Automated Projectile Design Software

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Projectile Design

- Ballistic Projectile Design
  - Performance Specs
  - System Interface
  - Candidate Design
    - Mass Properties
    - Aerodynamics
    - Ballistic Effectiveness
    - Payload Effectiveness

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- Guided Projectiles
  - Same as ballistic plus
  - Control mechanisms
  - Sensors
  - Autopilot
  - Guidance strategy

Mission

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  - How often will you hit the target (P_h)
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- Guided
  - Same as Ballistic, plus
  - Remove system errors
  - Trajectory shaping
    - Glide for extended range
    - Dive to clear obstacles or for lethality

Bottom Line

- You now have to:
  - Design the projectile
  - Decide on a control mechanism
  - Design the auto pilot
  - Implement a Guidance strategy

Commercial/Military Projectile Design Tools

- Custom/Proprietary Software
  - Developer uses different analysis modules handing off data from one to the other
  - Stand alone modelers
    - Model building (PRO-E or Solid Works)
    - Aerodynamic estimation (CFD, Missile DATCOM, MILS3 or AP)
  - Simulation codes
    - Hand coded custom solutions
    - Typically Project A evolves into Project B evolves into Project C
- PRODAS
  - Legacy codes embedded into an integrated software system
  - Validated simulations
  - Macro language
- MATLAB/Simulink
  - Like Legacy Simulation codes except within an environment
  - Pre-built simulation blocks and integration engines

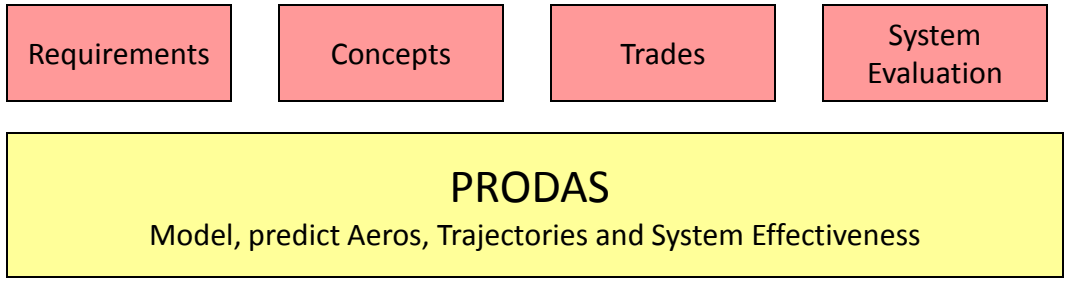
Software Metrics

Smart Weapon Development Levels

- First Level - Conceptual Design Studies (Proposal)
  - For a Given Projectile, What Improvements in Performance Can be Obtained IF a Control Force and/or Moment is Available?
  - Simple to model and assess the Benefit of a Flight Control System
- Second Level - Detailed Design Studies (Design)
  - Perform Parametric Trade Studies to design the details of the Control Mechanism
  - Assess the Performance of a Smart Weapon
- Third Level - Final Detailed Design (Test)
  - At this Stage, Detailed Models of the Sensor Suite and Control Law are Included in Analysis
  - Models will include real time loop rates
  - Model should generate C code for embedded processors

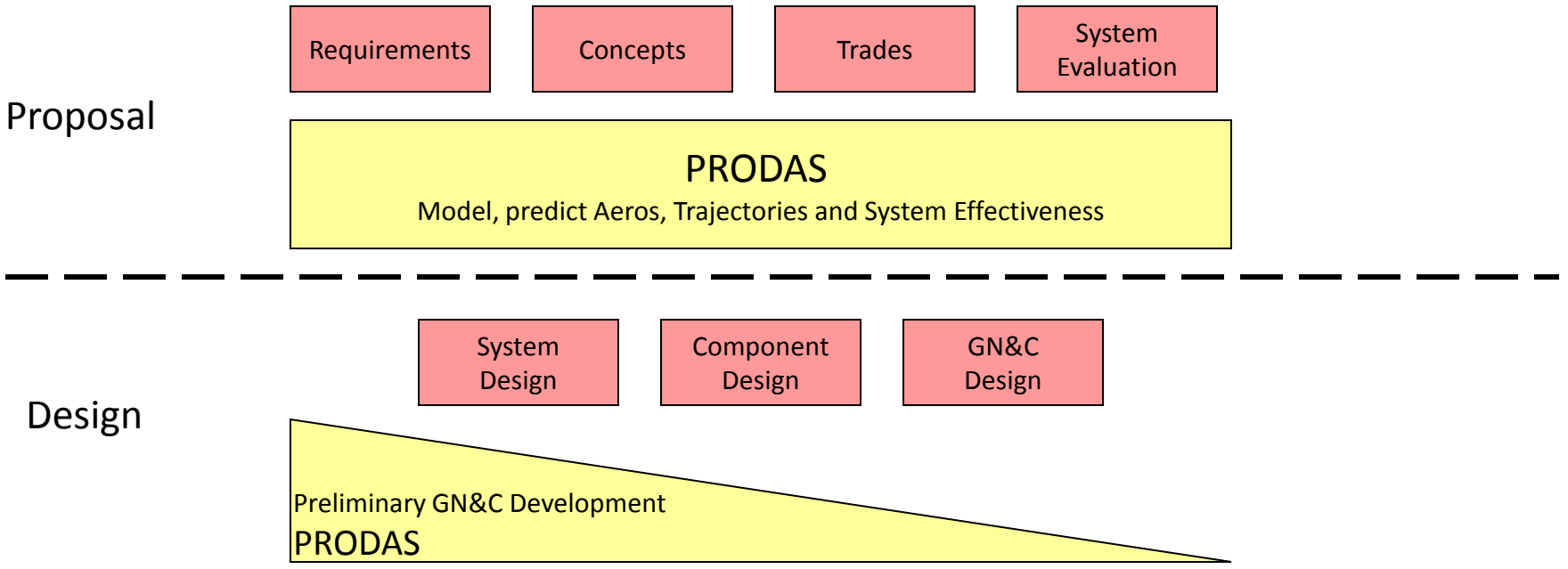
Guided Projectile Development Cycle

Proposal



ARROW TECH

Guided Projectile Development Cycle



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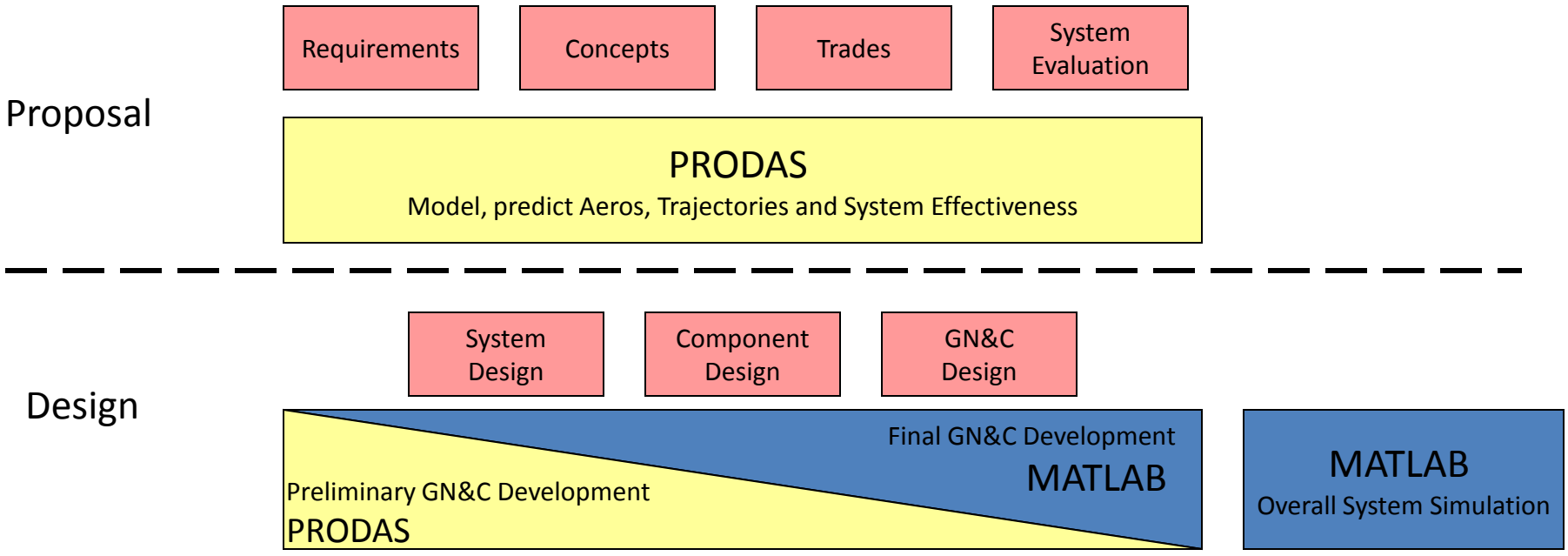
Guided Projectile Development Cycle



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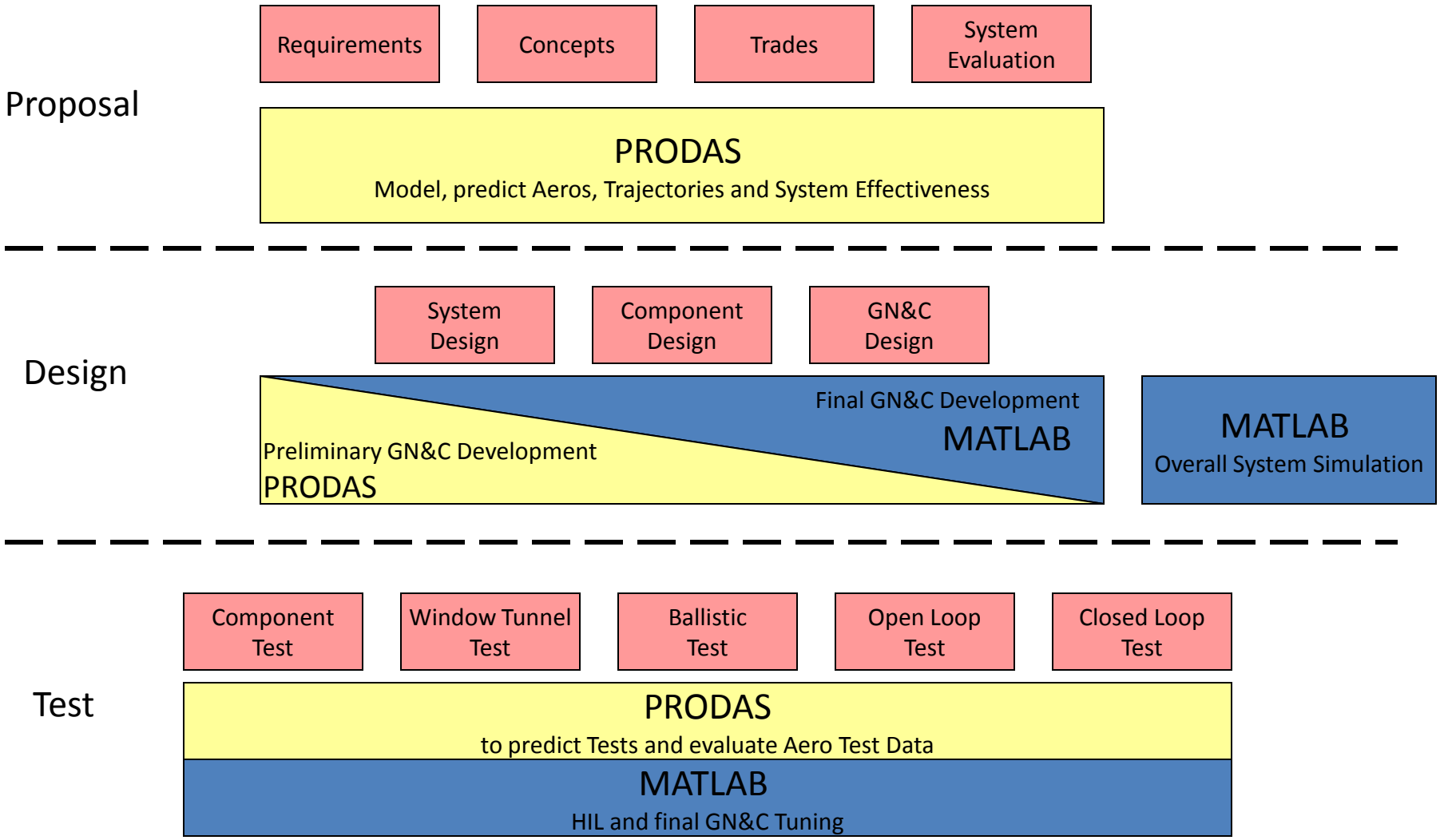
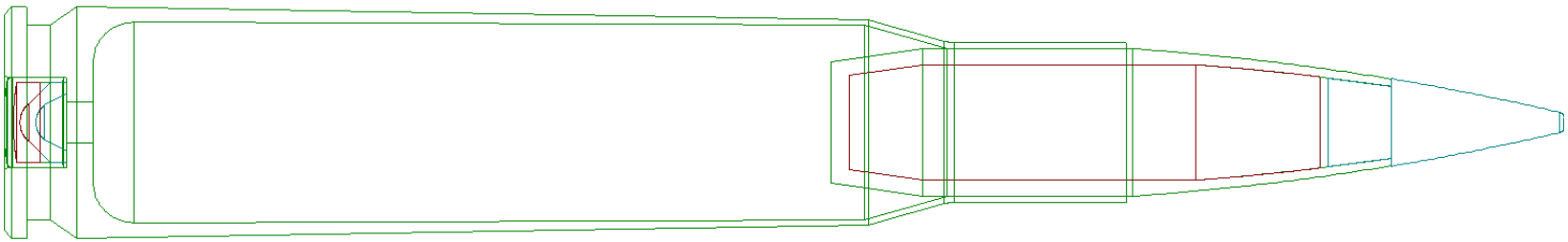
Guided Projectile Development Cycle



Example #1 Ballistic Projectile

- Design a 50 caliber projectile that will minimize wind sensitivity at 1000m
  - Start with basic shape
  - Vary boat tail length and Ogive length and shape



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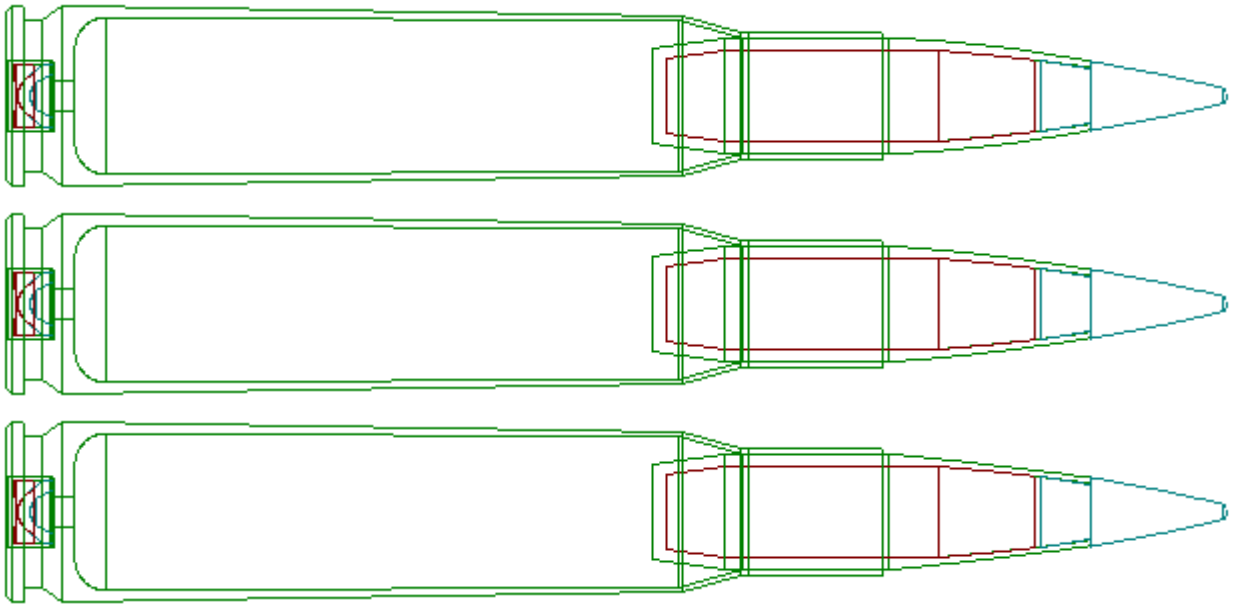
Subtle Changes to Ogive Shape



154mm radius

254mm radius

664cm radius

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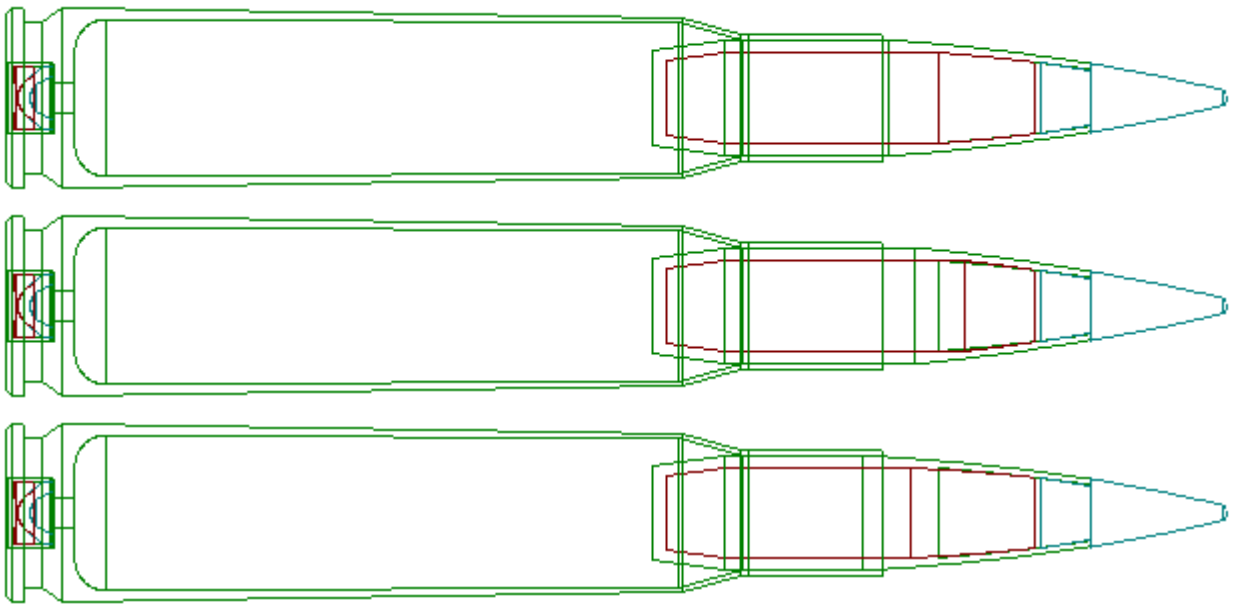
Not So Subtle Changes to Ogive Length



Standard

-3mm

+3mm

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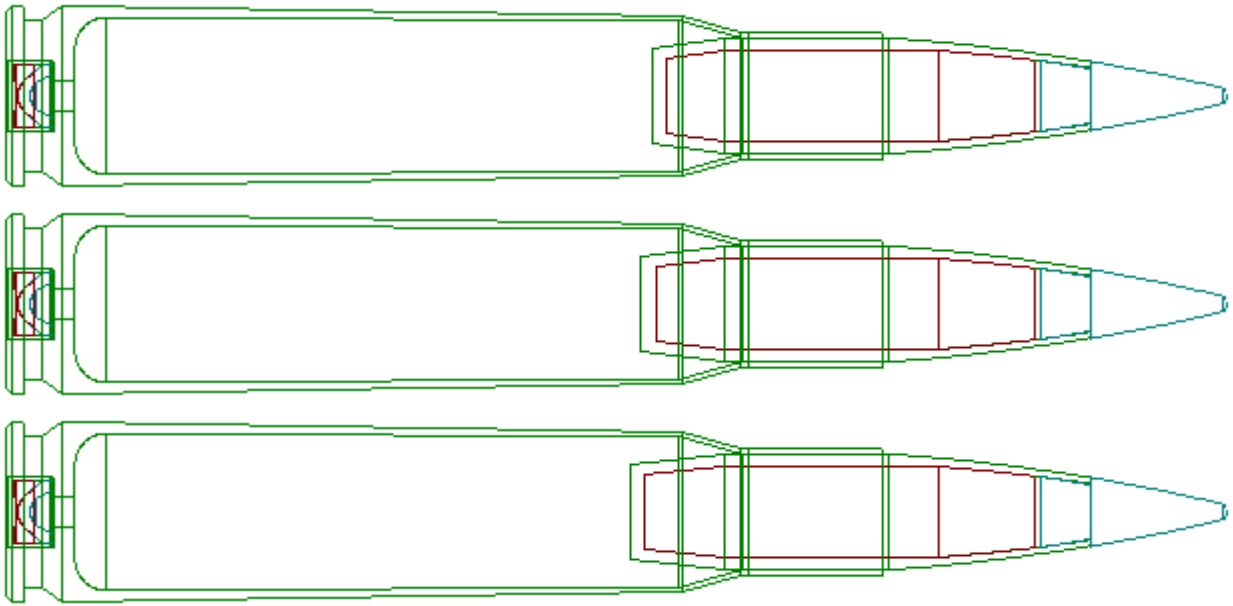
Not So Subtle Changes to Boat Tail



Standard

+15%

+30%

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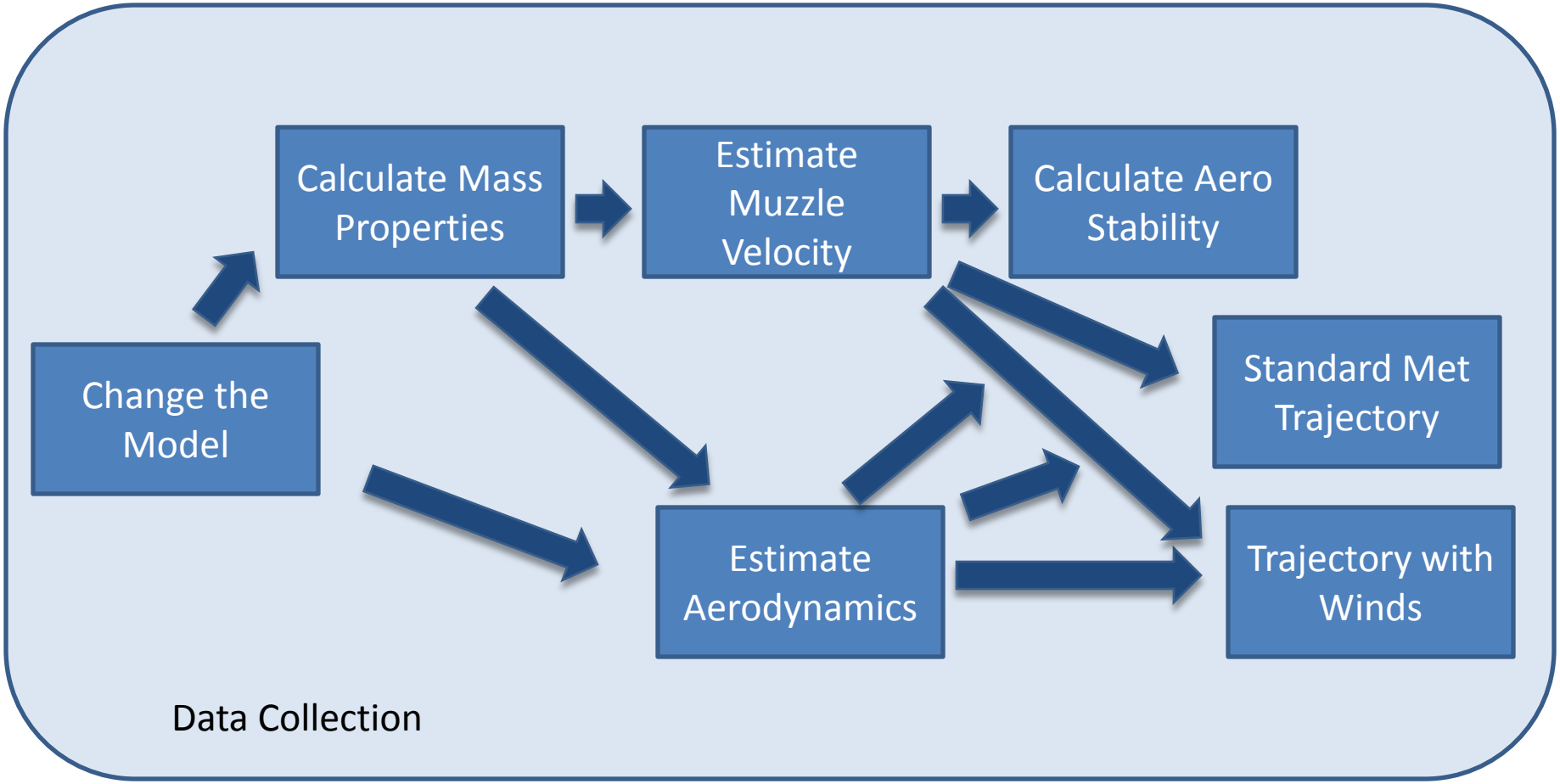
Analysis Map



ARROW TECH

Example #1 Metrics

- 27 designs evaluated
- 7 analysis modules executed
- 50 seconds run time
- 200 lines of PRODAS macro code
- 4 hours to develop
- 1 Excel file of results

- Results:
  - Decreased wind sensitivity by 7.6%
  - Some configurations increased by as much as 10%

Example #1 Extended Metrics

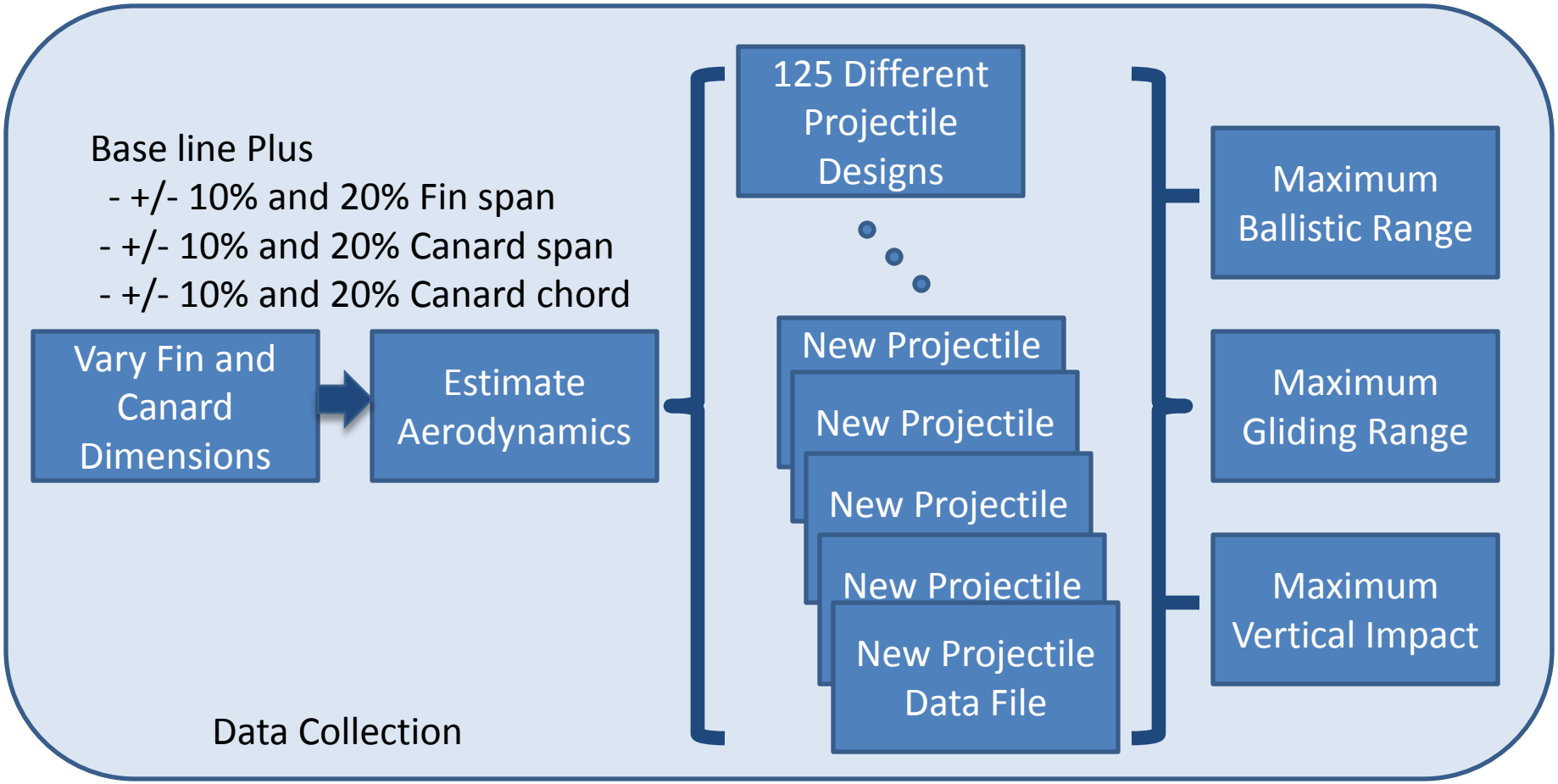
- Started with previous macro
- 125 designs evaluated
- 7 analysis modules executed
- 4 minutes run time
- 212 lines of PRODAS macro code
- 2 minutes to modify
- 1 Excel file of results

- Results:
  - Decreased wind sensitivity by 7.8%
  - Some configurations increased by as much as 25%

Example #2 Guided Projectile

- Basic design of mortar body is fixed, evaluate different fin/canard designs to meet multiple requirements.
  - Find maximum ballistic range
  - Find maximum gliding range using open loop control
  - Find maximum target range with vertical impact using open loop control

Analysis Map



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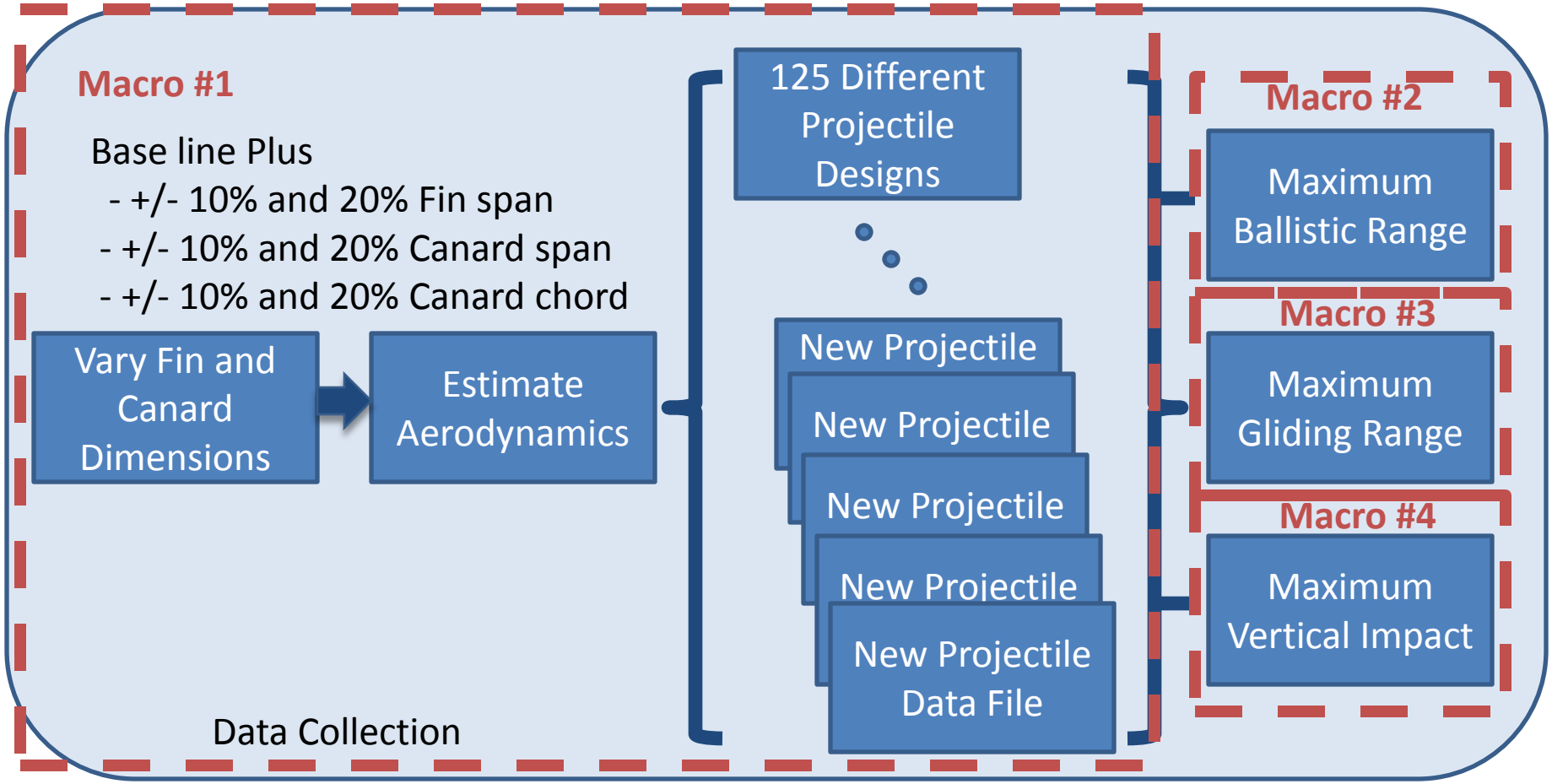
Macro Map



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Guided Flight Macros

- Simple open loop canard controller embedded in the GN&C Prototype tool
- Maximum Gliding Range Macro
  - Macro to iterate these design variables:
    - Quadrant elevation
    - Time Glide on
    - Canard application level to limit total AOA
- Maximum Range with Vertical Impact
  - Macro to iterate these design variables:
    - Quadrant elevation
    - Time Glide on
    - Time Dive on
    - Canard application level to limit total AOA

Example #2 Results

- About half of the configurations unstable
- 40% met the ballistic requirement
- 15% met the extended range
- 8% met all the requirements

- Iterated this analysis with three different air frames

Conclusions

- Thorough ballistic development is tough
  - Automation lessens the burden
  - Guided projectiles are even worse
- Match the tool to the job
  - Where are you in the development cycle?
  - Fast or Detailed?
  - Do you have to validate the sims?

- Tools are readily available

Example #1 PRODAS Script

- The following script is included as an example showing how to modify your model with code.
- It will:
  - Modify a base model
  - Calculate Mass Properties
  - Estimate muzzle velocity using Frankfort Interior ballistics
  - Estimate aerodynamics using Spinner 2000
  - Fly a 6DOF trajectory with no wind
  - Estimate stability at cold temperatures
  - Fly another trajectory with 10 knot cross wind
  - Prepare of comma separated value file with the results
- If you have questions or comments, please contact
  - Mark Steinhoff, Arrow Tech Associates (802) 865-3460 ext 18

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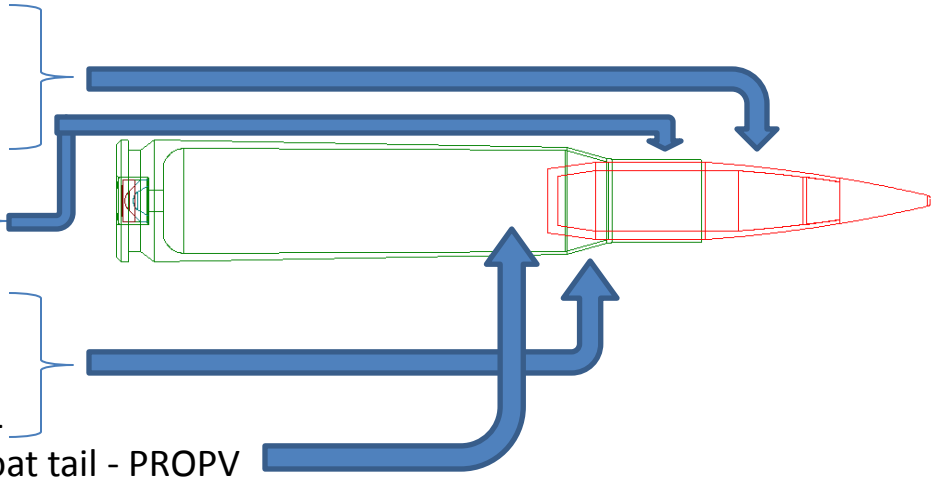
How to Run this Script

- Open a new PRODAS macro window
- Copy and Paste the lines from the following slides
- Change the path and projectile name of interest
  - The projectile model should include a case and propellant
- The script expects certain elements to be named in your projectile model
  - Name the :
    - Ogive outer skin – OG
    - Ogive void element – OGV
    - Lead that fills the Ogive – OGL
    - Body outer skin – BD
    - Body void element – BDV
    - Lead that fills the Body – BDL
    - Boat tail outer skin – BT
    - Boat tail void element – BTV
    - Lead that fills the Boat tail – BTL
    - Void in the propellant for the Boat tail - PROPV



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Example PRODAS Script

Page 1

```
SUB MAIN
    'PRODAS MACRO SCRIPT FILE 12/14/09
    'FILENAME= T:\PRODASV35\SCRIPTS\BUILDERV1.PVB

    PROJDIR  = "R:\ARROW TECH AUTHORED PAPERS 2010\"
    TESTPROJ = PROJDIR   & "50 CAL BALLISTIC SNIPER PROJECT.PR3"



     'INITIALIZE AN ARRAY TO STORE THE SUMMARY TABLE
    DIM LINEHDR(50)
    DIM LINECOL(50)
    ACTIVECOL=20

    LINEHDR(0)="CONFIG"
    LINEHDR(1)="MASS"
    LINEHDR(2)="IX"
    LINEHDR(3)="IY"
    LINEHDR(4)="CG"
    LINEHDR(5)="PROP"
    LINEHDR(6)="CHAMBER"
    LINEHDR(7)="MV"
    LINEHDR(8)="X1"
    LINEHDR(9)="Y1"
    LINEHDR(10)="Z1"
    LINEHDR(11)="MACH"
    LINEHDR(12)="GYRO"
    LINEHDR(13)="X2"
    LINEHDR(14)="Y2"
    LINEHDR(15)="Z2"
    LINEHDR(16)="TOF"
    LINEHDR(17)="X ERROR"
    LINEHDR(18)="Y ERROR"
    LINEHDR(19)="Z ERROR"
    LINEHDR(20)="RMS ERROR"
```

Example PRODAS Script

Page 2

```
'INITIALIZE THE TEXT FILE TO ACCUMULATE THE RESULTS
   SET RESULTS = MACROSYSTEM.INITIALIZERESULTSFILE
   RESULTSFILENAME = PROJDIR & "RESULT " & MONTH(DATE) & "-" & DAY(DATE) & " "  & HOUR(TIME) & "-"  & MINUTE(TIME) & ".TXT"


   RESULTS.OPENFILE  RESULTSFILENAME     'SET THE RESULTS PATH
   RESULTS.WRITEHEADER
   LINEOUT= ""
   RESULTS.WRITESTRING LINEOUT
   FOR J = 0 TO ACTIVECOL
      LINEOUT= LINEOUT & LINEHDR(J)
      IF J < ACTIVECOL THEN LINEOUT=LINEOUT & CHR(9)
   NEXT
   RESULTS.WRITESTRING LINEOUT
   FOR BTINDEX= 1 TO 3
      FOR OGLINDEX = 1 TO 3
         FOR OGRINDEX = 1 TO 3
            SET PROJ = MACROSYSTEM.INITIALIZEPROJECTILE          'INIT A PROJECTILE OBJECT
            IOPEN= PROJ.OPENDATAFILE(TESTPROJ)                   'LOAD THE PROJECTILE FILE
            PROJ.FORCEUNLOCKPROJECTILE   'MAKE SURE IT IS READY TO BE CHANGED
            SET MODEL = PROJ.MODEL("SYSTEM")

            SET BT = MODEL.RETURNNAMEDELEMENT("BT")
            SELECT CASE BTINDEX
               CASE 1    'DO NOTHING
                  DELTALENGTH = 0.0
               CASE 2
                  DELTALENGTH = BT.LENGTH * 0.15

               CASE 3
                  DELTALENGTH = BT.LENGTH * 0.3
            END SELECT
            BTTAG="BT+" & DELTALENGTH*1000 & "MM|"
```

Example PRODAS Script

Page 3

```
SET BTV = MODEL.RETURNNAMEDELEMENT("BTV")
SET BTL = MODEL.RETURNNAMEDELEMENT("BTL")
SET PROPV = MODEL.RETURNNAMEDELEMENT("PROPV")
BT.LENGTH = BT.LENGTH + DELTALENGTH
BT.REF_LENGTH= BT.REF_LENGTH- DELTALENGTH
BTV.LENGTH = BTV.LENGTH + DELTALENGTH
BTV.REF_LENGTH= BTV.REF_LENGTH- DELTALENGTH
BTL.LENGTH = BTL.LENGTH + DELTALENGTH
BTL.REF_LENGTH= BTL.REF_LENGTH- DELTALENGTH

PROPV.LENGTH = PROPV.LENGTH + DELTALENGTH
PROPV.REF_LENGTH= PROPV.REF_LENGTH- DELTALENGTH

SELECT CASE OGLINDEX
   CASE 1   'DO NOTHING
      DELTALENGTH = 0.00          'M
   CASE 2
      DELTALENGTH =-0.003         'M
   CASE 3
      DELTALENGTH = 0.003         'M
END SELECT
OGTAG="OG +" & DELTALENGTH*1000 & "MM|"
SET OG = MODEL.RETURNNAMEDELEMENT("OG")
SET OGV = MODEL.RETURNNAMEDELEMENT("OGV")
SET OGL = MODEL.RETURNNAMEDELEMENT("OGL")
SET BD = MODEL.RETURNNAMEDELEMENT("BD")
SET BDV = MODEL.RETURNNAMEDELEMENT("BDV")
SET BDL = MODEL.RETURNNAMEDELEMENT("BDL")

OG.LENGTH = OG.LENGTH + DELTALENGTH
OG.REF_LENGTH= OG.REF_LENGTH - DELTALENGTH

OGL.LENGTH = OGL.LENGTH + DELTALENGTH
OGL.REF_LENGTH= OGL.REF_LENGTH - DELTALENGTH
BD.LENGTH = BD.LENGTH - DELTALENGTH
BDV.LENGTH = BDV.LENGTH - DELTALENGTH
BDL.LENGTH = BDL.LENGTH - DELTALENGTH
```

Example PRODAS Script

Page 4

```
SELECT CASE OGRINDEX
        CASE 1   'DO NOTHING
           DELTARADIUS=  0.0          ' MUST BE IN METERS
        CASE 2
           DELTARADIUS=  -100.0/1000.0                    ' MUST BE IN METERS

        CASE 3
           DELTARADIUS=  400.0/1000.0                     ' MUST BE IN METERS
      END SELECT
      SET OG = MODEL.RETURNNAMEDELEMENT("OG")
      OG.RADIUS = OG.RADIUS + DELTARADIUS                 ' MUST BE IN METERS
      OGRTAG="OGR +" & DELTARADIUS *1000 & "MM|"


      INITIALPROP_VOLUME= PROJ.GETDATAPOINTVALUE("MASSPROP","CALC_PROPELLANT_VOLUME")


      PROJ.EXECUTEANALYSIS "MASS2000"
      WEIGHT= PROJ.GETDATAPOINTVALUE("MASSPROP","CALC_FLY_WEIGHT")

      AXIALINERTIA= PROJ.GETDATAPOINTVALUE("MASSPROP","CALC_FLY_AXIALINERTIA")
      TRANSINERTIA= PROJ.GETDATAPOINTVALUE("MASSPROP","CALC_FLY_TRANSINERTIA")
      CGNOSE= PROJ.GETDATAPOINTVALUE("MASSPROP","CALC_FLY_CGNOSE")
      LINECOL(0)=BTTAG & OGTAG & OGRTAG
      LINECOL(1)=WEIGHT *1000
      LINECOL(2)=AXIALINERTIA
      LINECOL(3)=TRANSINERTIA
      LINECOL(4)=CGNOSE  *1000



      PROP_WEIGHT= PROJ.GETDATAPOINTVALUE("MASSPROP","CALC_PROPELLANT_WEIGHT")
      PROP_VOLUME= PROJ.GETDATAPOINTVALUE("MASSPROP","CALC_PROPELLANT_VOLUME")
      LINECOL(5)=PROP_WEIGHT *1000
      LINECOL(6)=PROP_VOLUME*100*100*100
```

Example PRODAS Script

Page 5

```
PROJ.SETDATAPOINTVALUE "GUNINFO","CHAMBERVOLUME",PROP_VOLUME
        PROJ.SETDATAPOINTVALUE "INTERIORBALLISTICS","PROPMASS(FRANKFORT)" ,PROP_WEIGHT

        PROJ.EXECUTEANALYSIS "IBAL2000FRANKFORT"

        MV = PROJ.GETDATAPOINTVALUE("TRAJECTORY","MUZZLEVELOCITY")
        LINECOL(7)=MV

        PROJ.EXECUTEANALYSIS "SPIN2000"

        PROJ.SETDATAPOINTVALUE "TRAJECTORY","RANGEFINAL" ,1000
        PROJ.SETDATAPOINTVALUE "MET","METTYPE" ,3          'SET TO STD
        PROJ.EXECUTEANALYSIS "TRAJ20006D"
        SET TABLE= PROJ.OPENDATATABLE("TRAJECTORY","TRAJRESULTSDATA")        'INIT A DATA TABLE OBJECT
        LAUNCHMACH = TABLE.CELLVALUE(1,11)
        X1 =  TABLE.CELLVALUE(TABLE.ROWS,2)
        Y1 =  TABLE.CELLVALUE(TABLE.ROWS,3)
        Z1 =  TABLE.CELLVALUE(TABLE.ROWS,4)
        LINECOL(8)=X1
        LINECOL(9)=Y1
        LINECOL(10)=Z1

        PROJ.SETDATAPOINTVALUE "MET","METTYPE" ,1          'SET TO COLD

        PROJ.EXECUTEANALYSIS "SPINSTAB2000"
        SET TABLE= PROJ.OPENDATATABLE("AEROSTABILITY", "STABILITYBASIC")        'INIT A DATA TABLE OBJECT
        IF LAUNCHMACH < TABLE.CELLVALUE(1,1) THEN
           MYGYRO =  TABLE.CELLVALUE(1,2)
        ELSEIF LAUNCHMACH > TABLE.CELLVALUE(30,1) THEN
           MYGYRO =  TABLE.CELLVALUE(30,2)
        ELSE
           FOR I=2 TO TABLE.ROWS
              IF LAUNCHMACH < TABLE.CELLVALUE(I,1) THEN
                 RATIO = (TABLE.CELLVALUE(I,1)-LAUNCHMACH )/(TABLE.CELLVALUE(I,1)-TABLE.CELLVALUE(I-1,1))
                 MYGYRO =  TABLE.CELLVALUE(I,2) - RATIO * ( TABLE.CELLVALUE(I,2)- TABLE.CELLVALUE(I,1))
                EXIT FOR
              END IF
           NEXT
        END IF
```

Example PRODAS Script

Page 6

```
            LINECOL(11)=LAUNCHMACH
            LINECOL(12)=MYGYRO

            PROJ.SETDATAPOINTVALUE "MET","PRES AT SEA LEVEL", 1013.3
            PROJ.SETDATAPOINTVALUE "MET","TEMP AT SEA LEVEL", 15
            PROJ.SETDATAPOINTVALUE "MET","WIND DIRECTION",  0.0                    'FROM THE NORTH
            PROJ.SETDATAPOINTVALUE "MET","WIND SPEED",  5.14                       'M/SEC = 10 KNOTS
            PROJ.EXECUTEANALYSIS "MET2000"


            PROJ.SETDATAPOINTVALUE "MET","METTYPE", 6          ' USER MET
            PROJ.EXECUTEANALYSIS "TRAJ20006D"
            SET TABLE= PROJ.OPENDATATABLE("TRAJECTORY","TRAJRESULTSDATA")       'INIT A DATA TABLE OBJECT
            X2 =  TABLE.CELLVALUE(TABLE.ROWS,2)
            Y2 =  TABLE.CELLVALUE(TABLE.ROWS,3)
            Z2 =  TABLE.CELLVALUE(TABLE.ROWS,4)
            LINECOL(13)=X2
            LINECOL(14)=Y2
            LINECOL(15)=Z2
            LINECOL(16)= TABLE.CELLVALUE(TABLE.ROWS,1)
            LINECOL(17)= X1-X2
            LINECOL(18)= Y1-Y2
            LINECOL(19)= Z1-Z2
            LINECOL(20)= SQR((X1-X2)^2 + (Y1-Y2)^2 + (Z1-Z2)^2 )


            LINEOUT= ""
            FOR J = 0 TO ACTIVECOL
               LINEOUT= LINEOUT & LINECOL(J)
               IF J < ACTIVECOL THEN LINEOUT=LINEOUT & CHR(9)
            NEXT
            RESULTS.WRITESTRING LINEOUT
            NEWFILENAME = "50 CAL BALLISTIC SNIPER PROJECT" &BTINDEX & OGLINDEX &OGRINDEX  & ".PR3"
            PROJ.SAVEASDATAFILE PROJDIR & NEWFILENAME
            PROJ.CLOSEDATAFILE                 'YOU ARE DONE WITH THIS PROJECTILE

         NEXT
      NEXT
   NEXT

   RESULTS.CLOSEFILE                           'CLOSE THE RESULTS FILE
   SET RESULTS = NOTHING
   MSGBOX "RESULTS FILE CAN BE FOUND IN " & RESULTSFILENAME

END SUB
```