.9	.9	.8	.8	.8
1.5			.4	.4		
2			.2			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	1	1	1	1	1	
1		1	1	.9	.8	.8
1.5			.5	.4	.4	.4
2			.2	.2	.2	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	1	1	1	1	1	
1		1	1	1	.9	.8
1.5			.6	.5	.4	.4
2			.3	.2	.2	.2
3				0	0	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	1	1	1	1	1	
1		1	1	1	1	.9
1.5			.7	.5	.4	.4
2			.3	.3	.2	.2
3				0	0	0
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			.8	.6	.5	.4
2			.4	.3	.2	.2
3				.1	0	0
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		1	1	1	1	
1		1	1	1	1	1
1.5			.8	.8	.7	.6
2			.6	.5	.3	.3
3				.1	.1	.1
4				0	0	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			1	1	1	
1		.8	.9	1	1	1
1.5			.8	.8	.8	.8
2			.6	.6	.5	.4
3				.3	.1	.1
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				1	1	
1		.7	.8	1	1	1
1.5			.7	.8	.8	.8
2			.6	.6	.6	.5
3				.3	.2	.1
4				.1	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				1	1	
1		.6	.7	.9	1	1
1.5			.7	.7	.8	.8
2			.6	.6	.6	.6
3				.4	.3	.2
4				.2	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					1	
1			.5	.7	.8	.9
1.5			.5	.6	.7	.8
2			.5	.5	.6	.6
3				.4	.4	.4
4				.3	.2	.2
5				.2	.1	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				.5	.6	.7
1.5			.4	.5	.6	.6
2			.4	.4	.5	.6
3				.4	.4	.4
4				.3	.3	.3
5				.2	.2	.2

breakup γ of -3°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	1	1	1	1	1	
1		1	1	.9	.8	
1.5			.5			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	1	1	1	1	1	
1		1	1	1	.9	.8
1.5			.5	.5		
2			.3			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	1	1	1	1	1	
1		1	1	1	1	.9
1.5			.7	.6	.5	.5
2			.4	.3	.2	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			.8	.7	.6	.5
2			.5	.4	.3	.3
3				.1	.1	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			.8	.8	.7	.6
2			.6	.5	.4	.3
3				.1	.1	.1
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	.9	1	1	1	1	
1		.9	1	1	1	1
1.5			.8	.8	.7	.7
2			.6	.5	.4	.4
3				.2	.1	.1
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		.8	1	1	1	
1		.7	.8	1	1	1
1.5			.7	.8	.8	.8
2			.6	.6	.6	.5
3				.3	.2	.2
4				.1	.1	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			.7	1	1	
1		.6	.7	.8	1	1
1.5			.6	.7	.8	.8
2			.5	.6	.6	.6
3				.4	.3	.3
4				.2	.2	.1
5				.1	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				.8	1	
1		.5	.6	.7	.9	1
1.5			.5	.6	.7	.8
2			.5	.6	.6	.6
3				.4	.4	.3
4				.3	.2	.2
5				.2	.1	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				.7	.9	
1		.4	.5	.7	.8	.9
1.5			.5	.6	.7	.7
2			.5	.5	.6	.6
3				.4	.4	.4
4				.3	.3	.2
5				.2	.1	.1

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					.6	
1			.4	.5	.6	.7
1.5			.3	.4	.5	.6
2			.3	.4	.5	.5
3				.4	.4	.4
4				.3	.3	.3
5				.2	.2	.2

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				.3	.4	.5
1.5			.3	.3	.4	.5
2			.3	.3	.4	.4
3				.3	.3	.4
4				.3	.3	.3
5				.2	.2	.2

breakup γ of -5.5°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	1	1	1	1	1	
1		1	1	1	.9	
1.5			.5			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	1	1	1	1	1	
1		1	1	1	1	.9
1.5			.6	.5		
2			.3			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			.8	.7	.6	.5
2			.5	.4	.3	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	.9	1	1	1	1	
1		1	1	1	1	1
1.5			.8	.8	.7	.6
2			.6	.5	.4	.3
3				.2	.1	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	.8	1	1	1	1	
1		.9	1	1	1	1
1.5			.8	.8	.8	.7
2			.6	.6	.5	.4
3				.2	.1	.1
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	.7	.9	1	1	1	
1		.8	.9	1	1	1
1.5			.8	.8	.8	.7
2			.6	.6	.5	.5
3				.3	.2	.1
4				.1	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		.6	.8	1	1	
1		.6	.7	.9	1	1
1.5			.6	.7	.8	.8
2			.6	.6	.6	.6
3				.4	.3	.3
4				.2	.1	.1
5				.1	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			.6	.8	1	
1		.4	.6	.7	.8	.9
1.5			.5	.6	.7	.7
2			.5	.5	.6	.6
3				.4	.4	.4
4				.3	.2	.2
5				.2	.1	.1

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				.6	.9	
1		.4	.5	.6	.7	.8
1.5			.4	.5	.6	.7
2			.4	.5	.6	.6
3				.4	.4	.4
4				.3	.3	.2
5				.2	.2	.1

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				.6	.8	
1		.3	.4	.5	.7	.8
1.5			.4	.5	.6	.7
2			.4	.5	.5	.6
3				.4	.4	.4
4				.3	.3	.3
5				.2	.2	.2

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					.5	
1			.3	.4	.5	.6
1.5			.3	.3	.4	.5
2			.3	.3	.4	.5
3				.3	.3	.4
4				.3	.3	.3
5				.2	.2	.2

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				.3	.4	.4
1.5			.2	.3	.3	.4
2			.2	.3	.3	.4
3				.2	.3	.3
4				.2	.3	.3
5				.2	.2	.2

Table D-10. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h: breakup altitude of 44 nmi; T: breakup temperature of 1541°R; v: breakup v of 26000 ft/s

breakup γ of -0.5°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	1	1	1	1	1	
1		1	1	1	1	
1.5			.9			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			.9	.9		
2			.5			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	s	1	1	1	1	
1		1	1	1	1	1
1.5			1	.9	.9	.8
2			.6	.6	.5	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	s	s	1	1	1	
1		1	1	1	1	1
1.5			1	1	.9	.9
2			.7	.6	.6	.5
3				.3	.2	
4				.1		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	s	s	1	1	1	
1		1	1	1	1	1
1.5			1	1	.9	.9
2			.7	.6	.6	.6
3				.3	.2	.2
4				.1		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	s	s	s	1	1	
1		1	1	1	1	1
1.5			1	1	1	.9
2			.8	.7	.6	.6
3				.3	.3	.2
4				.1	.1	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		s	s	s	1	
1		s	s	1	1	1
1.5			1	1	1	1
2			1	.9	.7	.6
3				.3	.3	.3
4				.1	.1	.1
5				.1	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		s	s	s		
1		s	s	s	1	1
1.5			s	1	1	1
2			s	1	.9	.8
3				.5	.4	.3
4				.2	.2	.1
5				.1	.1	.1

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				s	s	
1		s	s	s	s	1
1.5			s	s	1	1
2			s	1	.9	.9
3				.6	.4	.4
4				.3	.2	.2
5				.1	.1	.1

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				s	s	
1		s	s	s	s	1
1.5			s	s	1	1
2			s	s	1	.9
3				.6	.5	.4
4				.3	.2	.2
5				.1	.1	.1

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					s	
1			s	s	s	s
1.5			s	s	s	s
2			s	s	s	s
3				s	s	.6
4				s	.4	.3
5				s	.2	.1

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				s	s	s
1.5			s	s	s	s
2			s	s	s	s
3				s	s	s
4				s	s	s
5				s	s	.2

breakup γ of -3°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	1	1	1	1	1	
1		1	1	1	1	
1.5			1			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			1	1		
2			.7			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			1	1	1	1
2			.8	.7	.6	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			1	1	1	1
2			.9	.8	.7	.7
3				.4	.3	
4				.2		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			1	1	1	1
2			.9	.9	.8	.7
3				.4	.4	.3
4				.2		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			1	1	1	1
2			.9	.9	.8	.8
3				.5	.4	.3
4				.2	.2	
5				.1		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		1	1	1	1	
1		1	1	1	1	1
1.5			1	1	1	1
2			.9	.9	.9	.9
3				.6	.5	.5
4				.4	.3	.2
5				.2	.1	.1

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			1	1	1	
1		.7	.9	1	1	1
1.5			.8	.9	1	1
2			.7	.8	.9	.9
3				.6	.6	.6
4				.5	.4	.3
5				.3	.2	.2

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				1	1	
1		.6	.8	1	1	1
1.5			.7	.9	1	1
2			.7	.8	.8	.9
3				.6	.6	.6
4				.5	.4	.4
5				.3	.3	.2

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				1	1	
1		.6	.7	.9	1	1
1.5			.7	.8	.9	1
2			.6	.7	.8	.9
3				.6	.6	.6
4				.5	.5	.4
5				.4	.3	.3

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					.9	
1			.5	.6	.8	.9
1.5			.5	.6	.7	.8
2			.5	.5	.7	.7
3				.5	.5	.6
4				.4	.5	.5
5				.4	.4	.4

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				.5	.6	.7
1.5			.4	.4	.6	.6
2			.4	.4	.5	.6
3				.4	.5	.5
4				.4	.4	.4
5				.3	.4	.4

breakup γ of -5.5°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	1	1	1	1	1	
1		1	1	1	1	
1.5			1			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			1	1		
2			.8			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			1	1	1	1
2			.9	.8	.7	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			1	1	1	1
2			.9	.9	.8	.8
3				.5	.4	
4				.2		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	1	1	1	1	1	
1		1	1	1	1	1
1.5			1	1	1	1
2			.9	.9	.9	.8
3				.5	.4	.4
4				.3		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	.9	1	1	1	1	
1		1	1	1	1	1
1.5			1	1	1	1
2			.9	.9	.9	.9
3				.6	.5	.4
4				.3	.2	
5				.2		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		.8	1	1	1	
1		.8	.9	1	1	1
1.5			.8	1	1	1
2			.8	.8	.9	.9
3				.6	.6	.6
4				.4	.4	.3
5				.3	.2	.2

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			.7	1	1	
1		.6	.7	.9	1	1
1.5			.7	.8	.9	1
2			.6	.7	.8	.9
3				.6	.6	.6
4				.5	.4	.4
5				.4	.3	.3

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				.8	1	
1		.5	.6	.8	1	1
1.5			.6	.7	.8	.9
2			.6	.6	.8	.8
3				.6	.6	.6
4				.5	.5	.4
5				.4	.3	.3

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				.7	1	
1		.4	.5	.7	.9	1
1.5			.5	.6	.8	.9
2			.5	.6	.7	.8
3				.5	.6	.6
4				.4	.5	.5
5				.4	.4	.3

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					.6	
1			.3	.5	.6	.7
1.5			.4	.4	.6	.7
2			.3	.4	.5	.6
3				.4	.5	.5
4				.4	.4	.4
5				.3	.4	.4

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				.3	.4	.5
1.5			.3	.3	.4	.5
2			.3	.3	.4	.5
3				.3	.4	.4
4				.3	.4	.4
5				.3	.3	.3

Table D-11. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

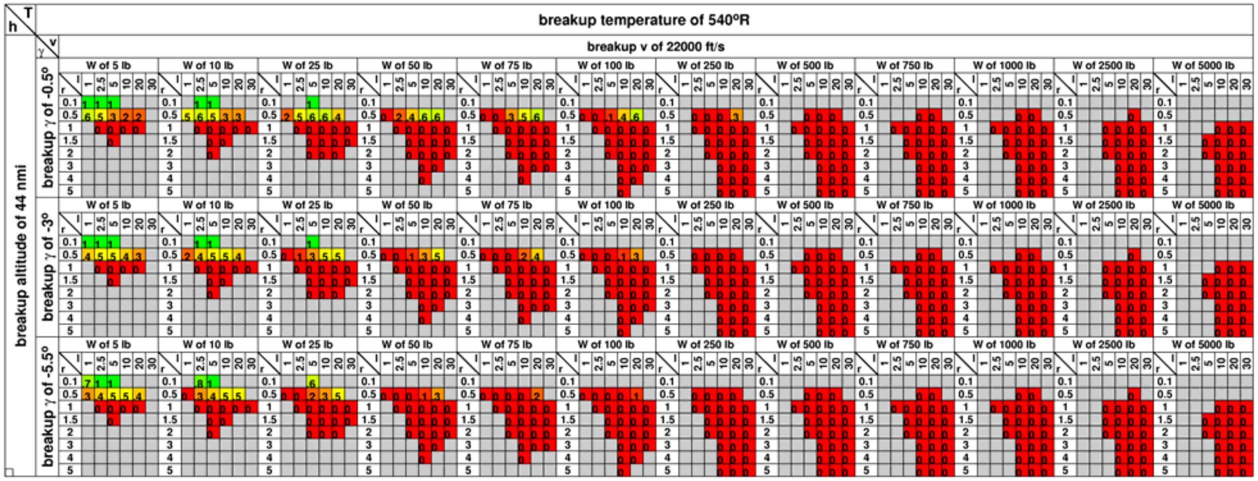


Table D-12. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

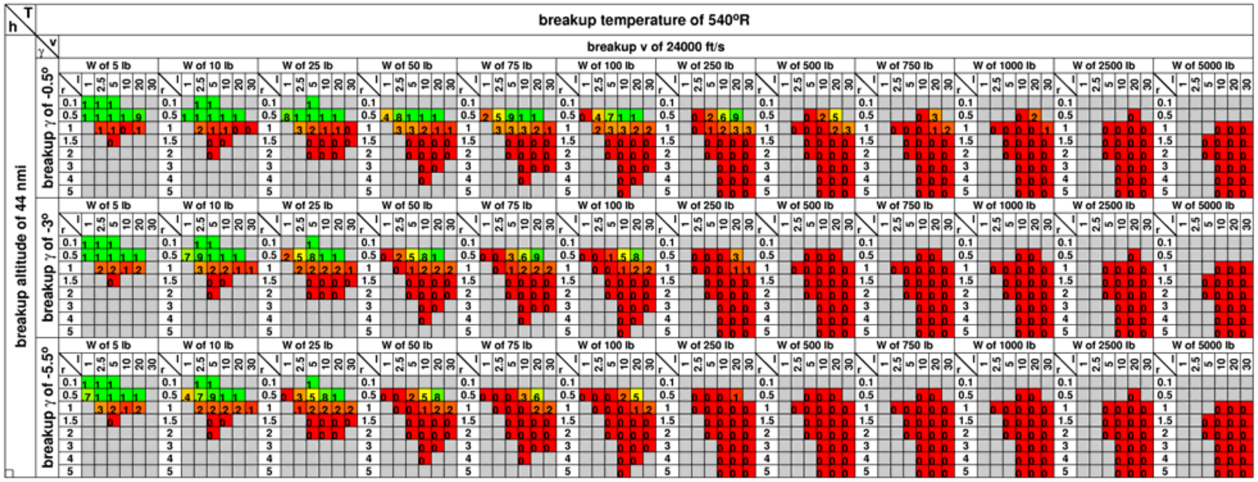


Table D-13. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

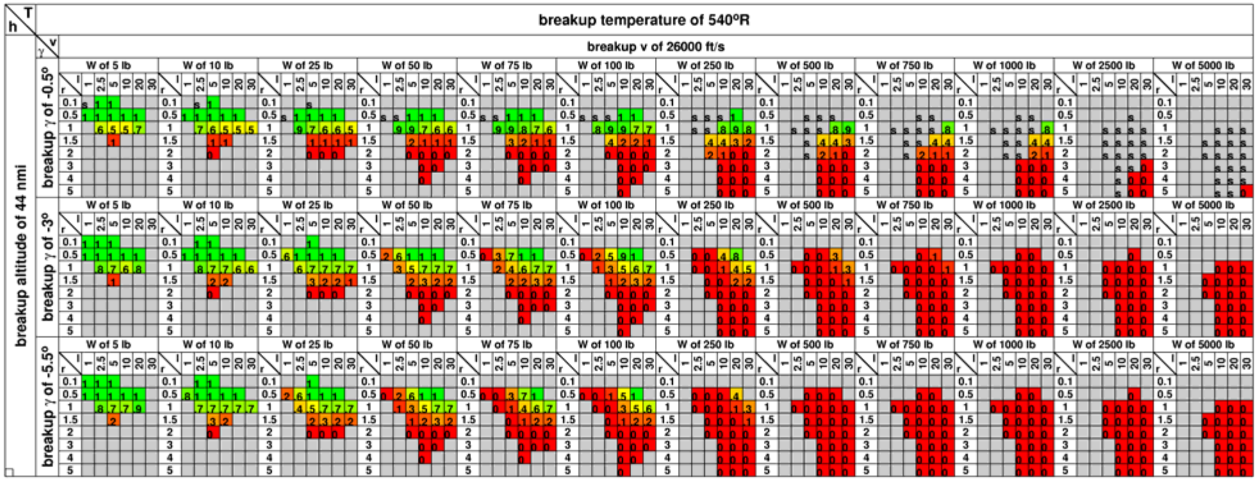


Table D-14. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

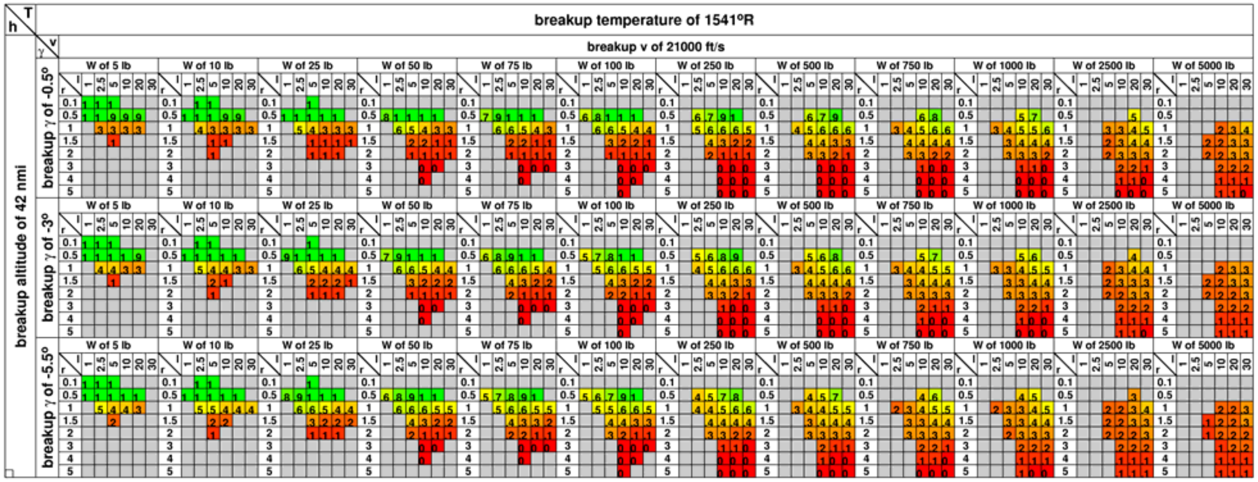


Table D-15. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

breakup altitude (h) of 42 nmi; breakup temperature (T) of 1541ºR; breakup v of 23000 ft/s

breakup γ of -0.5º

W (lb)	r \ l	1	2.5	5	10	20	30
5	0.1	1	1	1			
5	0.5	1	1	1	1	1	
5	1		.7	.7	.7	.7	
5	1.5			.4			
5	2						
5	3						
5	4						
5	5						
10	0.1		1	1			
10	0.5	1	1	1	1	1	
10	1		.8	.7	.7	.7	.7
10	1.5			.4	.4		
10	2			.2			
10	3						
10	4						
10	5						
25	0.1			1			
25	0.5	1	1	1	1	1	
25	1		.9	.8	.7	.7	.7
25	1.5			.4	.4	.4	.4
25	2			.3	.2	.2	
25	3						
25	4						
25	5						
50	0.1						
50	0.5	1	1	1	1	1	
50	1		1	.9	.8	.8	.7
50	1.5			.5	.4	.4	.4
50	2			.3	.3	.2	.2
50	3				.1	.1	
50	4				0		
50	5						
75	0.1						
75	0.5	1	1	1	1	1	
75	1		1	1	.9	.8	.7
75	1.5			.5	.5	.4	.4
75	2			.3	.3	.2	.2
75	3				.1	.1	.1
75	4				0		
75	5						
100	0.1						
100	0.5	1	1	1	1	1	
100	1		.9	1	.9	.8	.8
100	1.5			.6	.5	.4	.4
100	2			.3	.3	.3	.2
100	3				.1	.1	.1
100	4				0	0	
100	5				0		
250	0.1						
250	0.5		.9	1	1	1	
250	1		.8	.9	.9	.9	.9
250	1.5			.7	.6	.5	.5
250	2			.5	.4	.3	.3
250	3				.1	.1	.1
250	4				0	0	0
250	5				0	0	0
500	0.1						
500	0.5			.8	1	1	
500	1		.6	.7	.9	.9	1
500	1.5			.6	.7	.6	.6
500	2			.5	.5	.4	.3
500	3				.2	.1	.1
500	4				.1	0	0
500	5				0	0	0
750	0.1						
750	0.5				.9	1	
750	1		.5	.6	.8	.9	.9
750	1.5			.6	.6	.7	.6
750	2			.5	.5	.5	.4
750	3				.3	.2	.1
750	4				.1	.1	0
750	5				0	0	0
1000	0.1						
1000	0.5				.8	1	
1000	1		.5	.6	.7	.8	.9
1000	1.5			.5	.6	.6	.7
1000	2			.5	.5	.5	.4
1000	3				.3	.2	.2
1000	4				.1	.1	0
1000	5				0	0	0
2500	0.1						
2500	0.5					.7	
2500	1			.4	.5	.6	.7
2500	1.5			.4	.5	.6	.6
2500	2			.4	.4	.5	.5
2500	3				.3	.3	.3
2500	4				.2	.2	.1
2500	5				.1	.1	0
5000	0.1						
5000	0.5						
5000	1				.4	.5	.6
5000	1.5			.3	.4	.5	.5
5000	2			.3	.3	.4	.4
5000	3				.3	.3	.3
5000	4				.2	.2	.2
5000	5				.2	.2	.1

breakup γ of -3º

W (lb)	r \ l	1	2.5	5	10	20	30
5	0.1	1	1	1			
5	0.5	1	1	1	1	1	
5	1		.8	.8	.7	.7	
5	1.5			.4			
5	2						
5	3						
5	4						
5	5						
10	0.1		1	1			
10	0.5	1	1	1	1	1	
10	1		.9	.8	.8	.7	.7
10	1.5			.5	.4		
10	2			.3			
10	3						
10	4						
10	5						
25	0.1			1			
25	0.5	1	1	1	1	1	
25	1		.9	.9	.9	.8	.8
25	1.5			.5	.5	.4	.4
25	2			.3	.3	.3	
25	3						
25	4						
25	5						
50	0.1						
50	0.5	.9	1	1	1	1	
50	1		.9	.9	.9	.9	.8
50	1.5			.6	.6	.5	.5
50	2			.4	.3	.3	.3
50	3				.1	.1	
50	4				0		
50	5						
75	0.1						
75	0.5	.8	1	1	1	1	
75	1		.8	.9	.9	.9	.9
75	1.5			.6	.6	.5	.5
75	2			.4	.4	.3	.3
75	3				.1	.1	.1
75	4				0		
75	5						
100	0.1						
100	0.5	.7	.9	1	1	1	
100	1		.8	.9	.9	.9	.9
100	1.5			.6	.6	.6	.5
100	2			.5	.4	.3	.3
100	3				.2	.1	.1
100	4				.1	0	
100	5				0		
250	0.1						
250	0.5		.7	.8	1	1	
250	1		.6	.7	.8	.9	.9
250	1.5			.6	.6	.6	.6
250	2			.5	.5	.4	.4
250	3				.3	.2	.2
250	4				.1	.1	.1
250	5				0	0	0
500	0.1						
500	0.5			.6	.8	1	
500	1		.5	.6	.7	.8	.9
500	1.5			.5	.6	.6	.6
500	2			.4	.5	.5	.5
500	3				.3	.3	.2
500	4				.2	.1	.1
500	5				.1	0	0
750	0.1						
750	0.5				.7	.9	
750	1		.4	.5	.6	.7	.8
750	1.5			.5	.5	.6	.6
750	2			.4	.5	.5	.5
750	3				.3	.3	.3
750	4				.2	.2	.1
750	5				.1	.1	0
1000	0.1						
1000	0.5				.6	.8	
1000	1		.4	.4	.6	.7	.7
1000	1.5			.4	.5	.6	.6
1000	2			.4	.4	.5	.5
1000	3				.3	.3	.3
1000	4				.2	.2	.2
1000	5				.1	.1	.1
2500	0.1						
2500	0.5					.6	
2500	1			.3	.4	.5	.6
2500	1.5			.3	.4	.4	.5
2500	2			.3	.3	.4	.4
2500	3				.3	.3	.3
2500	4				.2	.2	.2
2500	5				.2	.2	.1
5000	0.1						
5000	0.5						
5000	1				.3	.4	.4
5000	1.5			.2	.3	.4	.4
5000	2			.2	.3	.3	.4
5000	3				.2	.3	.3
5000	4				.2	.2	.2
5000	5				.2	.2	.2

breakup γ of -5.5º

W (lb)	r \ l	1	2.5	5	10	20	30
5	0.1	1	1	1			
5	0.5	1	1	1	1	1	
5	1		.9	.8	.8	.8	
5	1.5			.5			
5	2						
5	3						
5	4						
5	5						
10	0.1		1	1			
10	0.5	1	1	1	1	1	
10	1		.9	.9	.8	.8	.7
10	1.5			.5	.5		
10	2			.3			
10	3						
10	4						
10	5						
25	0.1			1			
25	0.5	1	1	1	1	1	
25	1		.9	.9	.9	.8	.8
25	1.5			.6	.5	.5	.4
25	2			.4	.3	.3	
25	3						
25	4						
25	5						
50	0.1						
50	0.5	.8	1	1	1	1	
50	1		.8	.9	.9	.9	.9
50	1.5			.6	.6	.5	.5
50	2			.4	.4	.3	.3
50	3				.2	.1	
50	4				.1		
50	5						
75	0.1						
75	0.5	.7	.9	1	1	1	
75	1		.7	.8	.9	.9	.9
75	1.5			.6	.6	.6	.5
75	2			.5	.4	.4	.3
75	3				.2	.1	.1
75	4				.1		
75	5						
100	0.1						
100	0.5	.6	.8	1	1	1	
100	1		.7	.8	.9	.9	.9
100	1.5			.6	.6	.6	.6
100	2			.5	.5	.4	.4
100	3				.2	.2	.1
100	4				.1	.1	
100	5				0		
250	0.1						
250	0.5		.5	.7	.9	1	
250	1		.5	.6	.7	.8	.9
250	1.5			.5	.6	.6	.6
250	2			.5	.5	.5	.4
250	3				.3	.2	.2
250	4				.2	.1	.1
250	5				.1	0	0
500	0.1						
500	0.5			.5	.7	.9	
500	1		.4	.5	.6	.7	.8
500	1.5			.4	.5	.6	.6
500	2			.4	.4	.5	.5
500	3				.3	.3	.3
500	4				.2	.2	.1
500	5				.1	.1	.1
750	0.1						
750	0.5				.6	.7	
750	1		.3	.4	.5	.6	.7
750	1.5			.4	.5	.5	.6
750	2			.4	.4	.5	.5
750	3				.3	.3	.3
750	4				.2	.2	.2
750	5				.2	.1	.1
1000	0.1						
1000	0.5				.5	.7	
1000	1		.3	.4	.5	.6	.7
1000	1.5			.3	.4	.5	.5
1000	2			.3	.4	.4	.5
1000	3				.3	.3	.3
1000	4				.2	.2	.2
1000	5				.2	.1	.1
2500	0.1						
2500	0.5					.4	
2500	1			.2	.3	.4	.5
2500	1.5			.2	.3	.4	.4
2500	2			.2	.3	.3	.4
2500	3				.3	.3	.3
2500	4				.2	.2	.2
2500	5				.2	.2	.2
5000	0.1						
5000	0.5						
5000	1				.2	.3	.4
5000	1.5			.2	.2	.3	.3
5000	2			.2	.2	.3	.3
5000	3				.2	.2	.3
5000	4				.2	.2	.2
5000	5				.2	.2	.2

Table D-16. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

breakup altitude (h) of 42 nmi; breakup temperature (T) of 1541ºR; breakup v of 25000 ft/s

breakup γ of -0.5º

W (lb)	r \ l	1	2.5	5	10	20	30
5	0.1	1	1	1			
5	0.5	1	1	1	1	1	
5	1		1	1	1	1	
5	1.5			.8			
5	2						
5	3						
5	4						
5	5						
10	0.1		1	1			
10	0.5	1	1	1	1	1	
10	1		1	1	1	1	1
10	1.5			.8	.8		
10	2			.5			
10	3						
10	4						
10	5						
25	0.1			1			
25	0.5	1	1	1	1	1	
25	1		1	1	1	1	1
25	1.5			.8	.8	.8	.8
25	2			.6	.5	.5	
25	3						
25	4						
25	5						
50	0.1						
50	0.5	1	1	1	1	1	
50	1		1	1	1	1	1
50	1.5			.9	.8	.8	.8
50	2			.6	.6	.5	.5
50	3				.3	.3	
50	4				.2		
50	5						
75	0.1						
75	0.5	1	1	1	1	1	
75	1		1	1	1	1	1
75	1.5			.9	.9	.8	.8
75	2			.6	.6	.5	.5
75	3				.3	.3	.3
75	4				.2		
75	5						
100	0.1						
100	0.5	1	1	1	1	1	
100	1		1	1	1	1	1
100	1.5			1	.9	.8	.8
100	2			.7	.6	.6	.5
100	3				.3	.3	.3
100	4				.2	.2	
100	5				.1		
250	0.1						
250	0.5		1	1	1	1	
250	1		1	1	1	1	1
250	1.5			1	1	.9	.9
250	2			.8	.7	.6	.6
250	3				.3	.3	.3
250	4				.2	.2	.2
250	5				.1	.1	.1
500	0.1						
500	0.5			1	1	1	
500	1		1	1	1	1	1
500	1.5			.9	1	1	1
500	2			.8	.8	.7	.7
500	3				.4	.4	.3
500	4				.2	.2	.2
500	5				.1	.1	.1
750	0.1						
750	0.5				1	1	
750	1		.9	1	1	1	1
750	1.5			.9	1	1	1
750	2			.8	.8	.8	.7
750	3				.5	.4	.4
750	4				.3	.2	.2
750	5				.1	.1	.1
1000	0.1						
1000	0.5				1	1	
1000	1		.9	1	1	1	1
1000	1.5			.8	.9	1	1
1000	2			.7	.8	.8	.7
1000	3				.5	.4	.4
1000	4				.3	.2	.2
1000	5				.2	.1	.1
2500	0.1						
2500	0.5					1	
2500	1			.8	.9	1	1
2500	1.5			.7	.8	.9	.9
2500	2			.6	.7	.7	.8
2500	3				.5	.5	.5
2500	4				.4	.4	.3
2500	5				.3	.2	.2
5000	0.1						
5000	0.5						
5000	1				.8	.9	1
5000	1.5			.8	.7	.8	.8
5000	2			.5	.6	.7	.7
5000	3				.5	.5	.5
5000	4				.4	.4	.4
5000	5				.3	.3	.3

breakup γ of -3º

W (lb)	r \ l	1	2.5	5	10	20	30
5	0.1	1	1	1			
5	0.5	1	1	1	1	1	
5	1		1	1	1	1	
5	1.5			.8			
5	2						
5	3						
5	4						
5	5						
10	0.1		1	1			
10	0.5	1	1	1	1	1	
10	1		1	1	1	1	1
10	1.5			.9	.8		
10	2			.6			
10	3						
10	4						
10	5						
25	0.1			1			
25	0.5	1	1	1	1	1	
25	1		1	1	1	1	1
25	1.5			.9	.9	.8	.8
25	2			.7	.6	.6	
25	3						
25	4						
25	5						
50	0.1						
50	0.5	1	1	1	1	1	
50	1		1	1	1	1	1
50	1.5			1	.9	.9	.8
50	2			.7	.7	.6	.6
50	3				.3	.3	
50	4				.2		
50	5						
75	0.1						
75	0.5	1	1	1	1	1	
75	1		1	1	1	1	1
75	1.5			1	1	.9	.9
75	2			.7	.7	.6	.6
75	3				.4	.3	.3
75	4				.2		
75	5						
100	0.1						
100	0.5	1	1	1	1	1	
100	1		1	1	1	1	1
100	1.5			.9	1	.9	.9
100	2			.7	.7	.7	.6
100	3				.4	.3	.3
100	4				.2	.2	
100	5				.1		
250	0.1						
250	0.5		.9	1	1	1	
250	1		.8	.9	1	1	1
250	1.5			.8	.9	.9	.9
250	2			.7	.7	.7	.7
250	3				.5	.4	.4
250	4				.3	.2	.2
250	5				.2	.1	.1
500	0.1						
500	0.5			.8	1	1	
500	1		.6	.8	.9	1	1
500	1.5			.7	.8	.9	.9
500	2			.6	.7	.7	.7
500	3				.5	.5	.5
500	4				.4	.3	.3
500	5				.2	.2	.2
750	0.1						
750	0.5				.9	1	
750	1		.5	.7	.8	1	1
750	1.5			.6	.7	.8	.9
750	2			.6	.6	.7	.7
750	3				.5	.5	.5
750	4				.4	.3	.3
750	5				.3	.2	.2
1000	0.1						
1000	0.5				.8	1	
1000	1		.5	.6	.7	.9	1
1000	1.5			.6	.7	.8	.8
1000	2			.5	.6	.7	.7
1000	3				.5	.5	.5
1000	4				.4	.4	.3
1000	5				.3	.3	.2
2500	0.1						
2500	0.5					.7	
2500	1			.4	.5	.7	.8
2500	1.5			.4	.5	.6	.7
2500	2			.4	.5	.6	.6
2500	3				.4	.5	.5
2500	4				.4	.4	.4
2500	5				.3	.3	.3
5000	0.1						
5000	0.5						
5000	1				.4	.5	.6
5000	1.5			.3	.4	.5	.5
5000	2			.3	.4	.4	.5
5000	3				.3	.4	.4
5000	4				.3	.3	.4
5000	5				.3	.3	.3

breakup γ of -5.5º

W (lb)	r \ l	1	2.5	5	10	20	30
5	0.1	1	1	1			
5	0.5	1	1	1	1	1	
5	1		1	1	1	1	
5	1.5			.9			
5	2						
5	3						
5	4						
5	5						
10	0.1		1	1			
10	0.5	1	1	1	1	1	
10	1		1	1	1	1	1
10	1.5			.9	.9		
10	2			.6			
10	3						
10	4						
10	5						
25	0.1			1			
25	0.5	1	1	1	1	1	
25	1		1	1	1	1	1
25	1.5			1	.9	.9	.8
25	2			.7	.6	.6	
25	3						
25	4						
25	5						
50	0.1						
50	0.5	1	1	1	1	1	
50	1		1	1	1	1	1
50	1.5			.9	1	.9	.9
50	2			.7	.7	.7	.6
50	3				.4	.3	
50	4				.2		
50	5						
75	0.1						
75	0.5	.8	1	1	1	1	
75	1		1	1	1	1	1
75	1.5			.9	.9	.9	.9
75	2			.7	.7	.7	.7
75	3				.4	.4	.3
75	4				.2		
75	5						
100	0.1						
100	0.5	.8	1	1	1	1	
100	1		.9	1	1	1	1
100	1.5			.9	.9	.9	.9
100	2			.7	.7	.7	.7
100	3				.5	.4	.4
100	4				.3	.2	
100	5				.2		
250	0.1						
250	0.5		.7	.9	1	1	
250	1		.7	.8	.9	1	1
250	1.5			.7	.8	.9	.9
250	2			.6	.7	.7	.7
250	3				.5	.5	.4
250	4				.3	.3	.3
250	5				.2	.2	.2
500	0.1						
500	0.5			.6	.9	1	
500	1		.5	.6	.8	.9	1
500	1.5			.6	.7	.8	.9
500	2			.5	.6	.7	.7
500	3				.5	.5	.5
500	4				.4	.4	.3
500	5				.3	.2	.2
750	0.1						
750	0.5				.7	.9	
750	1		.4	.5	.7	.8	.9
750	1.5			.5	.6	.7	.8
750	2			.5	.6	.6	.7
750	3				.5	.5	.5
750	4				.4	.4	.4
750	5				.3	.3	.2
1000	0.1						
1000	0.5				.6	.8	
1000	1		.4	.5	.6	.7	.9
1000	1.5			.4	.6	.7	.7
1000	2			.4	.5	.6	.6
1000	3				.4	.5	.5
1000	4				.4	.4	.4
1000	5				.3	.3	.3
2500	0.1						
2500	0.5					.6	
2500	1			.3	.4	.5	.6
2500	1.5			.3	.4	.5	.6
2500	2			.3	.4	.5	.5
2500	3				.3	.4	.4
2500	4				.3	.3	.4
2500	5				.3	.3	.3
5000	0.1						
5000	0.5						
5000	1				.3	.4	.5
5000	1.5			.2	.3	.4	.4
5000	2			.2	.3	.4	.4
5000	3				.3	.3	.4
5000	4				.3	.3	.3
5000	5				.2	.3	.3

Table D-17. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

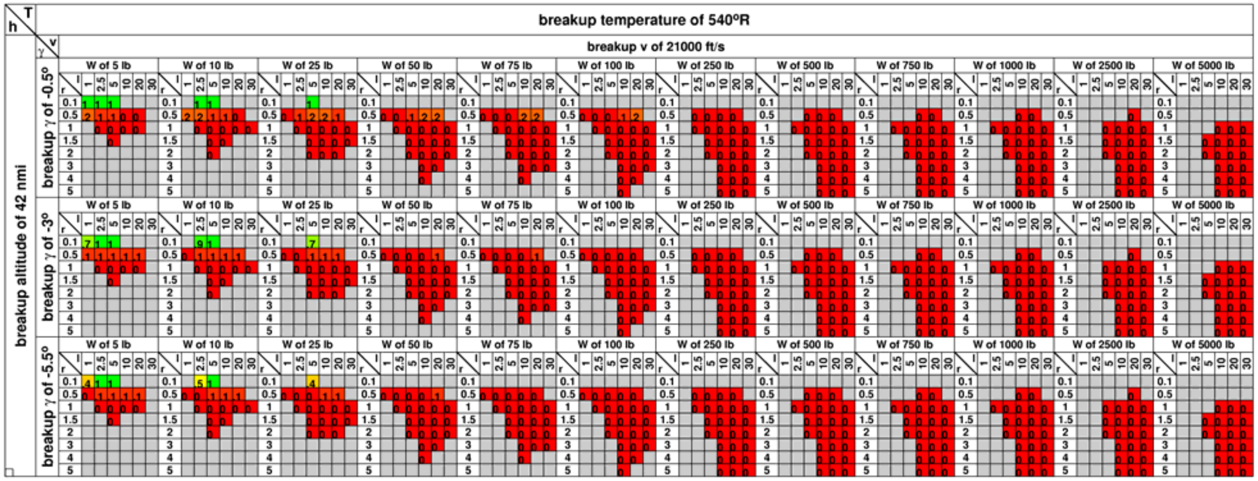


Table D-18. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

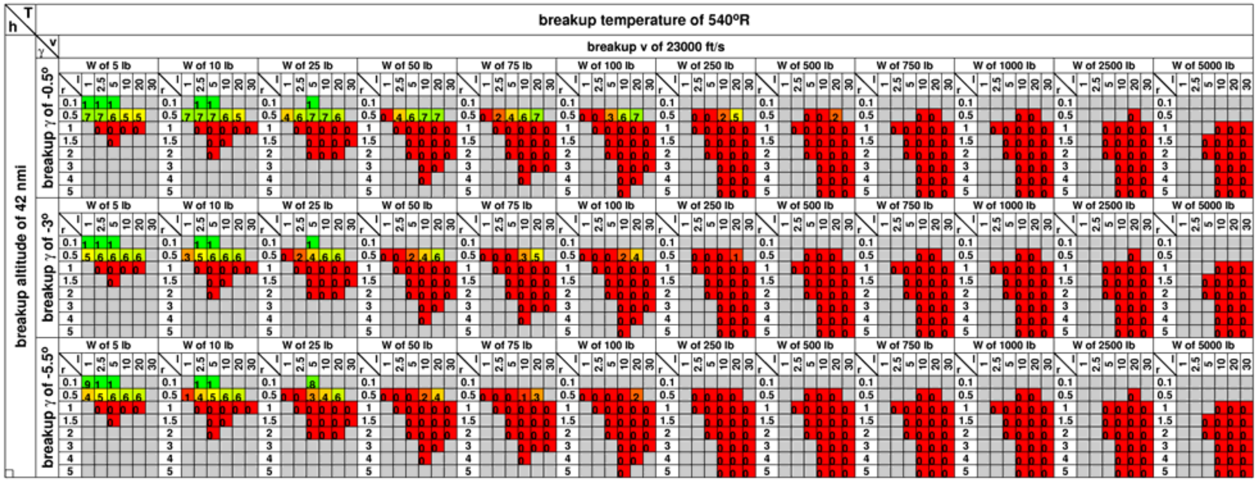


Table D-19. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

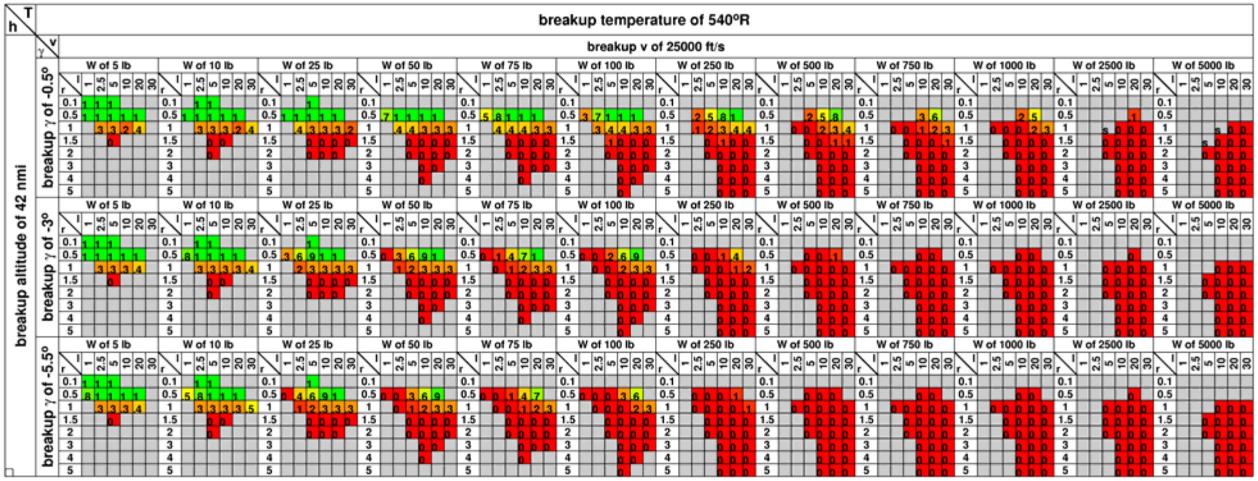


Table D-20. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

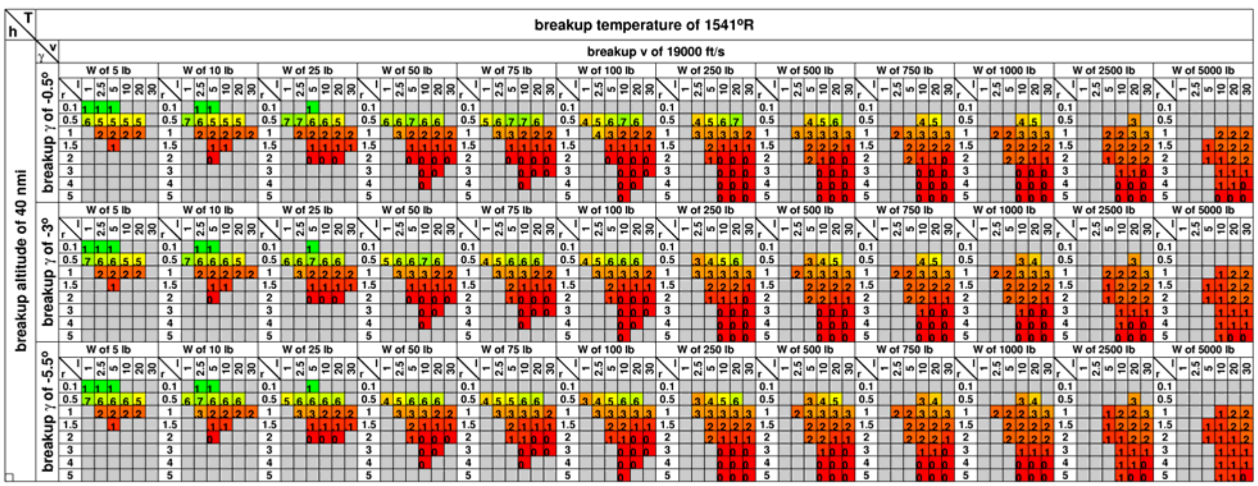


Table D-21. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h = breakup altitude of 40 nmi; T = breakup temperature of 1541°R; v = breakup v of 21000 ft/s

breakup γ of -0.5°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1									
0.5	1	1	1	1	.9		1	1	1	1	1		1	1	1	1	1		.8	1	1	1	1	
1		.4	.4	.4	.4			.5	.4	.4	.4	.4		.5	.5	.4	.4	.4		.6	.5	.5	.4	.4
1.5			.2						.2	.2					.2	.2	.2	.2			.3	.2	.2	.2
2									.1						.1	.1	.1				.2	.1	.1	.1
3																						.1	.1	
4																						0		
5																								

r \ l	W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5	.7	.9	1	1	1		.6	.8	1	1	1			.6	.7	.9	1				.6	.7	.9	
1		.6	.6	.5	.5	.4		.6	.6	.5	.5	.4		.5	.6	.6	.6	.5		.4	.5	.6	.6	.6
1.5			.3	.3	.2	.2			.3	.3	.2	.2			.4	.4	.3	.3			.4	.4	.4	.3
2			.2	.1	.1	.1			.2	.2	.1	.1			.3	.2	.2	.2			.3	.3	.2	.2
3				.1	.1	.1				.1	.1	.1				.1	.1	.1				.1	.1	.1
4				0						0	0					0	0	0				0	0	0
5										0						0	0	0				0	0	0

r \ l	W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5				.6	.8					.5	.7						.5							
1		.3	.4	.5	.6	.6		.3	.4	.5	.5	.6			.3	.3	.4	.5				.2	.3	.4
1.5			.4	.4	.4	.4			.3	.4	.4	.4			.2	.3	.4	.4			.2	.2	.3	.3
2			.3	.3	.2	.2			.3	.3	.3	.2			.2	.3	.3	.3			.2	.2	.3	.3
3				.1	.1	.1				.2	.1	.1				.2	.2	.2				.2	.2	.2
4				0	0	0				0	0	0				.1	.1	0				.1	.1	.1
5				0	0	0				0	0	0				.1	0	0				.1	.1	0

breakup γ of -3°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1									
0.5	1	1	1	1	1		1	1	1	1	1		.8	1	1	1	1		.7	.8	.9	1	1	
1		.5	.5	.4	.5			.5	.5	.5	.4	.4		.6	.5	.5	.5	.4		.6	.6	.5	.5	.5
1.5			.2						.3	.2					.3	.3	.2	.2			.3	.3	.3	.3
2									.2						.2	.2	.1				.2	.2	.2	.1
3																						.1	.1	
4																						0		
5																								

r \ l	W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5	.6	.7	.9	1	1		.5	.7	.8	.9	1			.5	.6	.7	.9				.5	.6	.7	
1		.6	.6	.6	.5	.5		.5	.6	.6	.5	.5		.4	.5	.5	.6	.6		.3	.4	.5	.5	.6
1.5			.4	.3	.3	.3			.4	.3	.3	.3			.4	.4	.4	.3			.4	.4	.4	.4
2			.2	.2	.2	.2			.2	.2	.2	.2			.3	.3	.2	.2			.3	.3	.3	.2
3				.1	.1	.1				.1	.1	.1				.1	.1	.1				.2	.1	.1
4				0						0	0					0	0	0				.1	0	0
5										0						0	0	0				0	0	0

r \ l	W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5				.5	.6					.4	.6						.4							
1		.3	.4	.4	.5	.5		.3	.3	.4	.5	.5			.2	.3	.4	.4				.2	.3	.3
1.5			.3	.4	.4	.4			.3	.3	.4	.4			.2	.3	.3	.3			.2	.2	.3	.3
2			.3	.3	.3	.3			.3	.3	.3	.3			.2	.2	.3	.3			.2	.2	.2	.3
3				.2	.1	.1				.2	.2	.1				.2	.2	.2				.2	.2	.2
4				.1	.1	0				.1	.1	.1				.1	.1	.1				.1	.1	.1
5				0	0	0				.1	0	0				.1	.1	.1				.1	.1	.1

breakup γ of -5.5°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1									
0.5	1	1	1	1	1		.9	1	1	1	1		.7	.9	1	1	1		.6	.7	.9	1	1	
1		.5	.5	.4	.5			.5	.5	.5	.4	.4		.6	.6	.5	.5	.5		.5	.6	.6	.5	.5
1.5			.3						.3	.3					.3	.3	.3	.3			.4	.3	.3	.3
2									.2						.2	.2	.2				.2	.2	.2	.2
3																						.1	.1	
4																						0		
5																								

r \ l	W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5	.5	.6	.8	.9	1		.4	.6	.7	.8	1			.4	.5	.6	.8				.4	.5	.6	
1		.5	.5	.6	.5	.5		.5	.5	.6	.6	.5		.4	.4	.5	.5	.6		.3	.4	.4	.5	.5
1.5			.4	.4	.3	.3			.4	.4	.3	.3			.4	.4	.4	.4			.3	.4	.4	.4
2			.3	.2	.2	.2			.3	.2	.2	.2			.3	.3	.3	.2			.3	.3	.3	.3
3				.1	.1	.1				.1	.1	.1				.1	.1	.1				.2	.2	.1
4				0						0	0					.1	0	0				.1	.1	.1
5										0						0	0	0				0	0	0

r \ l	W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5				.4	.6					.4	.5						.3							
1		.2	.3	.4	.5	.5		.2	.3	.3	.4	.5			.2	.2	.3	.4				.2	.2	.3
1.5			.3	.3	.4	.4			.3	.3	.3	.4			.2	.2	.3	.3			.1	.2	.2	.2
2			.3	.3	.3	.3			.2	.3	.3	.3			.2	.2	.2	.3			.1	.2	.2	.2
3				.2	.2	.2				.2	.2	.2				.2	.2	.2				.1	.2	.2
4				.1	.1	.1				.1	.1	.1				.1	.1	.1				.1	.1	.1
5				.1	0	0				.1	.1	0				.1	.1	.1				.1	.1	.1

Table D-22. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h = breakup altitude of 40 nmi; T = breakup temperature of 1541°R; v = breakup v of 23000 ft/s

breakup γ of -0.5°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1									
0.5	1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1	
1		.8	.8	.8	.8			.8	.8	.8	.8	.8		.9	.8	.8	.8	.8		.9	.9	.8	.8	.8
1.5			.5						.5	.5					.5	.5	.5	.5			.5	.5	.5	.5
2									.3						.3	.3	.3				.4	.3	.3	.3
3																						.2	.2	
4																						.1		
5																								

r \ l	W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5	1	1	1	1	1		.9	1	1	1	1			.9	1	1	1				.8	1	1	
1		.9	.9	.9	.8	.8		.9	.9	.9	.8	.8		.8	.8	.9	.9	.9		.6	.7	.8	.9	.9
1.5			.6	.5	.5	.5			.6	.5	.5	.5			.6	.6	.6	.5			.6	.6	.6	.6
2			.4	.4	.3	.3			.4	.4	.3	.3			.5	.4	.4	.4			.5	.5	.4	.4
3				.2	.2	.2				.2	.2	.2				.2	.2	.2				.2	.2	.2
4				.1						.1	.1					.1	.1	.1				.1	.1	.1
5										.1						.1	.1	.1				.1	.1	.1

r \ l	W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5				.9	1					.8	1						.7							
1		.5	.6	.8	.9	.9		.5	.6	.7	.8	.9			.4	.5	.6	.7				.4	.5	.6
1.5			.6	.6	.6	.6			.5	.6	.6	.6			.4	.5	.5	.6			.3	.4	.5	.5
2			.5	.5	.5	.4			.5	.5	.5	.5			.4	.4	.5	.5			.3	.3	.4	.4
3				.3	.2	.2				.3	.3	.2				.3	.3	.3				.3	.3	.3
4				.2	.1	.1				.2	.1	.1				.2	.2	.2				.2	.2	.2
5				.1	.1	.1				.1	.1	.1				.2	.1	.1				.2	.2	.1

breakup γ of -3°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1									
0.5	1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		.9	1	1	1	1	
1		.8	.8	.8	.8			.9	.8	.8	.8	.8		.9	.9	.8	.8	.8		.8	.9	.9	.8	.8
1.5			.5						.5	.5					.6	.5	.5	.5			.6	.6	.5	.5
2									.4						.4	.4	.3				.4	.4	.4	.4
3																						.2	.2	
4																						.1		
5																								

r \ l	W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5	.8	1	1	1	1		.7	.9	1	1	1			.6	.8	1	1				.6	.8	1	
1		.8	.8	.9	.9	.8		.8	.8	.9	.9	.9		.6	.7	.8	.8	.9		.5	.6	.7	.8	.8
1.5			.6	.6	.6	.5			.6	.6	.6	.5			.6	.6	.6	.6			.5	.6	.6	.6
2			.4	.4	.4	.4			.5	.4	.4	.4			.5	.5	.4	.4			.4	.5	.5	.5
3				.2	.2	.2				.2	.2	.2				.3	.2	.2				.3	.3	.3
4				.1						.1	.1					.2	.1	.1				.2	.2	.1
5										.1						.1	.1	.1				.1	.1	.1

r \ l	W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5				.7	.9					.6	.8						.5							
1		.4	.5	.6	.7	.8		.4	.4	.5	.7	.7			.3	.4	.5	.6				.3	.4	.4
1.5			.4	.5	.6	.6			.4	.5	.5	.6			.3	.4	.4	.5			.2	.3	.3	.4
2			.4	.4	.5	.5			.4	.4	.5	.5			.3	.3	.4	.4			.2	.3	.3	.4
3				.3	.3	.3				.3	.3	.3				.3	.3	.3				.2	.3	.3
4				.2	.2	.2				.2	.2	.2				.2	.2	.2				.2	.2	.2
5				.1	.1	.1				.2	.1	.1				.2	.2	.2				.2	.2	.2

breakup γ of -5.5°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1									
0.5	1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		.8	1	1	1	1	
1		.9	.8	.8	.8			.9	.9	.8	.8	.8		.9	.9	.9	.8	.8		.8	.8	.9	.9	.8
1.5			.5						.5	.5					.6	.6	.5	.5			.6	.6	.6	.5
2									.4						.4	.4	.4				.5	.4	.4	.4
3																						.2	.2	
4																						.1		
5																								

r \ l	W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5	.7	.8	1	1	1		.6	.8	.9	1	1			.5	.7	.9	1				.5	.7	.8	
1		.7	.8	.8	.9	.9		.7	.7	.8	.9	.9		.5	.6	.7	.8	.8		.4	.5	.6	.7	.7
1.5			.6	.6	.6	.6			.6	.6	.6	.6			.5	.6	.6	.6			.4	.5	.6	.6
2			.5	.4	.4	.4			.5	.5	.4	.4			.4	.5	.5	.4			.4	.4	.5	.5
3				.2	.2	.2				.3	.2	.2				.3	.3	.3				.3	.3	.3
4				.1						.1	.1					.2	.2	.1				.2	.2	.2
5										.1						.1	.1	.1				.2	.1	.1

r \ l	W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																								
0.5				.6	.7					.5	.7						.4							
1		.3	.4	.5	.6	.7		.3	.4	.5	.6	.6			.2	.3	.4	.5				.2	.3	.4
1.5			.4	.4	.5	.6			.3	.4	.5	.5			.2	.3	.4	.4			.2	.2	.3	.3
2			.4	.4	.4	.5			.3	.4	.4	.4			.2	.3	.3	.4			.2	.2	.3	.3
3				.3	.3	.3				.3	.3	.3				.3	.3	.3				.2	.2	.3
4				.2	.2	.2				.2	.2	.2				.2	.2	.2				.2	.2	.2
5				.2	.1	.1				.2	.2	.1				.2	.2	.2				.2	.2	.2

Table D-23. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

breakup temperature of 540ºR

breakup v of 19000 ft/s

breakup altitude of 40 nmi

breakup γ of -0.5º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	.5	1	1					.6	1						.4																					
0.5	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	
1		0	0	0	0			0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0
1.5			0						0	0					0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2									0						0	0	0				0	0	0	0			0	0	0	0			0	0	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		0	0	0	0				0	0	0					0	0					0	0						0							
1		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0			0	0	0	0				0	0	0
1.5			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
3				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

breakup γ of -3º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	.2	.7	1					.3	.6						.1																					
0.5	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	
1		0	0	0	0			0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0
1.5			0						0	0					0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2									0						0	0	0				0	0	0	0			0	0	0	0			0	0	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		0	0	0	0				0	0	0					0	0					0	0						0							
1		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0			0	0	0	0				0	0	0
1.5			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
3				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

breakup γ of -5.5º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	0	.4	.8					.1	.4						0																					
0.5	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	
1		0	0	0	0			0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0
1.5			0						0	0					0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2									0						0	0	0				0	0	0	0			0	0	0	0			0	0	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		0	0	0	0				0	0	0					0	0					0	0						0							
1		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0			0	0	0	0				0	0	0
1.5			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
3				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

Table D-24. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

breakup temperature of 540ºR

breakup v of 21000 ft/s

breakup altitude of 40 nmi

breakup γ of -0.5º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1																					
0.5	.1	0	0	0	0		.1	.1	0	0	0		0	0	.1	0	0		0	0	0	.1	0		0	0	0	.1	.1		0	0	0	0	.1	
1		0	0	0	0			0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0
1.5			0						0	0					0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2									0						0	0	0				0	0	0	0			0	0	0	0			0	0	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		0	0	0	0				0	0	0					0	0					0	0						0							
1		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0			0	0	0	0				0	0	0
1.5			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
3				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

breakup γ of -3º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	.7	1	1					.8	1						.6																					
0.5	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	
1		0	0	0	0			0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0
1.5			0						0	0					0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2									0						0	0	0				0	0	0	0			0	0	0	0			0	0	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		0	0	0	0				0	0	0					0	0					0	0						0							
1		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0			0	0	0	0				0	0	0
1.5			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
3				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

breakup γ of -5.5º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	.4	1	1					.5	.9						.3																					
0.5	0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0	
1		0	0	0	0			0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0
1.5			0						0	0					0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2									0						0	0	0				0	0	0	0			0	0	0	0			0	0	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		0	0	0	0				0	0	0					0	0					0	0						0							
1		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0		0	0	0	0	0			0	0	0	0				0	0	0
1.5			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
3				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

Table D-25. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

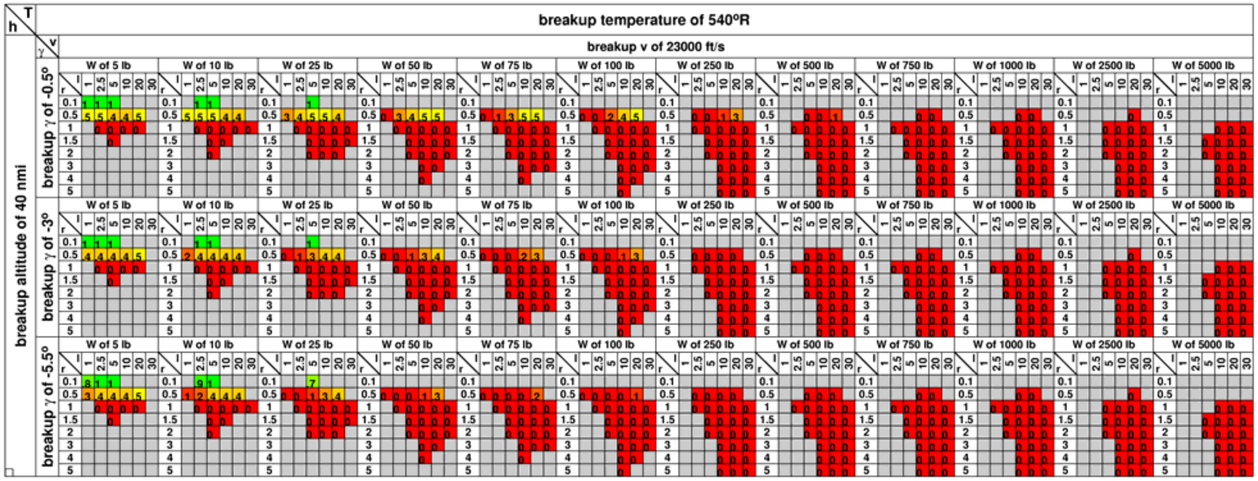


Table D-26. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

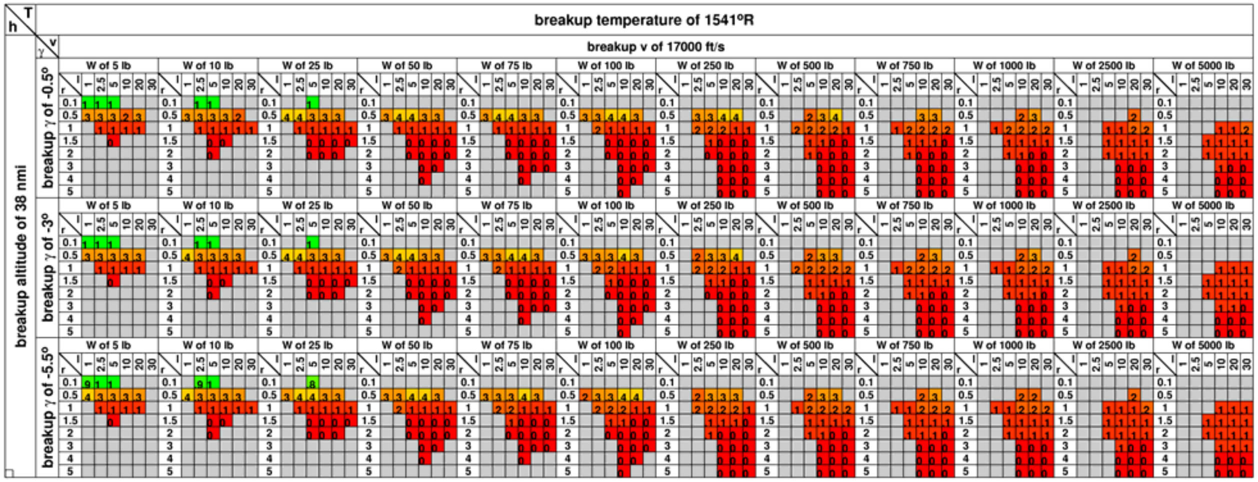


Table D-27. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

Breakup altitude h of 38 nmi; breakup temperature T of 1541ºR; breakup v of 19000 ft/s

Breakup γ of -0.5º

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	6	6	6	5	5	
1		2	2	2	3	
1.5			1			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	6	6	6	5	5	
1		2	2	2	2	3
1.5			1	1		
2			1			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	6	6	6	6	6	
1		3	2	2	2	2
1.5			1	1	1	1
2			1	1	1	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	5	6	6	6	6	
1		3	3	2	2	2
1.5			1	1	1	1
2			1	1	1	1
3				0	0	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	5	6	6	6	6	
1		3	3	3	2	2
1.5			1	1	1	1
2			1	1	1	1
3				0	0	0
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	5	6	6	6	
1		3	3	3	2	2
1.5			2	1	1	1
2			1	1	1	1
3				0	0	0
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		4	5	6	6	
1		3	3	3	3	3
1.5			2	2	1	1
2			1	1	1	1
3				0	0	0
4				0	0	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			4	5	6	
1		3	3	3	3	3
1.5			2	2	2	1
2			2	1	1	1
3				0	0	0
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				4	5	
1		2	3	3	3	3
1.5			2	2	2	2
2			2	2	1	1
3				0	0	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				4	5	
1		2	3	3	3	3
1.5			2	2	2	2
2			2	2	1	1
3				1	0	0
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					3	
1			2	2	3	3
1.5			2	2	2	2
2			2	2	2	2
3				1	1	1
4				1	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				2	2	3
1.5			1	2	2	2
2			1	1	2	2
3				1	1	1
4				1	1	0
5				0	0	0

Breakup γ of -3º

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	6	6	6	6	6	
1		3	2	2	3	
1.5			1			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	6	6	6	6	6	
1		3	3	2	2	3
1.5			1	1		
2			1			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	6	6	6	6	6	
1		3	3	3	2	2
1.5			1	1	1	1
2			1	1	1	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	5	6	6	6	6	
1		3	3	3	3	2
1.5			2	1	1	1
2			1	1	1	1
3				0	0	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	5	6	6	6	
1		3	3	3	3	3
1.5			2	2	1	1
2			1	1	1	1
3				0	0	0
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	5	5	6	6	
1		3	3	3	3	3
1.5			2	2	1	1
2			1	1	1	1
3				0	0	0
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		3	4	5	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			2	1	1	1
3				0	0	0
4				0	0	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			3	4	5	
1		2	3	3	3	3
1.5			2	2	2	2
2			2	2	1	1
3				1	0	0
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				4	5	
1		2	2	3	3	3
1.5			2	2	2	2
2			2	2	1	1
3				1	1	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				3	4	
1		2	2	3	3	3
1.5			2	2	2	2
2			2	2	2	1
3				1	1	1
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					3	
1			2	2	2	3
1.5			1	2	2	2
2			1	2	2	2
3				1	1	1
4				1	1	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				1	2	2
1.5			1	1	2	2
2			1	1	2	2
3				1	1	1
4				1	1	1
5				1	0	0

Breakup γ of -5.5º

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	6	6	6	6	6	
1		3	3	2	3	
1.5			1			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	6	6	6	6	6	
1		3	3	3	2	3
1.5			1	1		
2			1			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	5	6	6	6	6	
1		3	3	3	3	2
1.5			2	1	1	1
2			1	1	1	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	5	6	6	6	
1		3	3	3	3	3
1.5			2	2	1	1
2			1	1	1	1
3				0	0	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	5	5	6	6	
1		3	3	3	3	3
1.5			2	2	2	1
2			1	1	1	1
3				0	0	0
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	3	4	5	6	6	
1		3	3	3	3	3
1.5			2	2	2	1
2			1	1	1	1
3				0	0	0
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		3	4	5	5	
1		3	3	3	3	3
1.5			2	2	2	2
2			2	1	1	1
3				1	0	0
4				0	0	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			3	4	5	
1		2	2	3	3	3
1.5			2	2	2	2
2			2	2	1	1
3				1	1	0
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				3	4	
1		2	2	3	3	3
1.5			2	2	2	2
2			2	2	2	2
3				1	1	1
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				3	4	
1		2	2	2	3	3
1.5			2	2	2	2
2			2	2	2	2
3				1	1	1
4				1	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					2	
1			1	2	2	2
1.5			1	2	2	2
2			1	1	2	2
3				1	1	1
4				1	1	1
5				1	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				1	2	2
1.5			1	1	2	2
2			1	1	2	2
3				1	1	1
4				1	1	1
5				1	1	1

Table D-28. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

Breakup altitude h of 38 nmi; breakup temperature T of 1541ºR; breakup v of 21000 ft/s

Breakup γ of -0.5º

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	1	1	9	9	9	
1		5	5	5	5	
1.5			3			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	1	1	1	9	9	
1		5	5	5	5	5
1.5			3	3		
2			2			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	9	1	1	1	9	
1		5	5	5	5	5
1.5			3	3	3	3
2			2	2	2	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	8	9	1	1	1	
1		6	5	5	5	5
1.5			3	3	3	3
2			2	2	2	2
3				1	1	
4				1		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	7	9	1	1	1	
1		6	5	5	5	5
1.5			3	3	3	3
2			2	2	2	2
3				1	1	1
4				1		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	6	8	9	1	1	
1		6	6	5	5	5
1.5			3	3	3	3
2			2	2	2	2
3				1	1	1
4				1	1	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		6	7	9	1	
1		5	5	6	5	5
1.5			4	4	3	3
2			3	2	2	2
3				1	1	1
4				1	1	1
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			6	7	9	
1		4	5	5	6	5
1.5			4	4	4	3
2			3	3	2	2
3				1	1	1
4				1	1	1
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				6	8	
1		3	4	5	5	6
1.5			4	4	4	4
2			3	3	3	2
3				1	1	1
4				1	1	1
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				5	7	
1		3	4	5	5	6
1.5			3	4	4	4
2			3	3	3	3
3				2	1	1
4				1	1	1
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					5	
1			3	3	4	5
1.5			3	3	4	4
2			2	3	3	3
3				2	2	2
4				1	1	1
5				1	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				3	3	4
1.5			2	2	3	3
2			2	2	3	3
3				2	2	2
4				2	1	1
5				1	1	1

Breakup γ of -3º

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	1	1	1	9	9	
1		5	5	5	5	
1.5			3			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	9	1	1	1	9	
1		5	5	5	5	5
1.5			3	3		
2			2			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	8	9	1	1	1	
1		5	5	5	5	5
1.5			3	3	3	3
2			2	2	2	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	7	8	9	9	1	
1		5	5	5	5	5
1.5			3	3	3	3
2			2	2	2	2
3				1	1	
4				1		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	6	7	8	9	1	
1		5	5	5	5	5
1.5			4	3	3	3
2			2	2	2	2
3				1	1	1
4				1		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	5	7	8	9	9	
1		5	5	5	5	5
1.5			4	3	3	3
2			3	2	2	2
3				1	1	1
4				1	1	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		5	6	7	8	
1		4	5	5	5	5
1.5			4	4	4	3
2			3	3	2	2
3				1	1	1
4				1	1	1
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			5	6	7	
1		3	4	5	5	5
1.5			3	4	4	4
2			3	3	3	3
3				2	1	1
4				1	1	1
5				1	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				5	6	
1		3	3	4	5	5
1.5			3	3	4	4
2			3	3	3	3
3				2	2	1
4				1	1	1
5				1	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				4	6	
1		3	3	4	5	5
1.5			3	3	4	4
2			3	3	3	3
3				2	2	2
4				1	1	1
5				1	1	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					4	
1			2	3	4	4
1.5			2	3	3	3
2			2	2	3	3
3				2	2	2
4				2	1	1
5				1	1	1

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				2	3	3
1.5			2	2	2	3
2			2	2	2	3
3				2	2	2
4				1	1	1
5				1	1	1

Breakup γ of -5.5º

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	1	1	1	1	1	
1		5	5	5	5	
1.5			3			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	9	9	1	1	1	
1		5	5	5	5	5
1.5			3	3		
2			2			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	7	8	9	9	1	
1		5	5	5	5	5
1.5			3	3	3	3
2			2	2	2	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	6	7	8	9	9	
1		5	5	5	5	5
1.5			4	3	3	3
2			3	2	2	2
3				1	1	
4				1		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	5	6	7	8	9	
1		5	5	5	5	5
1.5			4	4	3	3
2			3	2	2	2
3				1	1	1
4				1		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	6	7	8	9	
1		5	5	5	5	5
1.5			4	4	3	3
2			3	3	2	2
3				1	1	1
4				1	1	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		4	5	6	8	
1		4	4	5	5	5
1.5			4	4	4	4
2			3	3	3	3
3				2	1	1
4				1	1	1
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			4	5	6	
1		3	3	4	5	5
1.5			3	3	4	4
2			3	3	3	3
3				2	2	2
4				1	1	1
5				1	1	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				4	5	
1		2	3	4	4	5
1.5			3	3	4	4
2			2	3	3	3
3				2	2	2
4				1	1	1
5				1	1	1

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				4	5	
1		2	3	3	4	4
1.5			3	3	3	4
2			2	3	3	3
3				2	2	2
4				1	1	1
5				1	1	1

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					3	
1			2	2	3	3
1.5			2	2	3	3
2			2	2	2	3
3				2	2	2
4				1	1	1
5				1	1	1

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				2	2	3
1.5			1	2	2	2
2			1	2	2	2
3				1	2	2
4				1	1	1
5				1	1	1

Table D-29. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

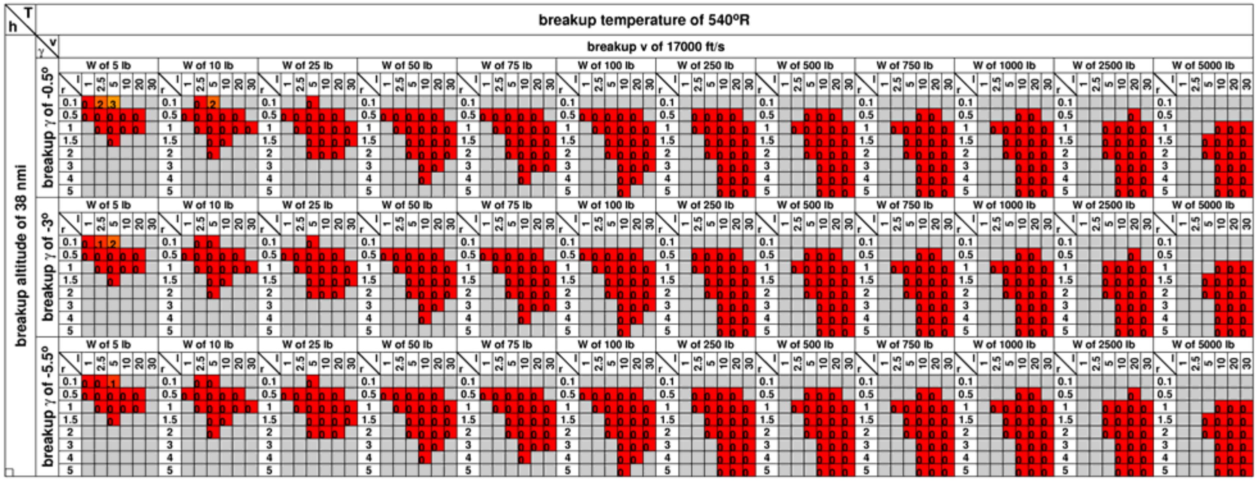


Table D-30. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

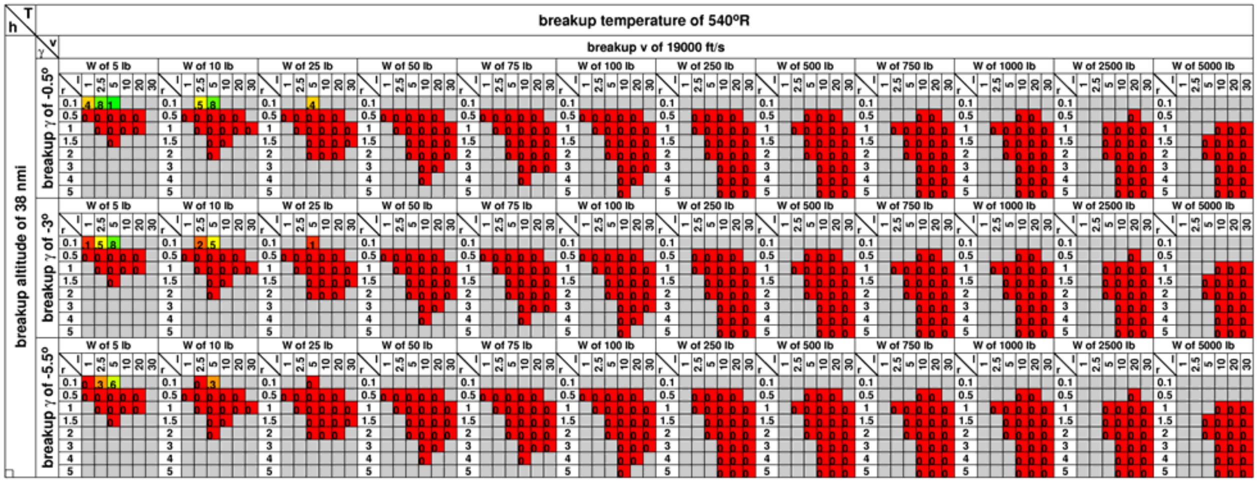


Table D-31. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

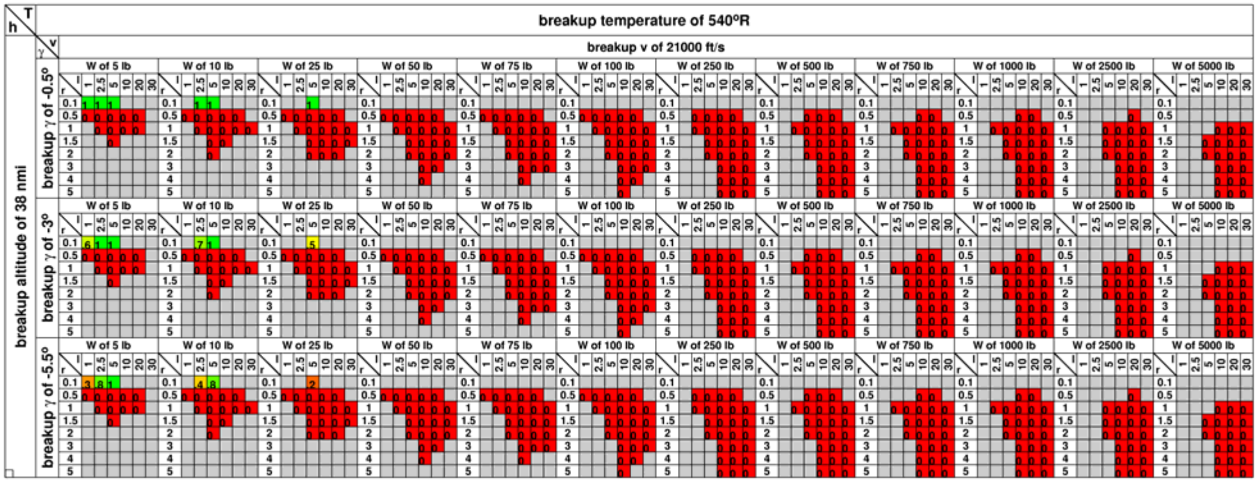


Table D-32. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

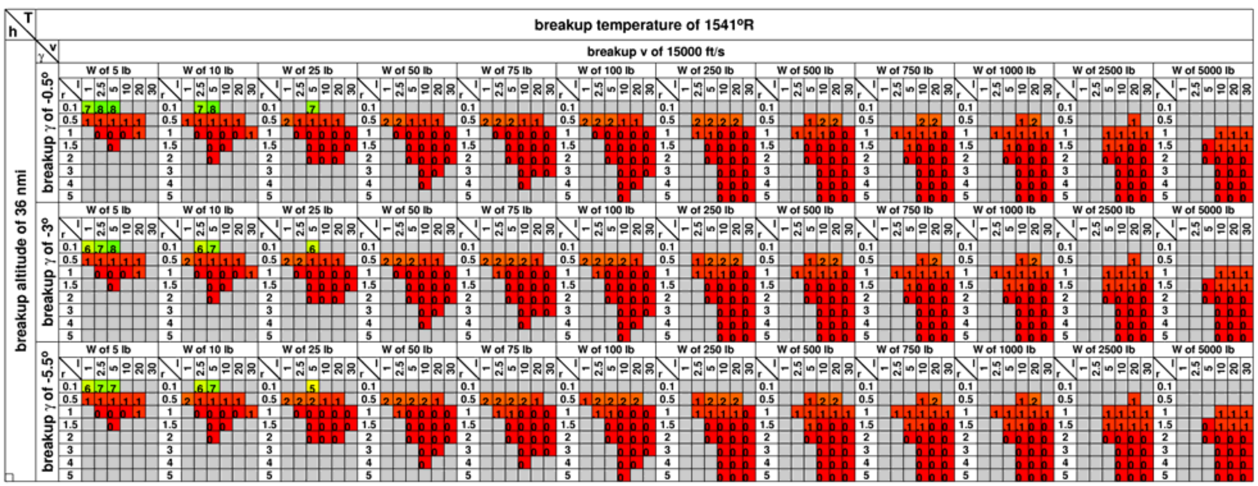


Table D-33. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h: breakup altitude of 36 nmi; T: breakup temperature of 1541ºR; v: breakup v of 17000 ft/s

breakup γ of -0.5°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	3	3	3	3	3	
1		1	1	1	2	
1.5			1			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	3	3	3	3	3	
1		1	1	1	1	2
1.5			1	1		
2			0			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	4	3	3	3	3	
1		1	1	1	1	1
1.5			1	1	1	1
2			0	0	0	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	3	4	3	3	3	
1		1	1	1	1	1
1.5			1	1	1	1
2			0	0	0	0
3				0	0	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	3	4	4	3	3	
1		2	1	1	1	1
1.5			1	1	1	1
2			0	0	0	0
3				0	0	0
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	3	3	4	3	3	
1		2	1	1	1	1
1.5			1	1	1	1
2			0	0	0	0
3				0	0	0
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		3	3	4	4	
1		2	2	2	1	1
1.5			1	1	1	1
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			2	3	3	
1		2	2	2	2	1
1.5			1	1	1	1
2			1	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				3	3	
1		1	2	2	2	2
1.5			1	1	1	1
2			1	1	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				2	3	
1		1	2	2	2	2
1.5			1	1	1	1
2			1	1	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					2	
1			1	1	2	2
1.5			1	1	1	1
2			1	1	1	1
3				0	0	0
4				0	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				1	1	2
1.5			1	1	1	1
2			1	1	1	1
3				1	0	0
4				0	0	0
5				0	0	0

breakup γ of -3°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	9	1	1			
0.5	3	3	3	3	3	
1		1	1	1	2	
1.5			1			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	4	3	3	3	3	
1		1	1	1	1	2
1.5			1	1		
2			0			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			9			
0.5	3	3	3	3	3	
1		1	1	1	1	1
1.5			1	1	1	1
2			0	0	0	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	3	3	3	3	3	
1		2	1	1	1	1
1.5			1	1	1	1
2			0	0	0	0
3				0	0	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	3	3	3	3	3	
1		2	2	1	1	1
1.5			1	1	1	1
2			0	0	0	0
3				0	0	0
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	2	3	3	3	3	
1		2	2	1	1	1
1.5			1	1	1	1
2			0	0	0	0
3				0	0	0
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		2	3	3	3	
1		2	2	2	2	1
1.5			1	1	1	1
2			1	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			2	3	3	
1		2	2	2	2	2
1.5			1	1	1	1
2			1	1	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				2	3	
1		1	2	2	2	2
1.5			1	1	1	1
2			1	1	1	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				2	3	
1		1	1	2	2	2
1.5			1	1	1	1
2			1	1	1	1
3				0	0	0
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					2	
1			1	1	2	2
1.5			1	1	1	1
2			1	1	1	1
3				1	0	0
4				0	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				1	1	1
1.5			1	1	1	1
2			1	1	1	1
3				1	1	0
4				0	0	0
5				0	0	0

breakup γ of -5.5°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	8	1	1			
0.5	3	3	3	3	3	
1		1	1	1	2	
1.5			1			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		9	1			
0.5	4	3	3	3	3	
1		1	1	1	1	2
1.5			1	1		
2			0			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			8			
0.5	3	3	3	3	3	
1		2	1	1	1	1
1.5			1	1	1	1
2			0	0	0	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	3	3	3	3	3	
1		2	2	1	1	1
1.5			1	1	1	1
2			0	0	0	0
3				0	0	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	2	3	3	3	3	
1		2	2	2	1	1
1.5			1	1	1	1
2			0	0	0	0
3				0	0	0
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	2	3	3	3	3	
1		2	2	2	1	1
1.5			1	1	1	1
2			0	0	0	0
3				0	0	0
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		2	3	3	3	
1		2	2	2	2	2
1.5			1	1	1	1
2			1	1	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			2	2	3	
1		1	2	2	2	2
1.5			1	1	1	1
2			1	1	1	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				2	3	
1		1	1	2	2	2
1.5			1	1	1	1
2			1	1	1	1
3				0	0	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				2	2	
1		1	1	2	2	2
1.5			1	1	1	1
2			1	1	1	1
3				0	0	0
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					2	
1			1	1	1	2
1.5			1	1	1	1
2			1	1	1	1
3				1	1	0
4				0	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				1	1	1
1.5			1	1	1	1
2			1	1	1	1
3				1	1	1
4				0	0	0
5				0	0	0

Table D-34. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h: breakup altitude of 36 nmi; T: breakup temperature of 1541ºR; v: breakup v of 19000 ft/s

breakup γ of -0.5°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	6	6	6	5	6	
1		3	3	3	4	
1.5			2			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	6	6	6	5	5	
1		3	3	3	3	3
1.5			2	2		
2			1			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	6	6	6	6	5	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	5	6	6	6	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	1
3				1	1	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	5	6	6	6	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	1
3				1	1	1
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	5	6	6	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	1
3				1	1	1
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		4	5	6	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	1
3				1	1	1
4				0	0	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			4	5	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			2	1	1	1
3				1	1	1
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				4	5	
1		2	3	3	3	3
1.5			2	2	2	2
2			2	2	1	1
3				1	1	1
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				4	5	
1		2	3	3	3	3
1.5			2	2	2	2
2			2	2	1	1
3				1	1	1
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					3	
1			2	2	3	3
1.5			2	2	2	2
2			2	2	2	2
3				1	1	1
4				1	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				2	2	3
1.5			1	2	2	2
2			1	1	2	2
3				1	1	1
4				1	1	1
5				1	0	0

breakup γ of -3°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	6	6	6	6	6	
1		3	3	3	4	
1.5			2			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	6	6	6	6	6	
1		3	3	3	3	3
1.5			2	2		
2			1			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	5	6	6	6	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	5	5	6	6	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	1
3				1	1	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	5	5	6	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	1
3				1	1	1
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	5	5	6	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	1
3				1	1	1
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		3	4	5	5	
1		3	3	3	3	3
1.5			2	2	2	2
2			2	1	1	1
3				1	1	1
4				0	0	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			3	4	5	
1		2	3	3	3	3
1.5			2	2	2	2
2			2	2	1	1
3				1	1	1
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				3	4	
1		2	2	3	3	3
1.5			2	2	2	2
2			2	2	2	1
3				1	1	1
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				3	4	
1		2	2	3	3	3
1.5			2	2	2	2
2			2	2	2	2
3				1	1	1
4				1	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					3	
1			2	2	2	3
1.5			1	2	2	2
2			1	2	2	2
3				1	1	1
4				1	1	1
5				1	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				1	2	2
1.5			1	1	2	2
2			1	1	2	2
3				1	1	1
4				1	1	1
5				1	1	0

breakup γ of -5.5°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	1	1	1			
0.5	6	6	6	6	6	
1		3	3	3	4	
1.5			2			
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		1	1			
0.5	6	6	6	6	6	
1		3	3	3	3	3
1.5			2	2		
2			1			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	5	5	6	6	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	5	5	6	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	1
3				1	1	
4				0		
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	4	4	5	5	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	1
3				1	1	1
4				0		
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	3	4	5	5	6	
1		3	3	3	3	3
1.5			2	2	2	2
2			1	1	1	1
3				1	1	1
4				0	0	
5				0		

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		3	4	4	5	
1		3	3	3	3	3
1.5			2	2	2	2
2			2	2	1	1
3				1	1	1
4				0	0	0
5				0	0	0

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			3	4	4	
1		2	2	3	3	3
1.5			2	2	2	2
2			2	2	2	1
3				1	1	1
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				3	4	
1		2	2	3	3	3
1.5			2	2	2	2
2			2	2	2	2
3				1	1	1
4				1	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				3	3	
1		2	2	2	3	3
1.5			2	2	2	2
2			2	2	2	2
3				1	1	1
4				1	1	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					2	
1			1	2	2	2
1.5			1	2	2	2
2			1	1	2	2
3				1	1	1
4				1	1	1
5				1	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				1	2	2
1.5			1	1	2	2
2			1	1	1	2
3				1	1	1
4				1	1	1
5				1	1	1

Table D-35. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

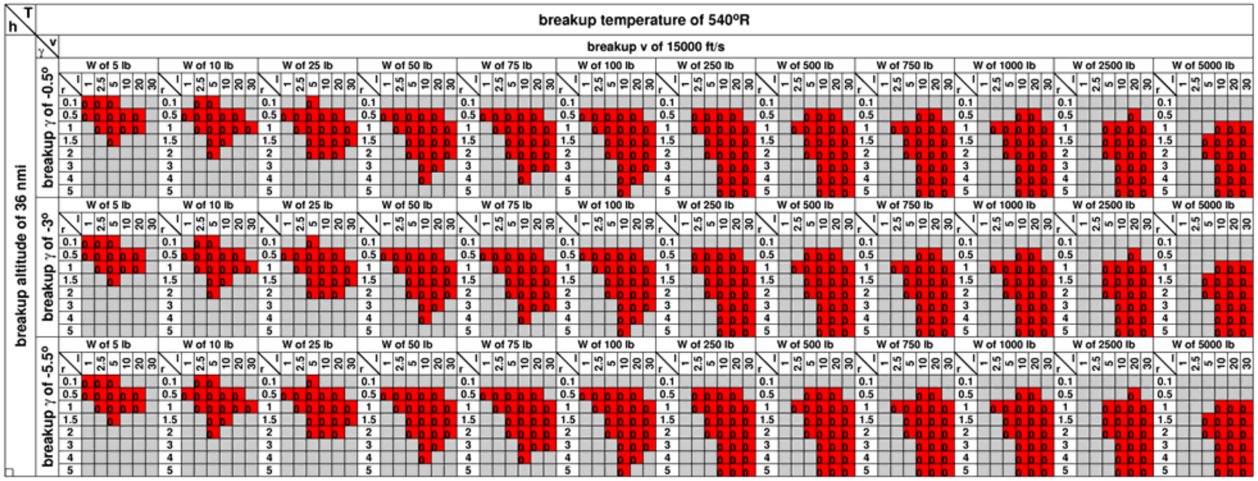


Table D-36. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

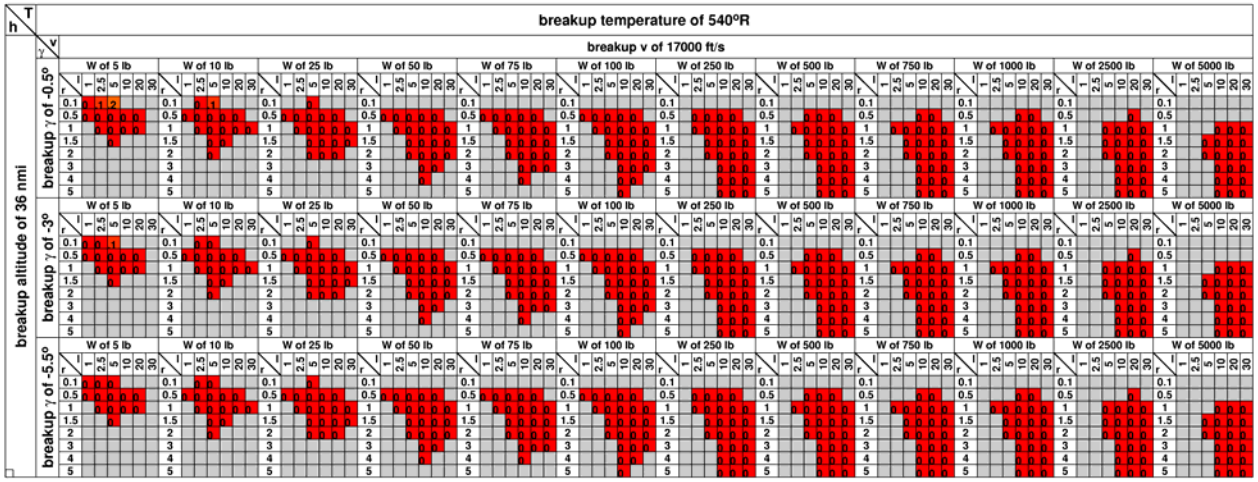


Table D-37. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

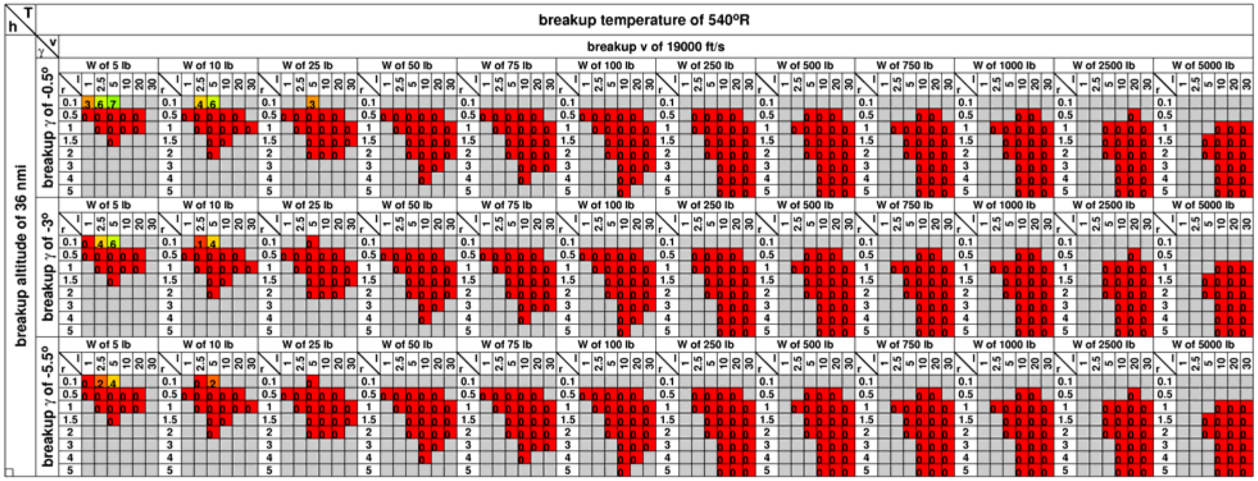


Table D-38. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

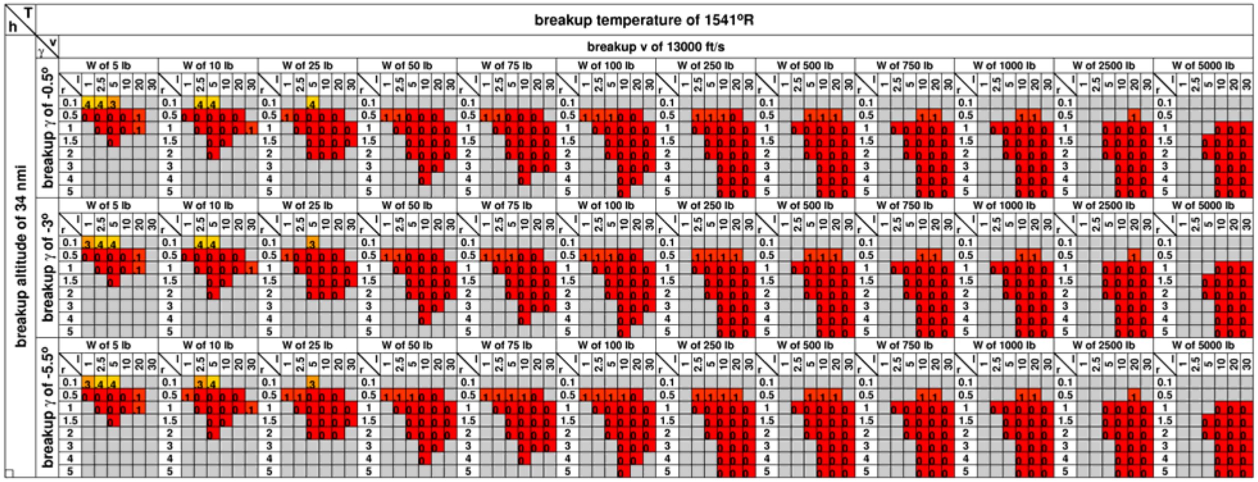


Table D-39. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

breakup temperature of 1541°R; breakup v of 15000 ft/s; breakup altitude of 34 nmi

breakup γ of -0.5°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	7	7	7					7	7						6																					
0.5	1	1	1	1	2		1	1	1	1	1		2	2	1	1	1		2	2	2	1	1		2	2	2	1	1		2	2	2	2	1	
1		0	0	1	2			0	0	0	1	1		0	0	0	0	0		0	0	0	0	0		1	0	0	0	0		1	0	0	0	0
1.5			0						0	0					0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2									0						0	0	0				0	0	0	0			0	0	0	0			0	0	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		2	2	2	2				2	2	2					2	2					1	2						1							
1		1	1	1	0	0		1	1	1	1	0		1	1	1	1	1		1	1	1	1	1			1	1	1	1				1	1	1
1.5			0	0	0	0			0	0	0	0			1	0	0	0			1	0	0	0			1	1	1	0			0	1	1	1
2			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
3				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

breakup γ of -3°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	6	7	7					6	7						6																					
0.5	1	1	1	1	2		2	1	1	1	1		2	2	2	1	1		2	2	2	2	1		2	2	2	2	1		2	2	2	2	2	
1		0	0	1	2			0	0	0	1	1		1	0	0	0	0		1	1	0	0	0		1	1	0	0	0		1	1	1	0	0
1.5			0						0	0					0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2									0						0	0	0				0	0	0	0			0	0	0	0			0	0	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		1	2	2	2				1	2	2					1	2					1	2						1							
1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1			1	1	1	1				1	1	1
1.5			0	0	0	0			1	0	0	0			1	0	0	0			1	1	0	0			1	1	1	1			0	1	1	1
2			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
3				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

breakup γ of -5.5°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	5	6	7					6	6						5																					
0.5	2	1	1	1	2		2	2	1	1	1		2	2	2	1	1		2	2	2	2	1		2	2	2	2	2		1	2	2	2	2	
1		0	0	1	2			0	0	0	1	1		1	0	0	0	0		1	1	0	0	0		1	1	1	0	0		1	1	1	1	0
1.5			0						0	0					0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
2									0						0	0	0				0	0	0	0			0	0	0	0			0	0	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		1	2	2	2				1	2	2					1	2					1	2						1							
1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1	1			1	1	1	1				1	1	1
1.5			0	0	0	0			1	0	0	0			1	1	0	0			1	1	0	0			1	1	1	1			0	1	1	1
2			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0			0	0	0	0
3				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

Table D-40. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

breakup temperature of 1541°R; breakup v of 17000 ft/s; breakup altitude of 34 nmi

breakup γ of -0.5°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	1	1	1					1	1						1																					
0.5	3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3	
1		1	1	2	3			1	1	1	2	3		1	1	1	1	1		2	1	1	1	1		2	1	1	1	1		2	2	1	1	1
1.5			1						1	1					1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
2									1						0	1	1				0	0	1	1			0	0	0	1			0	0	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		3	3	3	3				2	3	3					3	3					2	3						2							
1		2	2	2	1	1		2	2	2	2	1		1	2	2	2	2		1	2	2	2	2			1	1	2	2				1	1	2
1.5			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
2			1	1	0	0			1	1	1	0			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
3				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				1	1	0
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

breakup γ of -3°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	9	1	1					9	1						9																					
0.5	3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		2	3	3	3	3	
1		1	1	2	3			1	1	1	2	3		2	1	1	1	1		2	2	1	1	1		2	2	2	1	1		2	2	2	1	1
1.5			1						1	1					1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
2									1						0	1	1				1	0	1	1			1	1	0	1			1	1	0	0
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		2	3	3	3				2	3	3					2	3					2	3						2							
1		2	2	2	2	2		2	2	2	2	2		1	2	2	2	2		1	1	2	2	2			1	1	2	2				1	1	1
1.5			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
2			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
3				0	0	0				0	0	0				0	0	0				0	0	0				1	0	0				1	1	1
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

breakup γ of -5.5°

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	8	1	1					8	1						8																					
0.5	3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		3	3	3	3	3		2	3	3	3	3		2	3	3	3	3	
1		1	1	2	3			1	1	1	2	3		2	2	1	1	1		2	2	2	1	1		2	2	2	1	1		2	2	2	2	1
1.5			1						1	1					1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
2									1						1	1	1				1	1	1	1			1	1	1	1			1	1	1	1
3																						0	0					0	0	0				0	0	0
4																						0						0						0	0	
5																																		0		

r \ l	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		2	2	3	3				2	2	3					2	3					2	2						2							
1		2	2	2	2	2		1	2	2	2	2		1	1	2	2	2		1	1	2	2	2			1	1	1	2				1	1	1
1.5			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
2			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1			1	1	1	1
3				0	0	0				0	0	0				0	0	0				0	0	0				1	1	0				1	1	1
4				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0
5				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0				0	0	0

Table D-41. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h: breakup altitude of 34 nmi; T: breakup temperature of 540ºR; v: breakup v of 13000 ft/s

breakup γ of -0.5º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	p	p	p					p	p						p																						
0.5	p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p	
1		p	p	p	p			p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p
1.5			p						p	p					p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2									p						p	p	p				p	p	p	p			p	p	p	p			p	p	p	p
3																						p	p					p	p	p				p	p	p
4																						p						p						p	p	
5																																		p		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		p	p	p	p				p	p	p					p	p					p	p						p							
1		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p			p	p	p	p				p	p	p
1.5			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
3				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
4				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
5				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p

breakup γ of -3º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	p	p	p					p	p						p																						
0.5	p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p	
1		p	p	p	p			p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p
1.5			p						p	p					p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2									p						p	p	p				p	p	p	p			p	p	p	p			p	p	p	p
3																						p	p					p	p	p				p	p	p
4																						p						p						p	p	
5																																		p		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		p	p	p	p				p	p	p					p	p					p	p						p							
1		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p			p	p	p	p				p	p	p
1.5			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
3				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
4				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
5				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p

breakup γ of -5.5º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	p	p	p					p	p						p																						
0.5	p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p	
1		p	p	p	p			p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p
1.5			p						p	p					p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2									p						p	p	p				p	p	p	p			p	p	p	p			p	p	p	p
3																						p	p					p	p	p				p	p	p
4																						p						p						p	p	
5																																		p		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		p	p	p	p				p	p	p					p	p					p	p						p							
1		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p			p	p	p	p				p	p	p
1.5			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
3				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
4				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
5				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p

Table D-42. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h: breakup altitude of 34 nmi; T: breakup temperature of 540ºR; v: breakup v of 15000 ft/s

breakup γ of -0.5º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	p	p	p					p	p						p																						
0.5	p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p	
1		p	p	p	p			p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p
1.5			p						p	p					p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2									p						p	p	p				p	p	p	p			p	p	p	p			p	p	p	p
3																						p	p					p	p	p				p	p	p
4																						p						p						p	p	
5																																		p		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		p	p	p	p				p	p	p					p	p					p	p						p							
1		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p			p	p	p	p				p	p	p
1.5			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
3				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
4				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
5				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p

breakup γ of -3º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	p	p	p					p	p						p																						
0.5	p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p	
1		p	p	p	p			p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p
1.5			p						p	p					p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2									p						p	p	p				p	p	p	p			p	p	p	p			p	p	p	p
3																						p	p					p	p	p				p	p	p
4																						p						p						p	p	
5																																		p		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		p	p	p	p				p	p	p					p	p					p	p						p							
1		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p			p	p	p	p				p	p	p
1.5			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
3				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
4				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
5				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p

breakup γ of -5.5º

	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	p	p	p					p	p						p																						
0.5	p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p	
1		p	p	p	p			p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p
1.5			p						p	p					p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2									p						p	p	p				p	p	p	p			p	p	p	p			p	p	p	p
3																						p	p					p	p	p				p	p	p
4																						p						p						p	p	
5																																		p		

	W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
r \ l	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1																																				
0.5		p	p	p	p				p	p	p					p	p					p	p						p							
1		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p		p	p	p	p	p			p	p	p	p				p	p	p
1.5			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
2			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p			p	p	p	p
3				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
4				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p
5				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p				p	p	p

Table D-43. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

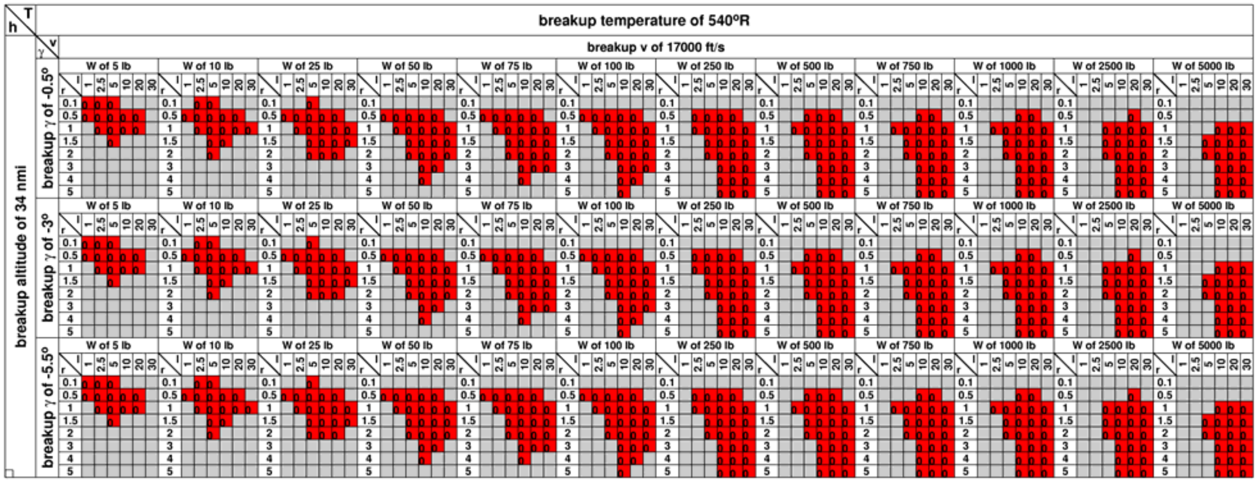


Table D-44. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

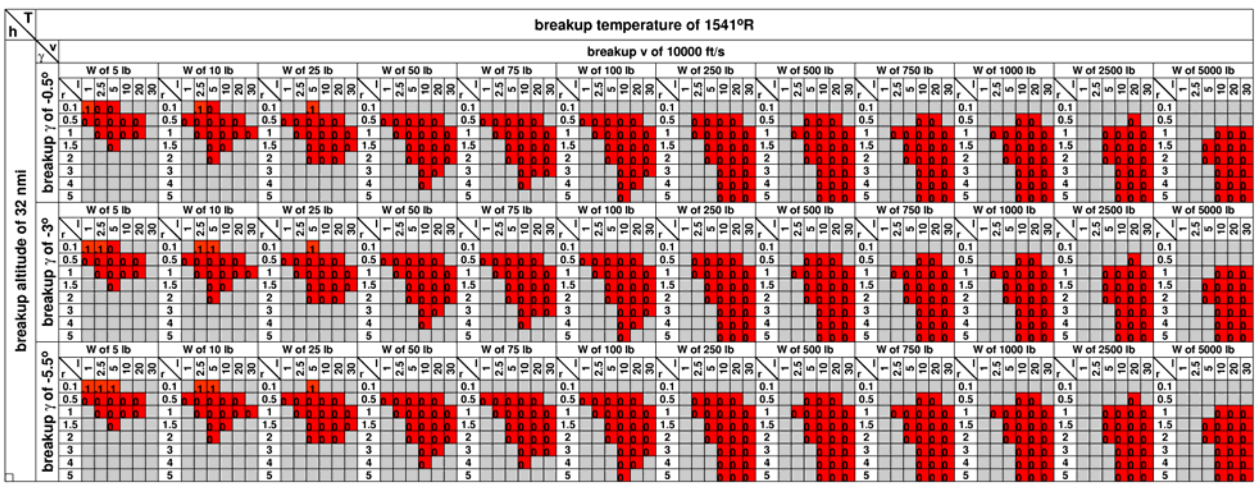


Table D-45. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

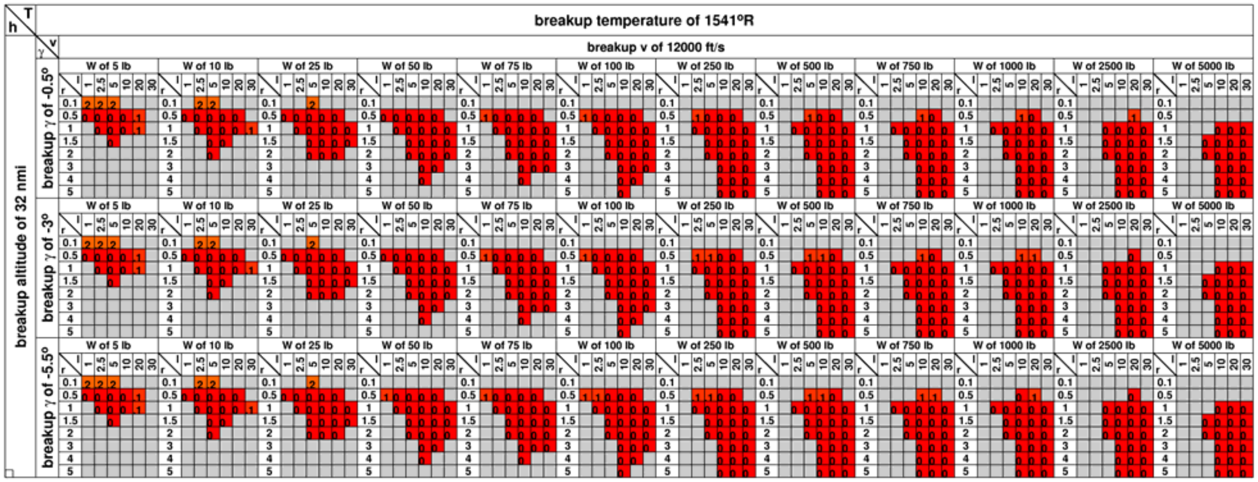


Table D-46. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

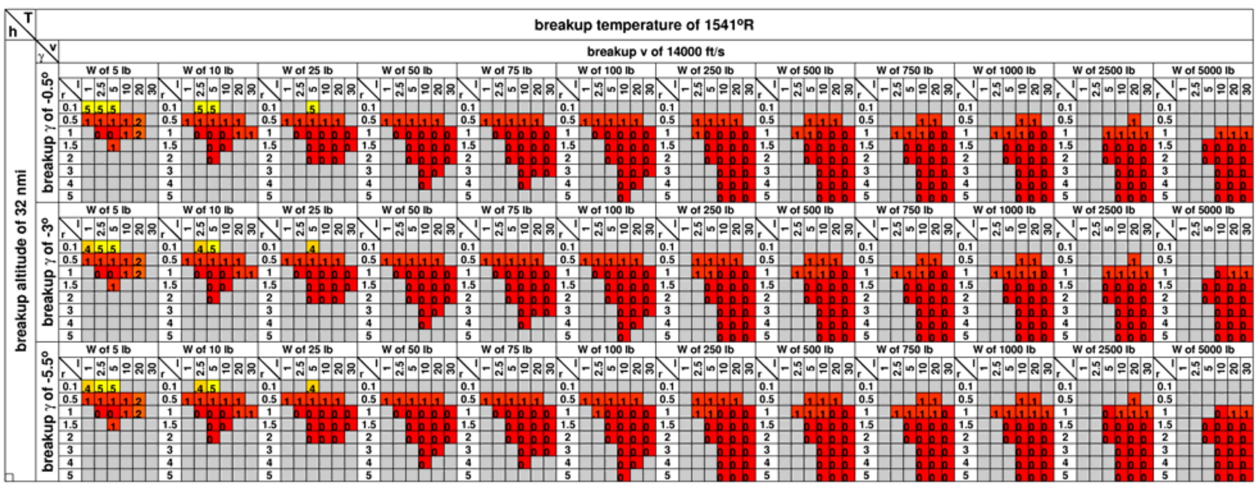


Table D-47. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h \ T: breakup temperature of 540ºR

γ \ v: breakup v of 10000 ft/s

h: breakup altitude of 32 nmi

breakup γ of -0.5º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	D	D	D					D	D						D																																																									
0.5	D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D					D	D					D	D						D							
1		D	D	D	D			D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D
1.5			D						D	D					D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
2									D						D	D	D				D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
3																						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
4																						D						D						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
5																																		D						D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D

breakup γ of -3º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	D	D	D					D	D						D																																																										
0.5	D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D					D	D					D	D						D							
1		D	D	D	D			D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D
1.5			D						D	D					D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
2									D						D	D	D				D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
3																						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
4																						D						D						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
5																																		D						D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D

breakup γ of -5.5º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	D	D	D					D	D						D																																																											
0.5	D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D					D	D					D	D						D							
1		D	D	D	D			D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D
1.5			D						D	D					D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
2									D						D	D	D				D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
3																						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
4																						D						D						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
5																																		D						D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D

Table D-48. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

h \ T: breakup temperature of 540ºR

γ \ v: breakup v of 12000 ft/s

h: breakup altitude of 32 nmi

breakup γ of -0.5º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	D	D	D					D	D						D																																																											
0.5	D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D					D	D					D	D						D							
1		D	D	D	D			D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D
1.5			D						D	D					D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
2									D						D	D	D				D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
3																						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
4																						D						D						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
5																																		D						D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D

breakup γ of -3º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	D	D	D					D	D						D																																																												
0.5	D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D					D	D					D	D						D							
1		D	D	D	D			D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D
1.5			D						D	D					D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
2									D						D	D	D				D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
3																						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
4																						D						D						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
5																																		D						D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D

breakup γ of -5.5º

r \ l	W of 5 lb						W of 10 lb						W of 25 lb						W of 50 lb						W of 75 lb						W of 100 lb						W of 250 lb						W of 500 lb						W of 750 lb						W of 1000 lb						W of 2500 lb						W of 5000 lb					
	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30	1	2.5	5	10	20	30
0.1	D	D	D					D	D						D																																																												
0.5	D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D					D	D					D	D						D							
1		D	D	D	D			D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D		D	D	D	D	D			D	D	D	D				D	D	D
1.5			D						D	D					D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
2									D						D	D	D				D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D			D	D	D	D
3																						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
4																						D						D						D	D					D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D
5																																		D						D	D	D				D	D	D				D	D	D				D	D	D				D	D	D				D	D	D

Table D-49. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

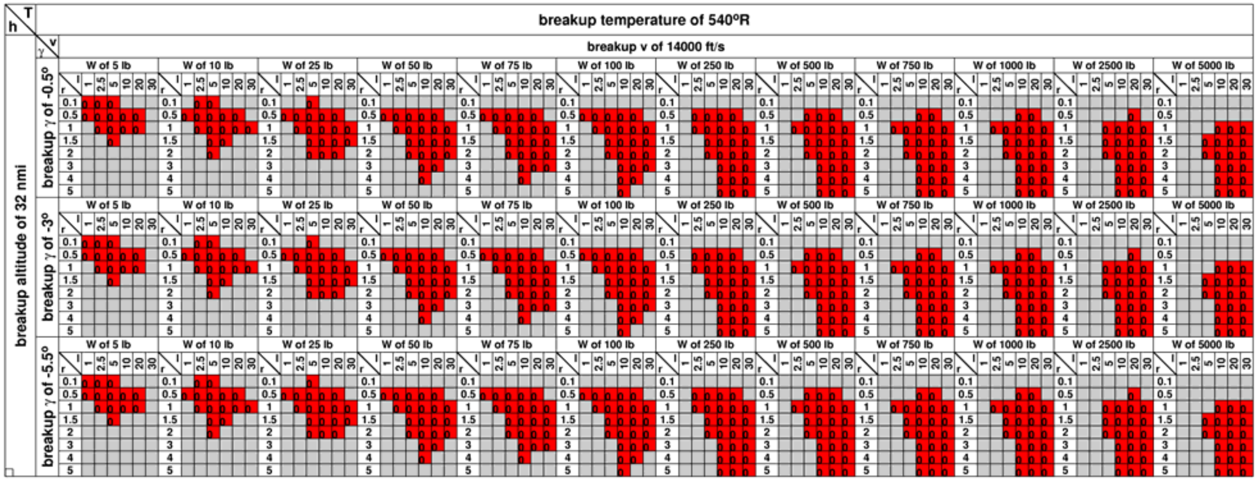


Table D-50. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

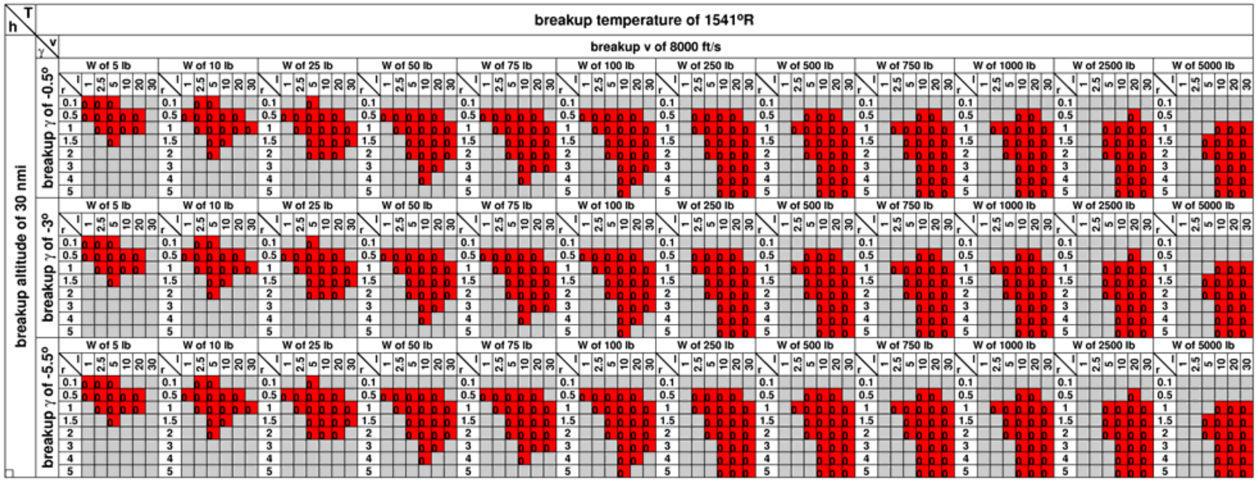


Table D-51. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

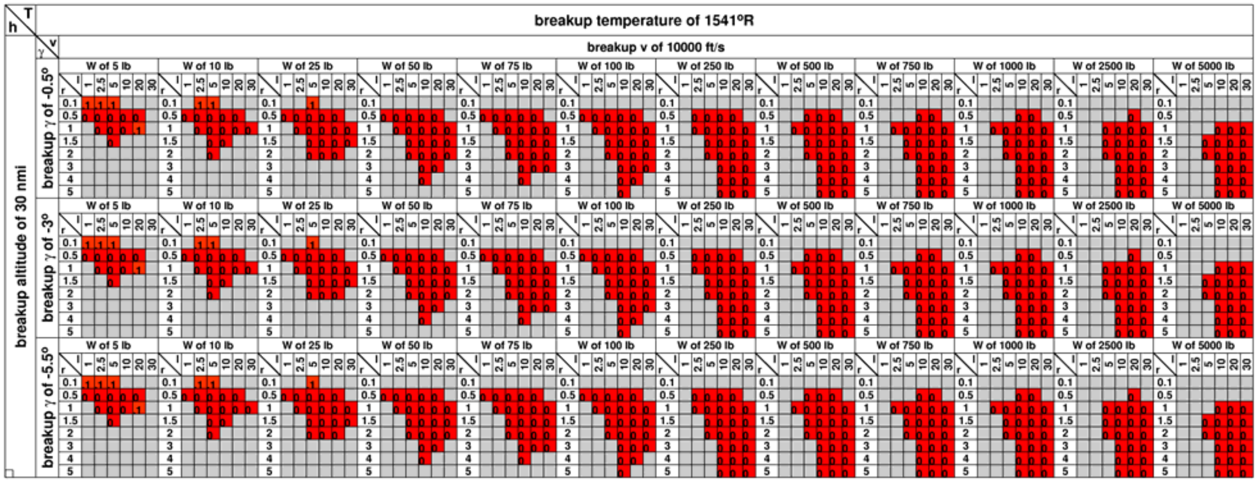


Table D-52. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

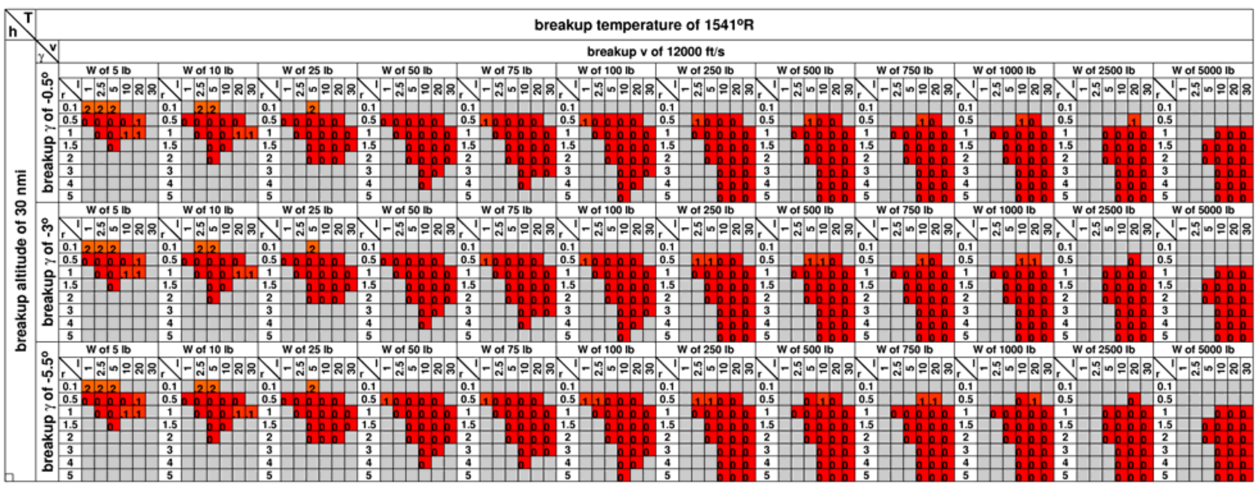


Table D-53. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

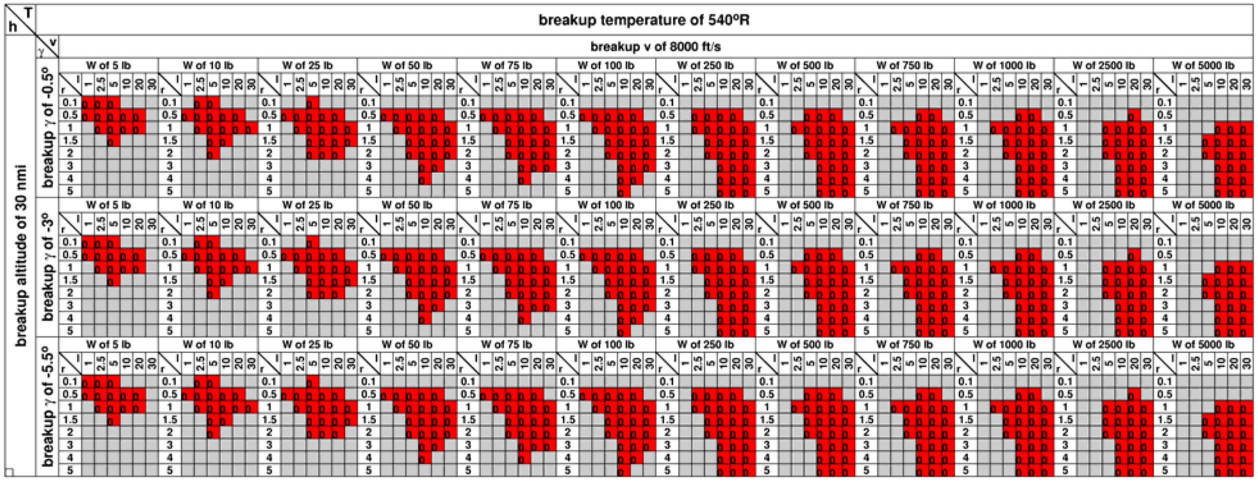


Table D-54. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

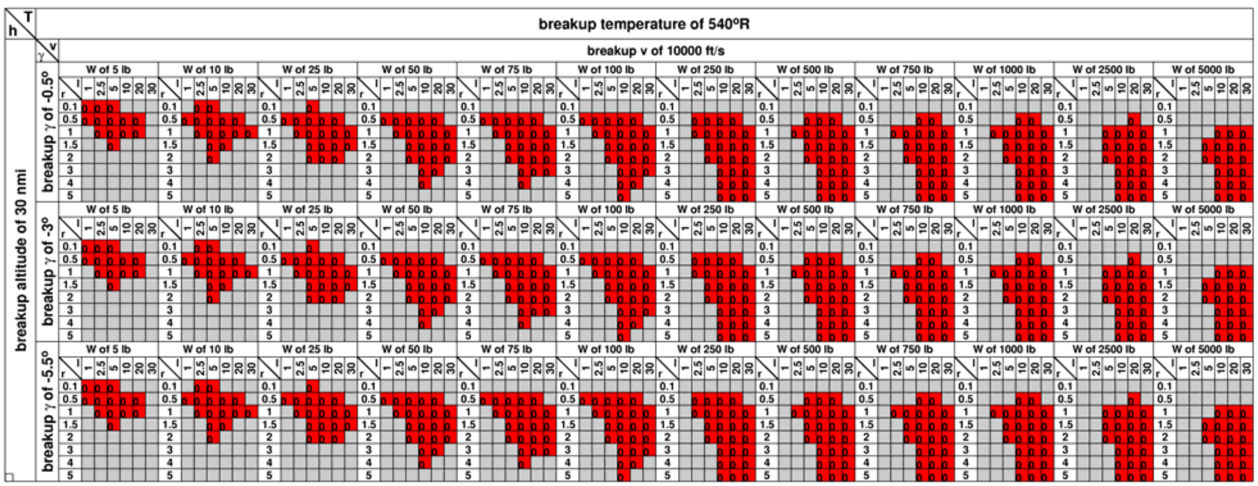


Table D-55. Aluminum 2024-T8xx Tumbling Hollow Cylinder Survivability

breakup temperature of 540ºR

breakup v of 12000 ft/s

breakup altitude of 30 nmi

breakup γ of -0.5°

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	p	p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	
	1.5			p			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p		
	2			p			
	3						
	4						
	5						
W of 25 lb	0.1			p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4				p		
	5						
W of 75 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p		
	5						
W of 100 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	
	5				p		
W of 250 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 500 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 750 lb	0.1						
	0.5				p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 1000 lb	0.1						
	0.5				p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 2500 lb	0.1						
	0.5					p	
	1			p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 5000 lb	0.1						
	0.5						
	1				p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p

breakup γ of -3°

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	p	p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	
	1.5			p			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p		
	2			p			
	3						
	4						
	5						
W of 25 lb	0.1			p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4				p		
	5						
W of 75 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p		
	5						
W of 100 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	
	5				p		
W of 250 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 500 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 750 lb	0.1						
	0.5				p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 1000 lb	0.1						
	0.5				p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 2500 lb	0.1						
	0.5					p	
	1			p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 5000 lb	0.1						
	0.5						
	1				p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p

breakup γ of -5.5°

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	p	p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	
	1.5			p			
	2						
	3						
	4						
	5						
W of 10 lb	0.1		p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p		
	2			p			
	3						
	4						
	5						
W of 25 lb	0.1			p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4				p		
	5						
W of 75 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p		
	5						
W of 100 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	
	5				p		
W of 250 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 500 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 750 lb	0.1						
	0.5				p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 1000 lb	0.1						
	0.5				p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 2500 lb	0.1						
	0.5					p	
	1			p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 5000 lb	0.1						
	0.5						
	1				p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p

D.2 Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability Table

Table D-56. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

h \ T: breakup altitude of 46 nmi; breakup temperature of 1541ºR

γ \ v: breakup v of 23000 ft/s

breakup γ of -0.5º

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	0	0	0			
0.5	0	0	0	0	0	
1		0	0			
1.5						
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1	0	0	0			
0.5	0	0	0	0	0	
1		0	0	0		
1.5			0			
2						
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1		0	0			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0		
2			0			
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1			0			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0		
3						
4						
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	
3				0		
4						
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0		
4						
5						

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	
5				0		

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					0	
1			0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

breakup γ of -3º

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	0	0	0			
0.5	0	0	0	0	0	
1		0	0			
1.5						
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1	1	0	0			
0.5	0	0	0	0	0	
1		0	0	0		
1.5			0			
2						
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1		1	0			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0		
2			0			
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0		
3						
4						
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	
3				0		
4						
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0		
4						
5						

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	
5				0		

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					0	
1			0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

breakup γ of -5.5º

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	0	0	0			
0.5	0	0	0	0	0	
1		0	0			
1.5						
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1	1	0	0			
0.5	0	0	0	0	0	
1		0	0	0		
1.5			0			
2						
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1		1	0			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0		
2			0			
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1			1			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0		
3						
4						
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1			0			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	
3				0		
4						
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0		
4						
5						

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	
5				0		

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5				0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					0	
1			0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

Table D-57. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

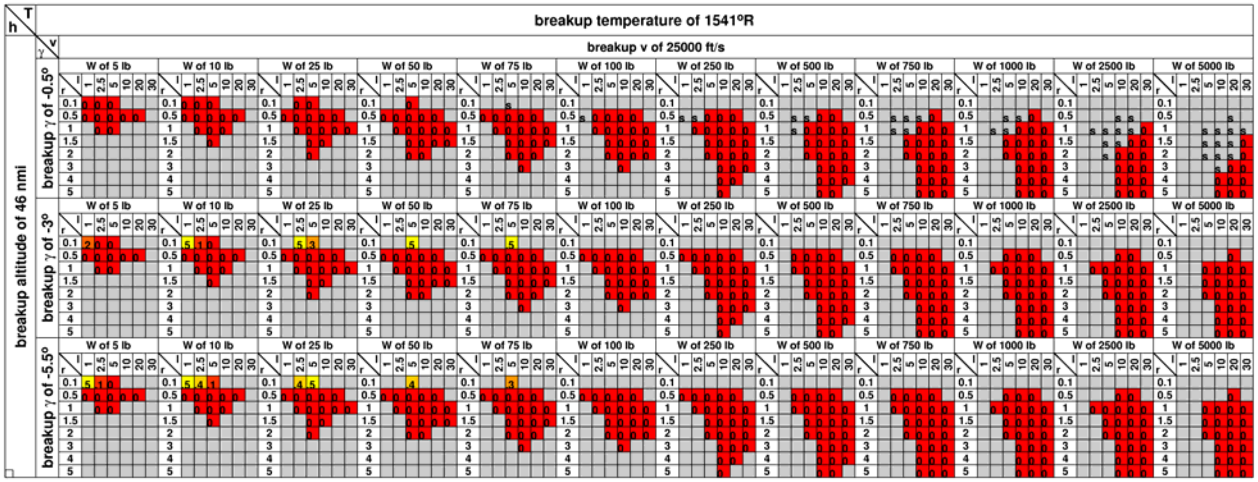


Table D-58. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

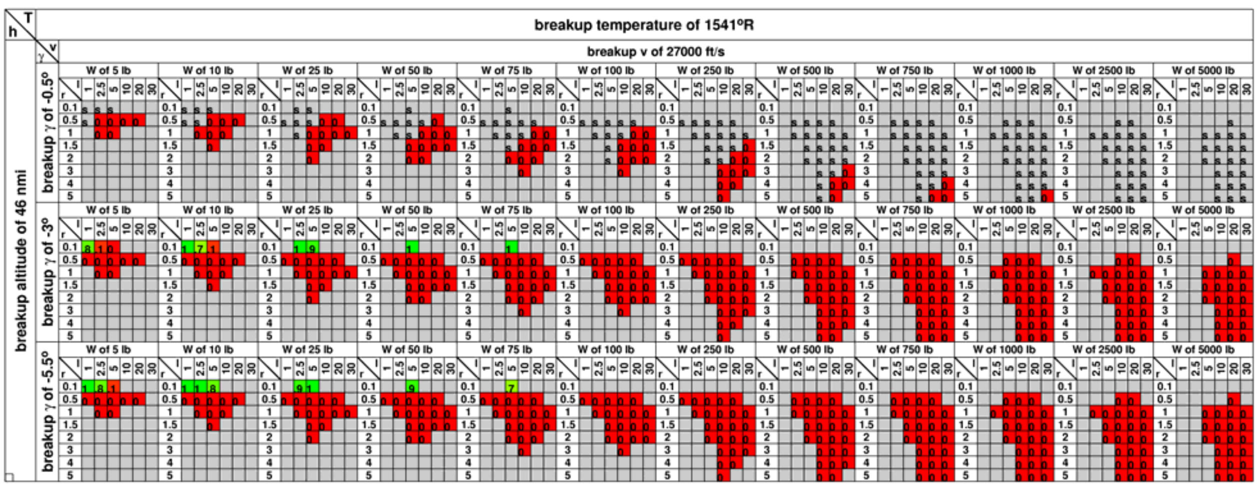


Table D-59. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

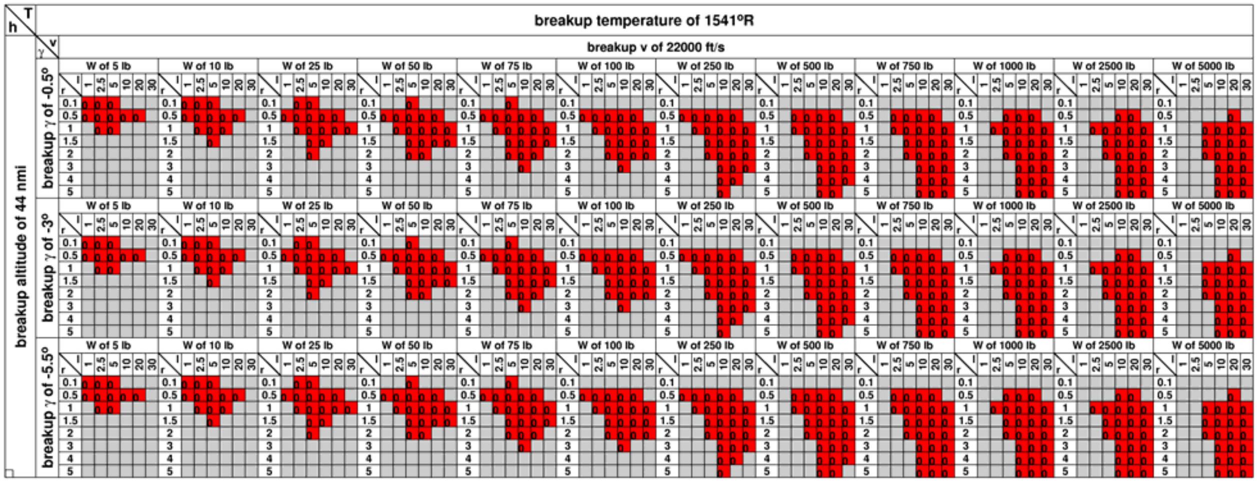


Table D-60. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

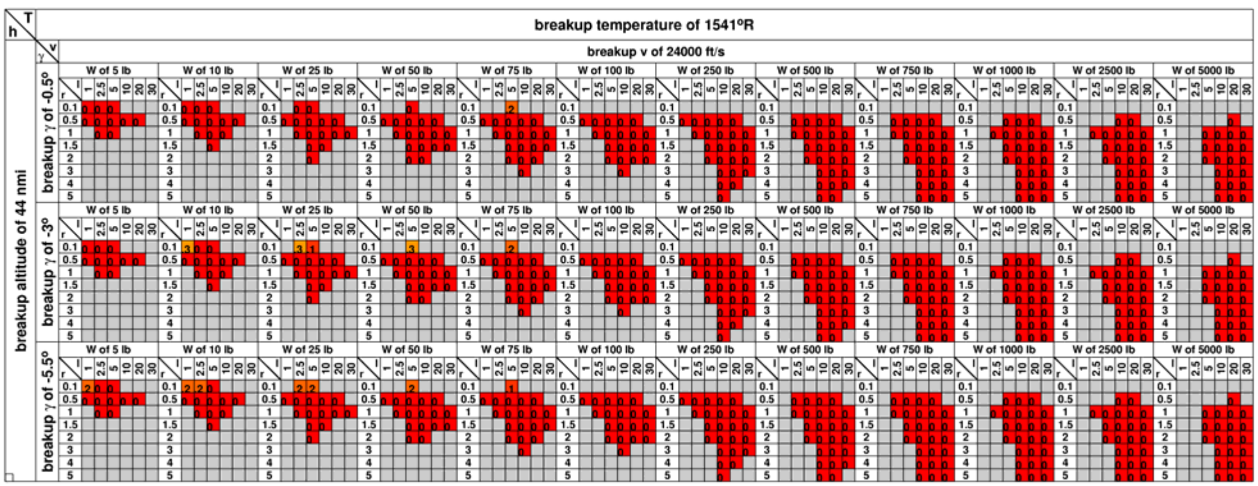


Table D-61. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

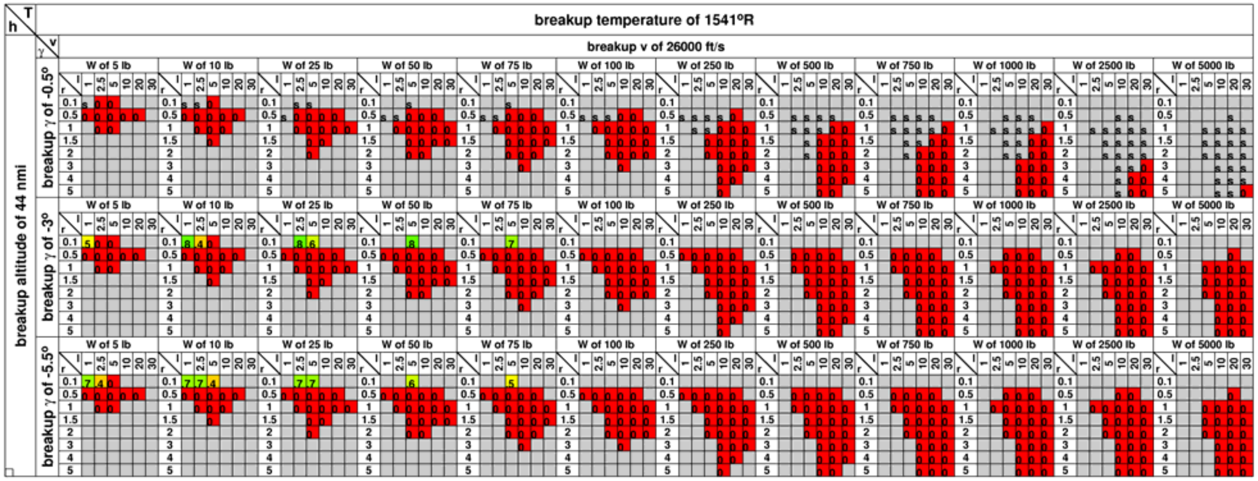


Table D-62. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

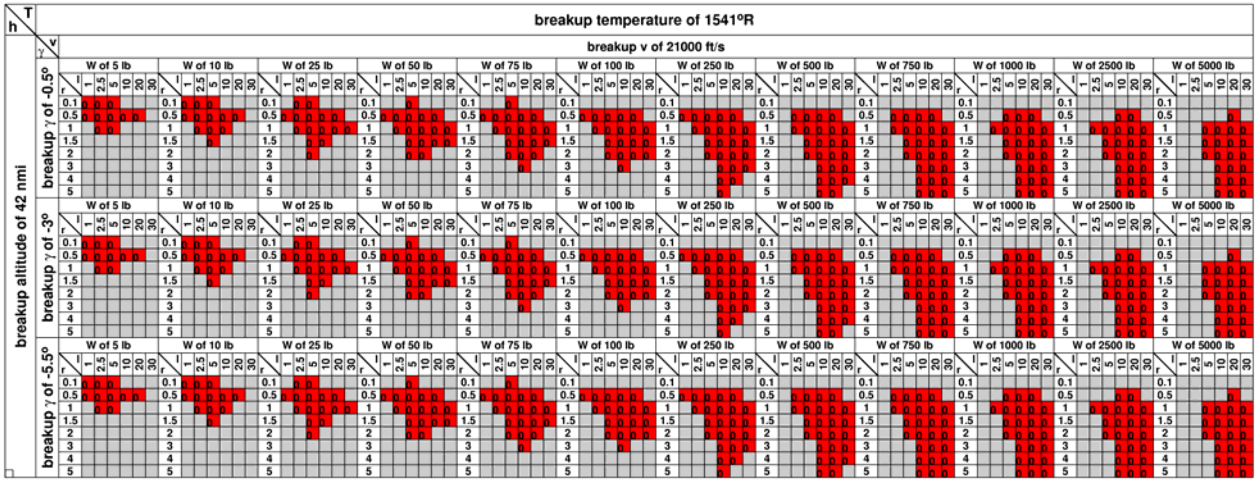


Table D-63. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

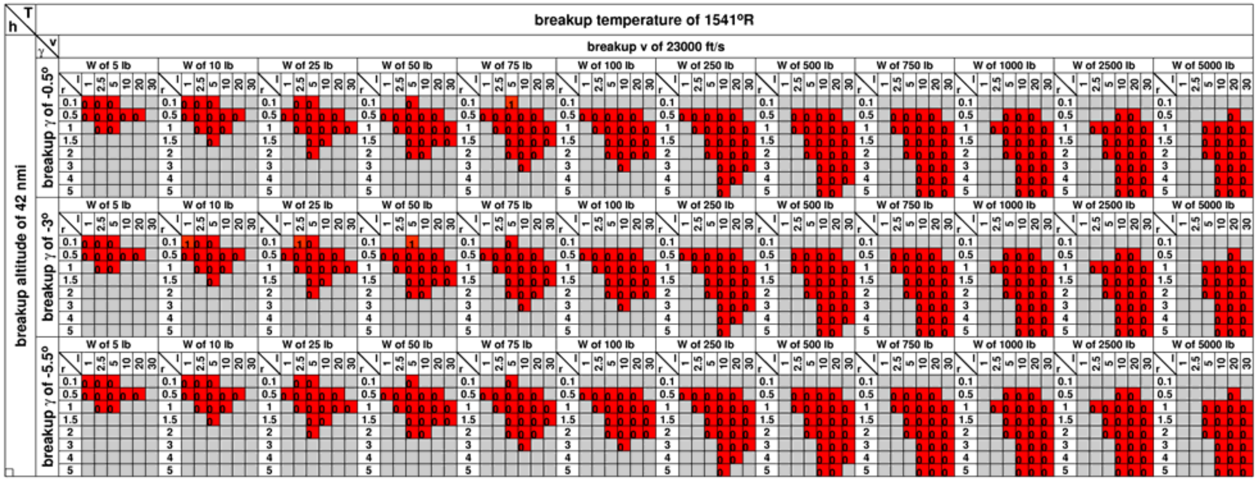


Table D-64. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

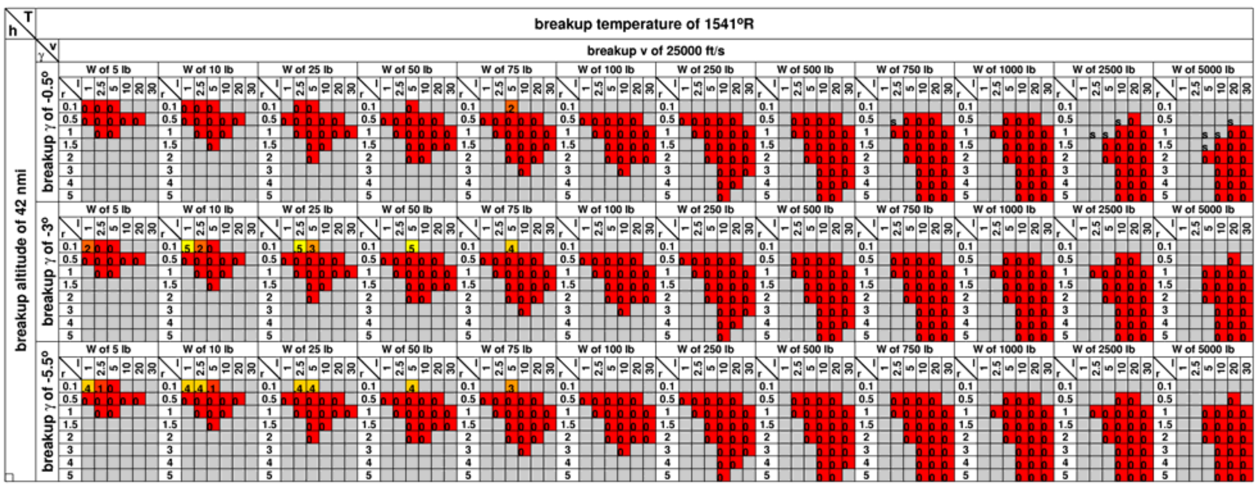


Table D-65. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

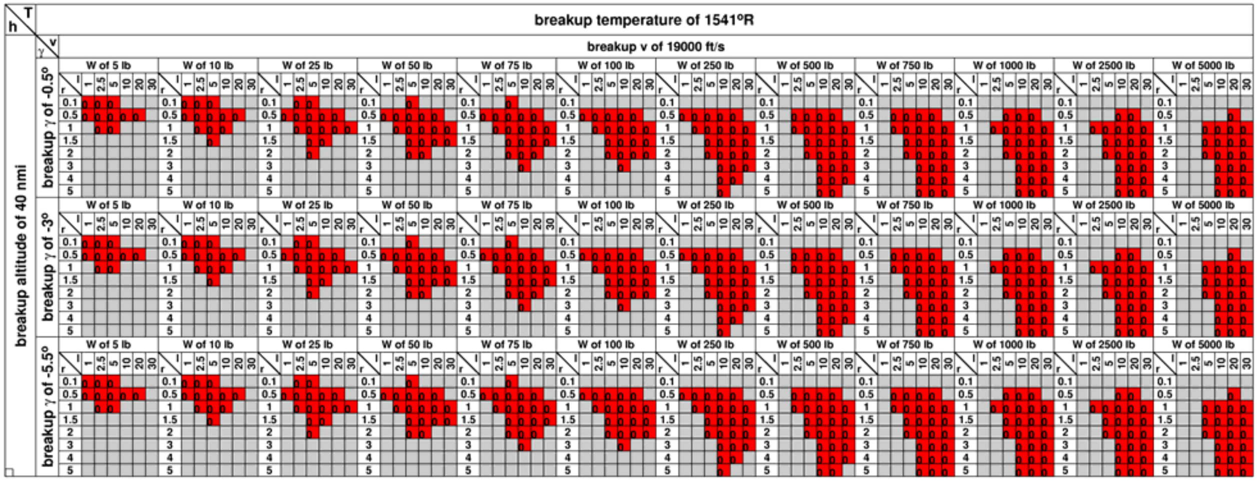


Table D-66. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

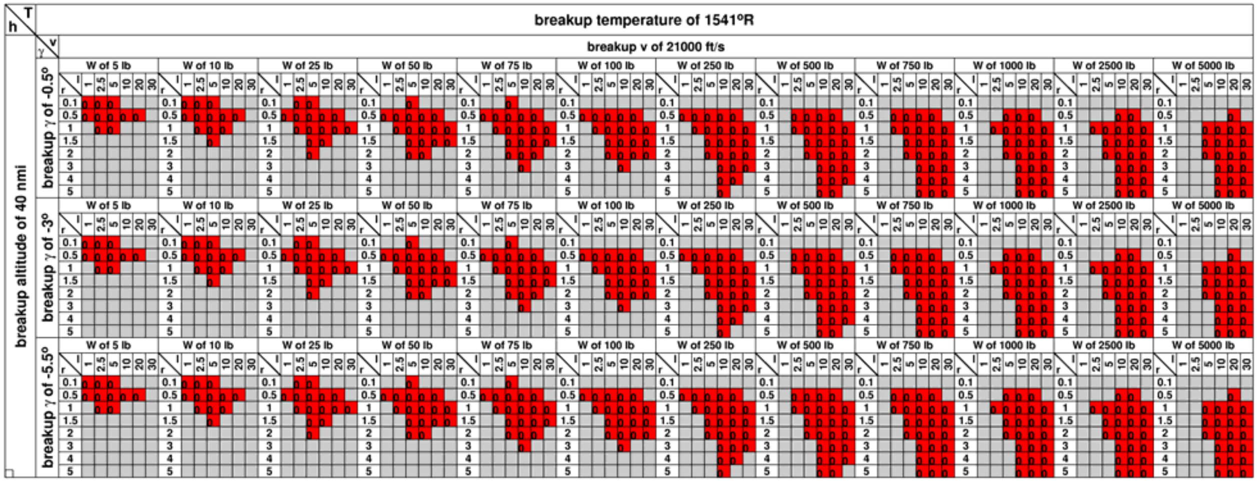


Table D-67. Stainless Steel 21-6-9 Tumbling Hollow Cylinder Survivability

breakup altitude (h) of 40 nmi; breakup temperature (T) of 1541ºR; breakup v of 23000 ft/s

breakup γ of -0.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	0	0	0			
	0.5	0	0	0	0	0	
	1		0	0			
	1.5						
	2						
	3						
	4						
	5						
W of 10 lb	0.1	0	0	0			
	0.5	0	0	0	0	0	
	1		0	0	0		
	1.5			0			
	2						
	3						
	4						
	5						
W of 25 lb	0.1		0	0			
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0		
	2			0			
	3						
	4						
	5						
W of 50 lb	0.1			0			
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0		
	3						
	4						
	5						
W of 75 lb	0.1			1			
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	
	3				0		
	4						
	5						
W of 100 lb	0.1						
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0		
	4						
	5						
W of 250 lb	0.1						
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	
	5				0		
W of 500 lb	0.1						
	0.5		0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	
W of 750 lb	0.1						
	0.5		0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 1000 lb	0.1						
	0.5			0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 2500 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 5000 lb	0.1						
	0.5					0	
	1			0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0

breakup γ of -3º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	0	0	0			
	0.5	0	0	0	0	0	
	1		0	0			
	1.5						
	2						
	3						
	4						
	5						
W of 10 lb	0.1	0	0	0			
	0.5	0	0	0	0	0	
	1		0	0	0		
	1.5			0			
	2						
	3						
	4						
	5						
W of 25 lb	0.1		0	0			
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0		
	2			0			
	3						
	4						
	5						
W of 50 lb	0.1			0			
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0		
	3						
	4						
	5						
W of 75 lb	0.1			0			
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	
	3				0		
	4						
	5						
W of 100 lb	0.1						
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0		
	4						
	5						
W of 250 lb	0.1						
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	
	5				0		
W of 500 lb	0.1						
	0.5		0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	
W of 750 lb	0.1						
	0.5		0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 1000 lb	0.1						
	0.5			0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 2500 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 5000 lb	0.1						
	0.5					0	
	1			0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0

breakup γ of -5.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	0	0	0			
	0.5	0	0	0	0	0	
	1		0	0			
	1.5						
	2						
	3						
	4						
	5						
W of 10 lb	0.1	0	0	0			
	0.5	0	0	0	0	0	
	1		0	0	0		
	1.5			0			
	2						
	3						
	4						
	5						
W of 25 lb	0.1		0	0			
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0		
	2			0			
	3						
	4						
	5						
W of 50 lb	0.1			0			
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0		
	3						
	4						
	5						
W of 75 lb	0.1			0			
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	
	3				0		
	4						
	5						
W of 100 lb	0.1						
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0		
	4						
	5						
W of 250 lb	0.1						
	0.5	0	0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	
	5				0		
W of 500 lb	0.1						
	0.5		0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	
W of 750 lb	0.1						
	0.5		0	0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 1000 lb	0.1						
	0.5			0	0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 2500 lb	0.1						
	0.5				0	0	
	1		0	0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0
W of 5000 lb	0.1						
	0.5					0	
	1			0	0	0	0
	1.5			0	0	0	0
	2			0	0	0	0
	3				0	0	0
	4				0	0	0
	5				0	0	0

D.3 Titanium (6 Al-4 V) Tumbling Hollow Cylinder Survivability Tables

Table D-68. Titanium (6 Al-4 V) Tumbling Hollow Cylinder Survivability

h \ T: breakup altitude of 46 nmi; breakup temperature of 1541°R

γ \ v: breakup v of 23000 ft/s

breakup γ of -0.5°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	0	0	0			
0.5	0	0	0	0	0	
1		0	0	0		
1.5						
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		0	0			
0.5	0	0	0	0	0	
1		0	0	0	0	
1.5			0	0		
2			0			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			0			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0		
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0		
4						
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	
4						
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	
4				0		
5						

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					0	
1			0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

breakup γ of -3°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	0	0	0			
0.5	0	0	0	0	0	
1		0	0	0		
1.5						
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		0	0			
0.5	0	0	0	0	0	
1		0	0	0	0	
1.5			0	0		
2			0			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			0			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0		
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0		
4						
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	
4						
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	
4				0		
5						

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					0	
1			0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

breakup γ of -5.5°

W of 5 lb

r \ l	1	2.5	5	10	20	30
0.1	0	0	0			
0.5	0	0	0	0	0	
1		0	0	0		
1.5						
2						
3						
4						
5						

W of 10 lb

r \ l	1	2.5	5	10	20	30
0.1		0	0			
0.5	0	0	0	0	0	
1		0	0	0	0	
1.5			0	0		
2			0			
3						
4						
5						

W of 25 lb

r \ l	1	2.5	5	10	20	30
0.1			0			
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0		
3						
4						
5						

W of 50 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0		
4						
5						

W of 75 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	
4						
5						

W of 100 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5	0	0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	
4				0		
5						

W of 250 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	

W of 500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5		0	0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 750 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 1000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5			0	0	0	
1		0	0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 2500 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5					0	
1			0	0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

W of 5000 lb

r \ l	1	2.5	5	10	20	30
0.1						
0.5						
1				0	0	0
1.5			0	0	0	0
2			0	0	0	0
3				0	0	0
4				0	0	0
5				0	0	0

Table D-69. Titanium (6 Al-4 V) Tumbling Hollow Cylinder Survivability

breakup altitude (h) of 46 nmi; breakup temperature (T) of 1541ºR; breakup v of 25000 ft/s

breakup γ of -0.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	p	p	p			
	0.5	p	p	p	p	p	
	1		p	p	p		
	1.5						
	2						
	3						
	4						
	5						
W of 10 lb	0.1		p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	
	1.5			p	p		
	2			p			
	3						
	4						
	5						
W of 25 lb	0.1			p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p		
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p		
	4						
	5						
W of 75 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4						
	5						
W of 100 lb	0.1						
	0.5	s	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4				p		
	5						
W of 250 lb	0.1						
	0.5		s	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	
W of 500 lb	0.1						
	0.5		s	s	p	p	
	1		s	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 750 lb	0.1						
	0.5			s	s	p	
	1		s	s	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 1000 lb	0.1						
	0.5			s	s	p	
	1		s	s	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 2500 lb	0.1						
	0.5					s	
	1			s	s	s	p
	1.5			s	s	p	p
	2			s	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 5000 lb	0.1						
	0.5						
	1				s	s	s
	1.5			s	s	s	p
	2			s	s	s	p
	3				s	p	p
	4				p	p	p
	5				p	p	p

breakup γ of -3º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	p	p	p			
	0.5	p	p	p	p	p	
	1		p	p	p		
	1.5						
	2						
	3						
	4						
	5						
W of 10 lb	0.1		p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	
	1.5			p	p		
	2			p			
	3						
	4						
	5						
W of 25 lb	0.1			p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p		
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p		
	4						
	5						
W of 75 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4						
	5						
W of 100 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4				p		
	5						
W of 250 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	
W of 500 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 750 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 1000 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 2500 lb	0.1						
	0.5					p	
	1			p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 5000 lb	0.1						
	0.5						
	1				p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p

breakup γ of -5.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	p	p	p			
	0.5	p	p	p	p	p	
	1		p	p	p		
	1.5						
	2						
	3						
	4						
	5						
W of 10 lb	0.1		p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	
	1.5			p	p		
	2			p			
	3						
	4						
	5						
W of 25 lb	0.1			p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p		
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p		
	4						
	5						
W of 75 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4						
	5						
W of 100 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4				p		
	5						
W of 250 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	
W of 500 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 750 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 1000 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 2500 lb	0.1						
	0.5					p	
	1			p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 5000 lb	0.1						
	0.5						
	1				p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p

Table D-70. Titanium (6 Al-4 V) Tumbling Hollow Cylinder Survivability

breakup altitude (h) of 46 nmi; breakup temperature (T) of 1541ºR; breakup v of 27000 ft/s

breakup γ of -0.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	s	s	s			
	0.5	s	p	p	p	p	
	1		p	p	p		
	1.5						
	2						
	3						
	4						
	5						
W of 10 lb	0.1		s	s			
	0.5	s	s	p	p	p	
	1		p	p	p	p	
	1.5			p	p		
	2			p			
	3						
	4						
	5						
W of 25 lb	0.1			s			
	0.5	s	s	s	p	p	
	1		s	p	p	p	p
	1.5			p	p	p	p
	2			p	p		
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	s	s	s	s	p	
	1		s	s	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p		
	4						
	5						
W of 75 lb	0.1						
	0.5	s	s	s	s	s	
	1		s	s	s	p	p
	1.5			s	p	p	p
	2			p	p	p	p
	3				p	p	
	4						
	5						
W of 100 lb	0.1						
	0.5	s	s	s	s	s	
	1		s	s	s	p	p
	1.5			s	p	p	p
	2			s	p	p	p
	3				p	p	
	4				p		
	5						
W of 250 lb	0.1						
	0.5		s	s	s	s	
	1		s	s	s	s	s
	1.5			s	s	s	p
	2			s	s	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	
W of 500 lb	0.1						
	0.5		s	s	s	s	
	1		s	s	s	s	s
	1.5			s	s	s	s
	2			s	s	s	s
	3				s	s	p
	4				s	p	p
	5				s	p	p
W of 750 lb	0.1						
	0.5			s	s	s	
	1		s	s	s	s	s
	1.5			s	s	s	s
	2			s	s	s	s
	3				s	s	s
	4				s	s	p
	5				s	p	p
W of 1000 lb	0.1						
	0.5			s	s	s	
	1		s	s	s	s	s
	1.5			s	s	s	s
	2			s	s	s	s
	3				s	s	s
	4				s	s	s
	5				s	s	p
W of 2500 lb	0.1						
	0.5					s	
	1			s	s	s	s
	1.5			s	s	s	s
	2			s	s	s	s
	3				s	s	s
	4				s	s	s
	5				s	s	s
W of 5000 lb	0.1						
	0.5						
	1				s	s	s
	1.5			s	s	s	s
	2			s	s	s	s
	3				s	s	s
	4				s	s	s
	5				s	s	s

breakup γ of -3º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	p	p	p			
	0.5	p	p	p	p	p	
	1		p	p	p		
	1.5						
	2						
	3						
	4						
	5						
W of 10 lb	0.1		p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	
	1.5			p	p		
	2			p			
	3						
	4						
	5						
W of 25 lb	0.1			p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p		
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p		
	4						
	5						
W of 75 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4						
	5						
W of 100 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4				p		
	5						
W of 250 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	
W of 500 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 750 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 1000 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 2500 lb	0.1						
	0.5					p	
	1			p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 5000 lb	0.1						
	0.5						
	1				p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p

breakup γ of -5.5º

W	r \ l	1	2.5	5	10	20	30
W of 5 lb	0.1	p	p	p			
	0.5	p	p	p	p	p	
	1		p	p	p		
	1.5						
	2						
	3						
	4						
	5						
W of 10 lb	0.1		p	p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	
	1.5			p	p		
	2			p			
	3						
	4						
	5						
W of 25 lb	0.1			p			
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p		
	3						
	4						
	5						
W of 50 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p		
	4						
	5						
W of 75 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4						
	5						
W of 100 lb	0.1						
	0.5	p	p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	
	4				p		
	5						
W of 250 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	
W of 500 lb	0.1						
	0.5		p	p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 750 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 1000 lb	0.1						
	0.5			p	p	p	
	1		p	p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 2500 lb	0.1						
	0.5					p	
	1			p	p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p
W of 5000 lb	0.1						
	0.5						
	1				p	p	p
	1.5			p	p	p	p
	2			p	p	p	p
	3				p	p	p
	4				p	p	p
	5				p	p	p

APPENDIX E
TUMBLING FLAT PLATE SURVIVABILITY TABLES

Table E-1 shows the survivability legend used for the tumbling flat plate survivability tables in Appendix E. Instructions for use of the tables are given in Section 3.

Table E-1. Legend for Survivability Tables in Appendix E

T – debris temperature at breakup point (°R)
h – altitude at breakup point (nmi)
v – Earth relative velocity at breakup point (ft/s)
γ – geocentric Earth relative flight path angle at breakup point (deg)
W – weight at breakup point (lb)
l – length of flat plate at breakup point (ft)
w – width of flat plate at breakup point (ft)

Liquid fraction values

0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1

s Symbol if trajectory skips out of atmosphere (geocentric Earth relative flight path increases to greater than 0°)

Symbol if flat plate thickness (assuming evenly distributed mass) is greater than 10% of width

Symbol if wall thickness (assuming evenly distributed mass) is less than 0.01% of width

Symbol if width is greater than length

Symbol if length is more than 15 times width

E.1 Aluminum 2024-T8xx Tumbling Flat Plate Survivability Tables

Table E-2. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

breakup altitude (h) of 46 nmi; breakup temperature (T) of 1541°R; breakup v of 23000 ft/s

breakup γ	W	w \ l	1	1.5	2	3	5	7.5	10
-0.5°	W of 1 lb	1	3	3	3	3	3	2	2
-0.5°	W of 1 lb	1.5		1	1	1	1	1	1
-0.5°	W of 1 lb	2			0	0	0		
-0.5°	W of 1 lb	3				0			
-0.5°	W of 1 lb	5							
-0.5°	W of 1 lb	7.5							
-0.5°	W of 1 lb	10							
-0.5°	W of 5 lb	1	5	4	4	3	3	3	3
-0.5°	W of 5 lb	1.5		2	1	1	1	1	1
-0.5°	W of 5 lb	2			0	0	0	0	0
-0.5°	W of 5 lb	3				0	0	0	0
-0.5°	W of 5 lb	5					0		
-0.5°	W of 5 lb	7.5							
-0.5°	W of 5 lb	10							
-0.5°	W of 10 lb	1	5	5	5	4	3	3	3
-0.5°	W of 10 lb	1.5		2	2	2	1	1	1
-0.5°	W of 10 lb	2			1	1	0	0	0
-0.5°	W of 10 lb	3				0	0	0	0
-0.5°	W of 10 lb	5					0	0	0
-0.5°	W of 10 lb	7.5							
-0.5°	W of 10 lb	10							
-0.5°	W of 25 lb	1	6	5	5	5	5	4	4
-0.5°	W of 25 lb	1.5		3	3	3	2	2	1
-0.5°	W of 25 lb	2			2	1	1	1	0
-0.5°	W of 25 lb	3				0	0	0	0
-0.5°	W of 25 lb	5					0	0	0
-0.5°	W of 25 lb	7.5						0	0
-0.5°	W of 25 lb	10							
-0.5°	W of 50 lb	1	6	5	5	5	5	5	5
-0.5°	W of 50 lb	1.5		4	4	3	3	2	2
-0.5°	W of 50 lb	2			2	2	1	1	1
-0.5°	W of 50 lb	3				0	0	0	0
-0.5°	W of 50 lb	5					0	0	0
-0.5°	W of 50 lb	7.5						0	0
-0.5°	W of 50 lb	10							0
-0.5°	W of 75 lb	1		5	5	5	5	5	5
-0.5°	W of 75 lb	1.5		4	4	4	3	3	3
-0.5°	W of 75 lb	2			3	2	2	1	1
-0.5°	W of 75 lb	3				1	0	0	0
-0.5°	W of 75 lb	5					0	0	0
-0.5°	W of 75 lb	7.5						0	0
-0.5°	W of 75 lb	10							0
-0.5°	W of 100 lb	1			5	5	5	5	5
-0.5°	W of 100 lb	1.5		4	4	4	3	3	3
-0.5°	W of 100 lb	2			3	3	2	2	1
-0.5°	W of 100 lb	3				1	1	0	0
-0.5°	W of 100 lb	5					0	0	0
-0.5°	W of 100 lb	7.5						0	0
-0.5°	W of 100 lb	10							0
-0.5°	W of 250 lb	1						5	5
-0.5°	W of 250 lb	1.5				3	3	3	3
-0.5°	W of 250 lb	2			3	3	3	2	2
-0.5°	W of 250 lb	3				2	1	1	1
-0.5°	W of 250 lb	5					0	0	0
-0.5°	W of 250 lb	7.5						0	0
-0.5°	W of 250 lb	10							0
-0.5°	W of 500 lb	1							
-0.5°	W of 500 lb	1.5					3	3	3
-0.5°	W of 500 lb	2				3	3	3	3
-0.5°	W of 500 lb	3				2	2	2	1
-0.5°	W of 500 lb	5					1	0	0
-0.5°	W of 500 lb	7.5						0	0
-0.5°	W of 500 lb	10							0
-3°	W of 1 lb	1	4	4	3	3	3	3	3
-3°	W of 1 lb	1.5		1	1	1	1	1	1
-3°	W of 1 lb	2			0	0	0		
-3°	W of 1 lb	3				0			
-3°	W of 1 lb	5							
-3°	W of 1 lb	7.5							
-3°	W of 1 lb	10							
-3°	W of 5 lb	1	5	5	5	4	4	4	3
-3°	W of 5 lb	1.5		3	2	2	2	1	1
-3°	W of 5 lb	2			1	1	1	1	0
-3°	W of 5 lb	3				0	0	0	0
-3°	W of 5 lb	5					0		
-3°	W of 5 lb	7.5							
-3°	W of 5 lb	10							
-3°	W of 10 lb	1	5	5	5	5	5	4	4
-3°	W of 10 lb	1.5		3	3	3	2	2	2
-3°	W of 10 lb	2			2	1	1	1	1
-3°	W of 10 lb	3				0	0	0	0
-3°	W of 10 lb	5					0	0	0
-3°	W of 10 lb	7.5							
-3°	W of 10 lb	10							
-3°	W of 25 lb	1	5	5	5	5	5	5	5
-3°	W of 25 lb	1.5		3	3	3	3	3	2
-3°	W of 25 lb	2			2	2	2	1	1
-3°	W of 25 lb	3				1	0	0	0
-3°	W of 25 lb	5					0	0	0
-3°	W of 25 lb	7.5						0	0
-3°	W of 25 lb	10							
-3°	W of 50 lb	1	5	4	4	4	5	5	5
-3°	W of 50 lb	1.5		3	3	3	3	3	3
-3°	W of 50 lb	2			2	2	2	2	2
-3°	W of 50 lb	3				1	1	1	0
-3°	W of 50 lb	5					0	0	0
-3°	W of 50 lb	7.5						0	0
-3°	W of 50 lb	10							0
-3°	W of 75 lb	1		4	4	4	4	5	5
-3°	W of 75 lb	1.5		3	3	3	3	3	3
-3°	W of 75 lb	2			2	2	2	2	2
-3°	W of 75 lb	3				2	1	1	1
-3°	W of 75 lb	5					0	0	0
-3°	W of 75 lb	7.5						0	0
-3°	W of 75 lb	10							0
-3°	W of 100 lb	1			4	4	4	4	5
-3°	W of 100 lb	1.5		3	3	3	3	3	3
-3°	W of 100 lb	2			2	2	2	2	2
-3°	W of 100 lb	3				2	1	1	1
-3°	W of 100 lb	5					0	0	0
-3°	W of 100 lb	7.5						0	0
-3°	W of 100 lb	10							0
-3°	W of 250 lb	1						4	4
-3°	W of 250 lb	1.5				3	3	3	3
-3°	W of 250 lb	2			2	2	2	2	2
-3°	W of 250 lb	3				2	2	2	1
-3°	W of 250 lb	5					1	0	0
-3°	W of 250 lb	7.5						0	0
-3°	W of 250 lb	10							0
-3°	W of 500 lb	1							
-3°	W of 500 lb	1.5					3	3	3
-3°	W of 500 lb	2				2	2	2	2
-3°	W of 500 lb	3				2	2	2	2
-3°	W of 500 lb	5					1	1	1
-3°	W of 500 lb	7.5						0	0
-3°	W of 500 lb	10							0
-5.5°	W of 1 lb	1	4	4	4	3	3	3	3
-5.5°	W of 1 lb	1.5		2	2	1	1	1	1
-5.5°	W of 1 lb	2			1	1	0		
-5.5°	W of 1 lb	3				0			
-5.5°	W of 1 lb	5							
-5.5°	W of 1 lb	7.5							
-5.5°	W of 1 lb	10							
-5.5°	W of 5 lb	1	5	5	5	5	4	4	4
-5.5°	W of 5 lb	1.5		3	3	3	2	2	2
-5.5°	W of 5 lb	2			2	1	1	1	1
-5.5°	W of 5 lb	3				0	0	0	0
-5.5°	W of 5 lb	5					0		
-5.5°	W of 5 lb	7.5							
-5.5°	W of 5 lb	10							
-5.5°	W of 10 lb	1	4	4	5	5	5	5	4
-5.5°	W of 10 lb	1.5		3	3	3	3	2	2
-5.5°	W of 10 lb	2			2	2	1	1	1
-5.5°	W of 10 lb	3				1	0	0	0
-5.5°	W of 10 lb	5					0	0	0
-5.5°	W of 10 lb	7.5							
-5.5°	W of 10 lb	10							
-5.5°	W of 25 lb	1	4	4	4	4	5	5	5
-5.5°	W of 25 lb	1.5		3	3	3	3	3	3
-5.5°	W of 25 lb	2			2	2	2	2	2
-5.5°	W of 25 lb	3				1	1	1	0
-5.5°	W of 25 lb	5					0	0	0
-5.5°	W of 25 lb	7.5						0	0
-5.5°	W of 25 lb	10							
-5.5°	W of 50 lb	1	4	4	4	4	4	4	5
-5.5°	W of 50 lb	1.5		3	3	3	3	3	3
-5.5°	W of 50 lb	2			2	2	2	2	2
-5.5°	W of 50 lb	3				2	1	1	1
-5.5°	W of 50 lb	5					0	0	0
-5.5°	W of 50 lb	7.5						0	0
-5.5°	W of 50 lb	10							0
-5.5°	W of 75 lb	1		4	4	4	4	4	4
-5.5°	W of 75 lb	1.5		3	3	3	3	3	3
-5.5°	W of 75 lb	2			2	2	2	2	2
-5.5°	W of 75 lb	3				2	1	1	1
-5.5°	W of 75 lb	5					0	0	0
-5.5°	W of 75 lb	7.5						0	0
-5.5°	W of 75 lb	10							0
-5.5°	W of 100 lb	1			3	3	4	4	4
-5.5°	W of 100 lb	1.5		3	3	3	3	3	3
-5.5°	W of 100 lb	2			2	2	2	2	2
-5.5°	W of 100 lb	3				2	2	1	1
-5.5°	W of 100 lb	5					1	0	0
-5.5°	W of 100 lb	7.5						0	0
-5.5°	W of 100 lb	10							0
-5.5°	W of 250 lb	1						3	4
-5.5°	W of 250 lb	1.5				2	3	3	3
-5.5°	W of 250 lb	2			2	2	2	2	2
-5.5°	W of 250 lb	3				2	2	2	2
-5.5°	W of 250 lb	5					1	1	1
-5.5°	W of 250 lb	7.5						0	0
-5.5°	W of 250 lb	10							0
-5.5°	W of 500 lb	1							
-5.5°	W of 500 lb	1.5					2	2	2
-5.5°	W of 500 lb	2				2	2	2	2
-5.5°	W of 500 lb	3				1	1	2	2
-5.5°	W of 500 lb	5					1	1	1
-5.5°	W of 500 lb	7.5						0	0
-5.5°	W of 500 lb	10							0

Table E-3. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

breakup altitude (h) of 46 nmi; breakup temperature (T) of 1541°R; breakup v of 25000 ft/s

breakup γ	W	w \ l	1	1.5	2	3	5	7.5	10
-0.5°	W of 1 lb	1	6	6	6	5	5	5	5
-0.5°	W of 1 lb	1.5		3	3	3	3	3	3
-0.5°	W of 1 lb	2			2	2	2		
-0.5°	W of 1 lb	3				1			
-0.5°	W of 1 lb	5							
-0.5°	W of 1 lb	7.5							
-0.5°	W of 1 lb	10							
-0.5°	W of 5 lb	1	8	7	7	6	6	6	6
-0.5°	W of 5 lb	1.5		4	3	3	3	3	3
-0.5°	W of 5 lb	2			2	2	2	2	2
-0.5°	W of 5 lb	3				1	1	1	1
-0.5°	W of 5 lb	5					0		
-0.5°	W of 5 lb	7.5							
-0.5°	W of 5 lb	10							
-0.5°	W of 10 lb	1	8	8	8	7	6	6	6
-0.5°	W of 10 lb	1.5		5	4	4	3	3	3
-0.5°	W of 10 lb	2			2	2	2	2	2
-0.5°	W of 10 lb	3				1	1	1	1
-0.5°	W of 10 lb	5					0	0	0
-0.5°	W of 10 lb	7.5							
-0.5°	W of 10 lb	10							
-0.5°	W of 25 lb	1	9	8	8	8	8	7	7
-0.5°	W of 25 lb	1.5		6	5	5	4	4	3
-0.5°	W of 25 lb	2			3	3	2	2	2
-0.5°	W of 25 lb	3				1	1	1	1
-0.5°	W of 25 lb	5					0	0	0
-0.5°	W of 25 lb	7.5						0	0
-0.5°	W of 25 lb	10							
-0.5°	W of 50 lb	1	9	8	8	8	8	8	8
-0.5°	W of 50 lb	1.5		6	6	5	5	5	4
-0.5°	W of 50 lb	2			4	4	3	3	2
-0.5°	W of 50 lb	3				1	1	1	1
-0.5°	W of 50 lb	5					0	0	0
-0.5°	W of 50 lb	7.5						0	0
-0.5°	W of 50 lb	10							0
-0.5°	W of 75 lb	1		9	8	8	8	8	8
-0.5°	W of 75 lb	1.5		6	6	6	5	5	5
-0.5°	W of 75 lb	2			4	4	4	3	3
-0.5°	W of 75 lb	3				2	1	1	1
-0.5°	W of 75 lb	5					0	0	0
-0.5°	W of 75 lb	7.5						0	0
-0.5°	W of 75 lb	10							0
-0.5°	W of 100 lb	1			8	8	8	8	8
-0.5°	W of 100 lb	1.5		6	6	6	5	5	5
-0.5°	W of 100 lb	2			4	4	4	3	3
-0.5°	W of 100 lb	3				2	2	1	1
-0.5°	W of 100 lb	5					0	0	0
-0.5°	W of 100 lb	7.5						0	0
-0.5°	W of 100 lb	10							0
-0.5°	W of 250 lb	1						8	8
-0.5°	W of 250 lb	1.5				6	6	5	5
-0.5°	W of 250 lb	2			5	4	4	4	4
-0.5°	W of 250 lb	3				3	3	2	2
-0.5°	W of 250 lb	5					1	0	0
-0.5°	W of 250 lb	7.5						0	0
-0.5°	W of 250 lb	10							0
-0.5°	W of 500 lb	1							
-0.5°	W of 500 lb	1.5					6	5	5
-0.5°	W of 500 lb	2				5	4	4	4
-0.5°	W of 500 lb	3				3	3	3	2
-0.5°	W of 500 lb	5					1	1	1
-0.5°	W of 500 lb	7.5						0	0
-0.5°	W of 500 lb	10							0
-3°	W of 1 lb	1	7	7	6	6	6	6	6
-3°	W of 1 lb	1.5		4	3	3	3	3	3
-3°	W of 1 lb	2			2	2	2		
-3°	W of 1 lb	3				1			
-3°	W of 1 lb	5							
-3°	W of 1 lb	7.5							
-3°	W of 1 lb	10							
-3°	W of 5 lb	1	7	7	7	7	7	7	6
-3°	W of 5 lb	1.5		5	5	4	4	4	3
-3°	W of 5 lb	2			3	3	2	2	2
-3°	W of 5 lb	3				1	1	1	1
-3°	W of 5 lb	5					0		
-3°	W of 5 lb	7.5							
-3°	W of 5 lb	10							
-3°	W of 10 lb	1	7	7	7	7	7	7	7
-3°	W of 10 lb	1.5		5	5	5	5	4	4
-3°	W of 10 lb	2			4	3	3	3	2
-3°	W of 10 lb	3				1	1	1	1
-3°	W of 10 lb	5					0	0	0
-3°	W of 10 lb	7.5							
-3°	W of 10 lb	10							
-3°	W of 25 lb	1	6	6	6	7	7	7	7
-3°	W of 25 lb	1.5		5	5	5	5	5	5
-3°	W of 25 lb	2			4	4	4	3	3
-3°	W of 25 lb	3				2	2	1	1
-3°	W of 25 lb	5					0	0	0
-3°	W of 25 lb	7.5						0	0
-3°	W of 25 lb	10							
-3°	W of 50 lb	1	6	6	6	6	6	7	7
-3°	W of 50 lb	1.5		4	4	5	5	5	5
-3°	W of 50 lb	2			4	4	4	4	4
-3°	W of 50 lb	3				2	2	2	2
-3°	W of 50 lb	5					1	0	0
-3°	W of 50 lb	7.5						0	0
-3°	W of 50 lb	10							0
-3°	W of 75 lb	1		6	6	6	6	6	7
-3°	W of 75 lb	1.5		4	4	4	5	5	5
-3°	W of 75 lb	2			4	4	4	4	4
-3°	W of 75 lb	3				3	2	2	2
-3°	W of 75 lb	5					1	1	0
-3°	W of 75 lb	7.5						0	0
-3°	W of 75 lb	10							0
-3°	W of 100 lb	1			6	6	6	6	6
-3°	W of 100 lb	1.5		4	4	4	5	5	5
-3°	W of 100 lb	2			3	4	4	4	4
-3°	W of 100 lb	3				3	2	2	2
-3°	W of 100 lb	5					1	1	1
-3°	W of 100 lb	7.5						0	0
-3°	W of 100 lb	10							0
-3°	W of 250 lb	1						5	6
-3°	W of 250 lb	1.5				4	4	4	4
-3°	W of 250 lb	2			3	3	3	3	4
-3°	W of 250 lb	3				2	2	3	3
-3°	W of 250 lb	5					1	1	1
-3°	W of 250 lb	7.5						0	0
-3°	W of 250 lb	10							0
-3°	W of 500 lb	1							
-3°	W of 500 lb	1.5					4	4	4
-3°	W of 500 lb	2				3	3	3	3
-3°	W of 500 lb	3				2	2	2	2
-3°	W of 500 lb	5					2	1	1
-3°	W of 500 lb	7.5						1	1
-3°	W of 500 lb	10							0
-5.5°	W of 1 lb	1	7	7	7	7	6	6	6
-5.5°	W of 1 lb	1.5		4	4	4	3	3	3
-5.5°	W of 1 lb	2			2	2	2		
-5.5°	W of 1 lb	3				1			
-5.5°	W of 1 lb	5							
-5.5°	W of 1 lb	7.5							
-5.5°	W of 1 lb	10							
-5.5°	W of 5 lb	1	6	7	7	7	7	7	7
-5.5°	W of 5 lb	1.5		5	5	5	4	4	4
-5.5°	W of 5 lb	2			3	3	3	2	2
-5.5°	W of 5 lb	3				1	1	1	1
-5.5°	W of 5 lb	5					0		
-5.5°	W of 5 lb	7.5							
-5.5°	W of 5 lb	10							
-5.5°	W of 10 lb	1	6	6	6	7	7	7	7
-5.5°	W of 10 lb	1.5		5	5	5	5	5	4
-5.5°	W of 10 lb	2			4	4	3	3	3
-5.5°	W of 10 lb	3				2	1	1	1
-5.5°	W of 10 lb	5					0	0	0
-5.5°	W of 10 lb	7.5							
-5.5°	W of 10 lb	10							
-5.5°	W of 25 lb	1	5	5	5	6	6	7	7
-5.5°	W of 25 lb	1.5		4	4	5	5	5	5
-5.5°	W of 25 lb	2			4	4	4	4	3
-5.5°	W of 25 lb	3				2	2	2	2
-5.5°	W of 25 lb	5					0	0	0
-5.5°	W of 25 lb	7.5						0	0
-5.5°	W of 25 lb	10							
-5.5°	W of 50 lb	1	5	5	5	5	6	6	6
-5.5°	W of 50 lb	1.5		4	4	4	4	5	5
-5.5°	W of 50 lb	2			3	3	4	4	4
-5.5°	W of 50 lb	3				2	2	2	2
-5.5°	W of 50 lb	5					1	1	0
-5.5°	W of 50 lb	7.5						0	0
-5.5°	W of 50 lb	10							0
-5.5°	W of 75 lb	1		5	5	5	5	6	6
-5.5°	W of 75 lb	1.5		4	4	4	4	4	5
-5.5°	W of 75 lb	2			3	3	3	4	4
-5.5°	W of 75 lb	3				2	2	2	2
-5.5°	W of 75 lb	5					1	1	1
-5.5°	W of 75 lb	7.5						0	0
-5.5°	W of 75 lb	10							0
-5.5°	W of 100 lb	1			4	5	5	5	6
-5.5°	W of 100 lb	1.5		3	3	4	4	4	4
-5.5°	W of 100 lb	2			3	3	3	4	4
-5.5°	W of 100 lb	3				2	2	2	2
-5.5°	W of 100 lb	5					1	1	1
-5.5°	W of 100 lb	7.5						0	0
-5.5°	W of 100 lb	10							0
-5.5°	W of 250 lb	1						4	5
-5.5°	W of 250 lb	1.5				3	3	4	4
-5.5°	W of 250 lb	2			3	3	3	3	3
-5.5°	W of 250 lb	3				2	2	2	2
-5.5°	W of 250 lb	5					1	1	1
-5.5°	W of 250 lb	7.5						1	1
-5.5°	W of 250 lb	10							0
-5.5°	W of 500 lb	1							
-5.5°	W of 500 lb	1.5					3	3	3
-5.5°	W of 500 lb	2				2	2	3	3
-5.5°	W of 500 lb	3				2	2	2	2
-5.5°	W of 500 lb	5					1	1	1
-5.5°	W of 500 lb	7.5						1	1
-5.5°	W of 500 lb	10							0

Table E-4. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

breakup altitude (h) of 46 nmi; breakup temperature (T) of 1541ºR; breakup v of 27000 ft/s

breakup γ of -0.5º

w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb							
1	1	.9	.9	.9	.9	.9	.9
1.5		.6	.6	.6	.6	.6	.6
2			.4	.4	.4		
3				.2			
5							
7.5							
10							
W of 5 lb							
1	1	1	1	1	1	.9	.9
1.5		.6	.6	.6	.6	.6	.6
2			.4	.4	.4	.4	.4
3				.2	.2	.2	.2
5					.1		
7.5							
10							
W of 10 lb							
1	s	1	1	1	1	1	1
1.5		.7	.7	.6	.6	.6	.6
2			.4	.4	.4	.4	.4
3				.2	.2	.2	.2
5					.1	.1	.1
7.5							
10							
W of 25 lb							
1	s	s	s	1	1	1	1
1.5		s	.8	.7	.7	.6	.6
2			.5	.5	.4	.4	.4
3				.2	.2	.2	.2
5					.1	.1	.1
7.5						0	0
10							
W of 50 lb							
1	s	s	s	s	s	1	1
1.5		s	s	s	.8	.7	.7
2			s	.5	.5	.5	.4
3				.3	.2	.2	.2
5					.1	.1	.1
7.5						0	0
10							0
W of 75 lb							
1		s	s	s	s	s	1
1.5		s	s	s	s	.8	.7
2			s	s	.5	.5	.5
3				.3	.3	.2	.2
5					.1	.1	.1
7.5						0	0
10							0
W of 100 lb							
1			s	s	s	s	s
1.5		s	s	s	s	s	.8
2			s	s	s	.5	.5
3				s	.3	.2	.2
5					.1	.1	.1
7.5						0	0
10							0
W of 250 lb							
1						s	s
1.5				s	s	s	s
2			s	s	s	s	s
3				s	s	s	.3
5					s	.1	.1
7.5						0	0
10							0
W of 500 lb							
1							
1.5					s	s	s
2				s	s	s	s
3				s	s	s	s
5					s	s	s
7.5						s	0
10							0

breakup γ of -3º

w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb							
1	1	1	1	1	1	.9	.9
1.5		.6	.6	.6	.6	.6	.6
2			.4	.4	.4		
3				.2			
5							
7.5							
10							
W of 5 lb							
1	1	1	1	1	1	1	1
1.5		.7	.7	.7	.7	.6	.6
2			.5	.5	.5	.4	.4
3				.3	.2	.2	.2
5					.1		
7.5							
10							
W of 10 lb							
1	.9	.9	.9	1	1	1	1
1.5		.7	.7	.7	.7	.7	.7
2			.6	.5	.5	.5	.5
3				.3	.3	.2	.2
5					.1	.1	.1
7.5							
10							
W of 25 lb							
1	.8	.8	.8	.9	.9	1	1
1.5		.6	.7	.7	.7	.7	.7
2			.5	.5	.5	.5	.5
3				.4	.3	.3	.3
5					.1	.1	.1
7.5						0	0
10							
W of 50 lb							
1	.8	.8	.8	.8	.8	.9	.9
1.5		.6	.6	.6	.7	.7	.7
2			.5	.5	.5	.5	.5
3				.4	.4	.4	.3
5					.2	.1	.1
7.5						0	0
10							0
W of 75 lb							
1		.7	.7	.7	.8	.8	.9
1.5		.6	.6	.6	.6	.7	.7
2			.5	.5	.5	.5	.5
3				.4	.4	.4	.4
5					.2	.2	.1
7.5						0	0
10							0
W of 100 lb							
1			.7	.7	.8	.8	.8
1.5		.6	.5	.6	.6	.6	.7
2			.5	.5	.5	.5	.5
3				.4	.4	.4	.4
5					.2	.2	.2
7.5						.1	0
10							0
W of 250 lb							
1						.7	.7
1.5				.5	.5	.6	.6
2			.4	.4	.4	.5	.5
3				.3	.3	.4	.4
5					.2	.2	.2
7.5						.1	.1
10							0
W of 500 lb							
1							
1.5					.5	.5	.5
2				.4	.4	.4	.4
3				.3	.3	.3	.3
5					.2	.2	.2
7.5						.1	.1
10							.1

breakup γ of -5.5º

w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb							
1	1	1	1	1	1	1	1
1.5		.7	.7	.6	.6	.6	.6
2			.5	.4	.4		
3				.2			
5							
7.5							
10							
W of 5 lb							
1	.8	.9	.9	1	1	1	1
1.5		.7	.7	.7	.7	.7	.7
2			.5	.5	.5	.5	.5
3				.3	.3	.2	.2
5					.1		
7.5							
10							
W of 10 lb							
1	.7	.8	.8	.9	1	1	1
1.5		.6	.7	.7	.7	.7	.7
2			.5	.5	.5	.5	.5
3				.3	.3	.3	.3
5					.1	.1	.1
7.5							
10							
W of 25 lb							
1	.6	.7	.7	.7	.8	.9	.9
1.5		.5	.6	.6	.7	.7	.7
2			.5	.5	.5	.5	.5
3				.4	.4	.3	.3
5					.2	.1	.1
7.5						0	0
10							
W of 50 lb							
1	.6	.6	.6	.6	.7	.8	.8
1.5		.5	.5	.5	.6	.6	.7
2			.4	.5	.5	.5	.5
3				.4	.4	.4	.4
5					.2	.2	.2
7.5						0	0
10							0
W of 75 lb							
1		.6	.6	.6	.7	.7	.8
1.5		.5	.5	.5	.5	.6	.6
2			.4	.4	.5	.5	.5
3				.3	.4	.4	.4
5					.2	.2	.2
7.5						.1	.1
10							0
W of 100 lb							
1			.6	.6	.6	.7	.7
1.5		.4	.4	.5	.5	.6	.6
2			.4	.4	.4	.5	.5
3				.3	.3	.4	.4
5					.2	.2	.2
7.5						.1	.1
10							0
W of 250 lb							
1						.6	.6
1.5				.4	.4	.5	.5
2			.3	.3	.4	.4	.4
3				.3	.3	.3	.3
5					.2	.2	.2
7.5						.1	.1
10							.1
W of 500 lb							
1							
1.5					.4	.4	.4
2				.3	.3	.3	.4
3				.2	.3	.3	.3
5					.2	.2	.2
7.5						.1	.1
10							.1

Table E-5. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

breakup altitude (h) of 46 nmi; breakup temperature (T) of 540ºR; breakup v of 23000 ft/s

breakup γ of -0.5º

w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0		
3				0			
5							
7.5							
10							
W of 5 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							
W of 10 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							
W of 25 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							
W of 50 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 75 lb							
1		0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 100 lb							
1			0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 250 lb							
1						0	0
1.5				0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 500 lb							
1							
1.5					0	0	0
2				0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

breakup γ of -3º

w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0		
3				0			
5							
7.5							
10							
W of 5 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							
W of 10 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							
W of 25 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							
W of 50 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 75 lb							
1		0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 100 lb							
1			0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 250 lb							
1						0	0
1.5				0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 500 lb							
1							
1.5					0	0	0
2				0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

breakup γ of -5.5º

w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0		
3				0			
5							
7.5							
10							
W of 5 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							
W of 10 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							
W of 25 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							
W of 50 lb							
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 75 lb							
1		0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 100 lb							
1			0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 250 lb							
1						0	0
1.5				0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0
W of 500 lb							
1							
1.5					0	0	0
2				0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

Table E-6. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

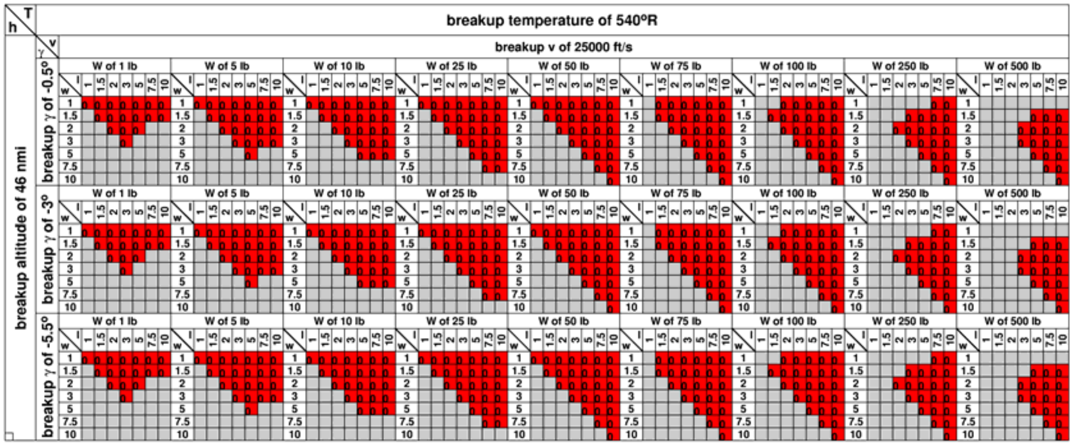


Table E-7. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

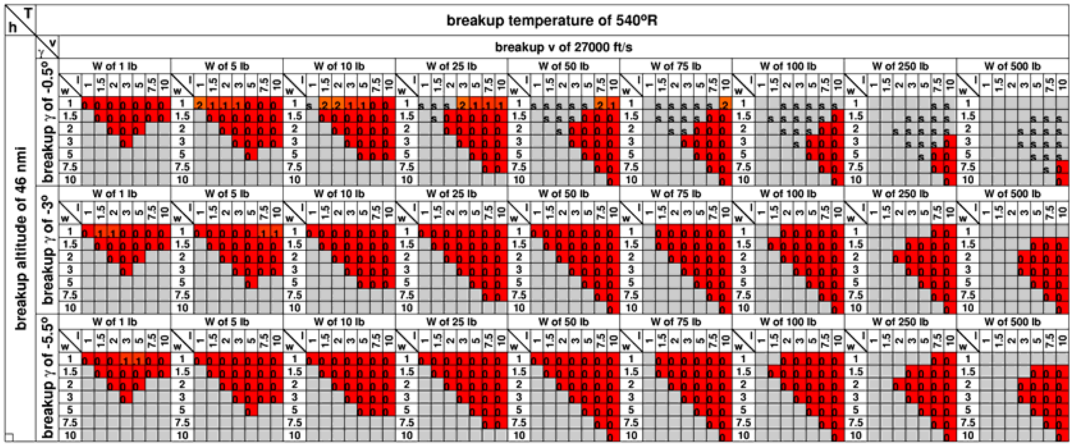


Table E-8. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h \ T: breakup altitude of 44 nmi; breakup temperature of 1541°R; γ \ v: breakup v of 22000 ft/s

breakup γ of -0.5°

	W of 1 lb							W of 5 lb							W of 10 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	3	3	3	3	3	2	2	4	3	3	3	3	3	3	4	4	4	3	3	3	3
1.5		1	1	1	1	1	1		2	1	1	1	1	1		2	2	2	1	1	1
2			1	1	1					1	1	1	1	1			1	1	1	1	1
3				0							0	0	0	0				0	0	0	0
5												0							0	0	0
7.5																					
10																					

	W of 25 lb							W of 50 lb							W of 75 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	3	3	5	4	4	4	4	4	4		4	4	4	4	4	4
1.5		3	2	2	2	2	1		3	3	3	2	2	2		3	3	3	3	2	2
2			1	1	1	1	1			2	2	1	1	1			2	2	1	1	1
3				0	0	0	0				0	0	0	0				1	0	0	0
5					0	0	0					0	0	0					0	0	0
7.5						0	0						0	0						0	0
10														0							0

	W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1			4	4	4	4	4						4	4							
1.5		3	3	3	3	2	2				3	3	3	3					3	3	3
2			2	2	2	1	1			2	2	2	2	2				2	2	2	2
3				1	0	0	0				1	1	1	1				1	1	1	1
5					0	0	0					0	0	0					0	0	0
7.5						0	0						0	0						0	0
10							0							0							0

breakup γ of -3°

	W of 1 lb							W of 5 lb							W of 10 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	3	3	3	3	3	3	3	4	4	4	3	3	3	3	4	4	4	4	3	3	3
1.5		1	1	1	1	1	1		2	2	2	2	1	1		2	2	2	2	2	2
2			1	1	1					1	1	1	1	1			1	1	1	1	1
3				0							0	0	0	0				0	0	0	0
5												0							0	0	0
7.5																					
10																					

	W of 25 lb							W of 50 lb							W of 75 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4	4	4	4	4	4	4	4		4	3	4	4	4	4
1.5		3	3	2	2	2	2		3	3	3	3	2	2		3	3	3	3	3	2
2			2	2	1	1	1			2	2	2	2	1			2	2	2	2	2
3				1	0	0	0				1	1	1	0				1	1	1	1
5					0	0	0					0	0	0					0	0	0
7.5						0	0						0	0						0	0
10														0							0

	W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1			3	3	4	4	4						3	3							
1.5		3	3	3	3	3	3				2	2	2	3					2	2	2
2			2	2	2	2	2			2	2	2	2	2				2	2	2	2
3				1	1	1	1				1	1	1	1				1	1	1	1
5					0	0	0					1	0	0					1	1	1
7.5						0	0						0	0						0	0
10							0							0							0

breakup γ of -5.5°

	W of 1 lb							W of 5 lb							W of 10 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	3	3	3	3	3	3	3	4	4	4	4	3	3	3	4	4	4	4	4	3	3
1.5		2	2	1	1	1	1		2	2	2	2	2	2		3	2	2	2	2	2
2			1	1	1					1	1	1	1	1			2	1	1	1	1
3				0							0	0	0	0				0	0	0	0
5												0							0	0	0
7.5																					
10																					

	W of 25 lb							W of 50 lb							W of 75 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	3	3	3	4	4	4	4	3	3	3	3	3	4	4		3	3	3	3	3	4
1.5		2	3	3	2	2	2		2	2	2	2	2	2		2	2	2	2	2	2
2			2	2	2	1	1			2	2	2	2	2			2	2	2	2	2
3				1	1	0	0				1	1	1	1				1	1	1	1
5					0	0	0					0	0	0					0	0	0
7.5						0	0						0	0						0	0
10														0							0

	W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1			3	3	3	3	3						3	3							
1.5		2	2	2	2	2	2				2	2	2	2					2	2	2
2			2	2	2	2	2			2	2	2	2	2				2	2	2	2
3				1	1	1	1				1	1	1	1				1	1	1	1
5					0	0	0					1	1	0					1	1	1
7.5						0	0						0	0						0	0
10							0							0							0

Table E-9. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h \ T: breakup altitude of 44 nmi; breakup temperature of 1541°R; γ \ v: breakup v of 24000 ft/s

breakup γ of -0.5°

	W of 1 lb							W of 5 lb							W of 10 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	5	5	5	5	5	5	5	6	6	5	5	5	5	5	6	6	6	6	5	5	5
1.5		3	3	3	3	3	3		3	3	3	3	3	3		4	3	3	3	3	3
2			2	2	2					2	2	2	2	2			2	2	2	2	2
3				1							1	1	1	1				1	1	1	1
5												0							0	0	0
7.5																					
10																					

	W of 25 lb							W of 50 lb							W of 75 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	7	6	6	6	6	6	5	7	6	6	6	6	6	6		7	6	6	6	6	6
1.5		4	4	4	3	3	3		5	4	4	4	4	3		5	4	4	4	4	4
2			3	2	2	2	2			3	3	3	2	2			3	3	3	3	2
3				1	1	1	1				1	1	1	1				2	1	1	1
5					0	0	0					0	0	0					0	0	0
7.5						0	0						0	0						0	0
10														0							0

	W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1			6	6	6	6	6						6	6							
1.5		5	4	4	4	4	4				4	4	4	4					4	4	4
2			3	3	3	3	3			4	3	3	3	3				3	3	3	3
3				2	1	1	1				2	2	2	2				2	2	2	2
5					0	0	0					1	0	0					1	1	1
7.5						0	0						0	0						0	0
10							0							0							0

breakup γ of -3°

	W of 1 lb							W of 5 lb							W of 10 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	5	5	5	5	5	5	5	6	6	6	6	5	5	5	5	6	6	6	6	5	5
1.5		3	3	3	3	3	3		4	4	3	3	3	3		4	4	4	4	3	3
2			2	2	2					2	2	2	2	2			3	3	2	2	2
3				1							1	1	1	1				1	1	1	1
5												0							0	0	0
7.5																					
10																					

	W of 25 lb							W of 50 lb							W of 75 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	5	5	5	5	6	6	6	5	5	5	5	5	5	6		5	5	5	5	5	5
1.5		4	4	4	4	4	4		4	4	4	4	4	4		4	4	4	4	4	4
2			3	3	3	3	2			3	3	3	3	3			3	3	3	3	3
3				2	1	1	1				2	2	2	1				2	2	2	2
5					0	0	0					1	0	0					1	1	0
7.5						0	0						0	0						0	0
10														0							0

	W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1			5	5	5	5	5						5	5							
1.5		4	3	4	4	4	4				3	3	3	4					3	3	3
2			3	3	3	3	3			3	3	3	3	3				3	3	3	3
3				2	2	2	2				2	2	2	2				2	2	2	2
5					1	1	1					1	1	1					1	1	1
7.5						0	0						0	0						1	0
10							0							0							0

breakup γ of -5.5°

	W of 1 lb							W of 5 lb							W of 10 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	6	5	5	5	5	5	5	5	5	6	6	5	5	5	5	5	5	5	6	6	5
1.5		3	3	3	3	3	3		4	4	4	3	3	3		4	4	4	4	4	3
2			2	2	2					3	3	2	2	2			3	3	3	2	2
3				1							1	1	1	1				1	1	1	1
5												0							0	0	0
7.5																					
10																					

	W of 25 lb							W of 50 lb							W of 75 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	4	4	5	5	5	5	5	4	4	4	4	5	5	5		4	4	4	4	5	5
1.5		4	4	4	4	4	4		3	3	3	4	4	4		3	3	3	3	4	4
2			3	3	3	3	3			3	3	3	3	3			3	3	3	3	3
3				2	2	1	1				2	2	2	2				2	2	2	2
5					0	0	0					1	1	0					1	1	1
7.5						0	0						0	0						0	0
10														0							0

	W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1			4	4	4	4	5						4	4							
1.5		3	3	3	3	4	4				3	3	3	3					3	3	3
2			3	3	3	3	3			2	2	2	3	3				2	2	2	2
3				2	2	2	2				2	2	2	2				2	2	2	2
5					1	1	1					1	1	1					1	1	1
7.5						0	0						1	0						1	1
10							0							0							0

Table E-10. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

breakup altitude (h) of 44 nmi; breakup temperature (T) of 1541°R; breakup v of 26000 ft/s

breakup γ of -0.5°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	8	8	8	8	8	8	8
	1.5		5	5	5	5	5	5
	2			4	4	4		
	3				2			
	5							
	7.5							
	10							
W of 5 lb	1	9	8	8	8	8	8	8
	1.5		5	5	5	5	5	5
	2			4	4	4	4	4
	3				2	2	2	2
	5					1		
	7.5							
	10							
W of 10 lb	1	9	9	9	8	8	8	8
	1.5		6	6	5	5	5	5
	2			4	4	4	4	4
	3				2	2	2	2
	5					1	1	1
	7.5							
	10							
W of 25 lb	1	1	9	9	9	9	8	8
	1.5		6	6	6	6	5	5
	2			4	4	4	4	4
	3				2	2	2	2
	5					1	1	1
	7.5						0	0
	10							
W of 50 lb	1	s	1	9	9	9	9	9
	1.5		7	7	6	6	6	6
	2			5	5	4	4	4
	3				3	2	2	2
	5					1	1	1
	7.5						0	0
	10							0
W of 75 lb	1		s	1	9	9	9	9
	1.5		7	7	6	6	6	6
	2			5	5	4	4	4
	3				3	3	2	2
	5					1	1	1
	7.5						0	0
	10							0
W of 100 lb	1			s	1	9	9	9
	1.5		s	7	7	6	6	6
	2			5	5	5	4	4
	3				3	3	2	2
	5					1	1	1
	7.5						0	0
	10							0
W of 250 lb	1						9	9
	1.5				s	7	6	6
	2			s	5	5	5	5
	3				4	3	3	3
	5					1	1	1
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					s	s	7
	2				s	s	5	5
	3				s	4	3	3
	5					2	2	1
	7.5						1	0
	10							0

breakup γ of -3°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	8	8	8	8	8	8	8
	1.5		5	5	5	5	5	5
	2			4	4	4		
	3				2			
	5							
	7.5							
	10							
W of 5 lb	1	8	8	8	8	8	8	8
	1.5		6	6	6	5	5	5
	2			4	4	4	4	4
	3				2	2	2	2
	5					1		
	7.5							
	10							
W of 10 lb	1	7	8	8	8	8	8	8
	1.5		6	6	6	6	5	5
	2			4	4	4	4	4
	3				3	2	2	2
	5					1	1	1
	7.5							
	10							
W of 25 lb	1	7	7	7	7	8	8	8
	1.5		5	5	6	6	6	6
	2			4	4	4	4	4
	3				3	3	3	2
	5					1	1	1
	7.5						0	0
	10							
W of 50 lb	1	7	6	6	7	7	7	8
	1.5		5	5	5	5	6	6
	2			4	4	4	4	4
	3				3	3	3	3
	5					1	1	1
	7.5						0	0
	10							0
W of 75 lb	1		6	6	6	7	7	7
	1.5		5	5	5	5	5	6
	2			4	4	4	4	4
	3				3	3	3	3
	5					2	1	1
	7.5						1	0
	10							0
W of 100 lb	1			6	6	6	7	7
	1.5		5	5	5	5	5	5
	2			4	4	4	4	4
	3				3	3	3	3
	5					2	1	1
	7.5						1	1
	10							0
W of 250 lb	1						6	6
	1.5				4	4	5	5
	2			4	4	4	4	4
	3				3	3	3	3
	5					2	2	2
	7.5						1	1
	10							0
W of 500 lb	1							
	1.5					4	4	4
	2				3	3	4	4
	3				3	3	3	3
	5					2	2	2
	7.5						1	1
	10							1

breakup γ of -5.5°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	8	8	8	8	8	8	8
	1.5		5	5	5	5	5	5
	2			4	4	4		
	3				2			
	5							
	7.5							
	10							
W of 5 lb	1	7	7	8	8	8	8	8
	1.5		6	6	6	6	5	5
	2			4	4	4	4	4
	3				3	2	2	2
	5					1		
	7.5							
	10							
W of 10 lb	1	6	7	7	7	8	8	8
	1.5		5	5	6	6	6	6
	2			4	4	4	4	4
	3				3	3	2	2
	5					1	1	1
	7.5							
	10							
W of 25 lb	1	6	6	6	6	7	7	8
	1.5		5	5	5	5	6	6
	2			4	4	4	4	4
	3				3	3	3	3
	5					1	1	1
	7.5						0	0
	10							
W of 50 lb	1	5	5	5	6	6	7	7
	1.5		4	4	5	5	5	5
	2			4	4	4	4	4
	3				3	3	3	3
	5					2	1	1
	7.5						1	0
	10							0
W of 75 lb	1		5	5	5	6	6	6
	1.5		4	4	4	5	5	5
	2			3	4	4	4	4
	3				3	3	3	3
	5					2	2	1
	7.5						1	1
	10							0
W of 100 lb	1			5	5	5	6	6
	1.5		4	4	4	4	5	5
	2			3	3	4	4	4
	3				3	3	3	3
	5					2	2	2
	7.5						1	1
	10							0
W of 250 lb	1						5	5
	1.5				3	4	4	4
	2			3	3	3	3	4
	3				2	3	3	3
	5					2	2	2
	7.5						1	1
	10							1
W of 500 lb	1							
	1.5					3	3	4
	2				3	3	3	3
	3				2	2	2	3
	5					2	2	2
	7.5						1	1
	10							1

Table E-11. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

breakup altitude (h) of 44 nmi; breakup temperature (T) of 540°R; breakup v of 22000 ft/s

breakup γ of -0.5°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

breakup γ of -3°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

breakup γ of -5.5°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

Table E-12. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

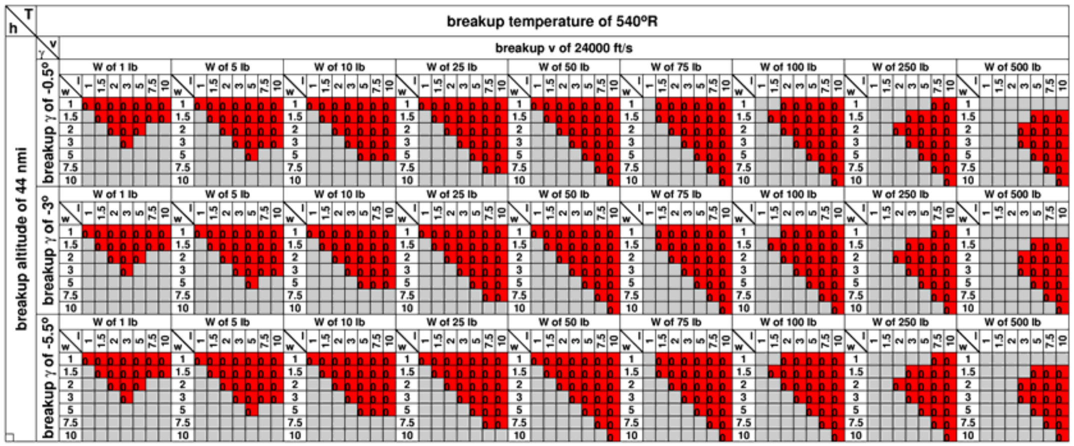


Table E-13. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

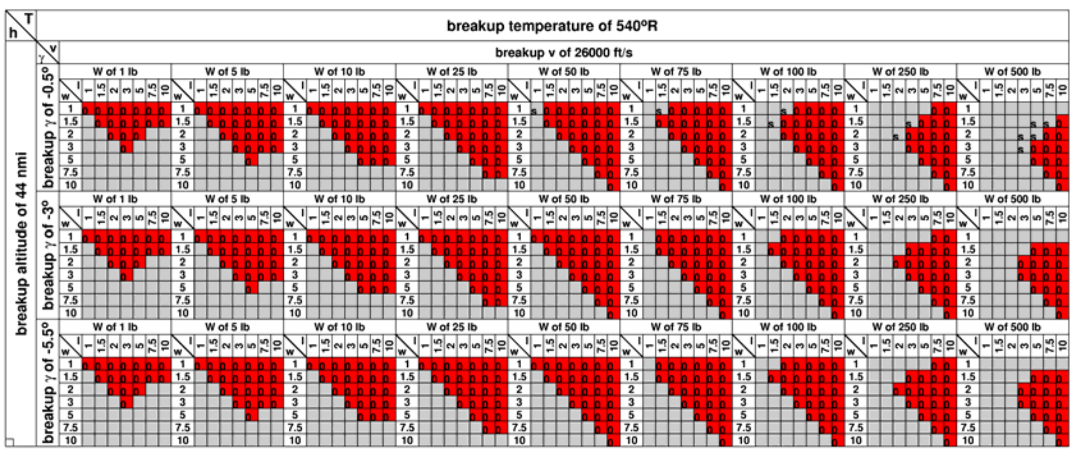


Table E-14. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h \ T: breakup altitude of 42 nmi — breakup temperature of 1541°R

γ \ v: breakup v of 21000 ft/s

breakup γ of -0.5°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	2	2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	3	3	2	2	2	2
1.5		2	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	3	3	3	3	2	2
1.5		2	2	2	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	3	3	3	3	3	3
1.5		2	2	2	2	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		4	3	3	3	3	3
1.5		2	2	2	2	2	2
2			2	1	1	1	1
3				1	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			3	3	3	3	3
1.5		2	2	2	2	2	2
2			2	2	1	1	1
3				1	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						3	3
1.5				2	2	2	2
2			2	2	2	1	1
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					2	2	2
2				2	2	2	2
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

breakup γ of -3°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	3	3	3	2	2	2
1.5		2	2	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	3	3	3	3	2	2
1.5		2	2	2	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	3	3	3	3	3	3
1.5		2	2	2	2	2	2
2			1	1	1	1	1
3				1	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	3	3	3	3	3	3
1.5		2	2	2	2	2	2
2			2	1	1	1	1
3				1	1	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		3	3	3	3	3	3
1.5		2	2	2	2	2	2
2			2	2	1	1	1
3				1	1	1	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			3	3	3	3	3
1.5		2	2	2	2	2	2
2			2	2	1	1	1
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						3	3
1.5				2	2	2	2
2			2	2	2	2	1
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					2	2	2
2				2	1	2	2
3				1	1	1	1
5					1	0	0
7.5						0	0
10							0

breakup γ of -5.5°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	2	2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	3	3	3	3	2	2
1.5		2	2	2	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	3	3	3	3	3	3
1.5		2	2	2	2	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	3	3	3	3	3	3
1.5		2	2	2	2	2	2
2			1	1	1	1	1
3				1	1	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	3	3	3	3	3	3	3
1.5		2	2	2	2	2	2
2			2	1	1	1	1
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		3	3	3	3	3	3
1.5		2	2	2	2	2	2
2			2	1	1	1	1
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			3	2	3	3	3
1.5		2	2	2	2	2	2
2			1	1	1	1	1
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						2	2
1.5				2	2	2	2
2			1	1	1	1	1
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					2	2	2
2				1	1	1	1
3				1	1	1	1
5					1	1	0
7.5						0	0
10							0

Table E-15. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h \ T: breakup altitude of 42 nmi — breakup temperature of 1541°R

γ \ v: breakup v of 23000 ft/s

breakup γ of -0.5°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		2	2	2	2	2	3
2			2	2	2		
3				1			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	3	2	2
2			2	2	2	2	2
3				1	1	1	1
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	5	5	4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				1	1	1	1
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	5	5	5	5	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				1	1	1	1
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	6	5	5	5	5	5	4
1.5		4	3	3	3	3	3
2			2	2	2	2	2
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		5	5	5	5	5	5
1.5		4	4	3	3	3	3
2			3	2	2	2	2
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			5	5	5	5	5
1.5		4	4	3	3	3	3
2			3	3	2	2	2
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						5	5
1.5				3	3	3	3
2			3	3	3	3	2
3				2	2	1	1
5					1	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					3	3	3
2				3	3	3	3
3				2	2	2	2
5					1	1	1
7.5						0	0
10							0

breakup γ of -3°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	2	2	3
2			2	2	2		
3				1			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				1	1	1	1
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				1	1	1	1
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				1	1	1	1
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		4	4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				2	1	1	1
5					1	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				2	2	1	1
5					1	1	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						4	4
1.5				3	3	3	3
2			2	2	2	2	2
3				2	2	2	2
5					1	1	1
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					3	3	3
2				2	2	2	2
3				2	2	2	2
5					1	1	1
7.5						0	0
10							0

breakup γ of -5.5°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	3	2	3
2			2	2	2		
3				1			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				1	1	1	1
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				1	1	1	1
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				1	1	1	1
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	4	4	4	4	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				2	1	1	1
5					1	1	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		3	3	3	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				2	2	1	1
5					1	1	1
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			3	3	4	4	4
1.5		3	3	3	3	3	3
2			2	2	2	2	2
3				2	2	2	1
5					1	1	1
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						3	3
1.5				2	2	3	3
2			2	2	2	2	2
3				1	2	2	2
5					1	1	1
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					2	2	2
2				2	2	2	2
3				1	1	1	2
5					1	1	1
7.5						1	0
10							0

Table E-16. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

breakup altitude (h) of 42 nmi; breakup temperature (T) of 1541ºR; breakup v of 25000 ft/s

breakup γ of -0.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	6	6	6	6	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3		
	3				2			
	5							
	7.5							
	10							
W of 5 lb	1	7	6	6	6	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1		
	7.5							
	10							
W of 10 lb	1	7	7	7	6	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5							
	10							
W of 25 lb	1	8	7	7	7	6	6	6
	1.5		5	5	5	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						0	0
	10							
W of 50 lb	1	8	7	7	7	7	7	6
	1.5		5	5	5	5	4	4
	2			4	4	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						0	0
	10							0
W of 75 lb	1		8	7	7	7	7	7
	1.5		5	5	5	5	5	4
	2			4	4	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						0	0
	10							0
W of 100 lb	1			7	7	7	7	7
	1.5		5	5	5	5	5	5
	2			4	4	4	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						0	0
	10							0
W of 250 lb	1						7	7
	1.5				5	5	5	5
	2			4	4	4	4	4
	3				3	3	2	2
	5					1	1	1
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					5	5	5
	2				4	4	4	4
	3				3	3	3	3
	5					1	1	1
	7.5						1	1
	10							0

breakup γ of -3º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	6	6	6	6	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3		
	3				2			
	5							
	7.5							
	10							
W of 5 lb	1	6	6	6	6	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1		
	7.5							
	10							
W of 10 lb	1	6	6	6	6	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5							
	10							
W of 25 lb	1	6	6	6	6	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						0	0
	10							
W of 50 lb	1	6	5	5	5	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						1	0
	10							0
W of 75 lb	1		5	5	5	5	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						1	1
	10							0
W of 100 lb	1			5	5	5	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						1	1
	10							0
W of 250 lb	1						5	5
	1.5				4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						1	1
	10							0
W of 500 lb	1							
	1.5					3	4	4
	2				3	3	3	3
	3				2	2	2	2
	5					2	1	1
	7.5						1	1
	10							0

breakup γ of -5.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	6	6	6	6	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3		
	3				2			
	5							
	7.5							
	10							
W of 5 lb	1	6	6	6	6	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1		
	7.5							
	10							
W of 10 lb	1	5	6	6	6	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5							
	10							
W of 25 lb	1	5	5	5	5	6	6	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						0	0
	10							
W of 50 lb	1	5	5	5	5	5	5	6
	1.5		4	4	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						1	1
	10							0
W of 75 lb	1		4	4	4	5	5	5
	1.5		3	3	4	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						1	1
	10							0
W of 100 lb	1			4	4	5	5	5
	1.5		3	3	3	4	4	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						1	1
	10							0
W of 250 lb	1						4	4
	1.5				3	3	3	4
	2			3	3	3	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						1	1
	10							0
W of 500 lb	1							
	1.5					3	3	3
	2				2	2	3	3
	3				2	2	2	2
	5					1	1	1
	7.5						1	1
	10							1

Table E-17. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

breakup altitude (h) of 42 nmi; breakup temperature (T) of 540ºR; breakup v of 21000 ft/s

breakup γ of -0.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

breakup γ of -3º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

breakup γ of -5.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

Table E-18. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

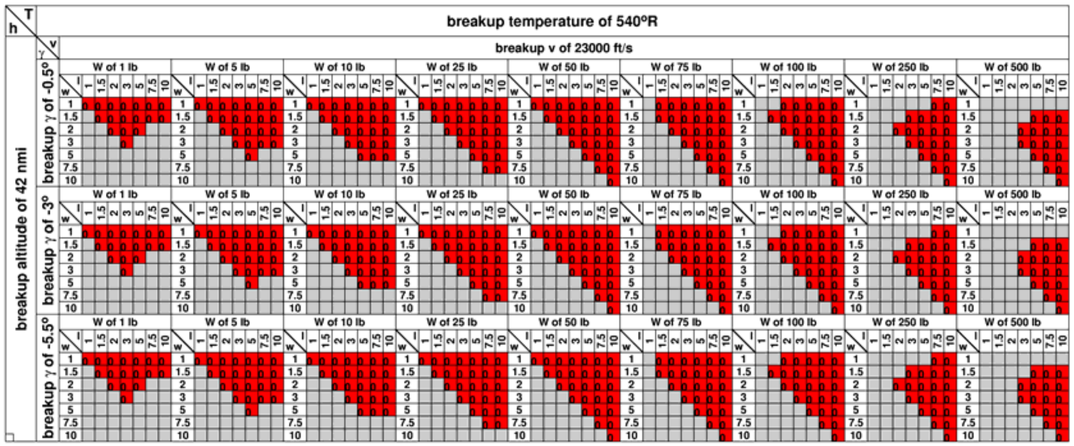


Table E-19. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

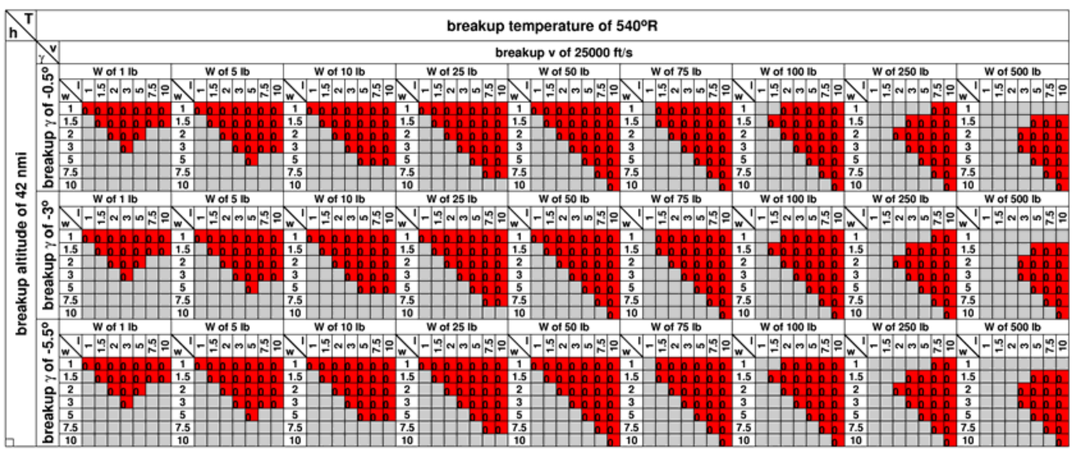


Table E-20. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

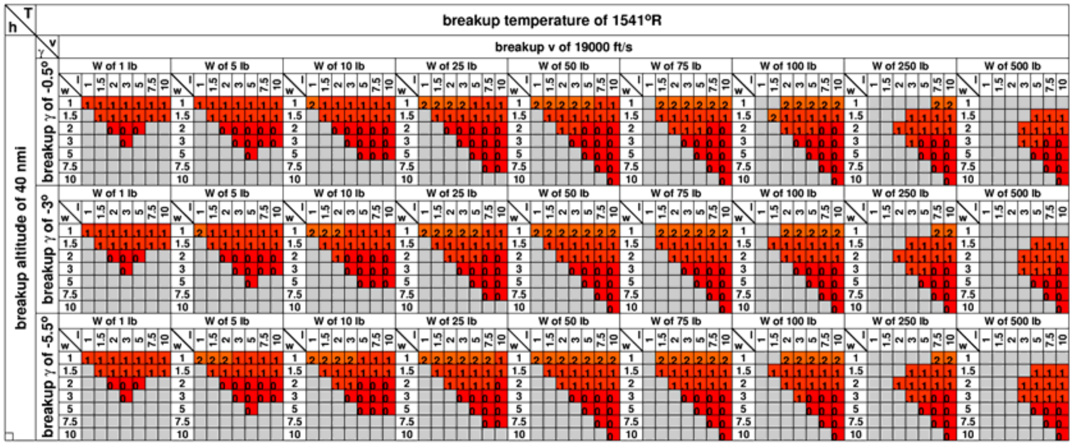


Table E-21. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

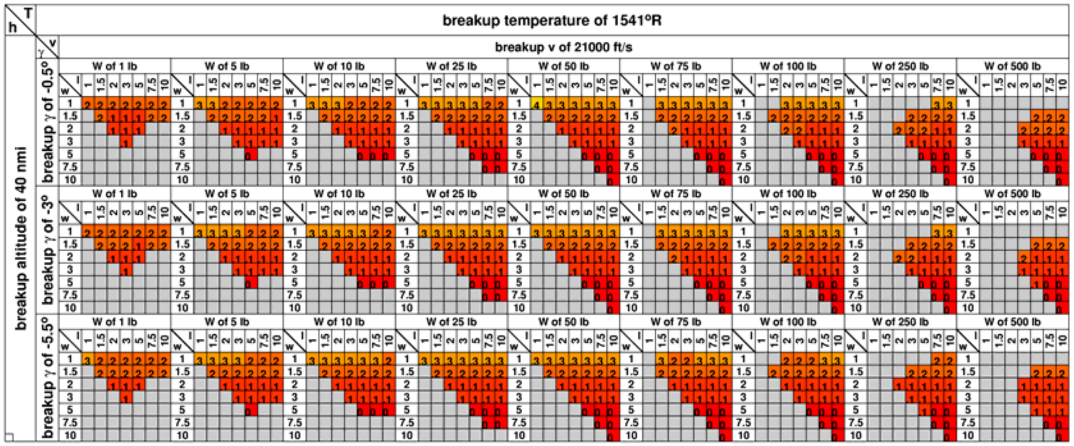


Table E-22. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h: breakup altitude of 40 nmi; T: breakup temperature of 1541°R; v: breakup v of 23000 ft/s

breakup γ of -0.5°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2		
	3				1			
	5							
	7.5							
	10							
W of 5 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1		
	7.5							
	10							
W of 10 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5							
	10							
W of 25 lb	1	5	5	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5						0	0
	10							
W of 50 lb	1	5	5	5	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5						0	0
	10							0
W of 75 lb	1		5	5	5	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5						0	0
	10							0
W of 100 lb	1			5	5	4	4	4
	1.5		4	3	3	3	3	3
	2			3	2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5						0	0
	10							0
W of 250 lb	1						4	4
	1.5				3	3	3	3
	2			3	3	2	2	2
	3				2	2	1	1
	5					1	1	1
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					3	3	3
	2				3	3	2	2
	3				2	2	2	2
	5					1	1	1
	7.5						0	0
	10							0

breakup γ of -3°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2		
	3				1			
	5							
	7.5							
	10							
W of 5 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1		
	7.5							
	10							
W of 10 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5							
	10							
W of 25 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5						0	0
	10							
W of 50 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5						0	0
	10							0
W of 75 lb	1		4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				2	1	1	1
	5					1	1	1
	7.5						0	0
	10							0
W of 100 lb	1			4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				2	1	1	1
	5					1	1	1
	7.5						0	0
	10							0
W of 250 lb	1						4	4
	1.5				3	3	3	3
	2			2	2	2	2	2
	3				2	2	2	2
	5					1	1	1
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					3	3	3
	2				2	2	2	2
	3				2	2	2	2
	5					1	1	1
	7.5						1	0
	10							0

breakup γ of -5.5°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2		
	3				1			
	5							
	7.5							
	10							
W of 5 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1		
	7.5							
	10							
W of 10 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5							
	10							
W of 25 lb	1	4	4	4	4	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5						0	0
	10							
W of 50 lb	1	4	3	3	3	4	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				2	1	1	1
	5					1	1	1
	7.5						0	0
	10							0
W of 75 lb	1		3	3	3	3	4	4
	1.5		3	3	3	3	3	3
	2			2	2	2	2	2
	3				2	2	1	1
	5					1	1	1
	7.5						0	0
	10							0
W of 100 lb	1			3	3	3	3	4
	1.5		2	2	2	3	3	3
	2			2	2	2	2	2
	3				2	2	1	1
	5					1	1	1
	7.5						0	0
	10							0
W of 250 lb	1						3	3
	1.5				2	2	2	3
	2			2	2	2	2	2
	3				1	1	2	2
	5					1	1	1
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					2	2	2
	2				2	2	2	2
	3				1	1	1	1
	5					1	1	1
	7.5						1	1
	10							0

Table E-23. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h: breakup altitude of 40 nmi; T: breakup temperature of 540°R; v: breakup v of 19000 ft/s

breakup γ of -0.5°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

breakup γ of -3°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

breakup γ of -5.5°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

Table E-24. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

breakup altitude (h) of 40 nmi; breakup temperature (T) of 540ºR; breakup v of 21000 ft/s

breakup γ of -0.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p		
	3				p			
	5							
	7.5							
	10							
W of 5 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p		
	7.5							
	10							
W of 10 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5							
	10							
W of 25 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							
W of 50 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 75 lb	1		p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 100 lb	1			p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 250 lb	1						p	p
	1.5				p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 500 lb	1							
	1.5					p	p	p
	2				p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p

breakup γ of -3º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p		
	3				p			
	5							
	7.5							
	10							
W of 5 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p		
	7.5							
	10							
W of 10 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5							
	10							
W of 25 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							
W of 50 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 75 lb	1		p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 100 lb	1			p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 250 lb	1						p	p
	1.5				p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 500 lb	1							
	1.5					p	p	p
	2				p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p

breakup γ of -5.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p		
	3				p			
	5							
	7.5							
	10							
W of 5 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p		
	7.5							
	10							
W of 10 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5							
	10							
W of 25 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							
W of 50 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 75 lb	1		p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 100 lb	1			p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 250 lb	1						p	p
	1.5				p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 500 lb	1							
	1.5					p	p	p
	2				p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p

Table E-25. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

breakup altitude (h) of 40 nmi; breakup temperature (T) of 540ºR; breakup v of 23000 ft/s

breakup γ of -0.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p		
	3				p			
	5							
	7.5							
	10							
W of 5 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p		
	7.5							
	10							
W of 10 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5							
	10							
W of 25 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							
W of 50 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 75 lb	1		p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 100 lb	1			p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 250 lb	1						p	p
	1.5				p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 500 lb	1							
	1.5					p	p	p
	2				p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p

breakup γ of -3º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p		
	3				p			
	5							
	7.5							
	10							
W of 5 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p		
	7.5							
	10							
W of 10 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5							
	10							
W of 25 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							
W of 50 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 75 lb	1		p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 100 lb	1			p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 250 lb	1						p	p
	1.5				p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 500 lb	1							
	1.5					p	p	p
	2				p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p

breakup γ of -5.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p		
	3				p			
	5							
	7.5							
	10							
W of 5 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p		
	7.5							
	10							
W of 10 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5							
	10							
W of 25 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							
W of 50 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 75 lb	1		p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 100 lb	1			p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 250 lb	1						p	p
	1.5				p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 500 lb	1							
	1.5					p	p	p
	2				p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p

Table E-26. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h: breakup altitude of 38 nmi — T: breakup temperature of 1541ºR — v: breakup v of 17000 ft/s

breakup γ of -0.5º

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	1
2			0	0	0		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		1	1	1	1	1	1
1.5		1	1	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			1	1	1	1	1
1.5		1	1	1	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						1	1
1.5				1	1	1	0
2			1	1	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					1	1	1
2				1	1	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

breakup γ of -3º

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	1
2			0	0	0		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	1	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		1	1	1	1	1	1
1.5		1	1	1	1	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			1	1	1	1	1
1.5		1	1	1	1	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						1	1
1.5				1	1	1	1
2			1	1	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					1	1	1
2				1	1	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

breakup γ of -5.5º

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	1
2			0	0	0		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	1	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		1	1	1	1	1	1
1.5		1	1	1	1	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			1	1	1	1	1
1.5		1	1	1	1	1	0
2			1	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						1	1
1.5				1	1	1	1
2			1	1	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					1	1	1
2				1	1	1	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

Table E-27. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h: breakup altitude of 38 nmi — T: breakup temperature of 1541ºR — v: breakup v of 19000 ft/s

breakup γ of -0.5º

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	1	1	1	1
2			1	1	1		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	1	1	1	1	1
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	2	2	1	1	1
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	2	2	2	1	1
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		2	2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						2	2
1.5				1	1	1	1
2			1	1	1	1	1
3				1	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					1	1	1
2				1	1	1	1
3				1	1	0	0
5					0	0	0
7.5						0	0
10							0

breakup γ of -3º

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	1	1	1	1
2			1	1	1		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	1	1	1	1	1	1
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	2	1	1	1	1
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	2	2	2	1	1
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		2	2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						2	2
1.5				1	1	1	1
2			1	1	1	1	1
3				1	1	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					1	1	1
2				1	1	1	1
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

breakup γ of -5.5º

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	1	1	1	1
2			1	1	1		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	1	1	1	1	1
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	2	2	1	1	1
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	2	2	2	2	1
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	2	2	2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		2	2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			2	2	2	2	2
1.5		1	1	1	1	1	1
2			1	1	1	1	1
3				1	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						2	2
1.5				1	1	1	1
2			1	1	1	1	1
3				1	1	1	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					1	1	1
2				1	1	1	1
3				1	1	1	1
5					0	0	0
7.5						0	0
10							0

Table E-28. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h: breakup altitude of 38 nmi; T: breakup temperature of 1541ºR; v: breakup v of 21000 ft/s

breakup γ of -0.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	2	2	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1		
	3				1			
	5							
	7.5							
	10							
W of 5 lb	1	3	2	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0		
	7.5							
	10							
W of 10 lb	1	3	3	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	3	3	3	3	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	4	3	3	3	3	3	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		3	3	3	3	3	3
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			3	3	3	3	3
	1.5		2	2	2	2	2	2
	2			2	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						3	3
	1.5				2	2	2	2
	2			2	2	2	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					2	2	2
	2				2	2	2	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0

breakup γ of -3º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	2	2	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1		
	3				1			
	5							
	7.5							
	10							
W of 5 lb	1	3	2	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0		
	7.5							
	10							
W of 10 lb	1	3	3	3	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	3	3	3	3	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	3	3	3	3	3	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		3	3	3	3	3	3
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			3	3	3	3	3
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						3	3
	1.5				2	2	2	2
	2			2	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					2	2	2
	2				1	1	1	1
	3				1	1	1	1
	5					1	1	0
	7.5						0	0
	10							0

breakup γ of -5.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	2	2	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1		
	3				1			
	5							
	7.5							
	10							
W of 5 lb	1	3	2	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0		
	7.5							
	10							
W of 10 lb	1	3	2	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	3	2	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	3	2	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		2	2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			2	2	2	2	2
	1.5		2	2	2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						2	2
	1.5				2	2	2	2
	2			1	1	1	1	1
	3				1	1	1	1
	5					1	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					2	2	2
	2				1	1	1	1
	3				1	1	1	1
	5					1	1	1
	7.5						0	0
	10							0

Table E-29. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h: breakup altitude of 38 nmi; T: breakup temperature of 540ºR; v: breakup v of 17000 ft/s

breakup γ of -0.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

breakup γ of -3º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

breakup γ of -5.5º

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0		
	3				0			
	5							
	7.5							
	10							
W of 5 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0		
	7.5							
	10							
W of 10 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5							
	10							
W of 25 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							
W of 50 lb	1	0	0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 75 lb	1		0	0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 100 lb	1			0	0	0	0	0
	1.5		0	0	0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 250 lb	1						0	0
	1.5				0	0	0	0
	2			0	0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0
W of 500 lb	1							
	1.5					0	0	0
	2				0	0	0	0
	3				0	0	0	0
	5					0	0	0
	7.5						0	0
	10							0

Table E-30. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h \ T: breakup temperature of 540ºR

γ \ v: breakup v of 19000 ft/s

breakup altitude of 38 nmi

breakup γ of -0.5º

w \ l	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p		p	p	p	p	p	p			p	p	p	p	p						p	p							
1.5		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p				p	p	p	p					p	p	p
2			p	p	p					p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p				p	p	p	p
3				p							p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p
5												p							p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p
7.5																											p	p						p	p						p	p						p	p						p	p						p	p
10																																			p							p							p							p							p

breakup γ of -3º

w \ l	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p		p	p	p	p	p	p			p	p	p	p	p						p	p							
1.5		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p				p	p	p	p					p	p	p
2			p	p	p					p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p				p	p	p	p
3				p							p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p
5												p							p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p
7.5																											p	p						p	p						p	p						p	p						p	p						p	p
10																																			p							p							p							p							p

breakup γ of -5.5º

w \ l	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p		p	p	p	p	p	p			p	p	p	p	p						p	p							
1.5		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p				p	p	p	p					p	p	p
2			p	p	p					p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p				p	p	p	p
3				p							p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p
5												p							p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p
7.5																											p	p						p	p						p	p						p	p						p	p						p	p
10																																			p							p							p							p							p

Table E-31. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h \ T: breakup temperature of 540ºR

γ \ v: breakup v of 21000 ft/s

breakup altitude of 38 nmi

breakup γ of -0.5º

w \ l	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p		p	p	p	p	p	p			p	p	p	p	p						p	p							
1.5		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p				p	p	p	p					p	p	p
2			p	p	p					p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p				p	p	p	p
3				p							p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p
5												p							p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p
7.5																											p	p						p	p						p	p						p	p						p	p						p	p
10																																			p							p							p							p							p

breakup γ of -3º

w \ l	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p		p	p	p	p	p	p			p	p	p	p	p						p	p							
1.5		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p				p	p	p	p					p	p	p
2			p	p	p					p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p				p	p	p	p
3				p							p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p
5												p							p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p
7.5																											p	p						p	p						p	p						p	p						p	p						p	p
10																																			p							p							p							p							p

breakup γ of -5.5º

w \ l	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p		p	p	p	p	p	p			p	p	p	p	p						p	p							
1.5		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p		p	p	p	p	p	p				p	p	p	p					p	p	p
2			p	p	p					p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p			p	p	p	p	p				p	p	p	p
3				p							p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p				p	p	p	p
5												p							p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p					p	p	p
7.5																											p	p						p	p						p	p						p	p						p	p						p	p
10																																			p							p							p							p							p

Table E-32. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h \ T: breakup temperature of 1541°R

γ \ v: breakup v of 15000 ft/s

breakup altitude of 36 nmi

breakup γ of -0.5°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		1	1	0	0	0	0
1.5	0	0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			1	1	0	0	0
1.5	0	0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						0	0
1.5				0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					0	0	0
2				0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

breakup γ of -3°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		1	1	0	0	0	0
1.5	0	0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			1	1	0	0	0
1.5	0	0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						1	0
1.5				0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					0	0	0
2				0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

breakup γ of -5.5°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	0	0	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	0	0	0	0
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		1	1	1	0	0	0
1.5	0	0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			1	1	0	0	0
1.5	0	0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						1	1
1.5				0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					0	0	0
2				0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

Table E-33. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h \ T: breakup temperature of 1541°R

γ \ v: breakup v of 17000 ft/s

breakup altitude of 36 nmi

breakup γ of -0.5°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	1	1
2			0	0	0		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		1	1	1	1	1	1
1.5		1	1	1	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			1	1	1	1	1
1.5		1	1	1	1	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						1	1
1.5				1	1	1	1
2			1	1	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					1	1	1
2				1	1	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

breakup γ of -3°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	1	1
2			0	0	0		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	1	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		1	1	1	1	1	1
1.5		1	1	1	1	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			1	1	1	1	1
1.5		1	1	1	1	1	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						1	1
1.5				1	1	1	1
2			1	1	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					1	1	1
2				1	1	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

breakup γ of -5.5°

W of 1 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	1	1
2			0	0	0		
3				0			
5							
7.5							
10							

W of 5 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		0	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0		
7.5							
10							

W of 10 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	0	0	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5							
10							

W of 25 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	1	0	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							

W of 50 lb

w \ l	1	1.5	2	3	5	7.5	10
1	1	1	1	1	1	1	1
1.5		1	1	1	1	0	0
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 75 lb

w \ l	1	1.5	2	3	5	7.5	10
1		1	1	1	1	1	1
1.5		1	1	1	1	1	1
2			0	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 100 lb

w \ l	1	1.5	2	3	5	7.5	10
1			1	1	1	1	1
1.5		1	1	1	1	1	1
2			1	0	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 250 lb

w \ l	1	1.5	2	3	5	7.5	10
1						1	1
1.5				1	1	1	1
2			1	1	0	0	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

W of 500 lb

w \ l	1	1.5	2	3	5	7.5	10
1							
1.5					1	1	1
2				1	1	1	0
3				0	0	0	0
5					0	0	0
7.5						0	0
10							0

Table E-34. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

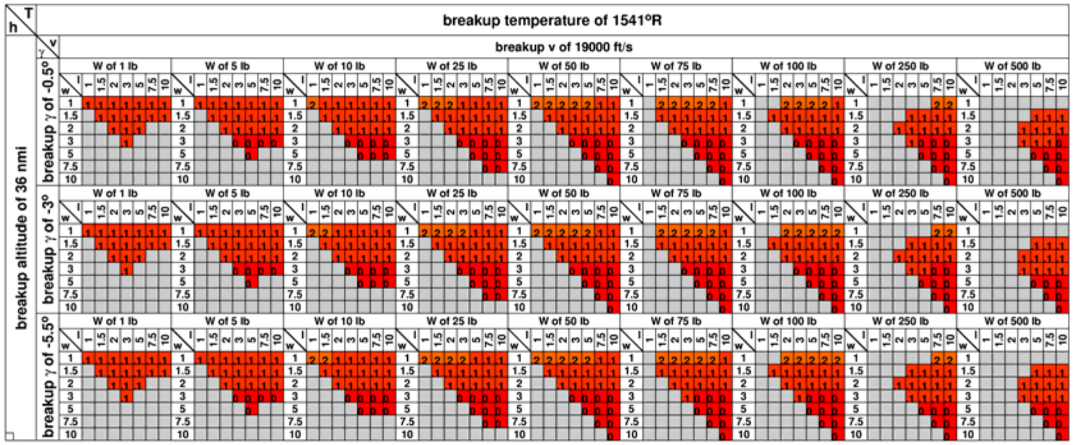


Table E-35. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

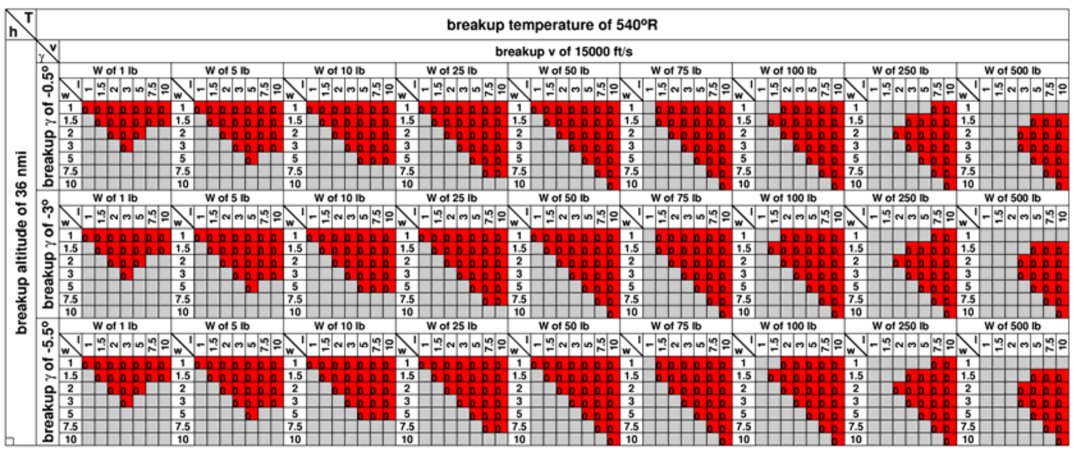


Table E-36. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

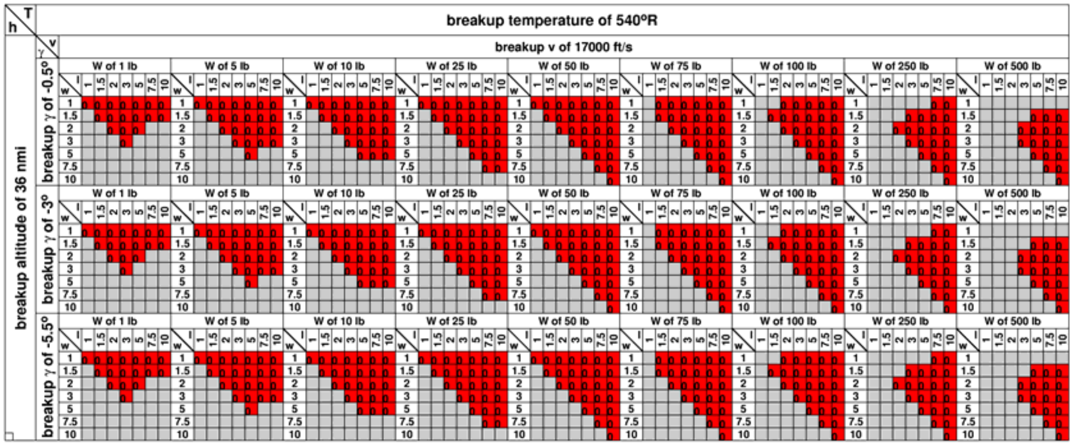


Table E-37. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

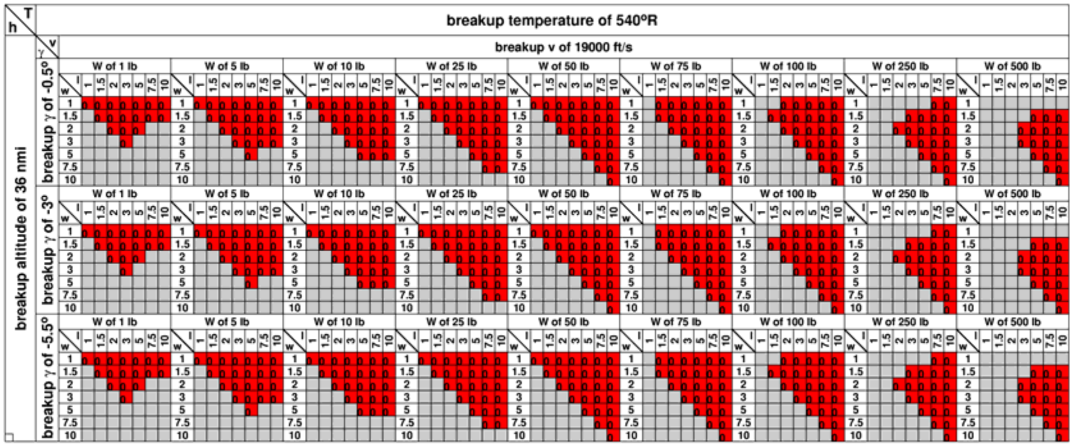


Table E-38. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

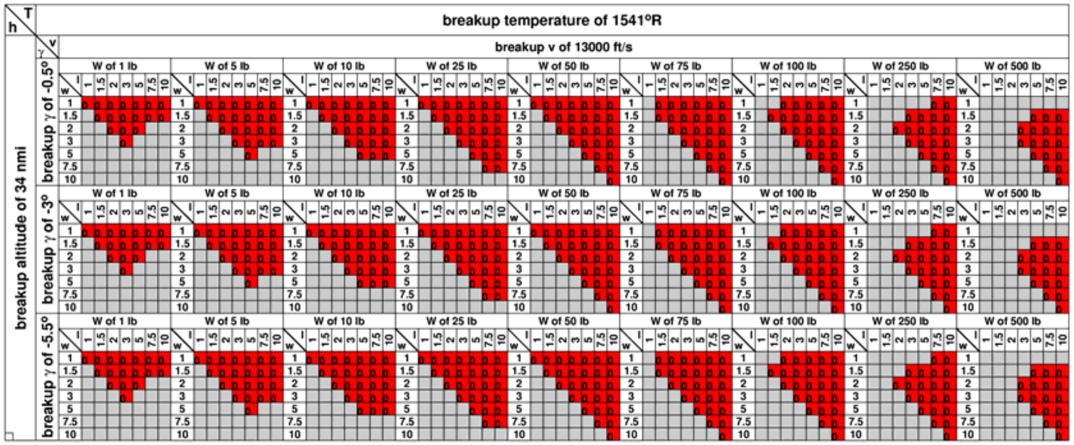


Table E-39. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

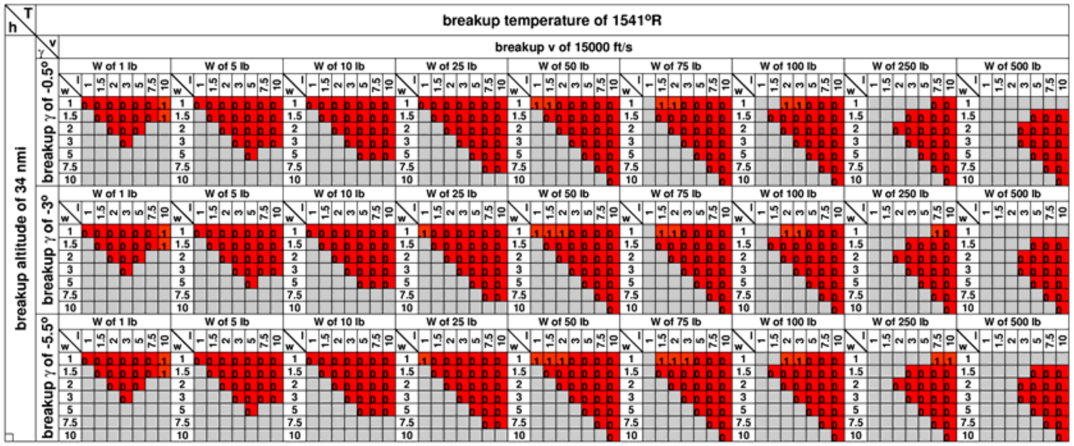


Table E-40. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

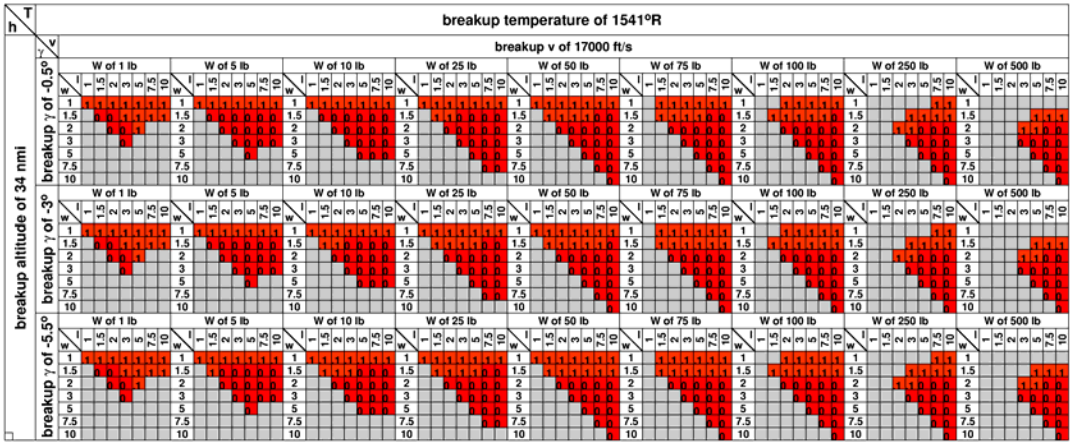


Table E-41. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

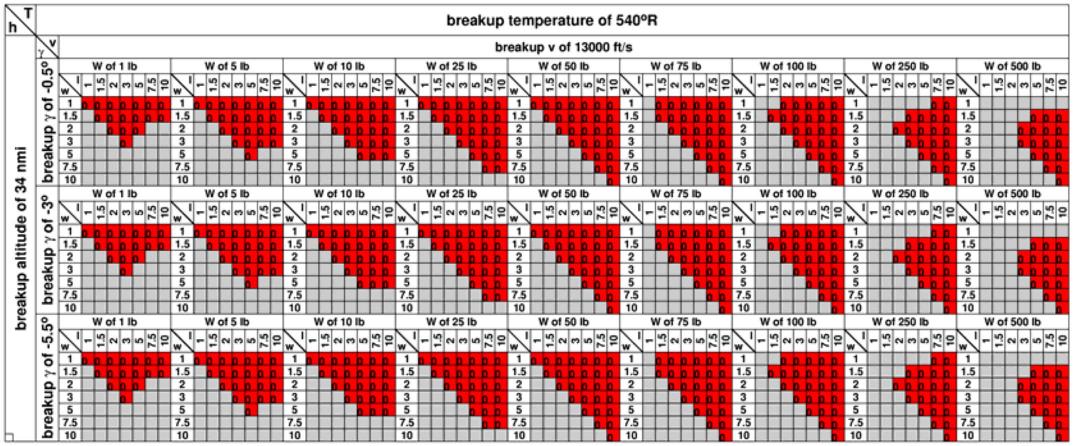


Table E-42. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

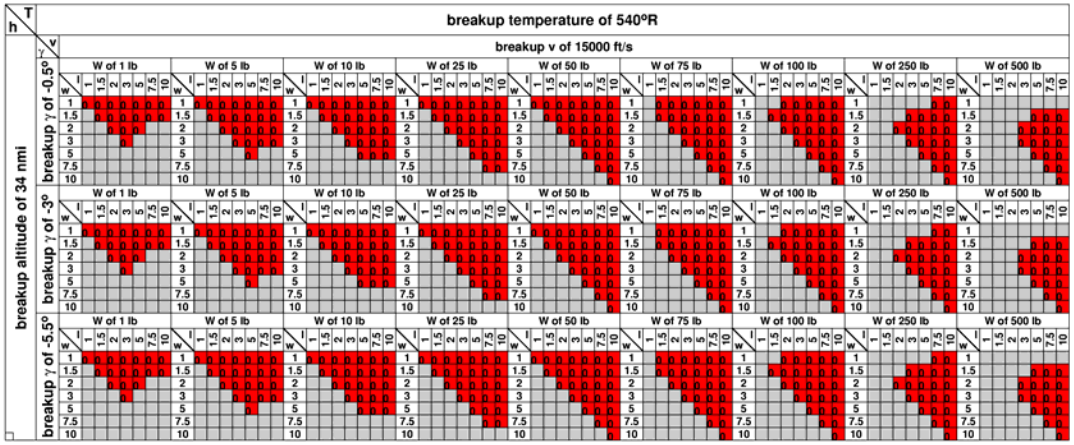


Table E-43. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

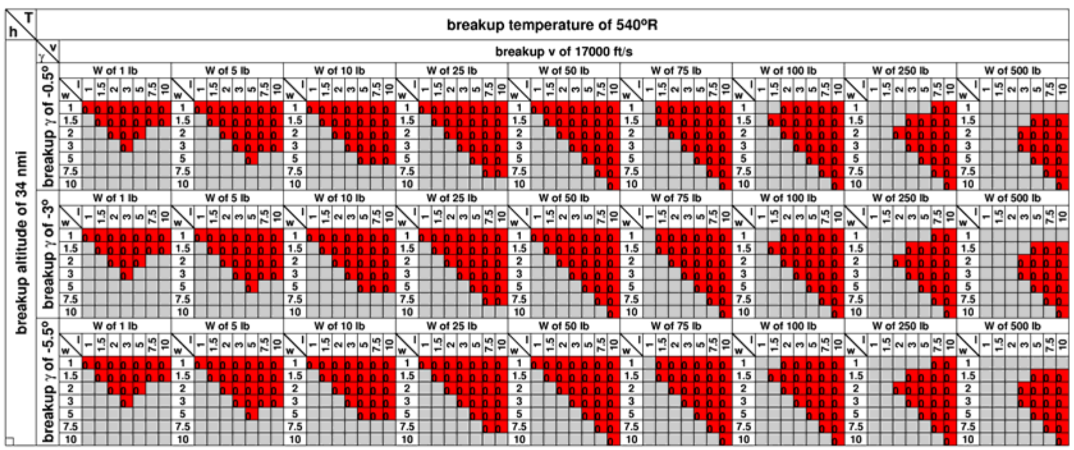


Table E-44. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

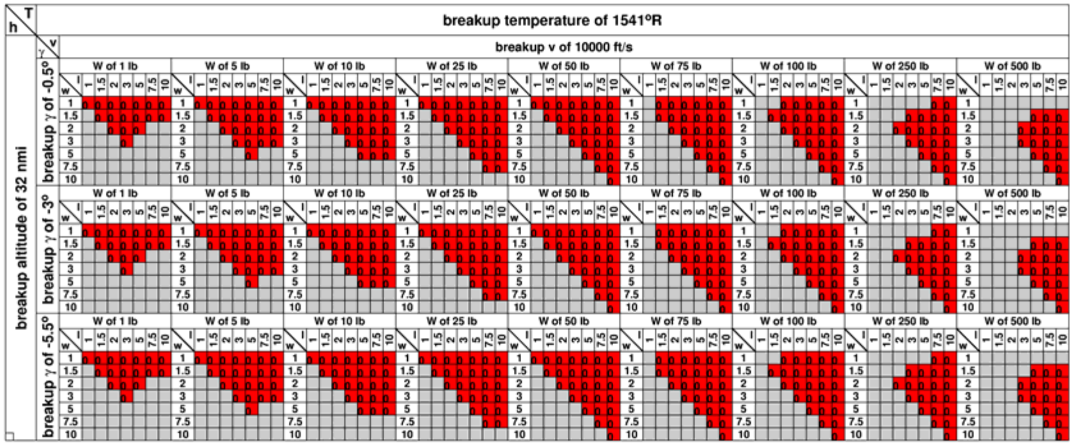


Table E-45. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

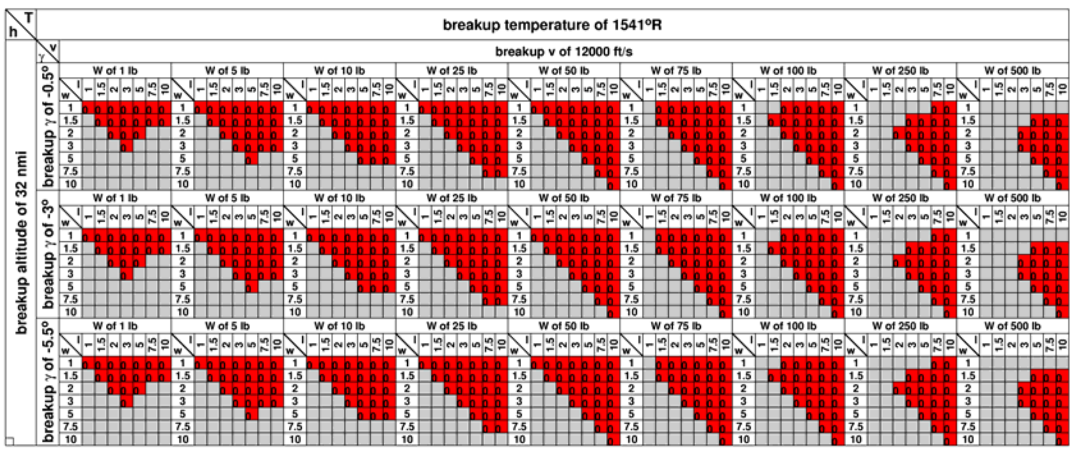


Table E-46. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

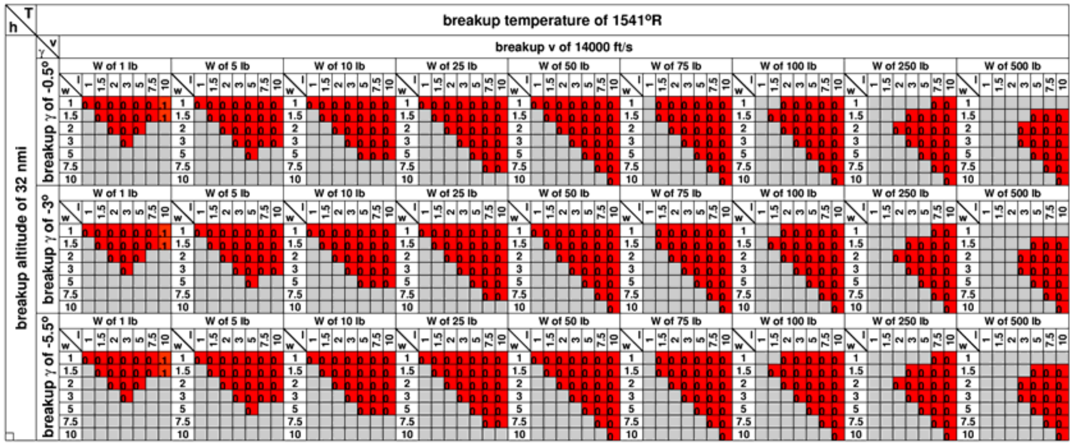


Table E-47. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

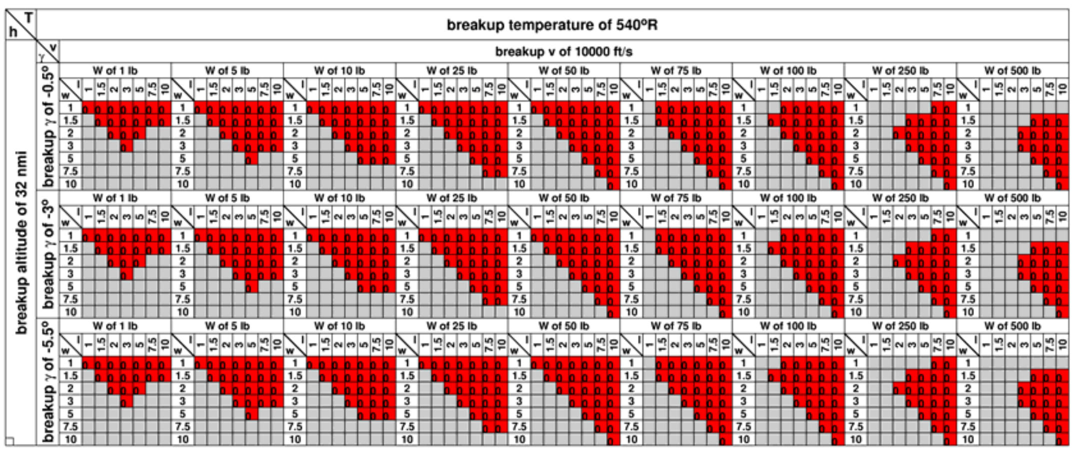


Table E-48. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

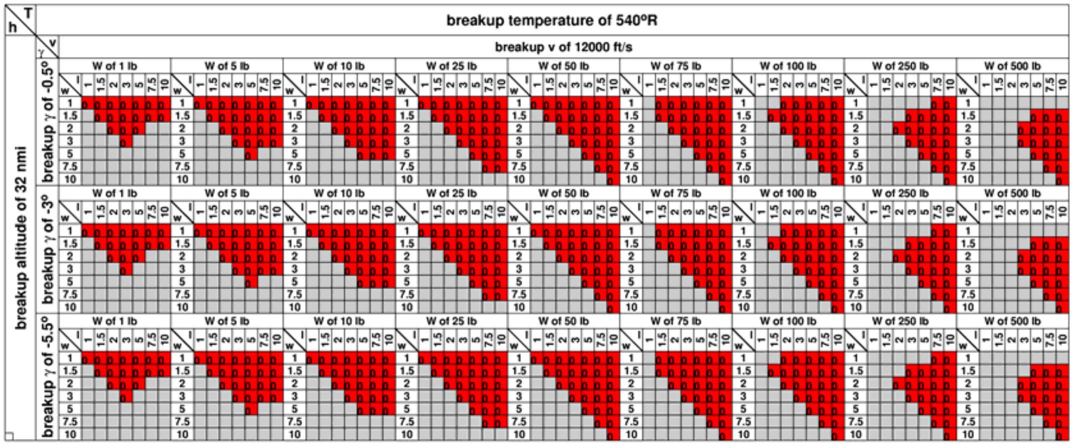


Table E-49. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

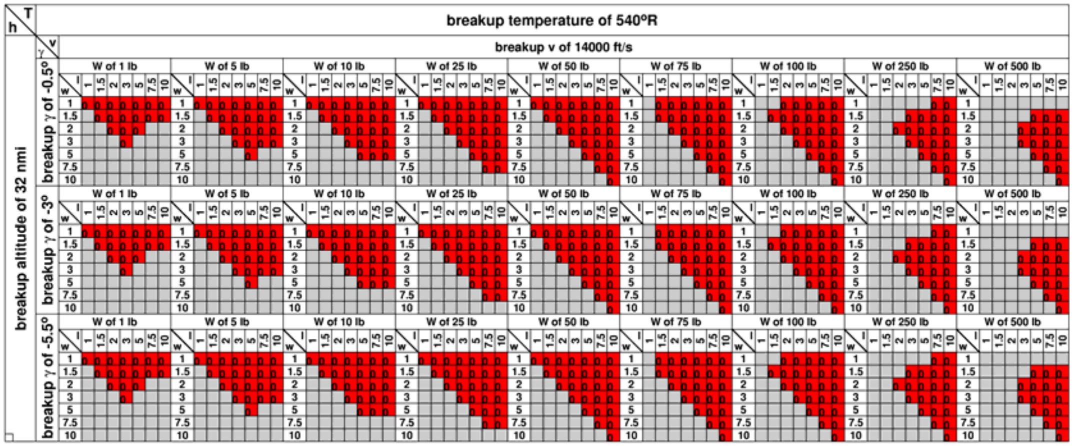


Table E-50. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

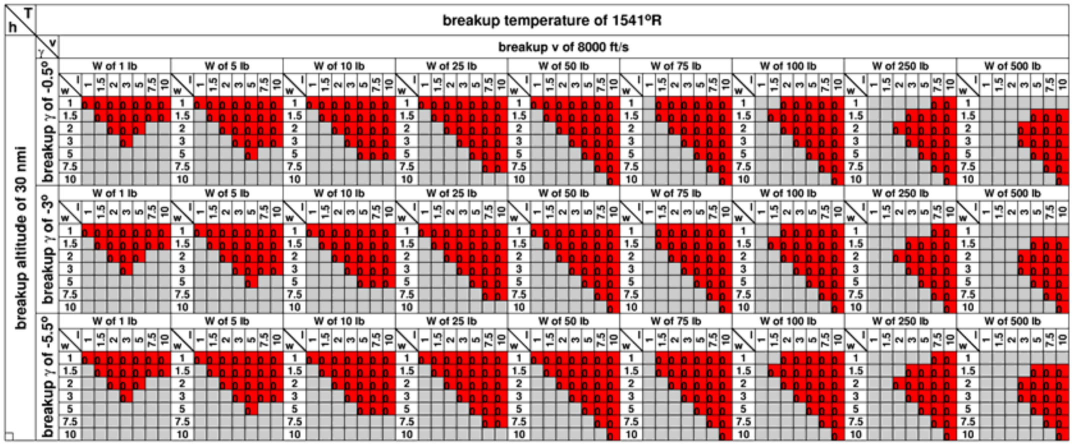


Table E-51. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

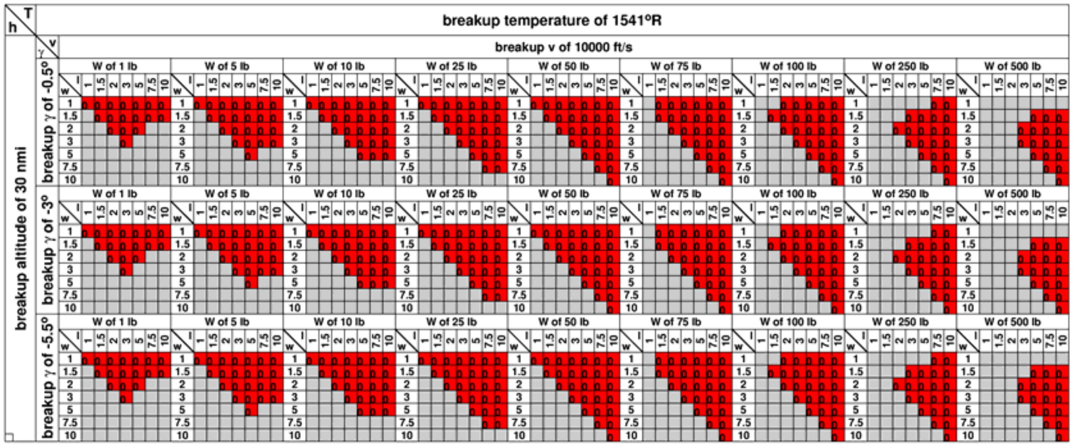


Table E-52. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

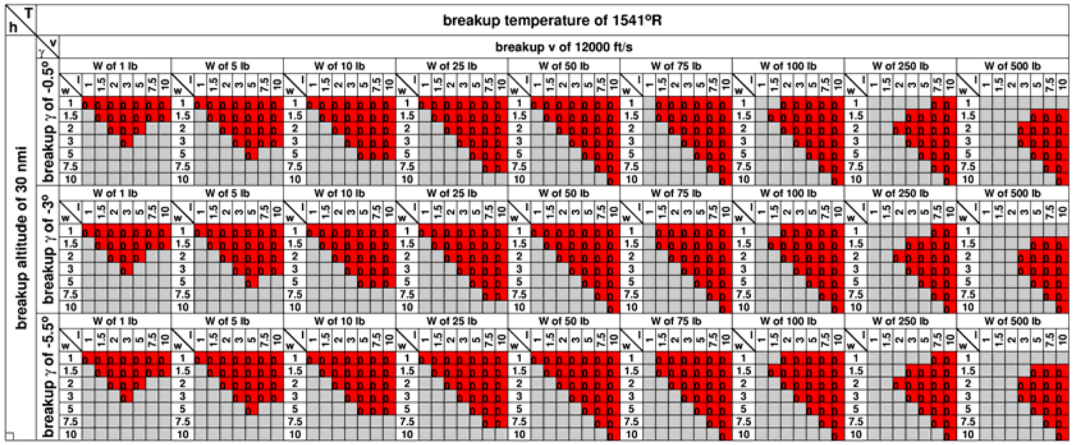


Table E-53. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

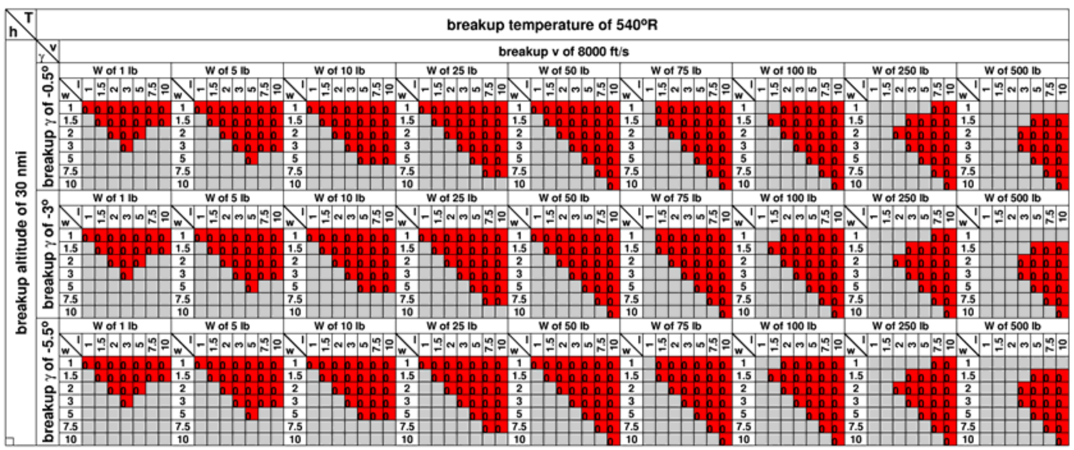


Table E-54. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h \ T: breakup temperature of 540ºR

γ \ v: breakup v of 10000 ft/s

h: breakup altitude of 30 nmi

breakup γ of -0.5º

	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0			0	0	0	0	0						0	0							
1.5		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0				0	0	0	0					0	0	0
2			0	0	0					0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0				0	0	0	0
3				0							0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0
5												0							0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0
7.5																											0	0						0	0						0	0						0	0						0	0						0	0
10																																			0							0							0							0							0

breakup γ of -3º

	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0			0	0	0	0	0						0	0							
1.5		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0				0	0	0	0					0	0	0
2			0	0	0					0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0				0	0	0	0
3				0							0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0
5												0							0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0
7.5																											0	0						0	0						0	0						0	0						0	0						0	0
10																																			0							0							0							0							0

breakup γ of -5.5º

	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0			0	0	0	0	0						0	0							
1.5		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0				0	0	0	0					0	0	0
2			0	0	0					0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0				0	0	0	0
3				0							0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0
5												0							0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0
7.5																											0	0						0	0						0	0						0	0						0	0						0	0
10																																			0							0							0							0							0

Table E-55. Aluminum 2024-T8xx Tumbling Flat Plate Survivability

h \ T: breakup temperature of 540ºR

γ \ v: breakup v of 12000 ft/s

h: breakup altitude of 30 nmi

breakup γ of -0.5º

	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0			0	0	0	0	0						0	0							
1.5		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0				0	0	0	0					0	0	0
2			0	0	0					0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0				0	0	0	0
3				0							0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0
5												0							0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0
7.5																											0	0						0	0						0	0						0	0						0	0						0	0
10																																			0							0							0							0							0

breakup γ of -3º

	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0			0	0	0	0	0						0	0							
1.5		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0				0	0	0	0					0	0	0
2			0	0	0					0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0				0	0	0	0
3				0							0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0
5												0							0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0
7.5																											0	0						0	0						0	0						0	0						0	0						0	0
10																																			0							0							0							0							0

breakup γ of -5.5º

	W of 1 lb							W of 5 lb							W of 10 lb							W of 25 lb							W of 50 lb							W of 75 lb							W of 100 lb							W of 250 lb							W of 500 lb						
w \ l	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10	1	1.5	2	3	5	7.5	10
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0			0	0	0	0	0						0	0							
1.5		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0		0	0	0	0	0	0				0	0	0	0					0	0	0
2			0	0	0					0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0			0	0	0	0	0				0	0	0	0
3				0							0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0				0	0	0	0
5												0							0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0					0	0	0
7.5																											0	0						0	0						0	0						0	0						0	0						0	0
10																																			0							0							0							0							0

E.2 Stainless Steel 21-6-9 Tumbling Flat Plate Survivability Table

Table E-56. Stainless Steel 21-6-9 Tumbling Flat Plate Survivability

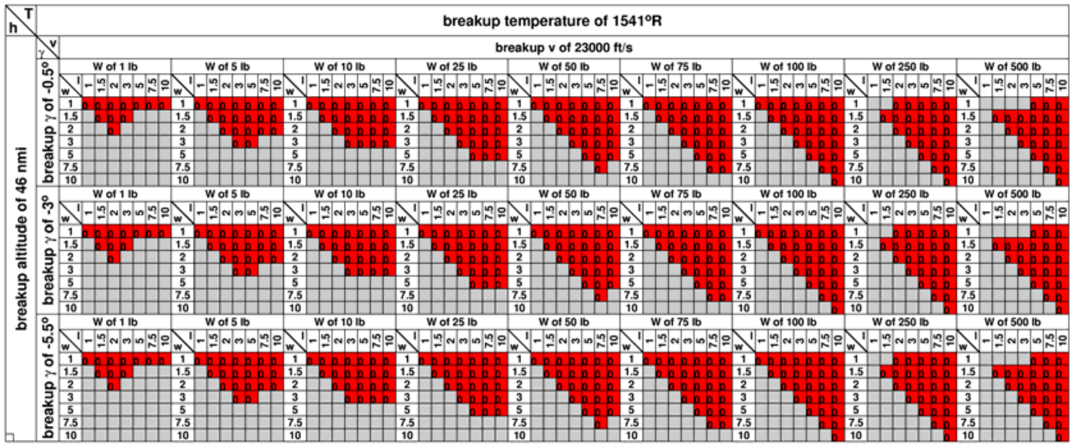


Table E-57. Stainless Steel 21-6-9 Tumbling Flat Plate Survivability

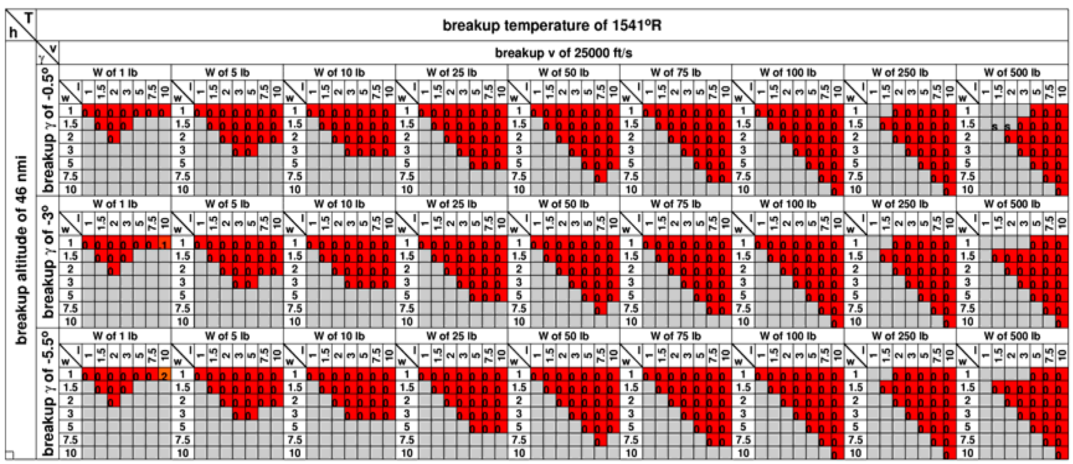
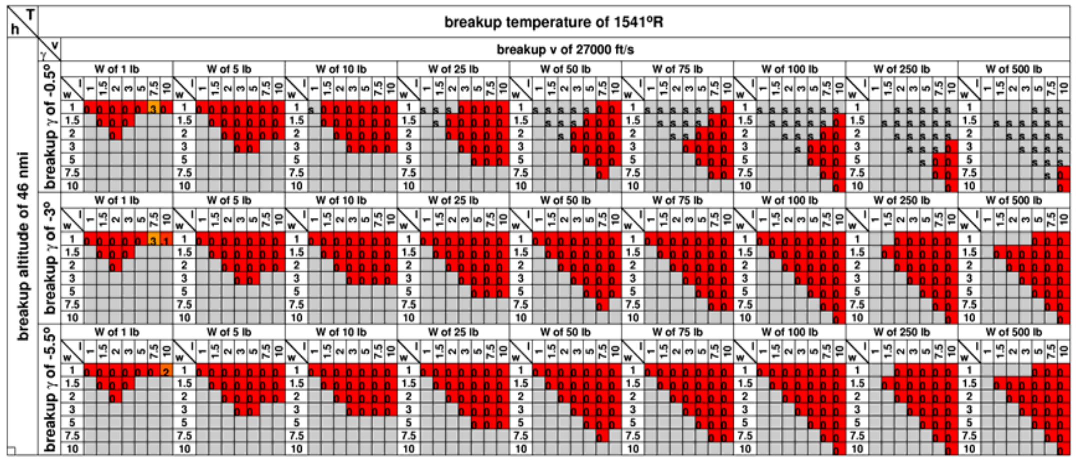


Table E-58. Stainless Steel 21-6-9 Tumbling Flat Plate Survivability



E.3 Titanium (6 Al-4 V) Tumbling Flat Plate Survivability Tables

Table E-59. Titanium (6 Al-4 V) Tumbling Flat Plate Survivability

h \ T: breakup temperature of 1541°R

γ \ v: breakup v of 23000 ft/s

breakup altitude of 46 nmi

breakup γ of -0.5°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	
	2			p	p			
	3							
	5							
	7.5							
	10							
W of 5 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5							
	7.5							
	10							
W of 10 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p		
	7.5							
	10							
W of 25 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	
	10							
W of 50 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							
W of 75 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 100 lb	1		p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 250 lb	1					p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 500 lb	1						p	p
	1.5				p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p

breakup γ of -3°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	
	2			p	p			
	3							
	5							
	7.5							
	10							
W of 5 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5							
	7.5							
	10							
W of 10 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p		
	7.5							
	10							
W of 25 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	
	10							
W of 50 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							
W of 75 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 100 lb	1		p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 250 lb	1					p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 500 lb	1						p	p
	1.5				p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p

breakup γ of -5.5°

W	w \ l	1	1.5	2	3	5	7.5	10
W of 1 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	
	2			p	p			
	3							
	5							
	7.5							
	10							
W of 5 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5							
	7.5							
	10							
W of 10 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p		
	7.5							
	10							
W of 25 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	
	10							
W of 50 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							
W of 75 lb	1	p	p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 100 lb	1		p	p	p	p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 250 lb	1					p	p	p
	1.5		p	p	p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p
W of 500 lb	1						p	p
	1.5				p	p	p	p
	2			p	p	p	p	p
	3				p	p	p	p
	5					p	p	p
	7.5						p	p
	10							p

Table E-60. Titanium (6 Al-4 V) Tumbling Flat Plate Survivability

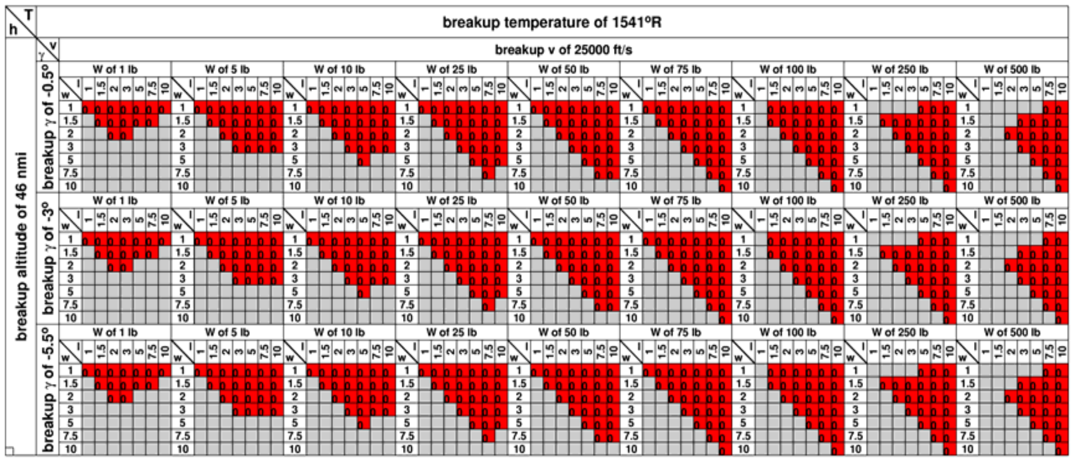


Table E-61. Titanium (6 Al-4 V) Tumbling Flat Plate Survivability