Modernization of the NSWC IHEODTD CADPROG Ballistic Computer Simulation Program

> Mr. Fred Silverman, AET Mr. Ted Witkamp, AET Mr. Dave Sorochty, NSWC IHEODTD

# **AET// Business Model**

### Key Processes

- Design
- Product Development
- Manufacturing (DFM)
- Process Hazard Analysis (PHA)
- Failure Analysis (FA)
- Training

## Key Resources

- Experienced People
- "To the Point" Technology
- Relevant Information
- Sub-Tier Partnerships



To solve problems and needs dealing with energetic/ordnance design, manufacturing, new growth initiatives, and training

## Profit Formula

Resource Velocity: Both AET and its Partners are small businesses that can react and deliver on demand services.

# CADPROG, Updated

- Contract: Noo174-16-P-0052
  - AET is creating a ballistic cartridge modeler using the platform MATLAB by translating, updating and improving the Government Furnished Material (GFM) CADPROG ballistic modeling program.
  - The new ballistics modeler is the property of the Navy.

# CADPROG, Basics

- 1. User supplied input parameters
- 2. "Hard-wired" parameters
- 3. Internally-computed parameters
- 4. Mass averaged thermodynamic properties of gas mixture
- 5. Model (time-dependent) variables



# CADPROG, V9

- Lumped Parameter Model for the interior ballistic performance of CAD's and PAD's
- Source Code is FORTRAN 77
- Platform: UNIX (SGI)
- Uses a 4<sup>th</sup> Order Runge Kutta integration scheme to calculate the dynamic responses from the initial conditions.
- Input, Interactive, CADPROG file, or ASCII Text File
- Output, ASCII Table (Unstructured Data) and External Graph, No Edit, "Picture"



http://www.navair.navy.mil/index.cfm?fuseaction=home.displayPlatform&key=FC59DB4C-5B6A-43F2-BD52-1D010A5847F5



# CADPROG, FORTRAN Version Generic Guillotine Cutter

# MATLAB R2016a Workspace Workflow CADPROG V10

- Add Workspace Variables
  - Chamber Model
  - Propellant Model
  - Granulation Model
- Run Simulations
  - Simulation Model
  - Create tables and graphs
- Automate Analysis
  - Maximum Conditions
  - Dynamic Response Index

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# CADPROG, V10

- Lumped Parameter Model for the interior ballistic performance of CAD's & PAD's, and Closed Bomb Test Fixtures
- Source Code is MATLAB, R2016a
- Uses a 4<sup>th</sup> Order Runge Kutta integration scheme to calculate the dynamic responses from the initial conditions.
- Input, Program Interactive, with "Help Function" or MATLAB file
- Output:
  - MATLAB Table Format, structured
  - HTML Report, structured
  - Plots, Edit Capable

# CADPROG V10: Program Help Screen Shot Generic Guillotine Cutter

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| Add-Ons<br>Add-Ons<br>c b pyro.mat<br>example.mat<br>fred.mat<br>gcutter.html<br>gcutter.html<br>report.html<br>run.mat  | <pre>&gt;&gt; help cadprog<br/>Contents of cadprog:<br/>chamber - Create Chamber Parameters used in a cadprog.model<br/>grain_perf_cylinder - Create Grain type circular cylinder with optional pe<br/>grain_slab - Create Grain type Slab<br/>grain_sphere - Create Grain type Sphere<br/>model - Create a cadprog Model<br/>plot - Generate a Pressure plot from the simulation<br/>propellant - Create a Pressure plot from the simulation<br/>propellant - Create a HTML5 Report from a cadprog simulation<br/>simulate - Produce a simulation result of a cadprog model<br/>table - Create a table from a cadprog simulation<br/>test - Run cadprog self test and report results</pre>  | Name Volue  c Volue  c Iv/ Struct  g Iv/ Struct  p Iv/ Struct  s Iv/ Struct  t 8x10 table | bles |
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# CADPROG V10: 'cadprog.simulate' Help Screen Shot



## CADPROG V10: 'cadprog.chamber' variable Screen Shot

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# CADPROG V10: `cadprog.simulate' Screen Shot

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# CADPROG V10, MATLAB Generic Guillotine Cutter Simulation Output

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# CADPROG V10, MATLAB Generic Guillotine Cutter

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#### CADPROG - Version 10 Engineering Ballistic Simulator

|             | Geometry      |              | Kinematics     | 3                  |                     | Loss Fa    | ctors   |          |   |              |
|-------------|---------------|--------------|----------------|--------------------|---------------------|------------|---------|----------|---|--------------|
| AHI         | 0.000000e+00  | THET         | 0.000000e+0    | 0                  | K1 0.               | 000000e+   | 00      |          |   |              |
| VHI         | 1.000000e+00  | W            | 5.700000e-0    | 1                  | K2 0.               | 000000e+   | 00      |          |   |              |
|             |               | SSP          | 6.000000e+0    | 2                  |                     |            |         |          |   |              |
|             |               | XMAX         | 1.000000e+0    | 0                  |                     |            |         |          |   |              |
|             | Time Step     |              | Igniter        |                    | Disp                | lacement i | Area Ta | bles     |   |              |
| DT          | 1.5e-05       | IM 9.        | .368000e-06    |                    |                     | х          |         | Area     | 1. E. |              |
| DTPR        | 10            | FI 1.        | .899000e+05    |                    | 5.0000              | 00e+00     | 1.5000  | 00e+00   | )   |              |
|             |               |              |                |                    | 0.0000              | 00e+00     | 0.0000  | 00e+00   | )   |              |
|             |               |              |                |                    | 0.0000              | 00e+00     | 0.0000  | 00e+00   | )   |              |
|             | Thermo        |              | Burn Rate Ta   | ble                |                     |            |         |          |   |              |
| CV          | 4.998000e+02  |              | R              | P                  |                     |            |         |          |   |              |
| TV          | 5.000000e+03  | 1.500        | 000e-01 2.5    | 00000e+01          |                     |            |         |          |   |              |
| N           | 4.730000e-02  | 2.800        | 000e-01 1.0    | 00000e+02          |                     |            |         |          |   |              |
| NU          | 5.000000e+03  | 3.600        | 000e-01 5.0    | 00000e+02          |                     |            |         |          |   |              |
| RHO         | 5.700000e-02  | 5.600        | 000e-01 7.5    | 00000e+02          |                     |            |         |          |   |              |
|             |               | 9.000        | 000e-01 1.2    | 50000e+03          |                     |            |         |          |   |              |
|             |               | 1.500        | 000e+00 2.0    | 00000e+03          |                     |            |         |          |   |              |
|             | Grain 1       |              | Computed Const | tants              |                     |            |         |          |   |              |
| D           | 0.01          | . GC         | 32.17          | 4                  |                     |            |         |          |   |              |
| H           | 0.003         | G            | 32.17          | 4                  |                     |            |         |          |   |              |
| PD          | 0.0075        | R            | 278            | 2                  |                     |            |         |          |   |              |
| A1          | 1.133333e+03  | F            | 65794          | 3                  |                     |            |         |          |   |              |
| A2          | -3.644444e+05 | GAMMA        | 1.2632         | 8                  |                     |            |         |          |   |              |
| A3          | 3.555556e+07  | W1           | 0.5            | 7                  |                     |            |         |          |   |              |
| CB          | 9.000000e-04  | PSI          | 0.6605         | 4                  |                     |            |         |          |   |              |
| WEB         | 1.500000e-03  | CHI          | 2.70386e-0     | 6                  |                     |            |         |          |   |              |
|             |               | VCHI         | 0.98421        | 1                  |                     |            |         |          |   |              |
|             |               | XMAX         |                | 1                  |                     |            |         | <b>_</b> |   |              |
| Time<br>Sec | Pressure Tem  | perature fra | action_Burned  | Displacement<br>TN | Velocity<br>TNI/SEC | Accelera   | ation   | IBS      | Length_Burn                               | Surface_Area |
| 0 0000      | 22            | 5000         | 0 0000         |                    | 0 00                |            | 0 00    | 22       | 0 000                                     | 0 0003       |
| 0.0002      | 367           | 5000         | 0.0478         | 0.00               | 0.00                |            | 0.00    | 550      | 0.000                                     | 0.0003       |
| 0.0002      | 893           | 4997         | 0 1210         | 0.00               | 4 50                | 225        | 0.62    | 1340     | 0.000                                     | 0.0002       |
| 0 0004      | 1889          | 4966         | 0 2692         | 0.02               | 21 59               | 497        | 2 23    | 2834     | 0.000                                     | 0.0002       |
| 0.0006      | 3287          | 4889         | 0.5234         | 0.09               | 54 38               | 864        | 9.16    | 4930     | 0.001                                     | 0.0002       |
| 0.0008      | 4148          | 4744         | 0.8091         | 0.23               | 102.76              | 1091       | 6.95    | 6223     | 0.001                                     | 0.0001       |
| 0.0009      | 3874          | 4530         | 0.9996         | 0.46               | 154.70              | 1019       | 3.69    | 5810     | 0.001                                     | 0.0001       |
| 0.0011      | 2819          | 4240         | 1.0000         | 0.78               | 196.85              | 741        | 8.65    | 4229     | 0.002                                     | 0.000        |
|             |               |              | 2.0000         |                    | 200.00              |            |         |          | 0.002                                     |              |

# CADPROG V10, MATLAB Generic Guillotine Cutter



# CADPROG V10, MATLAB Generic Guillotine Cutter

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# CADPROG V10, MATLAB Fifteen Test Cases



# CADPROGV9 compared to V10

| Attribute         | CADPROG Version 9  | CADPROG Version 10   |
|-------------------|--|--|
| User Platform     | UNIX (SGI)   | PC, Windows  |
| Source Language   | Fortran 77   | MATLAB R2016a  |
| Input             | Direct User Input, CADPROG file or ASCII<br>(matrix)   | Direct User Program Input or MATLAB file   |
| Tabular Output    | ASCII File, unstructured table   | MATLAB & HTML File, structured   |
| Graphic Output    | External Display Graphics, no edit capability, with Ten Overlaying Files                                 | <b>Embedded Plotting with Editing</b> and Ten<br>Overlaying Files  |
| Data Output       | Pressure, Velocity, Acceleration, Thrust,<br>Displacement, Time, DRI, Fraction Burned,<br>& Surface Area | Pressure, Velocity, Acceleration, Thrust,<br>Displacement, Time, DRI, Fraction Burned,<br>& Surface Area |
| Program Help      | External User Manual, Imbedded Error<br>Messages   | External User Manual, Imbedded Error<br>Messages & Imbedded Help   |
| Chambers (option) | Single or Two Chamber (High/Low)   | Single or Two Chamber (High/Low)   |
| Chamber Venting   | Both Chamber Option  | Both Chamber Option  |

# CADPROG V9 compared to V10 (continued)

| Attribute              | CADPROG Version 9                       | CADPROG Version 10                      |
|------------------------|---|---|
| Propellant Location    | Single/High Chamber                     | Single/High Chamber                     |
| Piston                 | Single (multiple areas for telescoping) | Single (multiple areas for telescoping) |
| Telescoping            | Three                                   | Three                                   |
| Number of Propellants  | Three                                   | Three                                   |
| Number of Granulations | Three                                   | Three                                   |
| Time Delay             | Three                                   | Three                                   |
| Release Pressure       | Yes                                     | Yes                                     |
| Mass w/piston          | Yes                                     | Yes                                     |
| Angle of Launch        | Yes                                     | Yes                                     |

# CADPROG V10, Conclusions

- AET progressing on Version 10 of CADPROG using MATLAB
- Version 10 will provide:
  - Same ballistic analysis capabilities as Version 9.
  - Combine ballistic modeler's computational scheme with graphical display of output data on PCs within a single program.
  - Speed up the CAD design process.
  - Allow more design options to be investigated.
  - Simplify troubleshooting and failure analysis of existing designs.
  - More user friendly than Fortran command line program running under UNIX.
- Contract work in progress, estimate completion: March 2017.
- A version of CADPROG that runs on a PC will be made available to CAD/PAD contractors who make a request in writing to cadpad@navy.mil