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HVL_CTH: A Simple Tool That Simulates the Hyper-Velocity Launch of a Flyer Plate

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HVL_CTH: A Simple Tool That Simulates The Hyper-Velocity Launch Of A Flyer Plate

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Abstract

Sandia National Laboratories has developed a unique method for a hyper-velocity launch (HVL), the three-stage gun. The three-stage gun is a modified two-stage light-gas gun, consisting of a piston used in the first stage, an impactor in the second stage, and a flyer plate in the third stage. The impactor is made up of different material layers that are increasing in shock impedance. The graded or pillowed layers allow the flyer to be launched at velocities up to 16 km/s without the formation of a single shock wave in the flyer plate and without it melting.

Under certain experimental conditions the flyer velocity cannot be measured by standard means, X-rays and VISAR. Also, there is a need to know the flyer velocity prior to a launch in order to calibrate instruments and determine the appropriate shot configuration. The objective of HVL_CTH is to produce an accurate forecast of the flyer plate velocity under different launch conditions.

CTH is a Eulerian shock physics computational analysis package developed at Sandia National Laboratories. Using CTH requires knowledge of its syntax and capabilities. HVL_CTH allows the user to easily interface with CTH, through the use of Fortran programs and batch files, in order to simulate the three-stage launch of a flyer plate. The program, HVL_CTH, requires little to no knowledge of the CTH program and greatly reduces the time needed to calculate the flyer velocity. Users of HVL_CTH are assumed to have no experience with CTH.

The results from HVL_CTH were compared to results of X-ray and VISAR measurements obtained from HVL experiments. The comparisons show that HVL_CTH was within 1-2% of the X-Ray and VISAR results most of the time.

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[2] Technical Advisor
[3] Mentor

Contents

1. Introduction

1.1 Purpose

This report describes the Hyper-Velocity Launch modeling package (HVL_CTH) used to determine the flyer velocity in a three-stage launch scenario. The illustration of HVL_CTH's properties and possibilities are entailed in this report, along with comparative results that confirm HVL_CTH's validity. X-ray and VISAR (Velocity Interferometer System for Any Reflector) data were used in the comparative analysis of HVL_CTH results.

1.2 Problem

We are interested in accurately and efficiently obtaining the flyer velocity during a three-stage launch. In order to calculate flyer velocity an analysis package, such as CTH, can be used. To use CTH requires knowledge of CTH syntax and capabilities. Even with adequate experience, manually changing all of the parameters in CTH involved with a three-stage launch is time consuming. The challenge for HVL_CTH was to allow user to interface with CTH and to eliminate many user calculations while maintaining parameter flexibility. Some of these parameters include impactor dimensions, flyer dimension, impactor velocity, CTH cell size, CTH run time, and CTH total mesh size.

1.3 Scope

The HVL_CTH package allows for the following user options:

- Default or user specified CTH run time, which is dependant on the projectile velocity.
- Default or user specified CTH mesh dimensions, which determine the coarseness or refinement of the CTH calculation and at the same time, shorten or lengthen the computer processing time.
- Default or user specified CTH total-mesh width, which is dependant on total material thickness.
- Default or user specified material thickness for specified materials.
- 2^{nd}-stage projectile velocity.

1.4 Limitations

Currently, HVL_CTH is a one-dimensional analysis tool, which satisfies important current demands, such as flyer velocity calculations. A two-dimension simulation package could be useful in modeling the event for presentation purposes and would allow the user to see exactly how CTH models the event, but otherwise does not enhance the current package.

The user must also be familiar with MS-DOS commands in order to run HVL_CTH from any directory on the computer. Some of the useful plots created by CTH are not run through the batch file, but instead the user must access them through the command prompt. Requiring the use of command prompt could be considered as a disadvantage.

The accuracy of HVL_CTH was only confirmed up to a flyer velocity of ~11 km/s. Comparing trends in HVL_CTH results to those from X-rays suggest that HVL_CTH more closely reproduces the measured flyer velocity as the impactor increases[4].

2. The Three-Stage Gun

The Three-Stage Gun (TSG) in operation at Sandia National Laboratories' STAR facility is a modified two-stage light-gas gun. The unique launch process enables experimental velocities to 16 km/s. Prior to the development of this technique, these kinds of velocities were impossible to achieve on a conventional light-gas gun. To initiate the process, an explosive charge launches the first-stage projectile, known as the piston, down a barrel filled with hydrogen gas. When the piston compresses the hydrogen to a specified pressure, a petal valve bursts and the second-stage projectile, referred to as the impactor, is launched. The impactor velocity is measured using the Optical Beam Reflectance (OBR) system, which allows for the determination of impactor velocity to better than 0.2% [1]. The impactor consists of thin layers of the following materials, each one increasing in density and shock impedance: TPX, magnesium, aluminum, titanium, copper, and tantalum. The density grading of the impactor, along with a TPX buffer, prevent the formation of a single shock wave in the third-stage projectile and keeps it from melting. The third-stage projectile, known as the flyer plate, is made of titanium. Flyer plates launched at 6 – 12 km/s have been used to study the equations of state of different materials and to study hyper-velocity impact phenomena and debris generation for applications such as orbital debris impacts on space vehicles [2].

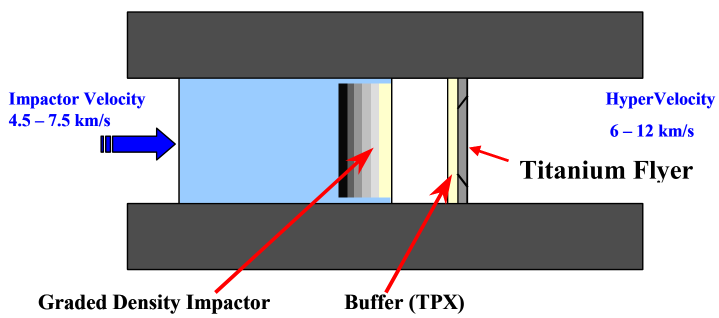

Figure 1. *Schematic of launch technique used in the three-stage gun to launch a titanium flyer plate to 6 – 12 km/s.*

[4] This trend may be observed in Figure 7.

3. Motivation For HVL_CTH Development

In earlier shots on the three-stage gun, the target assembly was mounted approximately 800 mm from the muzzle of the gun [3]. The flyer plate was mounted at the interior end of the muzzle, as seen in Figure 2. As the flyer traveled to the target, X-rays would capture images of the flyer. In order to calculate flyer velocity through X-rays, multiple X-ray images must be taken with calibrated references in view of each X-ray. Typically, five to six X-rays were used, but only two are necessary for terminal velocity calculation. When the flyer traveled 800 mm to the target, tilt and bowing of the flyer often occurred. To control impact planarity and resultant bowing, the target assembly was moved to approximately 30 mm from the muzzle of the gun [3]. Mounting of the flyer plate remains at the interior end of the muzzle. Since the gap between the muzzle and the target has been made considerably smaller, the space needed for the X-rays is no longer available. VISAR, a laser interferometer used to measure particle velocity, can only measure the flyer velocity when there is no target, as in calibration shots. Due to the elimination of X-rays and VISAR as possible flyer velocity data sources for regular experiments, the need for determining flyer velocity became apparent and the development of HVL_CTH was initiated.

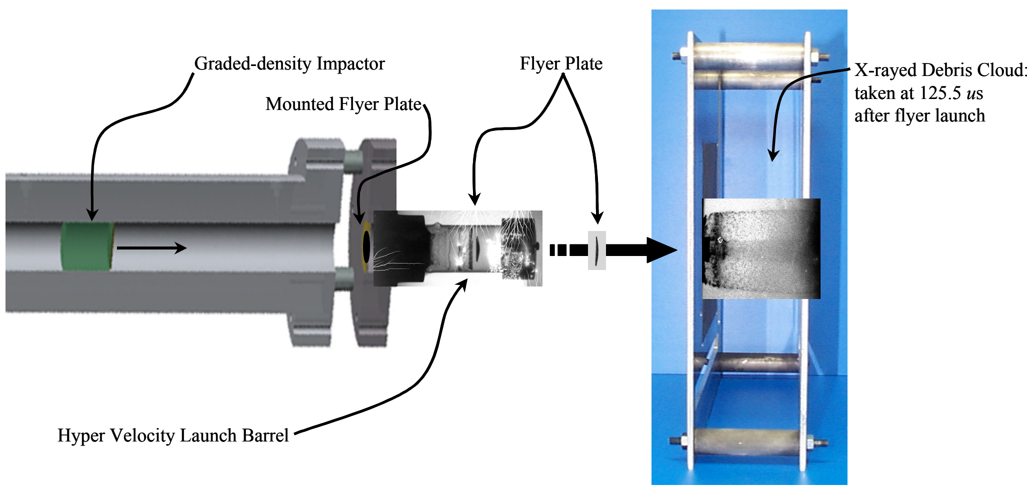

Figure 2. *Illustration of shot configuration for hyper-velocity launches.*

4. HVL_CTH Design

CTH was chosen as the base software package because it is a shock physics analysis package highly suited for hyper-velocity impacts. The CTH software family is a complete package for the initialization, integration through time, and visualization of complex shock physic events [4]. Accurate thermodynamic models are the bases for shock physic calculations. Phase changes, chemical changes, non-linear behavior, and fracture all play a large role in developing an accurate thermodynamic model; CTH factors in all of these conditions [5].

The first step in the processing procedure for HVL_CTH is running *HVL_CTH.bat* through a command screen in DOS. *HVL.exe*, a compiled Fortran program, is the initial executable run by *HVL_CTH.bat*. *HVL.exe* prompts the user for necessary HVL parameters and reads the user's input. *HVL.exe* then reads *Deck.txt*, which is the precursor to the real CTH deck, *output.txt*. Then *HVL_CTH.bat* runs *CTH*, which produces many files. One of the files produced is *hisplt*, which in turn creates *datout*. *Hisplt* is a sub-program of CTH. *Datout.exe,* also a compiled Fortran program, is the final executable to run. *Datout.exe* reads the *datout* file produced by CTH, interprets it, and then calculates the terminal flyer velocity. The flow chart below illustrates the computing process.

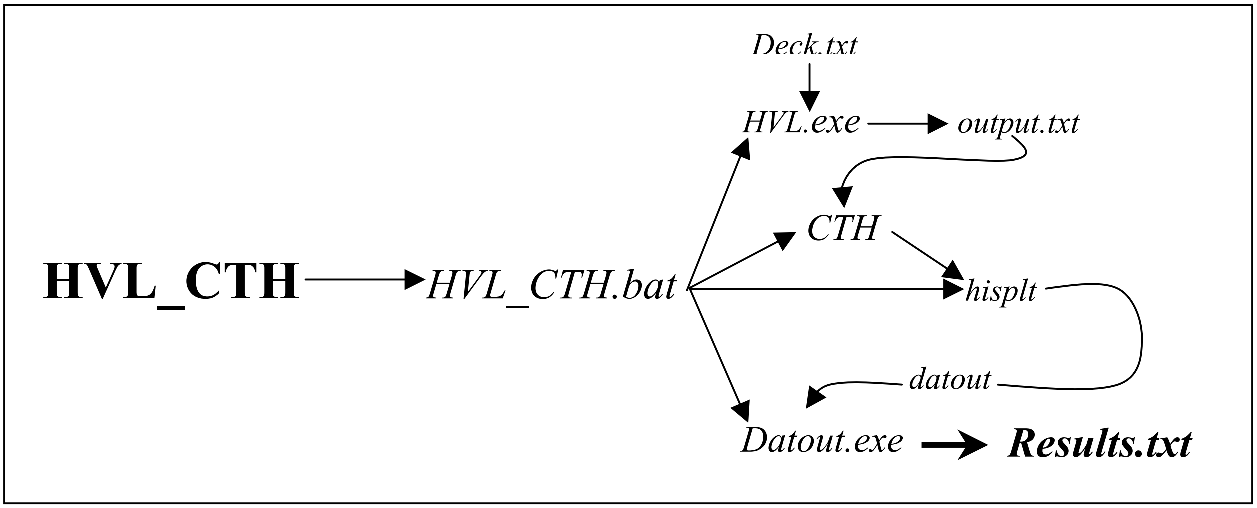

Figure 3. *The computing process for HVL_CTH.*

Output.txt referred to in Figure 3 contains important factors, which dictate how CTH will perform its calculation. The first major factor is that HVL_CTH is a 1D simulation. This allows for quicker processing time than 2D or 3D. A 2D simulation, however, has one main advantage; it can visually display the exact process of the third-stage launch. EOS records, strength records, and fracture records are also very important in flyer launch simulation. Displayed below are the choices made for these parameters.

```
*  eos records *****************************************************
eos
  mat1 sesame user eos 7593 feos 'aneos' * Lexan * sabot
  mat2 sesame user eos=3521 feos='aneos'
*
* original
* mat3 sesame copper feos 'aneos' * Copper
* modified due to note in tables.ref
* mat3 sesame user eos=3331 feos='aneos'
*
  mat3 sesame user eos=3336 feos='seslan' * Copper
  mat4 sesame ti_alloy feos 'aneos' * Ti6Al4V
  mat5 sesame aluminum feos 'sesame'  * Aluminum
  mat6 sesame magnesium feos 'aneos' * Magnesium
  mat7 sesame user eos=7171 feos='seslan'
              rp=.835 ce=1.8e5 pe=1.0e9 ps=5.0e9
  mat8 sesame user eos=7171 feos='seslan'
              rp=.835 ce=1.8e5 pe=1.0e9 ps=5.0e9
  mat9 mat4 * Titanium
ende
*
*  material strength records    **********************************************
```

```
*
*
*UNITS:
*yield & pfrac------dynes/cm^2
*tmelt----------------------------------------------------eV
epdata
* sabot
  matep=1  yield=6.12e8      tmelt=0.05          poisson=0.403
* Ta
  matep=2  yield=6.9e9       tmelt=0.374         poisson=0.432
* Cu
  matep=3  yield=1.0e9       tmelt=0.154         poisson=0.355
* Ti6Al4V
  matep=4  yield=1.33e10     tmelt=0.182         poisson=0.339
* Al
  matep=5  yield=2.9e9       tmelt=0.105         poisson=0.335
* Mg  (from Matweb for AZ31B-F)
  matep=6  yield=1.0e9       tmelt=0.076         poisson=0.350
* TPX
  matep=7  yield=0.10e9      tmelt=0.05          poisson=0.296
* TPX
  matep=8  yield=0.10e9      tmelt=0.05          poisson=0.296
* Ti6Al4V
  matep=9  yield=1.33e10     tmelt=0.182         poisson=0.339
*
  mix=3
ende
*
*  fracture records *********************************************************
*
fracts
  stress
  pfrac1  -1.6e09
  pfrac2  -4.4e10
  pfrac3  -1.2e10
  pfrac4  -2.5e10
  pfrac5  -1.2e10
* Mg ultimate tensile strength from Matweb for AZ31B-F
  pfrac6  -2.0e09
  pfrac7  -1.0e09
  pfrac8  -1.0e09
  pfrac9  -2.5e10
  pfmix  -30.e9
  pfvoid -30.e9
endf
************************************************************************
```

The multi-material property model chosen for HVL_CTH was “MMP1” as opposed to the default (MMP), which does not use compressibility weighting for the fluxing of materials. In a computational characterization study of flyer plate launch, simulations were run with and without facture being modeled, some materials did feel the effect of a release wave and the presence of fracture pressure allowed the simulation to run in a more robust fashion [7].

The datout file produced by CTH is an array of numbers that are in text format. Datout.exe reads from this text file and then determines which values to use in calculating the average terminal flyer velocity. Figure 4 illustrates the basic concept used in determining the terminal or average terminal flyer velocity. A specific example of how the velocity is calculated is found in Appendix F.

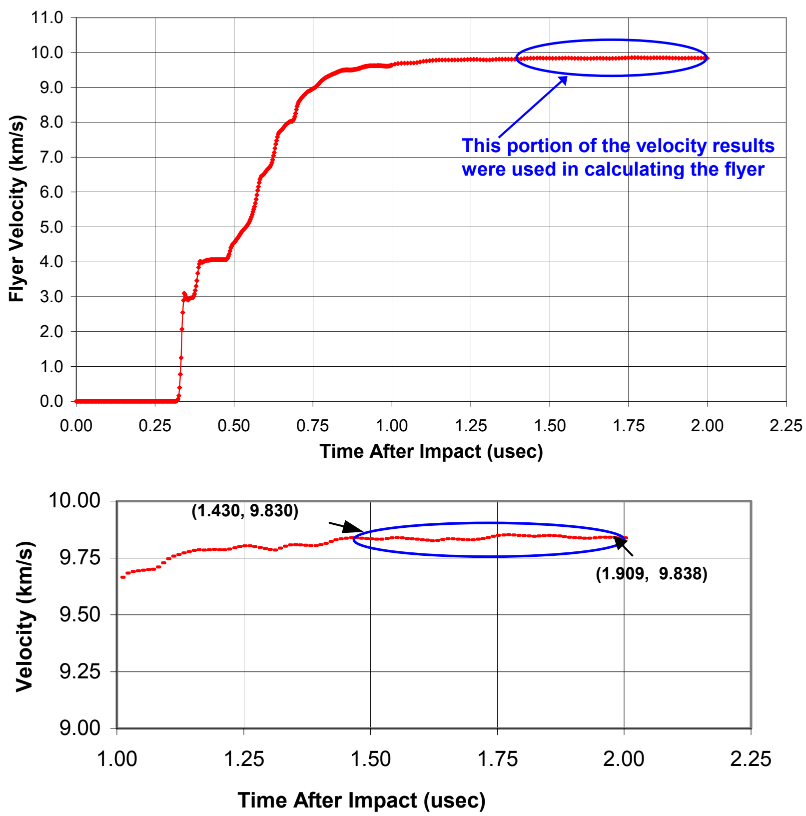

***Figure 4**. Velocity profile starting at time of impact from a datout file produced by CTH. The impactor velocity for this shot was 6.33 km/s.*

An accurate calculation of the flyer velocity is dependant on the plateau velocity records seen in the upper graph of Figure 4. The lower graph in Figure 4 with higher resolution contains fluctuation in velocity for the values within the blue circle. These fluctuations are most likely from wave reverberations, within the flyer, initiated during the third-stage launch.

CTH total run time was an important factor in the design of HVL_CTH. As the impactor velocity increases the time in which this plateau velocity is reached becomes shorter. For shots that are at lower speeds, the plateau velocity will take longer to reach. In general, most shots reach their plateau velocity within 1.5 µsec. To account for the possibility of not reaching this velocity plateau, a user option to change the total run time of the simulation was included in HVL_CTH. The user can verify that the results are satisfactory by looking at the velocity versus time graph, created by typing *popwin pophis* inside the command window.

CTH contains cells that have a user-designated material within. All of the cells combined are referred to as a mesh. Altering the number of cells in the mesh and holding the total mesh width constant can affect the accuracy of a simulation. A study was done to determine the most appropriate default number of cells. As illustrated in Figure 5, when the number of cells increases; the velocity calculated by HVL_CTH converges upon a value of 9.045 km/s and at the same time increases the computer processing time. The default number of cells (N) of 2500 (or mesh thickness = 0.004 cm) was decided upon, because it provides accurate values and at also can run in an acceptable amount of time on a personal computer. The user is given the option to change the mesh size.

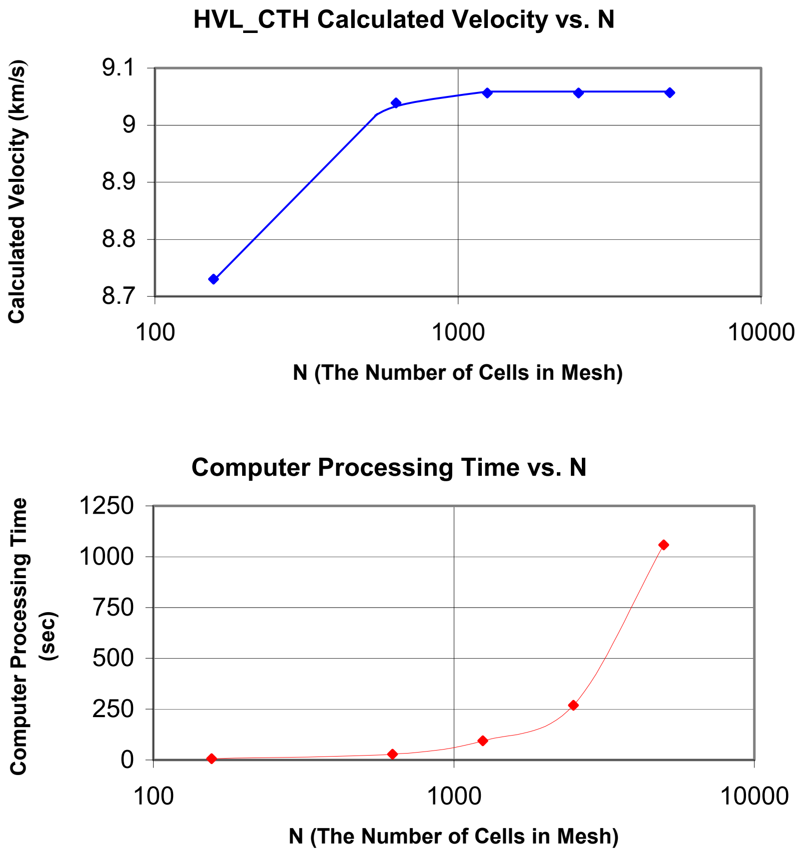

Figure 5. *These graphs illustrate how changing the number of cells in the CTH mesh affects accuracy and computation time.*

5. HVL_CTH Results and Validation

HVL_CTH results were compared to a large quantity of velocity values and can be seen in Table 1. The velocities produced by HVL_CTH were usually within 2% of the experimental velocities. The two types of experimental measurements used in the comparison were X-ray and VISAR. X-ray velocity was obtained by calculating the mean terminal velocity from X-ray heads at different positions. In a previous study X-ray precision was found to be better than 0.2% and VISAR precision, based on fringe sensitivity, was better than 0.6% [1].

Almost always HVL_CTH calculations are above experimental references, which is quite apparent in Figure 6. Uncertainties, which may contribute to error in calculations include EOS and strength uncertainties of all materials used, material re-shock, release paths, and cyclic loading paths - in addition to the tilt and bowing effects created while traversing from muzzle to target [7].

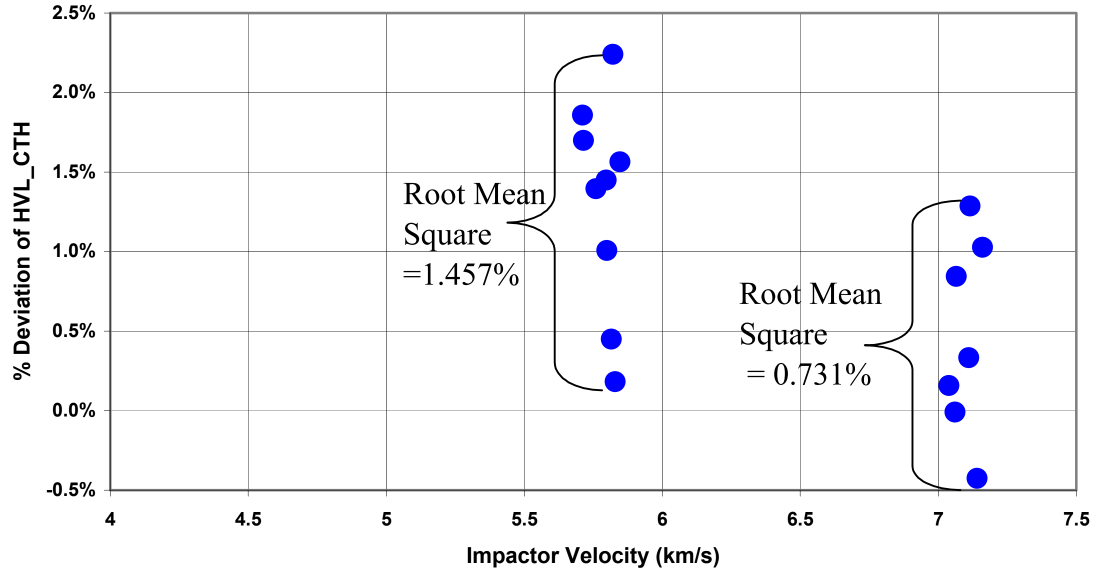

Figure 6. *Comparison of HVL_CTH calculations to X-ray measurements with respect to Impactor velocity.*

Figure 7 also illustrates HVL_CTH convergence on experimental measurements. Observe that HVL_CTH is almost always slightly above experimental measurements. Some of the strength records used in CTH may be more appropriate at higher velocities. This is a possible reason for HVL_CTH convergence.

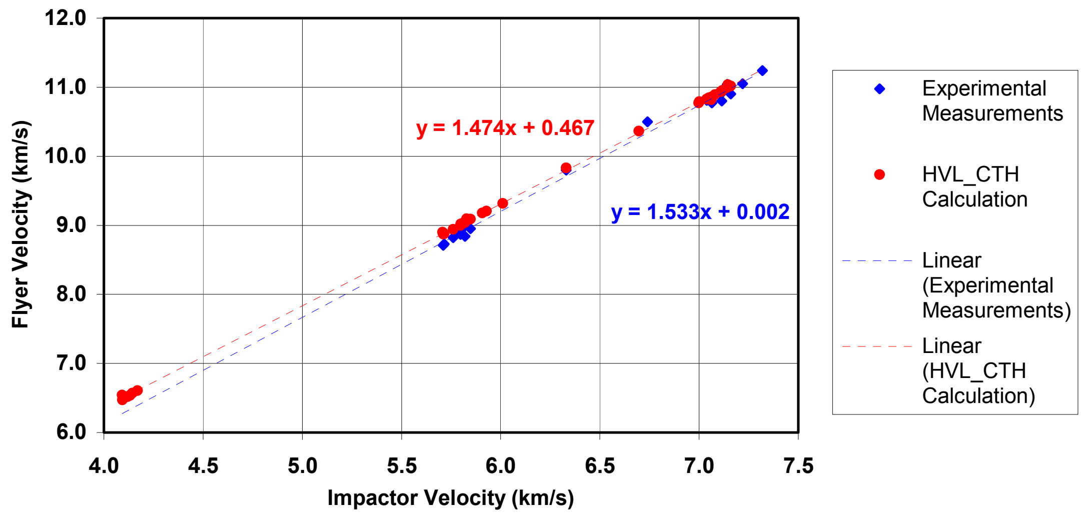

Figure 7. *Flyer velocity versus impactor velocity for experimental measurements and HVL_CTH calculations, including line of best fit for each data set.*

Exp #	Impactor Velocity	Mean X-ray Velocity	VISAR Velocity	HVL_CTH Velocity	Deviation of HVL_CTH
HVL-02	6.330		9.80	9.834	0.343
HVL-03	6.740	10.50	10.23		
HVL-04	7.220	11.05	11.04		
HVL-05[5]	7.320	11.24	11.15		
CLP-1	7.145			11.037	
CLP-2	4.144			6.570	
CLP-3	5.907			9.178	
CLP-4	6.697			10.367	
CLP-5	7.110	**10.90**		10.936	0.332%
CLP-6	6.010			9.320	
CLP-7	7.118			10.952	
CLP-8	5.797	**8.87**		8.999	1.449%
CLP-9	5.799	**8.93**		9.020	1.007%
CLP-10	5.847	**8.95**		9.090	1.564%
CLP-11	5.760	**8.82**		8.943	1.396%
CLP-12	7.141	**11.04**		10.993	**-0.426%**
CLP-13	5.711	**8.71**		8.872	1.858%
CLP-14	5.715	**8.73**		8.878	1.699%
CLP-15	7.039	**10.81**		10.827	0.157%
CLP-16	7.065	**10.77**		10.861	0.845%
CLP-17	5.815	**9.00**		9.041	0.450%
CLP-18[6]	7.061	**10.82**		10.819	**-0.009%**
NMD-1	4.119			6.5187	
NMD-2	4.133			6.5396	
NMD-3	4.170			6.6048	
NMD-4	4.093			6.4724	
NMD-5	4.092			6.5404	
NMD-6	5.707			8.9026	
NMD-7	5.829			9.0930	
NMD-8	5.821	**8.84**		9.0402	2.264%
NMD-9	7.115	**10.80**		10.9394	1.291%
NMD-10	7.160	**10.90**		11.0183	1.085%
NMD-11	7.001			10.7894	
NMD-12	6.998			10.7721	
NMD-13	5.929			9.2061	
NMD-14	7.081			10.8946	
NMD-15[7]	7.050			10.8451	
					Average=
					0.956%

Table 1. *Results from HVL_CTH and X-ray comparisons.*

5 [6]
6 [8]
7 [3]

It is important that the calculated terminal flyer velocity match experimental results, but it is also important for the velocity profiles to line up as well. Several experimental launches were done without targets. This target-less configuration allowed for VISAR measurements of the flyer velocity. HVL_CTH and VISAR velocity profiles agree reasonably well, which can be seen in Figure 7. Calculations with two cell sizes are included to illustrate, once again, that 0.004 cm is a suitable default cell size.

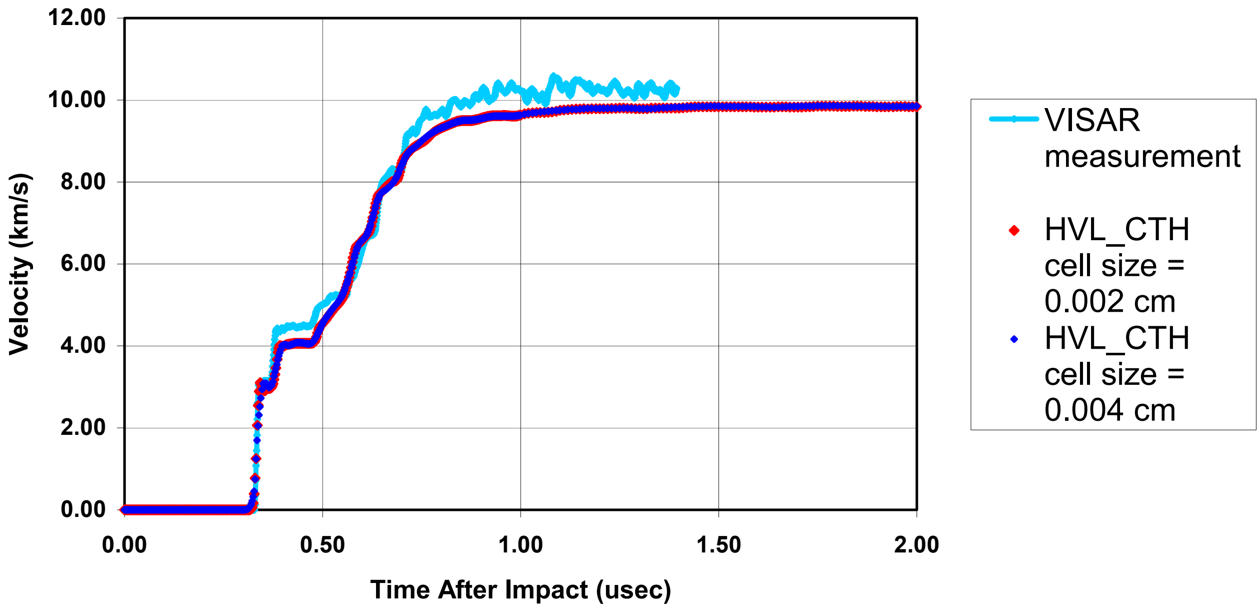

Figure 7. *Comparison of velocity profiles measured with VISAR and calculated with HVL_CTH for a shot with an impactor velocity of 6.33 km/s.*

6. Conclusions

HVL_CTH provides accurate flyer velocity calculations in a wide range of 5 – 16 km/s, through a quick and easy process. Comparisons with previous results show that HVL_CTH consistently provides terminal velocity results within 1-2% of experimental measurements, such as those from X-rays. Additionally, the velocity profiles produced by HVL_CTH were very close to those from VISAR. HVL_CTH provides an efficient way to determine flyer velocity, especially when it cannot be measured directly.

7. References

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6. L. C. Chhabildas, private communication.

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8. Current study at Sandia National Laboratories.

8. Appendix A

Source code for HVL.exe.

```
      program HVL

** This is a program designed to produce an ouput file that resembles a CTH *
* Deck.
*The output file can then be accessed thru CTH to produce valuable results *
* for studying HVL (Hyper Velocity Launches).

      Real Tstop, dx, w, xvel, Sabot, Ta, Cu, Ti, Al, Mg, Tpx1, Tpx2,
     + Flyer, np1, np2, np3, np4, np5, np6, np7, p0, p1, p2, x0, xact,
     + TaTrace, TiTrace, MgTrace

*--------------------------Variabl Definitions-------------------------
*     Tstop:      defines the total run time of the simulation.
*     dx:         the cell size in CTH
*     w:          the total width of the mesh in CTH
*     xvel:       the second-stage projectile velocity
*     Sabot...Tpx2 are all material thicknesses.
*     "np"        defines a negative point, it is used in CTH for
*                 positioning materials
*     "p"         defines a point, it is used in CTH for positioning
*                 materials
*The origin of these points is at the interface of the two TPX pieces *(0,0).
*     x0:         the left edge of the mesh and is derived by
*                 subtracting 0.5 from the left edge
*                 of the Lexan Sabot.
*     xact:       the point at which CTH activates cells for
*                 computation and is also dependant on the Lexan Sabot *
            position.
*     TaTrace, TiTrace, and MgTrace are all tracer positions
*----------------------------------------------------------------------
      Integer M, K

      Character*2 Ans,Y,N,contin,star
      Character*72 Title, I
*
*     Caution: Do not call any units 5 or 6 because these are the
*     default input and output devices(ie: the keyboard and the screen)
      open (unit=1, file = 'Deck.txt')
      open (unit=2, file = 'output.txt',status='replace')
      open (unit=3, file = 'User_info.txt')
*
      Sabot = 1.00
      p0=0.0

** Title
      write (*,*) '1D Launch Simulation'
      write (*,*) 'Enter Shot Number (ie: nmd 10) ='
      read (*,13) Title

** Run Time
```

```
  102 write (*,*) 'Enter run time(for default
     +value of 2.0e-6 sec enter 0)='
      read (*,*,err=102) Tstop
        If (Tstop.EQ.0) then
          Tstop = 2.0e-6
        Endif

** Mesh Dimensions
  104 write (*,*)'Enter mesh grid
     +size(default value of 0.004 cm enter 0)='
      read (*,*,err=104) dx
         If (dx.EQ.0) then
           dx = 0.004
         EndIf
** Mesh Width
  106 write (*,*)'Enter total mesh
     +width(default value of 6.0 cm enter 0)='
      read(*,*,err=106) w
            If (w.EQ.0) then
              w = 6.0
            EndIf
*
  101 format (A,F12.8)
      write (*,101) 'run time   = ', tstop
      write (*,101) 'mesh grid  = ', dx
      write (*,101) 'mesh width = ', w
*User go ahead
      write (*,*) 'Are you satisfied with what you entered (Y/N)?'
      read (*,*) Ans
            If (Ans.NE.'Y'.AND.Ans.NE.'y') then
                        goto 102
            EndIf
*
      write (3,101) 'run time   = ', tstop
      write (3,101) 'mesh grid  = ', dx
      write (3,101) 'mesh width = ', w


** Material Thicknesses
  112 write (*,*) 'Would you like to use all default thicknesses (Y/N)?'
      read (*,*) Ans
            If (Ans.EQ.'Y'.OR.Ans.EQ.'y') then
** The following are default values for material thicknesses:
                  Ta   =0.89
                  Cu   =0.29
                  Ti   =0.415
                  Al   =0.50
                  Mg   =0.56
                  Tpx1 =1.00
                  Tpx2 =1.37
                  Flyer=0.90
            Else
** The following are prompts for the user if they do not choose default
values:
  110             write (*,*) 'Tantalum thickness (mm) ?'
                  read (*,*,err=110) Ta
                  write (*,*) 'Copper thickness (mm) ?'
```

```
                  read (*,*,err=110) Cu
                  write (*,*) 'Titanium thickness (mm) ?'
                  read (*,*,err=110) Ti
                  write (*,*) 'Aluminum thickness (mm) ?'
                  read (*,*,err=110) Al
                  write (*,*) 'Magnesium thickness (mm) ?'
                  read (*,*,err=110) Mg
                  write (*,*) 'TPX 1 thickness (mm) ?'
                  read (*,*,err=110) Tpx1
                  write (*,*) 'TPX 2 thickness (mm) ?'
                  read (*,*,err=110) Tpx2
                  write (*,*) 'Ti Flyer thickness (mm) ?'
                  read (*,*,err=110) Flyer

            Endif
*
  103 format (A,F15.13)
      write (*,*) 'Units are in mm'
      write (*,103) 'Ta      = ',Ta
      write (*,103) 'Cu      = ',Cu
      write (*,103) 'Ti      = ',Ti
      write (*,103) 'Al      = ',Al
      write (*,103) 'Mg      = ',Mg
      write (*,103) 'TPX1    = ',Tpx1
      write (*,103) 'TPX2    = ',Tpx2
      write (*,103) 'Ti Flyer= ', Flyer
*User go ahead
      write (*,*) 'Are you satisfied with the
     +dimensions you entered (Y/N)?'
      read (*,*) Ans
            If (Ans.NE.'Y'.AND.Ans.NE.'y') then
                        goto 112
            EndIf
      write (3,*) 'Units are in mm'
      write (3,103) 'Ta      = ',Ta
      write (3,103) 'Cu      = ',Cu
      write (3,103) 'Ti      = ',Ti
      write (3,103) 'Al      = ',Al
      write (3,103) 'Mg      = ',Mg
      write (3,103) 'TPX1    = ',Tpx1
      write (3,103) 'TPX2    = ',Tpx2
      write (3,103) 'Ti Flyer= ', Flyer
                  Ta   =(Ta/10)
                  Cu   =(Cu/10)
                  Ti   =(Ti/10)
                  Al   =(Al/10)
                  Mg   =(Mg/10)
                  Tpx1 =(Tpx1/10)
                  Tpx2 =(Tpx2/10)
                  Flyer=(Flyer/10)


** Projectile Velocity


  114 write (*,*) 'Enter 2nd-stage projectile velocity (km/s)='
      read (*,*,err=114) xvel
```

```
      write (*,*) 'velocity (km/s) = ', xvel
      write (3,*) 'Projectile velocity (km/s) = ', xvel
      xvel = (xvel*1.0E5)
      write (*,*) 'velocity (cm/s) = ',xvel

**Directions to Continue Batch File
      write (*,*) 'Click "Yes" to continue.'
*
      p1 = (0.0+Tpx2)
      p2 = (Tpx2+Flyer)
      np1 = (0.0-Tpx1)
      np2 = (np1-Mg)
      np3 = (np2-Al)
      np4 = (np3-Ti)
      np5 = (np4-Cu)
      np6 = (np5-Ta)
      np7 = (np6-Sabot)
*
      x0=(np7-.5)
      xact = (np7-0.05)
*
      TaTrace  =(np5+np6)/2
      TiTrace  =(np3+np4)/2
      MgTrace  =(np1+np3)/2
*************************************************************************
** This is the point at which output is produced. It's written to
**    unit=2.



** The READ statements in capital letters READ the blank lines in the **CTH
Deck.
** The blanks are there to make the Deck for seperation to aid in **reading.
      READ (1,*)
      READ (1,*)
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K = 1, M
            read (1,13,err=10) I
            write (2,13) I
      enddo
   13 format (a)
   10 continue
*
      write (2,*) Title
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=12) I
            write (2,13) I
      enddo
   12 continue
```

```
*
      write (2,15)  Tstop
   15 format (2x, 'tstop = ', 2x, E12.4)
*

      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=14) I
            write (2,13) I
      enddo
   14 continue
*writing x0
      write (2,2) x0
    2 format (3x,'x0 =', E12.5)
*writing dx and w
      write (2,17) dx,dx,w
   17 format (3x,'x1 dxf = ',E9.4, 2x,'dxl = ',E9.4, 2x,'w = ',E9.4)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=16) I
            write (2,13) I
      enddo
   16 continue
*writing xact
      write (2,97) xact
   97 format (3x,'xact =',E12.6,2x,'0.025')
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=96) I
            write (2,13) I
      enddo
   96 continue
** Sabot *********************
      write (2,19) xvel
   19 format (6x,'xvel = ', E12.6)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=18) I
            write (2,13) I
      enddo
   18 continue
*
```

```
      write (2,21) np7
   21 format (9x,'p1 = ', E12.5)
*
      write (2,23) np6
   23 format (9x,'p2 = ', E12.5)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=20) I
            write (2,13) I
      enddo
   20 continue
** Tantalum *****************
      write (2,19) xvel
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=48) I
            write (2,13) I
      enddo
   48 continue
*
      write (2,25) np6
   25 format (9x,'p1 = ', E12.5)
*
      write (2,27) np5
   27 format (9x,'p2 = ', E12.5)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=22) I
            write (2,13) I
      enddo
   22 continue
** Copper *****************
      write (2,19) xvel
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=24) I
            write (2,13) I
      enddo
   24 continue
*
      write (2,29) np5
```

```
   29 format (9x,'p1 = ', E12.5)
*
      write (2,31) np4
   31 format (9x,'p2 = ', E12.5)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=26) I
            write (2,13) I
      enddo
   26 continue
** Titanium *****************
      write (2,19) xvel
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=28) I
            write (2,13) I
      enddo
   28 continue
*
      write (2,33) np4
   33 format (9x,'p1 = ', E12.5)
*
      write (2,35) np3
   35 format (9x,'p2 = ', E12.5)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=30) I
            write (2,13) I
      enddo
   30 continue
** Aluminum *****************
      write (2,19) xvel
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=50) I
            write (2,13) I
      enddo
   50 continue
*
      write (2,37) np3
   37 format (9x,'p1 = ', E12.5)
```

```
*
      write (2,39) np2
   39 format (9x,'p2 = ', E12.5)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=32) I
            write (2,13) I
      enddo
   32 continue
** Magnesium *****************
      write (2,19) xvel
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=34) I
            write (2,13) I
      enddo
   34 continue
*
      write (2,41) np2
   41 format (9x,'p1 = ', E12.5)
*
      write (2,43) np1
   43 format (9x,'p2 = ', E12.5)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=36) I
            write (2,13) I
      enddo
   36 continue
** TPX1 *****************
      write (2,19) xvel
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=38) I
            write (2,13) I
      enddo
   38 continue
*
      write (2,45) np1
   45 format (9x,'p1 = ', E12.5)
*
```

```
      write (2,47) p0
   47 format (9x,'p2 = ', E12.5)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=40) I
            write (2,13) I
      enddo
   40 continue
** TPX2 ******************

      write (2,49) p0
   49 format (9x,'p1 = ', E12.5)
*
      write (2,51) p1
   51 format (9x,'p2 = ', E12.5)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=42) I
            write (2,13) I
      enddo
   42 continue
** Ti Flyer ******************

      write (2,53) p1
   53 format (9x,'p1 = ', E12.5)
*
      write (2,55) p2
   55 format (9x,'p2 = ', E12.5)
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=44) I
            write (2,13) I
      enddo
   44 continue
***************Tracers ******************
** Sabot
      write (2,57) np7,np6
   57 format (2x,'add ', E12.5, 1x,'to ',E12.5, 1x, 'number 3')
** Tantalum
      write (2,59)'*tantalum'
   59 format (a)
      write (2,61) TaTrace
   61 format (2x,'add ',E12.5)
** Copper
      write (2,59)'*copper'
```

```
      write (2,63) np5,np4
   63 format (2x,'add ', E12.5, 1x,'to ',E12.5, 1x, 'number 3')
** Titanium
      write (2,59)'*titanium'
      write (2,65) TiTrace
   65 format (2x,'add ',E12.5)
** Aluminum
      write (2,59)'*aluminum'
      write (2,67) np3,np2
   67 format (2x,'add ', E12.5, 1x,'to ',E12.5, 1x, 'number 3')
** Magnesium
      write (2,59)'*magnesium'
      write (2,69) MgTrace
   69 format (2x,'add ',E12.5)
** TPX1
      write (2,59)'*TPX'
      write (2,71) np1,p0
   71 format (2x,'add ', E12.5, 1x,'to ',E12.5, 1x, 'number 3')
** TPX2
      write (2,59)'*TPX'
      write (2,73) p0,p1
   73 format (2x,'add ', E12.5, 1x,'to ',E12.5, 1x, 'number 3')
** Ti Flyer
      write (2,59)'*titanium'
      write (2,75) p1,p2
   75 format (2x,'add ', E12.5, 1x,'to ',E12.5, 1x, 'number 6')
*
      READ (1,*)
      READ (1,*)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=46) I
            write (2,13) I
      enddo
   46 continue
*
      READ (1,*)
      READ (1,*)
*
      write (2,77) Title
   77 format ('Title, ',a)
*
      read (1,*) M
      do K=1,M
            read (1,13,err=58) I
            write (2,13) I
      enddo
   48 continue
*
*
      READ (1,*)
      READ (1,*)
*
      write (2,77) Title
*
      read (1,*) M
```

```
      do K=1,M
            read (1,13,err=60) I
            write (2,13) I
      enddo
   50 continue
*
      READ (1,*)
      READ (1,*)
*
      write (2,77) Title
*
      read (1,*) M
      do K=1,M
            read (1,13,err=62) I
            write (2,13) I
      enddo
   52 continue
*
      READ (1,*)
      READ (1,*)
*
      write (2,77) Title
*
      read (1,*) M
      do K=1,M
            read (1,13,err=64) I
            write (2,13) I
      enddo
   54 continue
*


      End
```

9. Appendix B

CTH Deck produced by HVL.exe.

```
*eor* cthin
*
**********************************************************************
*
* Description of problem
*
* Simulation of HVL launch of the Ti plate
*
*
**********************************************************************
*
*  Title record
*
HVL_CTH Test
**********************************************************************
*
*  control records
*
*
restart
  nu = 1
endr
*
*
control
 mmp1            * multiple material temp and pressure model
* checkmesh        *  for checking mesh only, no matl insertion
*
*  dtcourant = 0.5
*
  ntbad = 999999999
  tstop =     0.2000E-05
 frac = 1
endc
*
*
**********************************************************************
*
*  mesh records
*     units : cm , seconds, gms, electron volts
*
mesh
  block 1  geom=1dr  type=e
*
*x0 is the left edge of the frame and is derived from subtracting
*    0.5 cm from the back of the Lexan Sabot.
*dxf and dxl are mesh subdivisions, the default values are 0.004 cm.
*w is the total width of the mesh, the dafault value is 6.0 cm.
*
   x0 =-0.18655E+01
   x1 dxf = .4000E-02  dxl = .4000E-02  w = .6000E+01
   endx
```

```
*
*xact is the point at which CTH activates cells for computation.
*
   xact =-.141550E+01  0.025
  endb
endm
*
************************************************************************
*
* material insertion records
*
diatom
*
   package 'sabot'
      material 1
      xvel = 0.989000E+06
      nsub=100
      insert box
         p1 = -0.13655E+01
         p2 = -0.36550E+00
      endi
   endp
*
   package 'Tantalum'
      material 2
      xvel = 0.989000E+06
      nsub=100
      insert box
         p1 = -0.36550E+00
         p2 = -0.27650E+00
      endi
   endp
*
   package 'Copper'
      material 3
      xvel = 0.989000E+06
      nsub=100
      insert box
         p1 = -0.27650E+00
         p2 = -0.24750E+00
      endi
   endp
*
   package 'Titanium'
      material 4
      xvel = 0.989000E+06
      nsub=100
      insert box
         p1 = -0.24750E+00
         p2 = -0.20600E+00
      endi
   endp
*
   package 'Aluminum'
      material 5
      xvel = 0.989000E+06
      nsub=100
```

```
      insert box
         p1 = -0.20600E+00
         p2 = -0.15600E+00
      endi
   endp
*
   package 'Magnesium'
      material 6
      xvel = 0.989000E+06
      nsub=100
      insert box
         p1 = -0.15600E+00
         p2 = -0.10000E+00
      endi
   endp
*
   package 'TPX'
      material 7
      xvel = 0.989000E+06
      nsub=100
      insert box
         p1 = -0.10000E+00
         p2 =  0.00000E+00
      endi
   endp
*
   package 'TPX'
      material 8
      nsub=100
      xvel = 0.0
     insert box
         p1 =  0.00000E+00
         p2 =  0.13700E+00
      endi
   endp
*
   package 'Titanium'
      material 9
      xvel = 0.0
      nsub=100
      insert box
         p1 =  0.13700E+00
         p2 =  0.22700E+00
      endi
   endp
*
enddiatom
*
*
**********************************************************************
*
*  eos records
*
*
eos
  mat1 sesame user eos 7593 feos 'aneos' * Lexan * sabot
  mat2 sesame user eos=3521 feos='aneos'
```

```
*
* original
* mat3 sesame copper feos 'aneos' * Copper
* modified due to note in tables.ref
* mat3 sesame user eos=3331 feos='aneos'
*
  mat3 sesame user eos=3336 feos='seslan' * Copper
  mat4 sesame ti_alloy feos 'aneos' * Ti6Al4V
  mat5 sesame aluminum feos 'sesame'  * Aluminum
  mat6 sesame magnesium feos 'aneos' * Magnesium
  mat7 sesame user eos=7171 feos='seslan'
            rp=.835 ce=1.8e5 pe=1.0e9 ps=5.0e9
  mat8 sesame user eos=7171 feos='seslan'
            rp=.835 ce=1.8e5 pe=1.0e9 ps=5.0e9
  mat9 mat4 * Titanium
ende
*
**********************************************************************
*
*  material strength records
*
epdata
* sabot
  matep=1  yield=6.12e8      tmelt=0.05           poisson=0.403
* Ta
  matep=2  yield=6.9e9       tmelt=0.374          poisson=0.432
* Cu
  matep=3  yield=1.0e9       tmelt=0.154          poisson=0.355
* Ti6Al4V
  matep=4  yield=1.33e10     tmelt=0.182          poisson=0.339
* Al
  matep=5  yield=2.9e9       tmelt=0.105          poisson=0.335
* Mg  from Matweb for AZ31B-F
  matep=6  yield=1.0e9       tmelt=0.076          poisson=0.350
* TPX
  matep=7  yield=0.10e9      tmelt=0.05           poisson=0.296
* TPX
  matep=8  yield=0.10e9      tmelt=0.05           poisson=0.296
* Ti6Al4V
  matep=9  yield=1.33e10     tmelt=0.182          poisson=0.339
*
  mix=3
ende
*
***********************************************************************
*
*  fracture records
*
fracts
  stress
  pfrac1  -1.6e09
  pfrac2  -4.4e10
  pfrac3  -1.2e10
  pfrac4  -2.5e10
  pfrac5  -1.2e10
* Mg ultimate tensile strength from Matweb for AZ31B-F
  pfrac6  -2.0e09
```

```
  pfrac7  -1.0e09
  pfrac8  -1.0e09
  pfrac9  -2.5e10
  pfmix  -30.e9
  pfvoid -30.e9
endf
*
***********************************************************************
*
* cell thermodynamics
*
cellthermo
    mmp1
endcellthermo
*
*
*
***********************************************************************
*
*  time step records
*
*mindt
*  time = 0.  dt = 1.e-9
*endn
*
maxdt
  time = 0.  dt = .01
endx
*
***********************************************************************
*
*  tracer records
*
tracer
*sabot
  add -0.13655E+01 to -0.36550E+00 number 3
*tantalum
  add -0.32100E+00
*copper
  add -0.27650E+00 to -0.24750E+00 number 3
*titanium
  add -0.22675E+00
*aluminum
  add -0.20600E+00 to -0.15600E+00 number 3
*magnesium
  add -0.15300E+00
*TPX
  add -0.10000E+00 to  0.00000E+00 number 3
*TPX
  add  0.00000E+00 to  0.13700E+00 number 3
*titanium
  add  0.13700E+00 to  0.22700E+00 number 6
endt
***********************************************************************
*  edit records
*
edit
```

```
  exact
  shortt
    time=0. dt = .5
   ends
  longt
    time = 0.  dt = 1.0
  endl
  plott
    time = 0.  dt =  1.0e-6
  endp
  histt
    time = 0.  dt = 0.0025e-6
    time = 1.0e-6  dt = 0.0100e-6
    htracer all
  endh
  restt
    time = 0.0e-6 dt=10.0e-6
  endr
ende
*
*
***********************************************************************
*
*  boundary condition records
*
boundary
   bhydro
     block 1
       bxb = 2  bxt = 2  * ????
     endb
   endh
endb
*
************************************************************************
*
*eor* hisin
*
************************************************************************
*
*
color table=6
color, foreground=1, text=0, background=7, logo=6, interior=7
*
Title, HVL_CTH Test
gtitle='Titanium Flyer Velocity'
color, foreground=1, text=0, background=7, logo=6, interior=7
plot time xvelocity.19 legend='TPX Ti interface'
color, foreground=2, text=0, background=7, logo=6, interior=7
plot time xvelocity.20 legend='Tracer 2' nf
color, foreground=3, text=0, background=7, logo=6, interior=7
plot time xvelocity.21 legend='Tracer 3' nf
color, foreground=4, text=0, background=7, logo=6, interior=7
plot time xvelocity.22 legend='Tracer 4' nf
color, foreground=5, text=0, background=7, logo=6, interior=7
plot time xvelocity.23 legend='Tracer 5' nf
color, foreground=6, text=0, background=7, logo=6, interior=7
plot time xvelocity.24 legend='Back of TiFlyer' nf
```

```
legendposition,lr
*
*
Title, HVL_CTH Test
gtitle='Titanium Flyer Temperature'
color, foreground=1, text=0, background=7, logo=6, interior=7
plot time temperature.19 legend='TPX Ti interface'
color, foreground=2, text=0, background=7, logo=6, interior=7
plot time temperature.20 legend='Tracer 2' nf
color, foreground=3, text=0, background=7, logo=6, interior=7
plot time temperature.21 legend='Tracer 3' nf
color, foreground=4, text=0, background=7, logo=6, interior=7
plot time temperature.22 legend='Tracer 4' nf
color, foreground=5, text=0, background=7, logo=6, interior=7
plot time temperature.23 legend='Tracer 5' nf
color, foreground=6, text=0, background=7, logo=6, interior=7
plot time temperature.24 legend='Back of TiFlyer' nf
legendposition,lr
*
*
Title, asdfbad
gtitle='Titanium Flyer Pressure'
color, foreground=1, text=0, background=7, logo=6, interior=7
plot time pressure.19 legend='TPX Ti interface'
color, foreground=2, text=0, background=7, logo=6, interior=7
plot time pressure.20 legend='Tracer 2' nf
color, foreground=3, text=0, background=7, logo=6, interior=7
plot time pressure.21 legend='Tracer 3' nf
color, foreground=4, text=0, background=7, logo=6, interior=7
plot time pressure.22 legend='Tracer 4' nf
color, foreground=5, text=0, background=7, logo=6, interior=7
plot time pressure.23 legend='Tracer 5' nf
color, foreground=6, text=0, background=7, logo=6, interior=7
plot time pressure.24 legend='Back of TiFlyer' nf
legendposition,ur
*
*
Title, HVL_CTH Test
gtitle='Titanium Flyer Density'
color, foreground=1, text=0, background=7, logo=6, interior=7
plot time density.19 legend='TPX Ti interface'
color, foreground=2, text=0, background=7, logo=6, interior=7
plot time density.20 legend='Tracer 2' nf
color, foreground=3, text=0, background=7, logo=6, interior=7
plot time density.21 legend='Tracer 3' nf
color, foreground=4, text=0, background=7, logo=6, interior=7
plot time density.22 legend='Tracer 4' nf
color, foreground=5, text=0, background=7, logo=6, interior=7
plot time density.23 legend='Tracer 5' nf
color, foreground=6, text=0, background=7, logo=6, interior=7
plot time density.24 legend='Back of TiFlyer' nf
legendposition,ur
*
gtitle='Center of Flyer used in datout'
plot time xvelocity.21 wrtout
*
gtitle='Back of Flyer used in datout'
```

```
plot time xvelocity.24 wrtout
*
gtitle='Left edge of Sabot'
plot time xvelocity.1
plot time xvelocity.2
*
gtitle='Sabot-Tantalum interface'
plot time xvelocity.3
plot time xvelocity.4
*
gtitle='Tantalum-Copper interface'
plot time xvelocity.5
plot time xvelocity.6
*
gtitle='Copper-Titanium interface'
plot time xvelocity.7
plot time xvelocity.8
*
gtitle='Titanium-Aluminum interface'
plot time xvelocity.9
plot time xvelocity.10
*
gtitle='Aluminum-Magnesium interface'
plot time xvelocity.11
plot time xvelocity.12
 *
gtitle='Magnesium-TPX interface'
plot time xvelocity.13
plot time xvelocity.14
plot time xvelocity.15
*
gtitle='TPX-TPX interface'
plot time xvelocity.16
plot time xvelocity.17
plot time xvelocity.18
*
gtitle='TPX-TiFlyer interface'
plot time xvelocity.19  V2=temperatute.19
plot time pressure.19  V2=density.19
*
gtitle='TiFlyer Tracer 2'
plot time xvelocity.20  V2=temperatute.20
plot time pressure.20  V2=density.20
*
gtitle='TiFlyer Tracer 3'
plot time xvelocity.21  V2=temperatute.21
plot time pressure.21  V2=density.21
*
gtitle='TiFlyer Tracer 4'
plot time xvelocity.22  V2=temperatute.22
plot time pressure.22  V2=density.22
*
gtitle='TiFlyer Tracer 5'
plot time xvelocity.23  V2=temperatute.23
plot time pressure.23  V2=density.23
*
gtitle='Back of TiFlyer'
```

```
plot time xvelocity.24  V2=temperatute.24
plot time pressure.24  V2=density.24
*
*
*
***********************************************************************
*
* end of cth input
```

10. Appendix C

Source code for Datout.exe.

```
      program datout

      integer N,K,M,R,Q
      character*72 I
      double precision A(600),C(600),Vstop,Vbreak,Sum,Avg
*---------------Variable Definitions--------------------
*     A(K):       time array created in CTH datout file
*     C(K): velocity array created in CTH datout file
*
*     Vstop:the last valid velocity value in datout file
*
*     Vbreak:velocity value in array that occurs after
*           the velocity reaches its plateau = 98% of Vstop
*
*     Sum:  sum of the velocity values from Vbreak to Vstop
*     Avg:  the average of Sum

      open (unit =1, file ='datout')
      open (unit =2, file ='readout.txt')
      open (unit =3, file ='User_info.txt')
      open (unit =4, file ='results.txt')
      N=1000
      bottom=-12345.
      read (1,*)
      read (1,*)
      read (1,*)
      read (1,*)
      read (1,*)

       do K=1,N
           read (1,*, end=10, err=10) A(K), C(K)
             write (2,*) A(K),C(K)
               if (C(K).EQ.bottom) then
               Vstop = C(K-1)
                   M = (K-1)
                write (2,*) 'vstop', C(K-1), M
               endif
       enddo
   10 continue
       do K=1,M
            if (C(K).GT.(0.980*Vstop)) then
               Vbreak = C(K)
               R = K
               write (2,*) '98%', (vstop*0.98)
               write (2,*) 'break', Vbreak, R
               write (2,*) 'Number', (M-R), (M-R)/3
              goto 11
            endif

       enddo
   11 continue
```

```
      Q = (M - R + 1)/3 + R
      Sum = 0
      write (2,*) 'one third', C(Q), Q
        do K = Q, M
         Sum = Sum + C(K)
         enddo
      Avg = Sum/(Float(M-Q+1))
      write (*,*) 'Flyer velocity', Avg, '(km/s)'
*

      do K=1,N
            read (3,13,err=12,end=12) I
            write (4,13) I
      enddo
   12 continue
   13 format (a)
      write (4,*) ' '
      write (4,*) 'Flyer velocity', Avg, '(km/s)'
      end
```

11. Appendix D

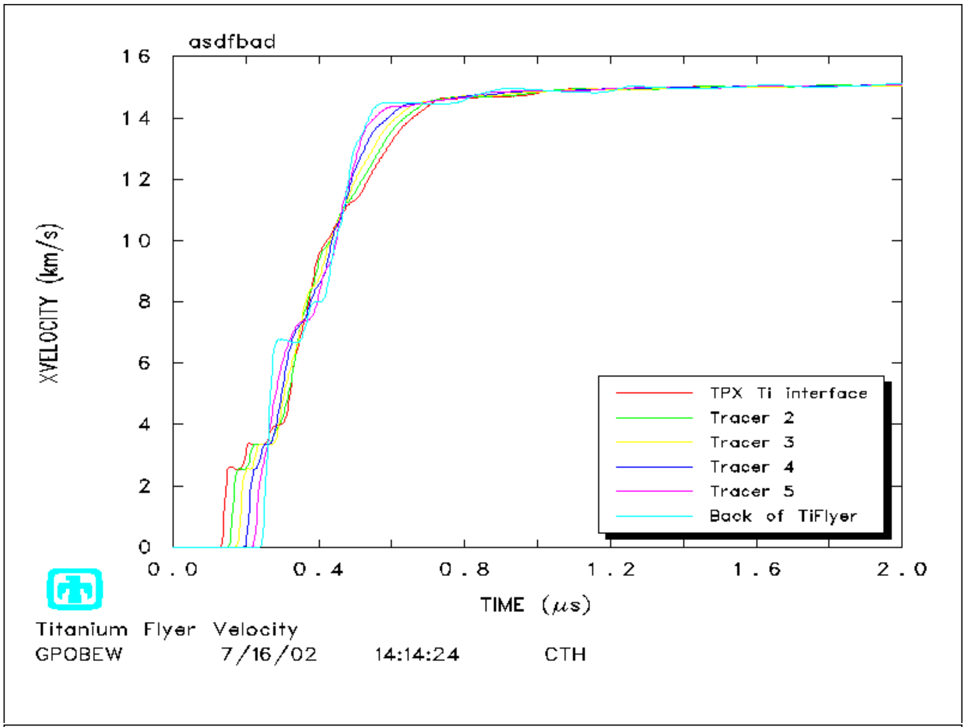
The following is an example of the results that would appear after HVL_CTH finished running.

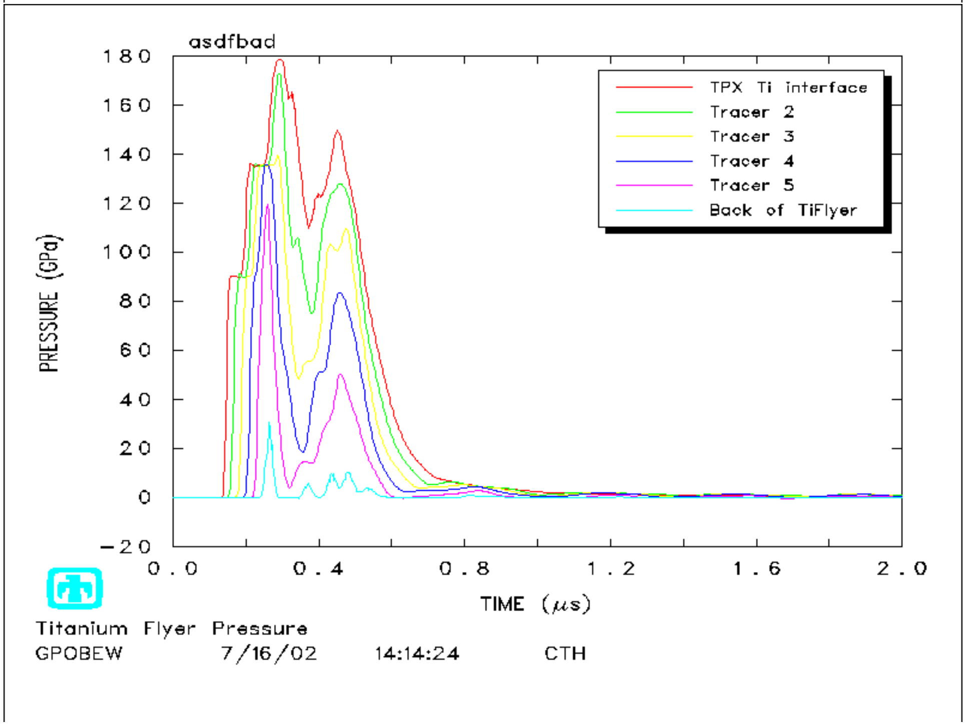
```
run time    (s)=   0.00000200
mesh grid  (cm)=   0.00400000
mesh width (cm)=   6.00000000
 Units are in mm
Ta       = 0.889999
Cu       = 0.289999
Ti       = 0.414999
Al       = 0.500000
Mg       = 0.560000
TPX1     = 1.000000
TPX2     = 1.370000
Ti Flyer= 0.899999
 Projectile velocity (km/s) =    9.890000
```

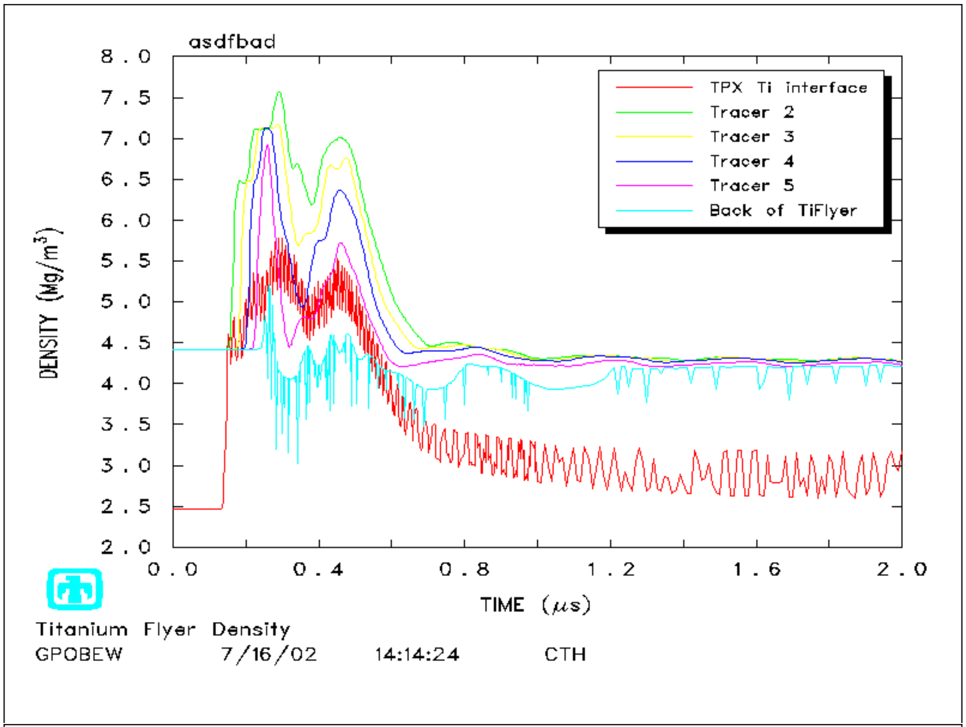
Flyer velocity = 14.9926559139785   (km/s)

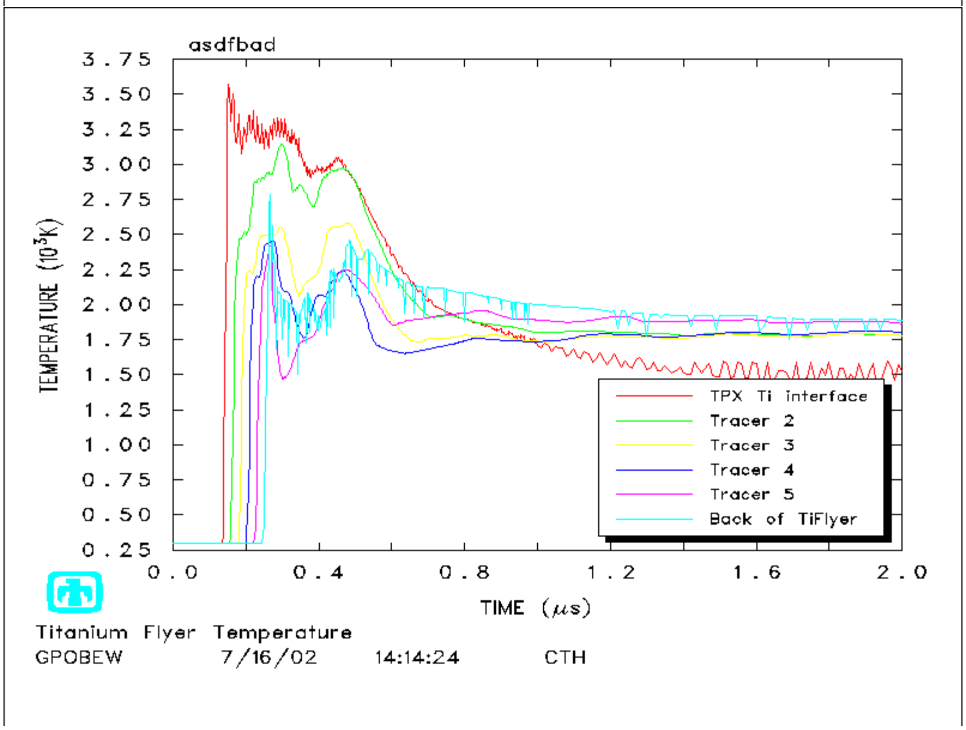
12. Appendix E

Examples of other data produced by HVL_CTH.






asdfbad
DENSITY (Mg/m^3)
TIME (μs)
TPX Ti interface
Tracer 2
Tracer 3
Tracer 4
Tracer 5
Back of TiFlyer
Titanium Flyer Density
GPOBEW 7/16/02 14:14:24 CTH


asdfbad
TEMPERATURE (10^3K)
TIME (μs)
TPX Ti interface
Tracer 2
Tracer 3
Tracer 4
Tracer 5
Back of TiFlyer
Titanium Flyer Temperature
GPOBEW 7/16/02 14:14:24 CTH

13. Appendix F

This is an example of how *datout.exe* calculates the mean flyer velocity from a velocity array created by datout.

	time (s)	velocity (cm/s)
N	9.9418E-07	8.9059E+05
	9.9689E-07	8.9078E+05
0	9.9912E-07	**8.9095E+05**
1	1.0092E-06	8.9195E+05
2	1.0187E-06	8.9311E+05
3	1.0297E-06	8.9461E+05
4	1.0394E-06	8.9586E+05
5	1.0490E-06	8.9684E+05
6	1.0587E-06	8.9755E+05
7	1.0699E-06	8.9812E+05
8	1.0796E-06	8.9857E+05
9	1.0895E-06	8.9910E+05
10	1.0993E-06	8.9975E+05
11	1.1092E-06	9.0052E+05
12	1.1192E-06	9.0121E+05
13	1.1293E-06	9.0180E+05
14	1.1394E-06	9.0228E+05
15	1.1497E-06	9.0270E+05
16	1.1587E-06	9.0305E+05
17	1.1691E-06	9.0345E+05
18	1.1796E-06	9.0378E+05
19	1.1900E-06	9.0400E+05
20	1.1988E-06	9.0414E+05
21	1.2090E-06	9.0433E+05
22	1.2192E-06	9.0452E+05
23	1.2295E-06	9.0479E+05
24	1.2399E-06	9.0518E+05
25	1.2488E-06	9.0562E+05
26	1.2592E-06	9.0621E+05
27	1.2696E-06	9.0681E+05
28	1.2785E-06	9.0729E+05
29	1.2889E-06	9.0778E+05
30	1.2993E-06	9.0816E+05
31	1.3097E-06	9.0841E+05
32	1.3186E-06	9.0852E+05
33	1.3290E-06	9.0854E+05
34	1.3394E-06	9.0851E+05
35	1.3498E-06	9.0852E+05
36	1.3587E-06	9.0859E+05
37	1.3691E-06	9.0873E+05
38	1.3795E-06	9.0883E+05
39	1.3899E-06	9.0887E+05
40	1.3988E-06	9.0883E+05
41	1.4091E-06	9.0876E+05
42	1.4195E-06	9.0873E+05
43	1.4299E-06	9.0876E+05
44	1.4388E-06	9.0882E+05
45	1.4492E-06	9.0886E+05
46	1.4596E-06	9.0887E+05
47	1.4700E-06	9.0883E+05
48	1.4789E-06	9.0876E+05
49	1.4893E-06	9.0866E+05
50	1.4997E-06	9.0852E+05

The following values were used to calculate the mean velocity.

33	9.0854E+05
34	9.0851E+05
35	9.0852E+05
36	9.0859E+05
37	9.0873E+05
38	9.0883E+05
39	9.0887E+05
40	9.0883E+05
41	9.0876E+05
42	9.0873E+05
43	9.0876E+05
44	9.0882E+05
45	9.0886E+05
46	9.0887E+05
47	9.0883E+05
48	9.0876E+05
49	9.0866E+05
50	9.0852E+05

	51	1.5086E-06	9.0839E+05			51	9.0839E+05
	52	1.5191E-06	9.0825E+05			52	9.0825E+05
	53	1.5295E-06	9.0815E+05			53	9.0815E+05
	54	1.5399E-06	9.0811E+05			54	9.0811E+05
	55	1.5489E-06	9.0821E+05			55	9.0821E+05
	56	1.5593E-06	9.0842E+05			56	9.0842E+05
	57	1.5697E-06	9.0866E+05			57	9.0866E+05
	58	1.5786E-06	9.0889E+05			58	9.0889E+05
	59	1.5892E-06	9.0917E+05			59	9.0917E+05
	60	1.5996E-06	9.0944E+05			60	9.0944E+05
	61	1.6100E-06	9.0967E+05			61	9.0967E+05
	62	1.6189E-06	9.0978E+05			62	9.0978E+05
	63	1.6293E-06	9.0980E+05			63	9.0980E+05
	64	1.6398E-06	9.0970E+05			64	9.0970E+05
	65	1.6487E-06	9.0960E+05			65	9.0960E+05
	66	1.6591E-06	9.0950E+05			66	9.0950E+05
	67	1.6695E-06	9.0942E+05			67	9.0942E+05
	68	1.6799E-06	9.0935E+05			68	9.0935E+05
	69	1.6888E-06	9.0929E+05			69	9.0929E+05
	70	1.6992E-06	9.0926E+05			70	9.0926E+05
	71	1.7096E-06	9.0925E+05			71	9.0925E+05
	72	1.7200E-06	9.0926E+05			72	9.0926E+05
	73	1.7289E-06	9.0928E+05			73	9.0928E+05
	74	1.7393E-06	9.0930E+05			74	9.0930E+05
	75	1.7497E-06	9.0930E+05			75	9.0930E+05
	76	1.7586E-06	9.0928E+05			76	9.0928E+05
	77	1.7690E-06	9.0923E+05			77	9.0923E+05
	78	1.7794E-06	9.0911E+05			78	9.0911E+05
	79	1.7898E-06	9.0896E+05			79	9.0896E+05
	80	1.7987E-06	9.0882E+05			80	9.0882E+05
	81	1.8094E-06	9.0866E+05			81	9.0866E+05
	82	1.8199E-06	9.0852E+05			82	9.0852E+05
	83	1.8288E-06	9.0843E+05			83	9.0843E+05
	84	1.8393E-06	9.0838E+05			84	9.0838E+05
	85	1.8497E-06	9.0839E+05			85	9.0839E+05
	86	1.8586E-06	9.0847E+05			86	9.0847E+05
	87	1.8691E-06	9.0864E+05			87	9.0864E+05
	88	1.8795E-06	9.0886E+05			88	9.0886E+05
	89	1.8899E-06	9.0910E+05			89	9.0910E+05
	90	1.8988E-06	9.0930E+05			90	9.0930E+05
	91	1.9093E-06	9.0950E+05			91	9.0950E+05
	92	1.9197E-06	9.0965E+05			92	9.0965E+05
	93	1.9286E-06	9.0971E+05			93	9.0971E+05
	94	1.9390E-06	9.0971E+05			94	9.0971E+05
	95	1.9495E-06	9.0965E+05			95	9.0965E+05
	96	1.9599E-06	9.0956E+05			96	9.0956E+05
	97	1.9688E-06	9.0948E+05			97	9.0948E+05
	98	1.9792E-06	9.0938E+05			98	9.0938E+05
	99	1.9896E-06	9.0930E+05			99	9.0930E+05
	100	1.9993E-06	**9.0927E+05** **vstop**			100	9.0927E+05
		-12345	-12345				
N/3				**98% of vtstop=**	**8.9108E+05**	**vel (cm/s)**	
33.3333333						**avg vel=**	**9.0900E+05**

14. Appendix G

HVL_CTH:
A Simple Tool That Runs In Conjunction With CTH To Simulate The Hyper-Velocity Launch Of A Flyer Plate.

Contacts To Obtain CTH:

- Bob Cole, to obtain disk.
- Randy Summers, to obtain license file.

Set-up:

- Install CTH
- Follow instructions on CTH disk on how to obtain license file and to set path directories for CTH.
- Download HVL_CTH folder from STARSERVER, under backup software, directly to your C drive.
- Create path directory for HVL_CTH.
    - Right click on *My Computer.*
    - Go to *Properties.*
    - Select the *Advanced* tab.
    - Click on *Environment Variables.*
    - Under *System Variables* find *Path.*
    - Select *Path* and hit *Edit.*
    - At the end of the *Variable Value* type ";C:\HVL_CTH"
    - Hit *OK* three times.
    - Path for HVL_CTH is complete.

Quick Reference For Use:

- After setup, go to Command Prompt and type in HVL_CTH for any desired directory and hit Return.
- Type input values when prompted.
- Follow the directions on the Command screen while HVL_CTH is running.
- Once HVL_CTH is finished, many other valuable files can be obtained.
- Some of these files are view graphs from *hisplt* (a CTH resultant file) and velocity records in *datout* (also a CTH resultant file).

To view graphs:

- type "popwin pophis" (in Command Prompt)
- type "s" for square frame.
- then choose the desired frame to view.

To obtain graph files:

- type "popgif pophis"
- type "D" for standard setup
- type "U" for square frame
- type "1.3333,1" to set frame size
- type "N" for normal format
- After you have chosen desired graphs to save type "e" to exit popgif

Distribution

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1		0819	R. M. Summers, 9231
1		0819	T. G. Trucano, 9211
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