EDA Engineering
Design and Analysis

BALLISTICS DESIGN, ANALYSIS and TEST Capabilities

January 2024

Content

COMPANY OVERVIEW

2003

Dr. Erdal Oktay

METU Technopolis, Ankara/TURKEY

Subject of study:

- Mechanical & Aeronautical Engineering

Sector:

- Defense and Aerospace Industry

Our Team

Field	Degree	Number	Avg. Years of Experience
Aeronautical & Mechanical Engineer	PhD.	1	42
Civil & Mechanical Engineer	Prof.	1	57
Mechanical Engineer	PhD.	1	37
Computer Engineer	PhD.	1	32
Chemical Engineer	Bs.	1	20
Aeronautical Engineer	Ms.	2	8
Computer Engineer	Bs.	1	5
	TOTAL	8	28.7

The Fields of Activity

Engineering Design Development & Improvement	› Used Computational Methods for Engineering Low Order Engineering Methods ➔ High Order Advanced Computational Methods
Engineering Analysis	› Software Tools • CAEeda - Computer Aided Engineering Design & Analysis Software • BALLISTICeda - Ballistic Design & Analysis Software
Software Development, Customization & Automation	› Objectives • Improving capabilities that are not available on the market yet • Using EDA's software for Design & Analysis independently • Gathering all Design & Analysis tools under a single software • Increasing cost efficiency of projects using customized software
FCI & TFT Creation, Fire Control Software	› Development of FCI (Fire Control Input) and TFT (Tabular Firing Table) › Fire Control Software Development
Firing Test	› Firing Test Planning › Firing Test Consultancy

Services*

MKE (*Mechanical and Chemical Industry Corporation*)

- Development of Ballistic Design & Analysis Software
- Engineering Services concerning Ammunition and Weapon System Design
- Development of Firing Control Inputs (FCI) for Firing Control Computers and Tabular Firing Tables (TFT) for Howitzers and Battle Tanks

TUBITAK-SAGE (*Defense Industries Research And Development Institute*)

- Development of Hybrid Mesh Generation Software
- Development of Grain Burnback Analysis Software for Solid Propellants of Rocket Motors
- Flutter Analysis of A Transonic Aircraft Wing

TEI (*TUSAS Engine Industries Inc.*)

- Development of Hybrid Mesh Generation Software

ROKETSAN (*Missile Industries Inc.*)

- Aerodynamic Heating Analysis of A High Supersonic Missile

(*) All these services have been performed by using EDA's Software

R&D Projects

- Development of A Parallel Fluid-Structure Interaction Software *
- Development of A Pre-Processor Software for CFD Applications *
- Development of Solid Model & Unstructured Mesh Generation Software for Parametric Complex Surface Geometries *
- (Awarded as a Success Story by TUBITAK TEYDEB, 2015)
- Adding Structural & Thermal Design Capabilities to CAEeda Software Package *
- A Software Development for Aerodynamics and Structural Design Optimization & Automation *
- Development of Structural Analysis and Design Automation Software for Composite Structures
- Software Development for Ballistic Design & Analysis
- Development of a CAD and Grain Burnback Analysis Software for Solid Propellant Rocket Motors

(*) Supported by TÜBİTAK-TEYDEB

Capabilities*

Topic	Capability	Service
Ballistic design, design optimization and analysis	✓	✓
Development of Fire Control Input (FCI) and Tabular Firing Tables for direct and indirect firings with respect to NATO standards	✓	✓
Gun barrel design and design optimization	✓	
Projectile, missile design and design optimization	✓	
Warhead design	✓	
Basebleed design and analysis	✓	
Design and analysis of Mine Clearing Line Charge (MICLIC)	✓	
Grain Burnback Analysis for Solid Propellant Rocket Motors	✓	✓
Development of fire control software	✓	
Design of guided ammunitions	✓	

(*) The weapon and ammunition related studies, carried out and completed, for serving to clients or acquiring new company talents.

Some projects realized and successfully completed for MKE

- Development of Firing Control Inputs (FCI) and Tabular Firing Tables (TFT) for 105mm Projectiles and Weapon System
- Development of Firing Control Inputs (FCI) and Tabular Firing Tables (TFT) for 120mm HE-T Projectile to use for Smooth Bore Weapon Systems
- Development of Firing Control Inputs (FCI) and Tabular Firing Tables (TFT) for Anti-Tank projectile to use Battle Tanks
- Development of Ballistic Design & Analysis Software

Software Products - CAEeda™

CAEeda

Computer Aided Engineering for Engineering Design & Analysis

CADeda	Computer Aided Design Software
MESHeda™	Mesh Generation Software
PREeda	Pre-processing Software
POSTeda	Post-processing Software
OPTIMIZER	Design Optimization Software
SOLVERS	
FAPeda™	*Flow Analysis Program*
SAPeda™	*Structural Analysis Program*
PANELeda	*Aerodynamic solver by Panel method*
BURNBACKeda	*Solid Propellant Grain Burnback Analysis software*
FSIeda	*Fluid Structure Interaction program*

About CAEeda™

- CAEeda™ software was developed for aeronautical, mechanical, naval and civil engineering applications
- It was developed to meet all needs in the Conceptual, Preliminary and Detail Design stages
- It can be used for Engineering Design Automation (EDA) and Optimization
- Additions of new capabilities and interface adjustments can be made upon request

Advanced Ballistic Analysis Capabilities of CAEeda

CFD Analysis

Example : Interactions of Canard – Body – Fin vortices

Test Case : NASA Tandem Missile Geometry Supersonic Test Case*

** Ref: NATO RTO Applied Vehicle Technology Panel (AVT) TG-082, "Assessment of Turbulence Modeling for High-Speed Vehicles", TR-AVT-082*

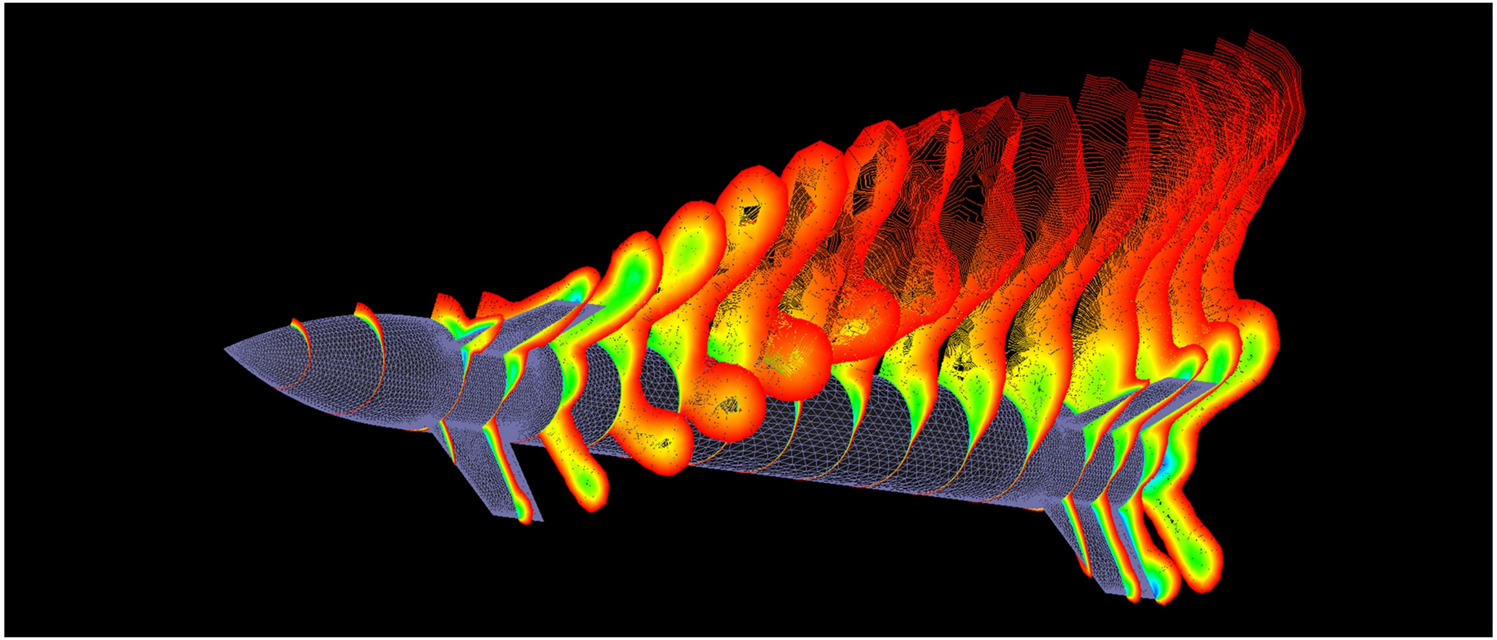


Figure : Unstructured surface mesh & total pressure contours at different body sections (M_∞=1.75, α=6deg)

CFD Solution of Store Separation

Test Case : AFRL-WPS (Air Force Research Laboratory – Wing, Pylon, Store)*

(*) Ref: Fox, J.H., "Chapter 23: Generic Wing, Pylon, and Moving Finned Store," In "Verification and Validation Data for Computational Unsteady Aerodynamics", RTO Technical Report , RTO-TR-26, 2000

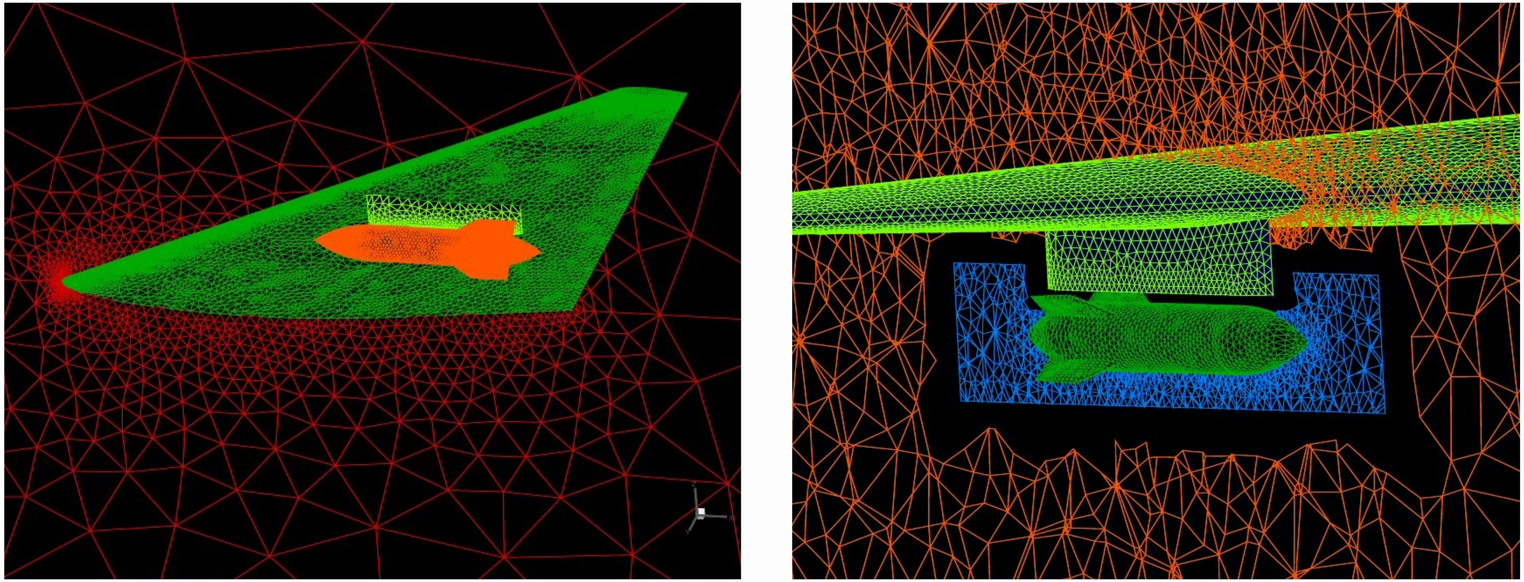
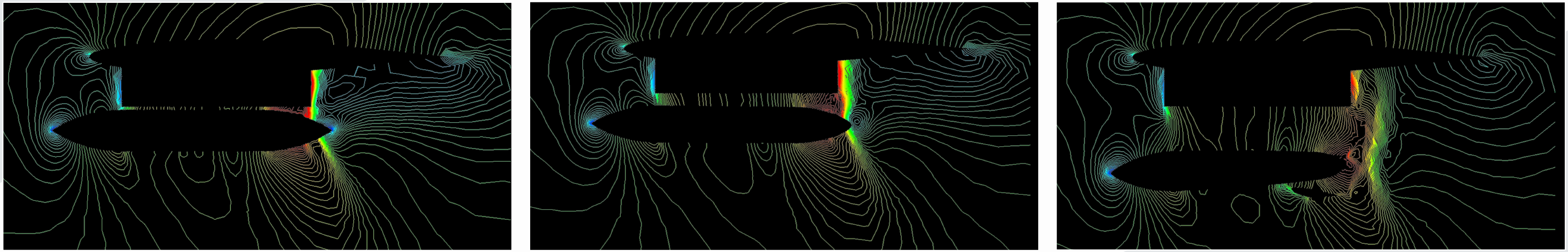
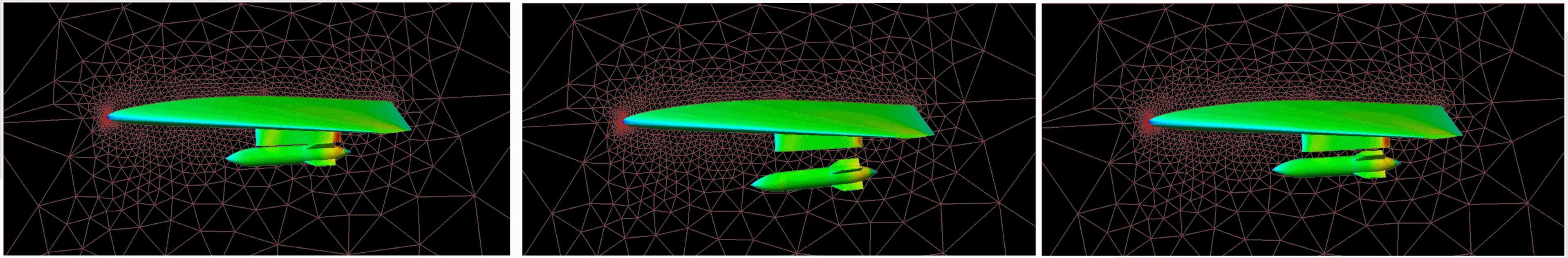


Figure : Unstructured surface mesh for wing and store using MESHeda

Cross-sectional Mach Contours



Surface Mach Contours

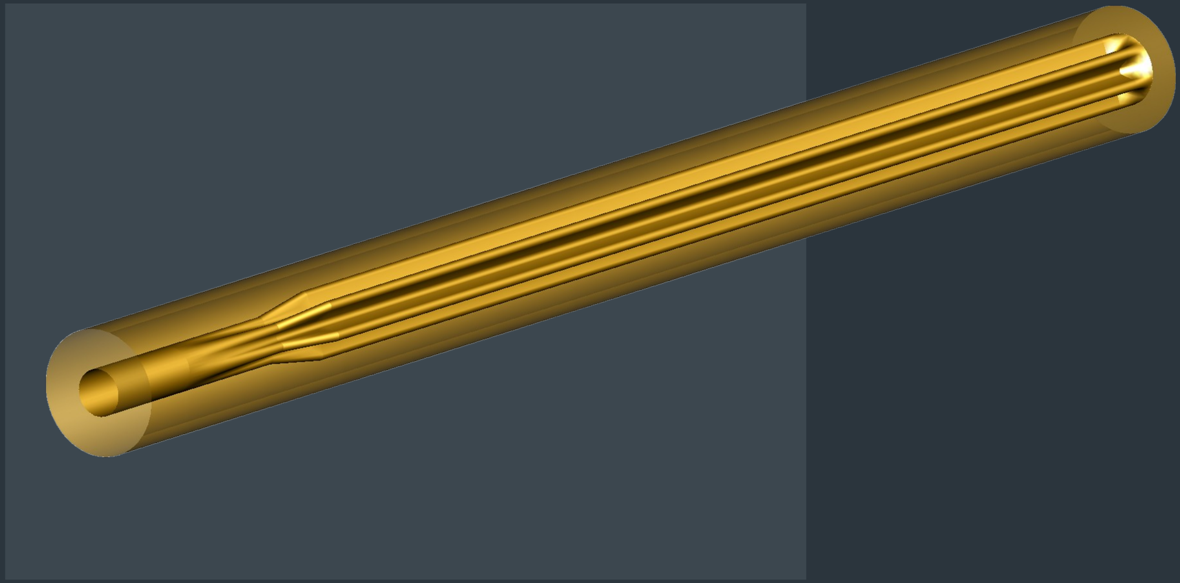


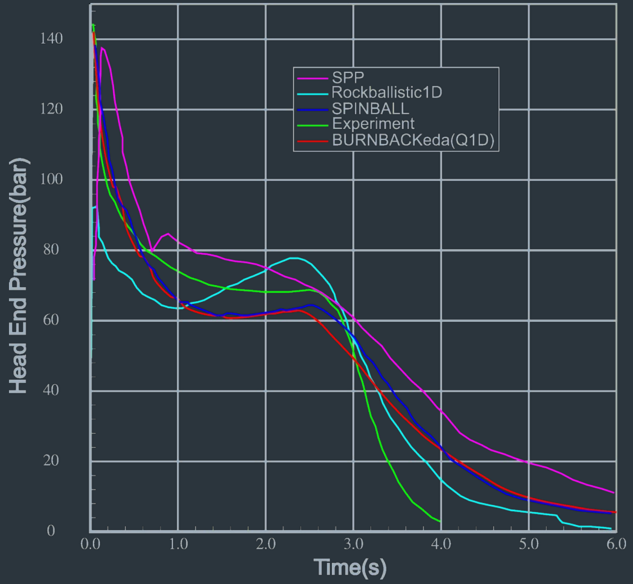
Ref : Oktay, E., Merttopcuoglu, O., Akay, H., "An Unstructured Hybrid Method For Store Separation Simulations", AIAC-2007-104, Ankara International Aerospace Conference, September 10-12, 2007, Ankara, Turkey.

Grain Burn-back Analysis of a Solid Rocket Motors

Example : NAWC motor no.6*

(*) Ref : Willcox M., Brewster M., Tang K., Steward D., and Kuznetsov I., "Solid Rocket Motor Internal Ballistic Simulation Using Three-Dimensional Grain Burnback. Journal of Propulsion and Power, volume 23(3):pages 575–584 (may-june 2007)





Software Products - BALLISTICeda

BALLISTICeda
Ballistic Design & Analysis Software

- Geometric Modeling and Design
- Computational Interior Ballistics
- Computational Aerodynamics
- Computational Flight Mechanics
- Post Processing

The Use of BALLISTICeda for Design and Analysis

- Geometry Module
  - Parametric 3D CAD geometry creation
    - Projectile, missile, barrel with rifled bore
- Aerodynamic analysis
- Flight Mechanic Analysis and Simulation
  - 3DOF, 4DOF-Modified Point Mass, 5DOF, 6DOF
- Internal Ballistic Analysis
- Automatization and Optimization
- Guidance-Navigation-Control Design and Simulation
  - Terminal base use from command line
  - Model base multidisciplinary dynamic system modeling
- Post Processing

Software To Be Developed

FCIpro / Fire Control Input (FCI) Creation Software

TFTpro / Tabular Firing Table (TFT) Creation Software

FCMpro / Fire Control Software

- Calculates the elevation angle and azimuth angle of the barrel to hit the target
- Gives coordinates of the impact point (distance to the weapon and side deviation from the line of sight) and trajectory
- Offers an easy-to-use graphical interface (GUI)
- Provides transformations of weapon and target location according to geographic and grid coordinate systems used in artillery
- Uses a selectable and reliable database that can be sorted with respect to compatible bullets, fuzes and projectiles to be used in the weapon system for any country

Desktop and Mobile Applications of Fire Control Software

- Used to specify a safe firing zone and operation
- Used for preparation of FCI and TFT

BALLISTIC CAPABILITIES

- Internal Ballistics
- External Ballistics
- Terminal Ballistics
- Projectile/Barrel Design & Design Optimization
- Aerodynamic Heating Analysis
- Fire Control & Test For Direct And Indirect Firing

Internal Ballistics

- Computation of propellant burning
- Computation and simulation of projectile motion in a rifled gun bore
- Structural and thermal analysis of gun barrels
- Computational analysis of basebleed

External Ballistics

- Calculation of aerodynamic coefficients (static and dynamic) of projectiles and missiles using engineering methods and CFD
- Flight simulation of spinning missiles and projectiles by using aerodynamic tables or CFD coupling
- Extraction of aerodynamic coefficients from radar data

Terminal Ballistics

- Dispersion analysis
- Hit target analysis

Projectile/Barrel Design & Design Optimization

- Aerodynamic shape optimization of projectiles
- Design and optimization of kinetic energy projectiles
- Sabot design
- Structural/thermal design and optimization of barrels

Aerodynamic Heating Analysis

- Engineering methods or CFD -CSD coupling

Fire Control & Test For Direct And Indirect Firing

- Development Of Fire Control Software
  - *Using NATO Ballistics Kernel (NABK)*
  - *Using inhouse BALLISTICeda software*
- Firing Test Planning
- Data Reduction Of Firing Test
- Development Of Fire Test Input (FCI)
- Development Of Tabular Firing Tables (TTF)

Ballistic Design of Projectiles

Objectives & Constraints

Performance criteria

- *Desired range*
- *Desired CEP*
- *Desired efficiency*
- *Weapon compatibility*

Cost & time limits of project

Design Stages

- Conceptual design
- Preliminary design
- Detail design
- Firing tests

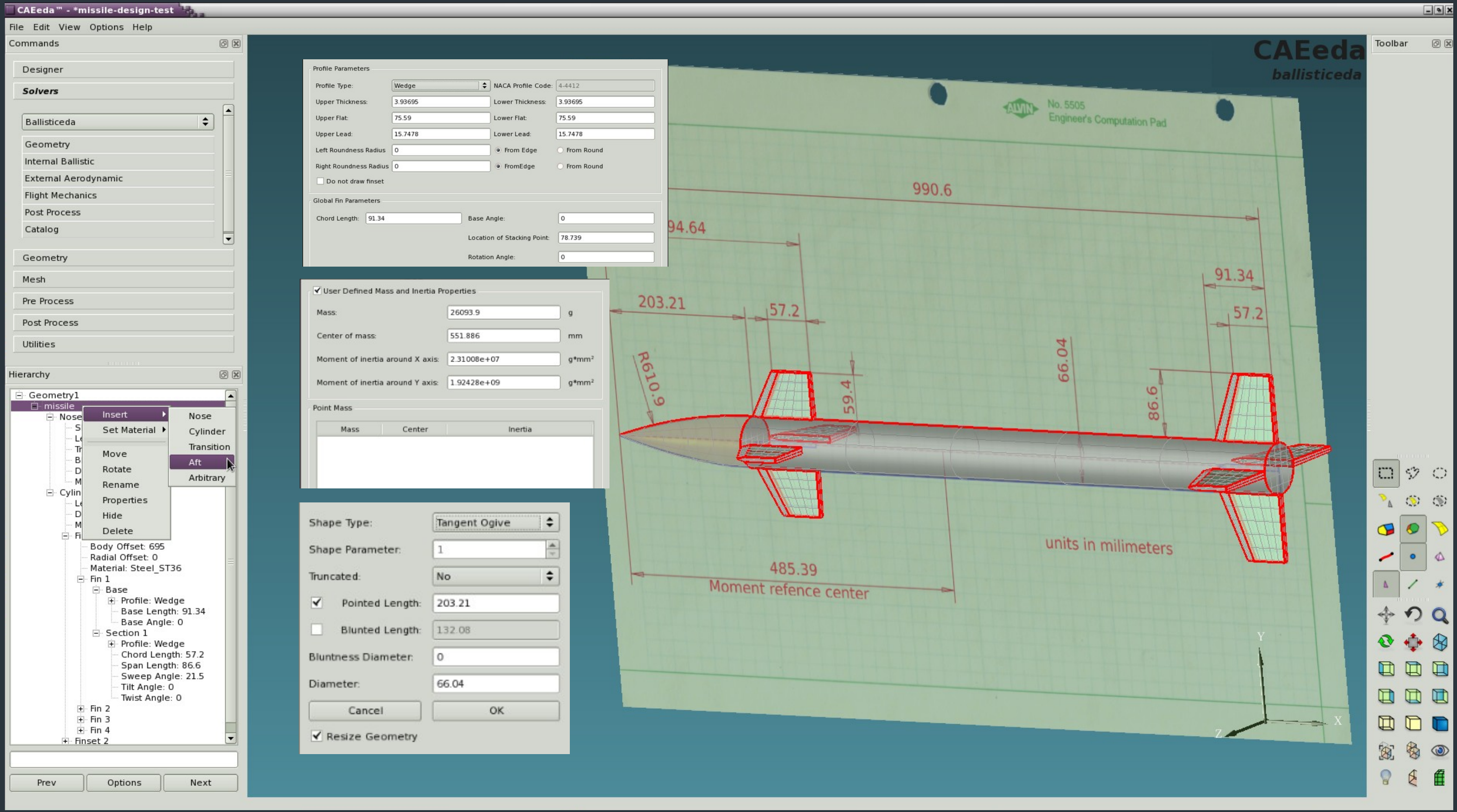
The Scope of Ballistic Design & Analysis

- Geometric modeling
- Aerodynamic analysis
- Internal ballistic analysis
- Flight mechanics analysis
- Structural mechanics analysis
- Thermal analysis
- Optimization
- Design automation
- Post processing (plots & animations)

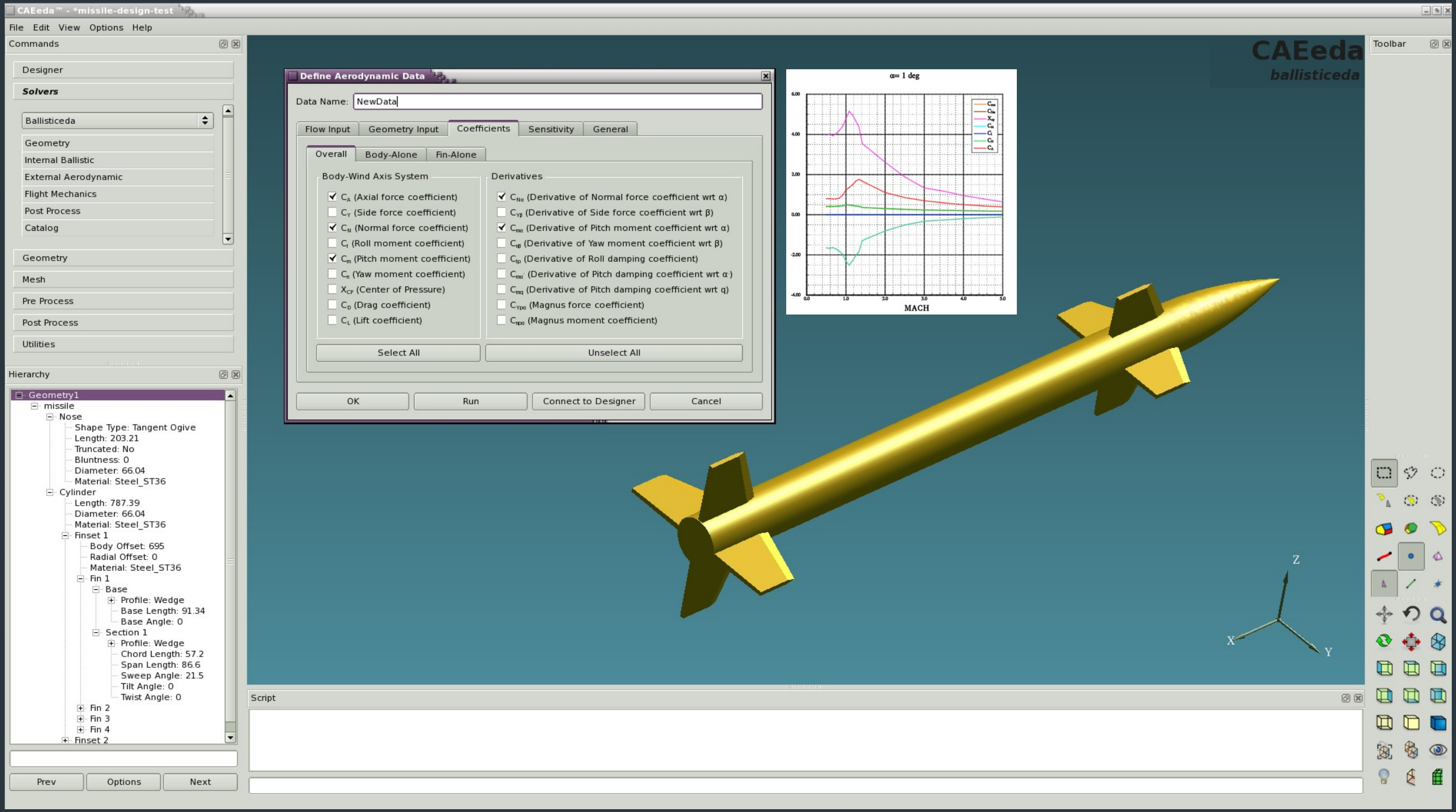
Tools and Methods Used

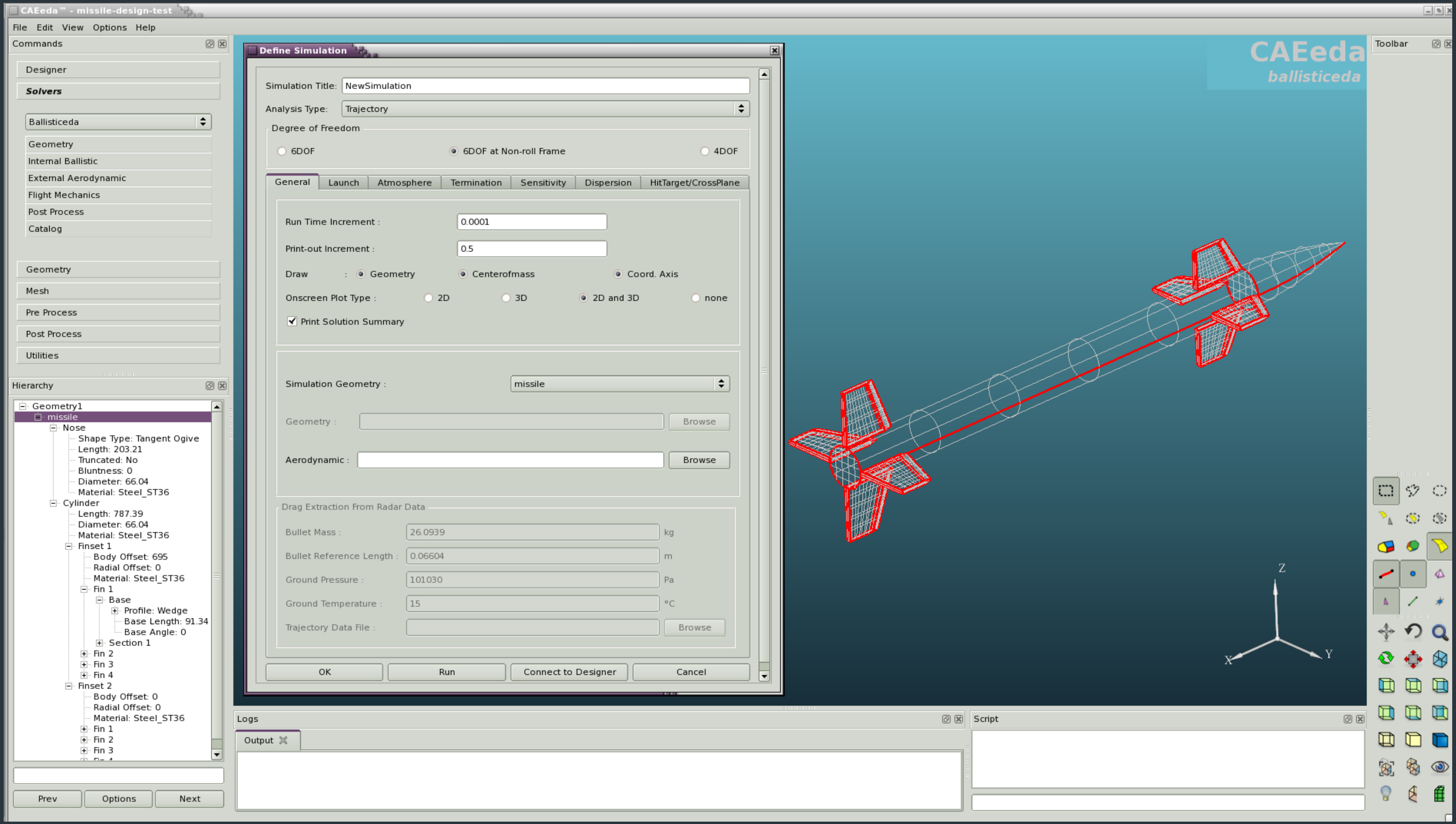
- Geometric modeling
  - *Automatic and parametric 2D & 3D CAD modeling using the Geometry Module of CAEeda*
  - *Automatic and parametric projectile & missile modeling using the Geometry Module of BALLISTICeda*
- Aerodynamic analysis
  - *Rough engineering solutions using the Aerodynamics module of BALLISTICeda*
  - *Precise CFD solutions using FAPeda module of CAEeda code*
- Internal Ballistic Analysis
  - *Rough engineering solutions using the Intenal-Ballistics module of BALLISTICeda*
  - *Precise CFD solutions using the FAPeda module of CAEeda*
- Flight Mechanics Analysis
  - *3DOF, Modified Point Mass, 5DOF, 6DOF solutions using Flight Mechanics module of BALLISTICeda*
- Structural mechanics analysis using the SAPeda module of CAEeda
- Heat transfer analysis using the TAPeda module of CAEeda
- Design optimization by designer module of CAEeda
- Post processing using POSTeda module of CAEeda

Creation of Parametric Geometry

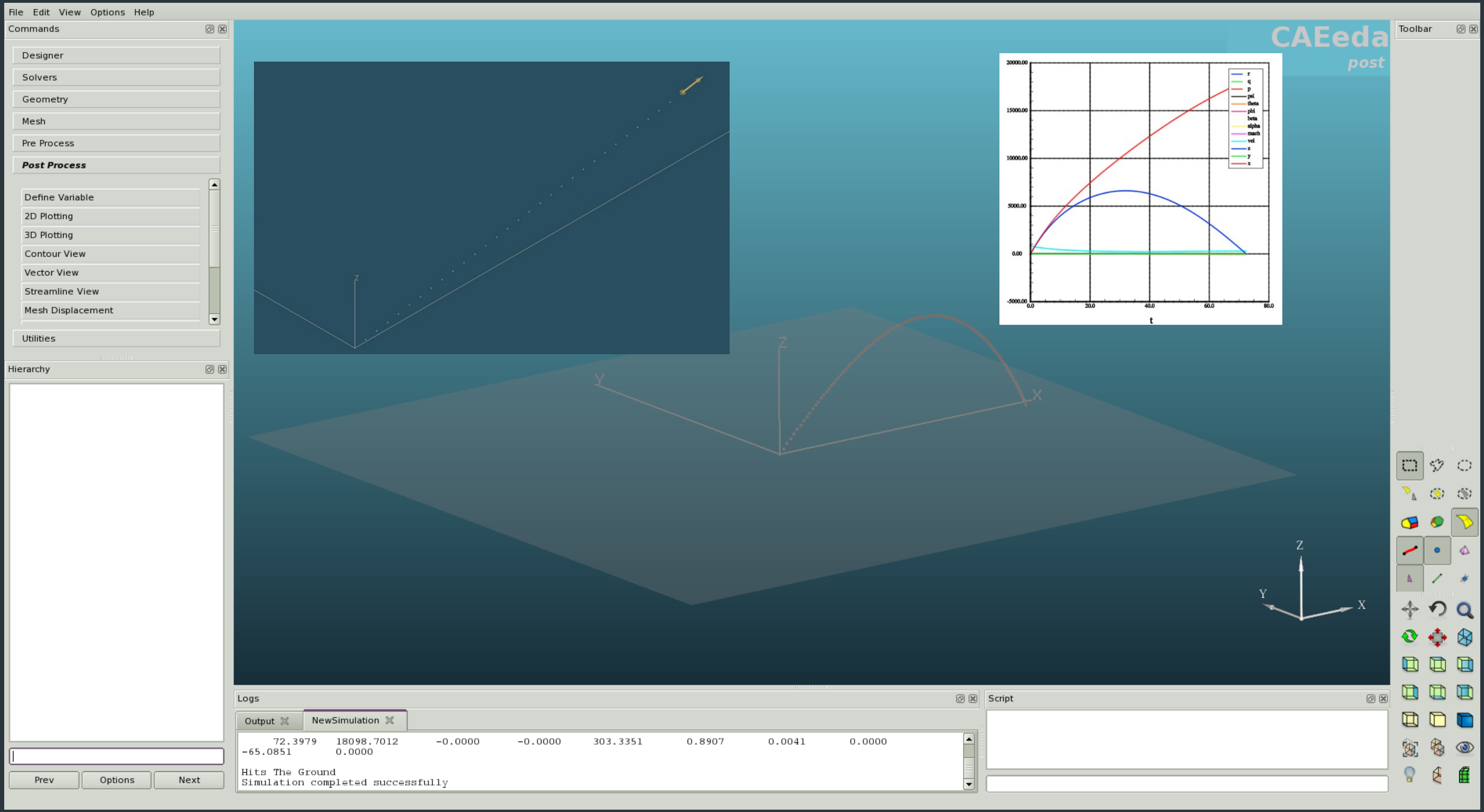


Aerodynamics Module



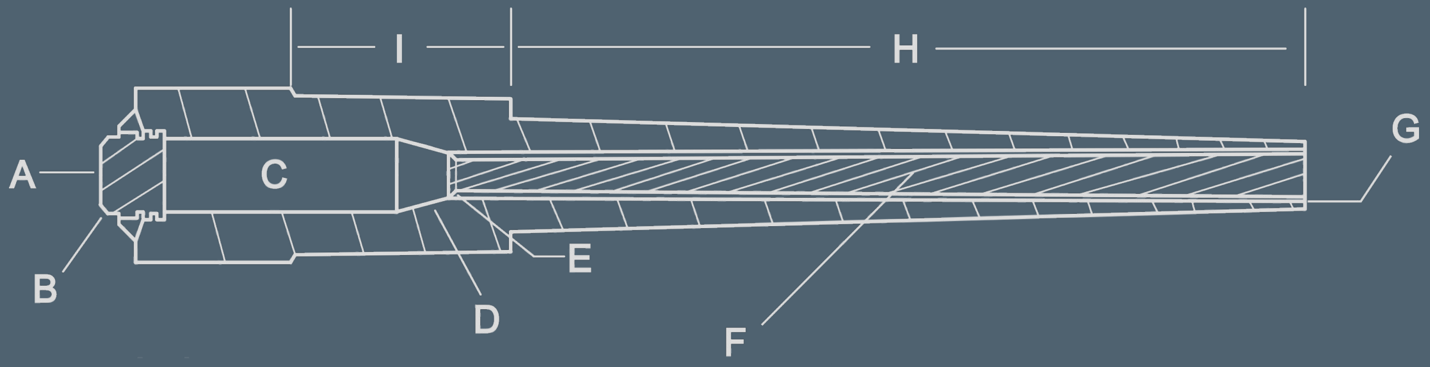

CAEeda™ - missile-design-test
File Edit View Options Help
Commands
Designer
Solvers
Ballisticeda
Geometry
Internal Ballistic
External Aerodynamic
Flight Mechanics
Post Process
Catalog
Geometry
Mesh
Pre Process
Post Process
Utilities
Hierarchy
Geometry1
missile
Nose
Shape Type: Tangent Ogive
Length: 203.21
Truncated: No
Bluntness: 0
Diameter: 66.04
Material: Steel_ST36
Cylinder
Length: 787.39
Diameter: 66.04
Material: Steel_ST36
Finset 1
Body Offset: 695
Radial Offset: 0
Material: Steel_ST36
Fin 1
Base
Profile: Wedge
Base Length: 91.34
Base Angle: 0
Section 1
Fin 2
Fin 3
Fin 4
Finset 2
Body Offset: 0
Radial Offset: 0
Material: Steel_ST36
Fin 1
Fin 2
Fin 3
Prev
Options
Next
Define Simulation
Simulation Title: NewSimulation
Analysis Type: Trajectory
Degree of Freedom
6DOF
6DOF at Non-roll Frame
4DOF
General
Launch
Atmosphere
Termination
Sensitivity
Dispersion
HitTarget/CrossPlane
Run Time Increment : 0.0001
Print-out Increment : 0.5
Draw : Geometry Centerofmass Coord. Axis
Onscreen Plot Type : 2D 3D 2D and 3D none
Print Solution Summary
Simulation Geometry : missile
Geometry : Browse
Aerodynamic : Browse
Drag Extraction From Radar Data
Bullet Mass : 26.0939 kg
Bullet Reference Length : 0.06604 m
Ground Pressure : 101030 Pa
Ground Temperature : 15 °C
Trajectory Data File : Browse
OK
Run
Connect to Designer
Cancel
CAEeda
ballisticeda
Toolbar
Z
X
Y
Logs
Output
Script

Flight Mechanics Module



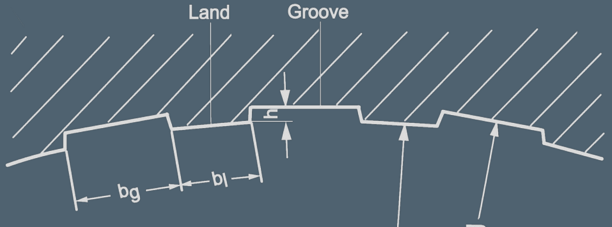
Internal Ballistics Module

Barrel Geometry

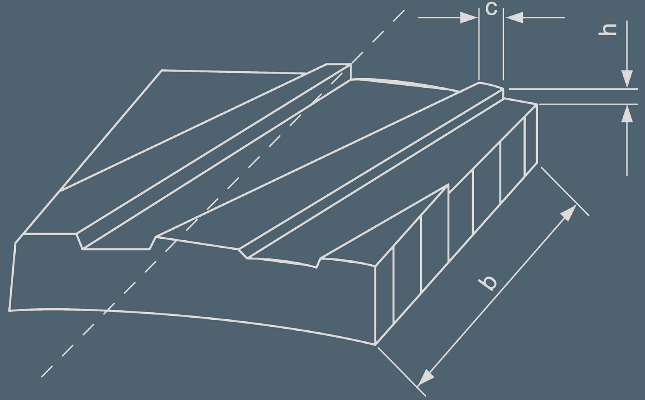


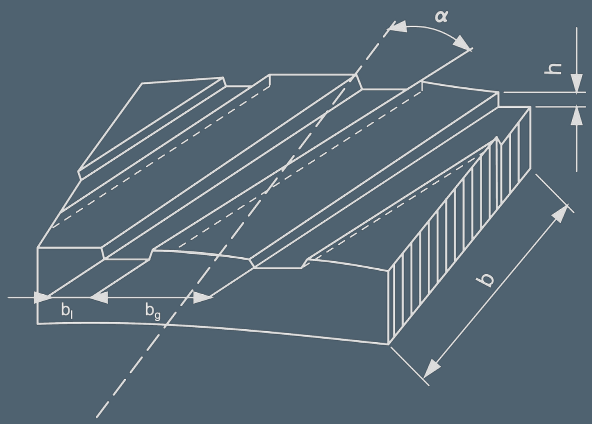
A : Breech
B : Breech block
C : Combustion chamber
D : Shoulder
E : Beginning of lands
F : Rifled bore
G : Muzzle
H : Chase
I : Slide cylinder

Rifle Parameters



d : Caliber
d_g : Diameter above the grooves
b_g : Groove width
b_l : Land width
h : Groove depth
(n = Number of grooves)





Internal Ballistics Module

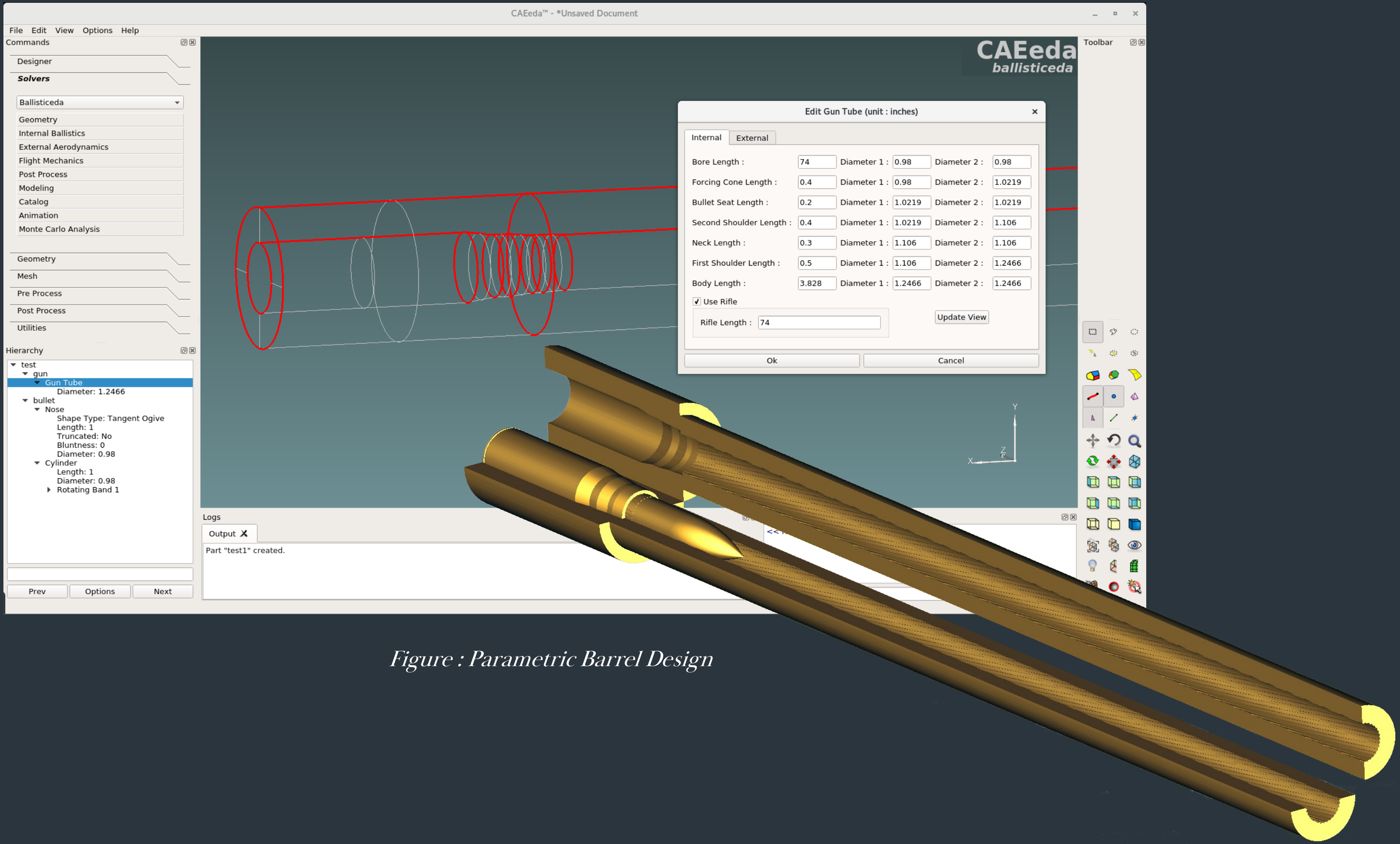
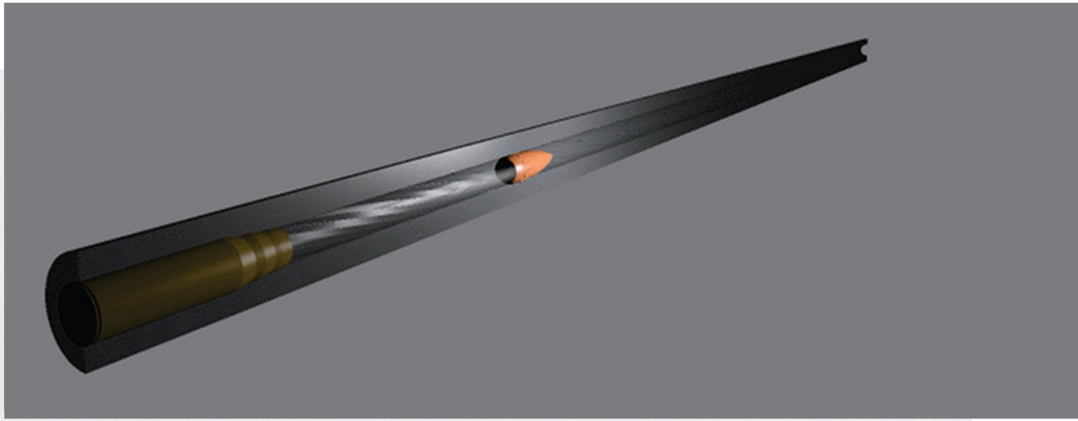
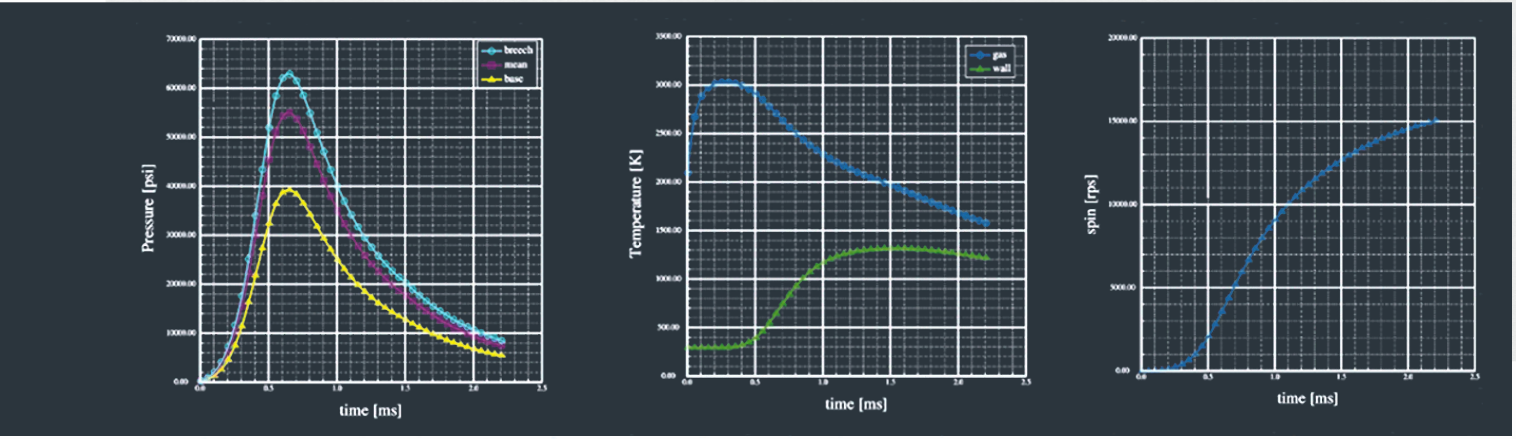


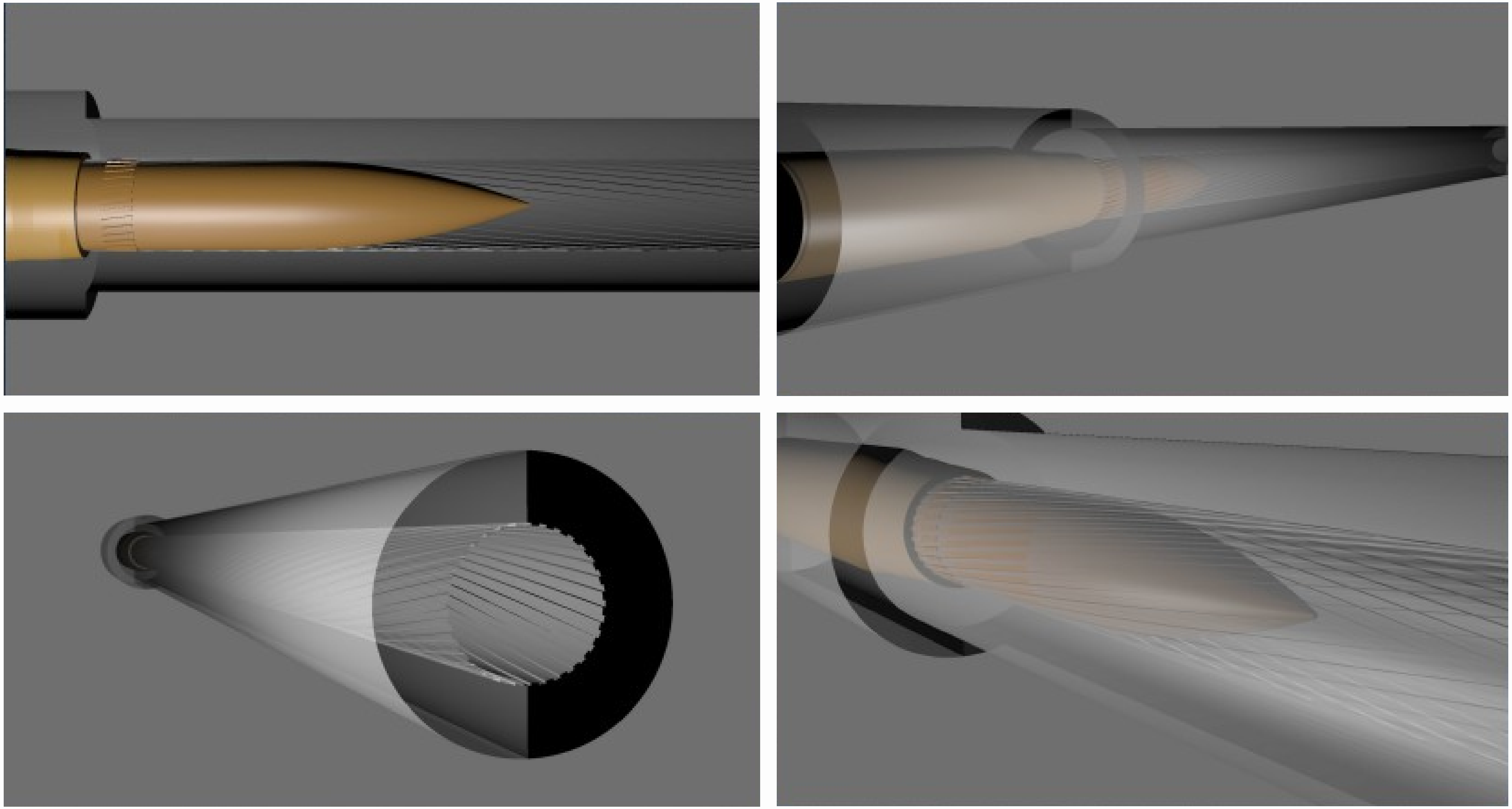
Figure : Parametric Barrel Design

The simulation of projectile motion in a rifled tube

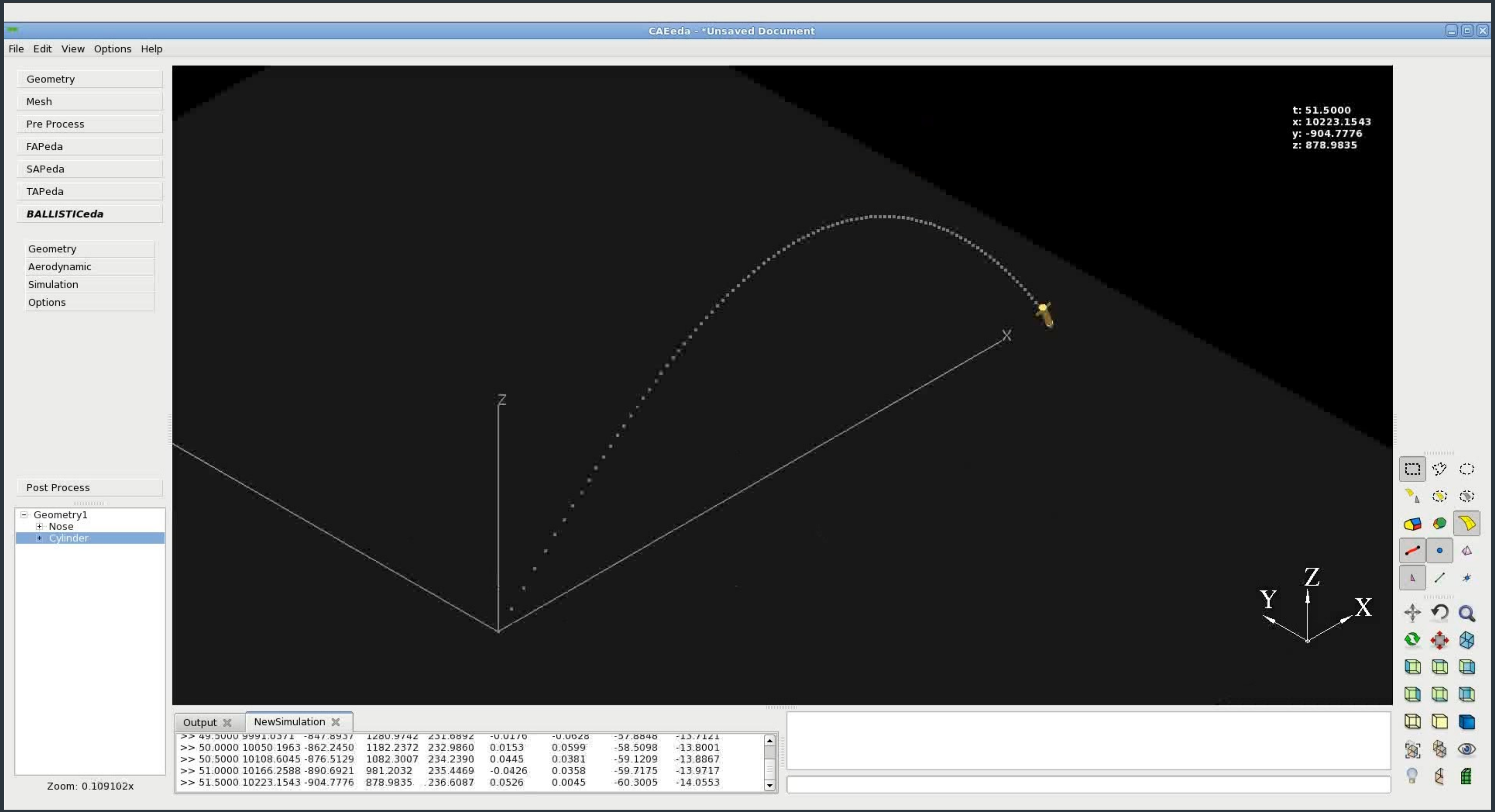




Simulation of in-bore projectile

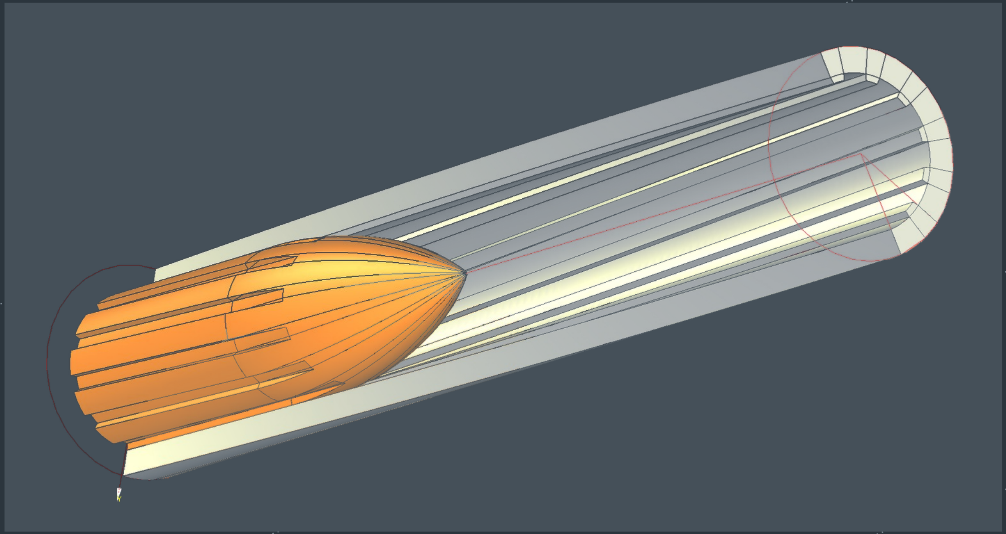


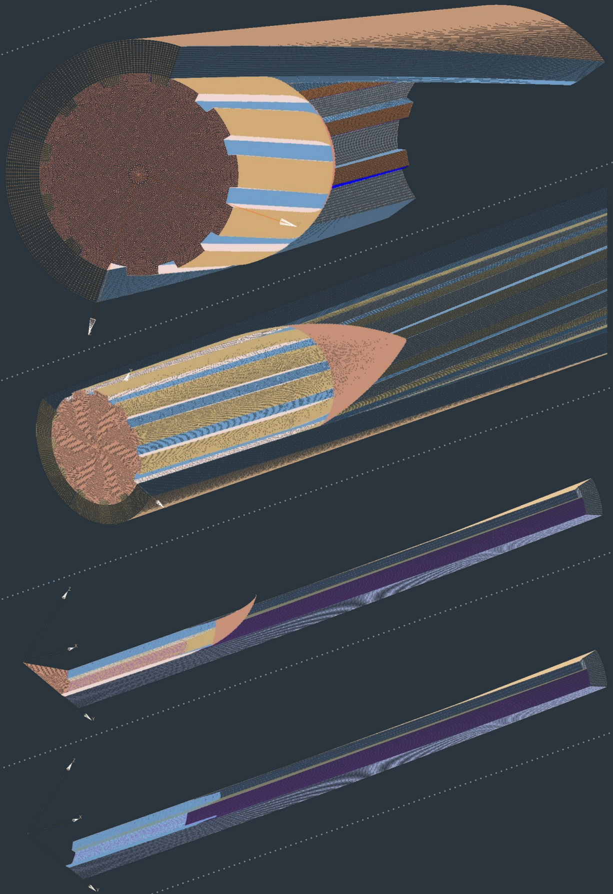
Aerodynamics - Flight Mechanics



Internal Ballistics – Structural Mechanics Interaction

Dynamic mesh coupling

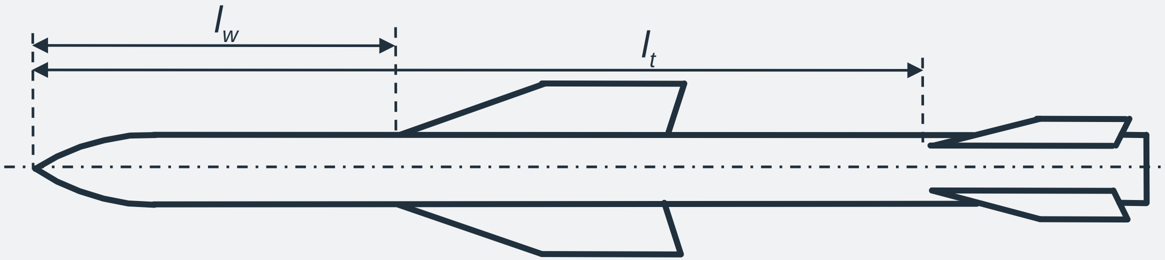




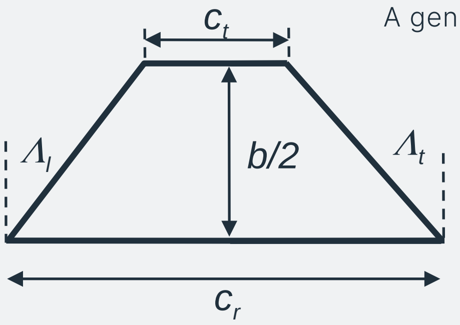
AIRFRAME SHAPE OPTIMIZATION FOR RANGE MAXIMIZATION

Missile Design Optimization Using Genetic Algorithm

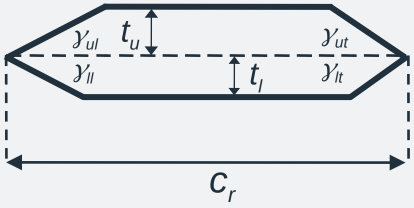
Design Parametrization



A generic missile geometry

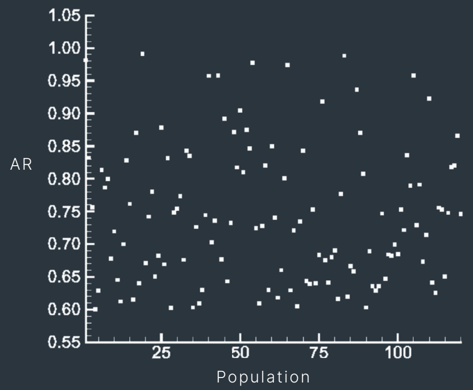


Horizontal cross-section of wing and tail fin

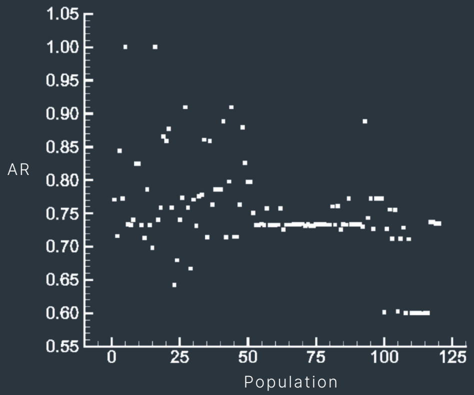


Vertical cross-section of wing and tail fin

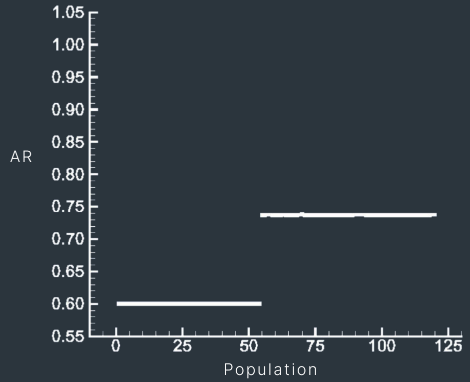
Design Steps



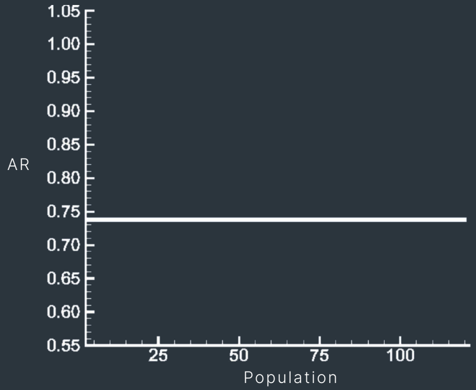
(1) Initial aspect ratio of the missile tail fin



(2) Intermediate aspect ratio of the missile tail fin



(3) Intermediate aspect ratio of the missile tail fin



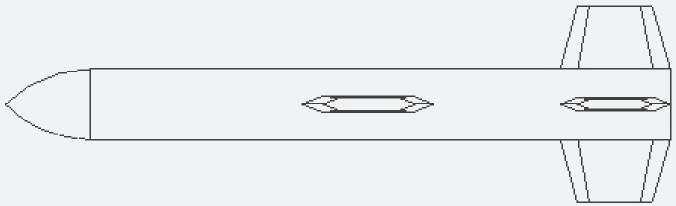
(4) Optimum aspect ratio of the missile tail fin

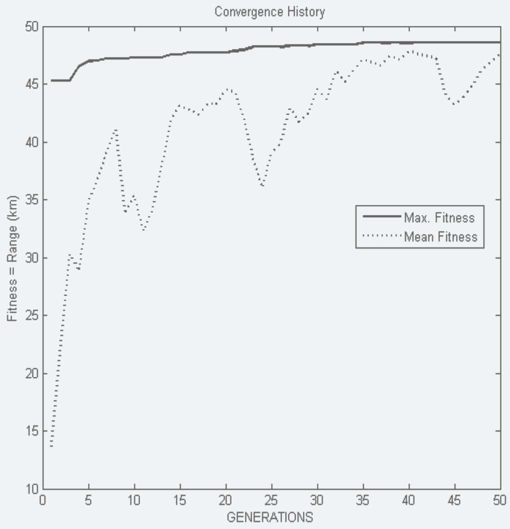
Final Design

CAD, MESH, CFD Coupling for Design Automation and Optimization

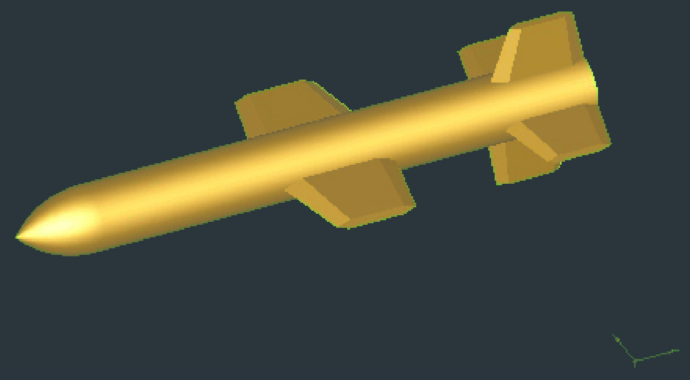
Sample Application :

Wing and Tail Shape Optimization to Extend the Range of a Missile





Design Parametrization



Objective	: Maximum range
Fixed geometries	: Nose and body
Variable geometries	: Wing and tail fins
Starting range	: 45 km
Final range	: 48 km

FCI & TFT CREATION

Fire Control Input (FCI) Creation

Preparation of input files (FCI) used by the fire control computer (AKB) during computer-aided firing with a weapon system for all kinds of heavy weapons and ammunition duos

- Howitzer
- Mortar
- Tank

Tabular Firing Table (TFT) Creation

Preparation of Tabular Firing Tables (TFT) for all kinds of heavy weapons and ammunition duos

- Howitzer
- Mortar
- Tank

Ability to use Fire Control Software

- NABK-based fire control software
- EDABK-based fire control software

Fire Control Inputs (FCI) & Tabular Fire Tables (TFT)

FCI Files

- Needed for fire control computer
- Consisting of four different files
- Contains ballistic performance information for the Gun & Bullet duo
- Must be rebuilt if the weapon or ammunition changes
- Required to create TFT

Weapon File

- Bore diameter, barrel length, riffle twist

Fuse File

- Type and specifications of the fuse

Projectile File

- Aerodynamic coefficients
- Diameter, mass and inertial moments
- “Fitting” inputs
- “Management” inputs
- “Probable Error” inputs
- Charge performance inputs
- Basebleed performance inputs
- Weapon information inputs
- “Fitting”, “Management”, “Probable Error” and weapon information inputs are calculated separately for each propellant charge

Tabular Fire Tables (TFT)

- These are the tables used to calculate the elevation and bearing of the barrel in order to hit the target, and fuse settings.
- They consist of A, B (B1, B2), C, D, E, F (F1, F2, F3), G (G1, G2), H, I, J(J1, J2), K tables.

TABLE F (i)
BASIC DATA AND CORRECTIONS TO BEARING

PROJ, HE, M111
FUZE, PD, M222

CHARGE
V_0 = 317.2 M

1	2	3	4	5	6	7	8	9
RANGE	QUADRANT ELEVATION FOR STANDARD CONDITIONS	FUZE SETTING FOR GRAZE BURST	CORRECTION TO FUZE SETTING TO CHANGE HEIGHT OF BURST DOWN BY 10M	EFFECT ON RANGE FOR INCREASE OF ONE MIL IN ELEVATION	FORK	TIME OF FLIGHT	CORRECTIONS TO BEARING ($\Delta_C A_{BG}$) DRIFT (CORRECTION TO LEFT)	1 KNOT CROSSWIND
(X)	(A_{QE})	(FS)	($\Delta_C FS$/ -10M Y_b)	(ΔX/ 1 MIL A_{QE})	(F)	(TOF)	(A_d)	(1KT W_z)
M	MIL			M	MIL	S	MIL	MIL
0	0.0				0	0.0	0.0	0.00
100	5.1	0.3	1.24		0	0.3	0.1	0.00
200	10.0	0.7	1.10		0	0.7	0.2	0.00
300	15.0	1.1	0.97		0	1.1	0.3	0.00

TABLE F (ii)
CORRECTIONS TO RANGE FOR NON-STANDARD CONDITIONS

J, HE, M111
E, PD, M222

CHARGE 5
V_0 = 317.2 M/S

1	10	11	12	13	14	15	16	17	18	19
RANGE	RANGE CORRECTIONS (Δ_c X)									
(X)	MUZZLE VELOCITY (V_0) (1 M/S)		RANGE WIND (W_X) (1 KT)		BALLISTIC AIR TEMPERATURE (T_B) (1%)		BALLISTIC AIR DENSITY (D_B) (1%)		PROJ MASS (2 SQ STD) (1 SQ)	
	DEC (-)	INC (+)	HEAD ($\overline{W}$)	TAIL ($\underline{W}$)	DEC (-)	INC (+)	DEC (-)	INC (+)	DEC (-)	INC (+)
M	M	M	M	M	M	M	M	M	M	M
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
100	0.7	-0.7	0.1	0.0	0.1	0.0	0.0	0.0	-2	2
200	1.4	-1.5	0.1	0.0	0.2	0.0	0.0	0.0	-3	3

Figure: A part of a sample F table prepared for indirect firing

Tabular Fire Tables (TFT)

- Prepared by using FCI
- Prepared for a weapon and bullet combination specifically.
- Based on standard atmospheric conditions (ICAO)
- Prepared in a specific format in NATO standards
- Prepared different approaches for direct and indirect firing and each propellant charge separately
- Calculations for aiming can be done manually by using TTF, but it requires experience, and non-computerized manual calculations take time.
- TFT-based calculations are not as accurate as FCI-based computational simulations (nonlinear), as they require a lot of interpolation (a linear approach).

Development of FCI and TFT

Determination of Project Stages

The number of stages and their contents are determined depending on the requirements defined in SOW and the parameters affecting them.

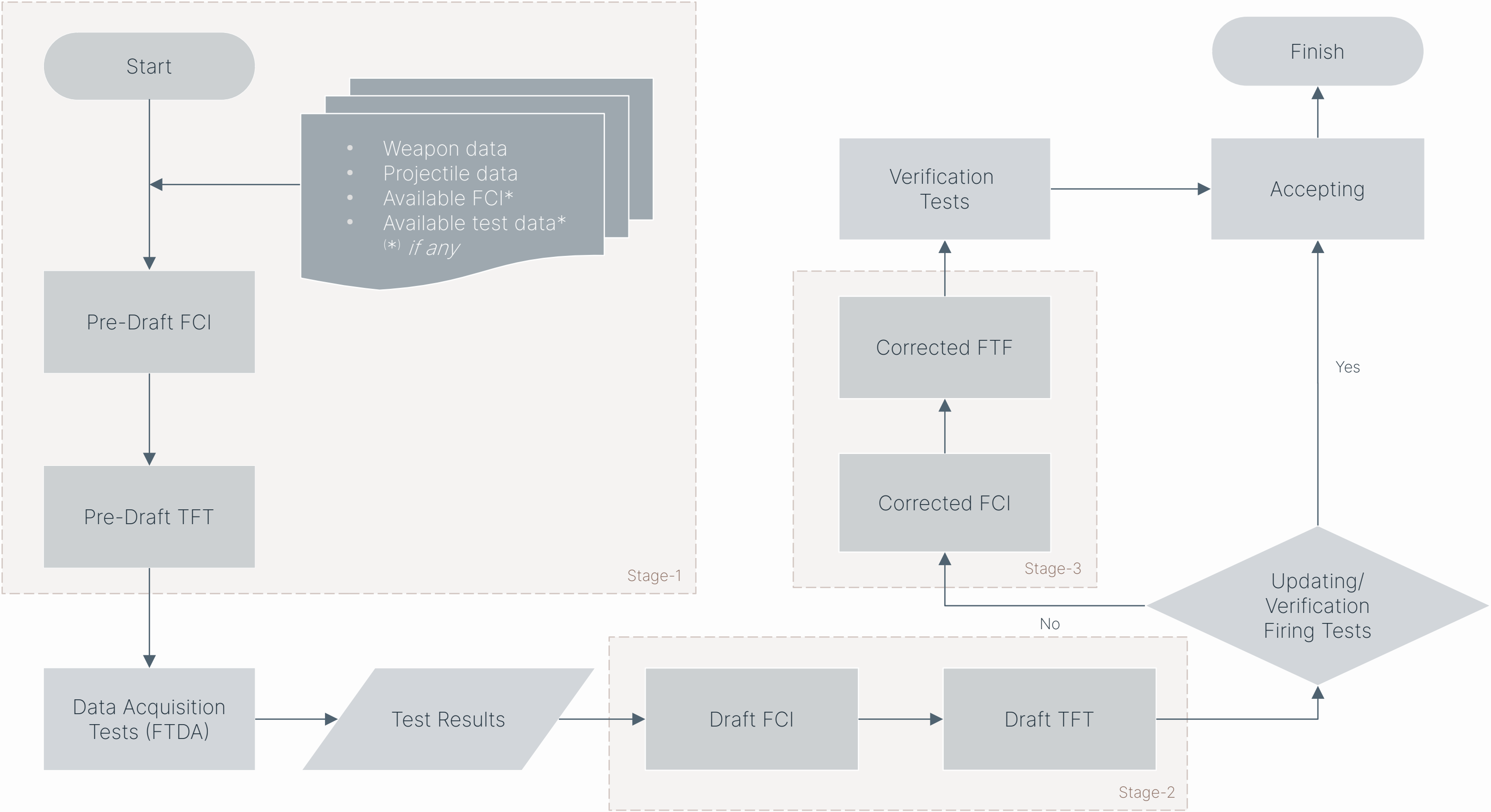
- **Requirements**
  - Sufficient information about weapon and ammunition
  - Existing FCI files for ammunition and weapon and the conditions for the preparation of these files (if any)
  - Actual fire test results for existing ammunition and weapon (if any)
- **Parameters for Requirements :**
  - Difficulty level of engineering problem
  - Technical uncertainties
  - Expected performance and acceptance criteria limitations

Determination of Project Stages

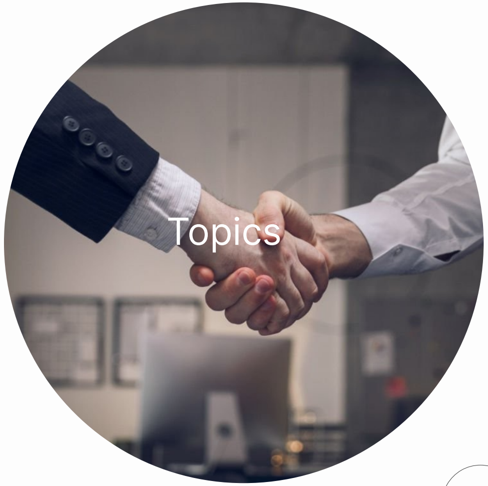
Stage-1 Preparation of Preliminary Draft FCI & TFT	Examining the source documents and input information to decide their adequacy
	Determining the methods to be applied
	Planning R&D studies if necessary
	Planning firing test for data acquisition (FTDA) and determining number of necessary number of rounds and shots and conditions
Firing Tests for Data Acquisition (FTDA)	
Stage-2 Development of Draft FCI & TFT	Evaluation of results of the FTDA
	Updating Pre-Drafts and Developing new Draft FCI & TFT
Firing Tests for Verification (Accepted-or-not/Correction) (FTV) *	
Stage-3 ** Preparation of Corrected FCI & TFT	Evaluation of results of the FTV
	Updating Draft FCI & FTA
Firing Tests for Acceptance (FTA)	

** If the Draft FCI & TFT are verified by FTV, these tests are "Verification Tetst"; otherwise it is referred to as "Correction Tests" since it will be passed to Stage-3.*
*** Includes corrective action if FCI & TFT obtained in Stage-2 cannot be verified.*

FCI & TFT Development Process



PROJECTS TO BE INVOLVED IN



- Certification of ammunition for weapons (FCI, AAC preparation)
  - For mortars (indirect firing)
  - For howitzers (indirect firing)
  - For snipers (direct firing)
  - For mortars (indirect firing)
- Ammunition design, optimization and analysis
  - Heavy weapon ammunitions
  - Small weapon ammunitions
  - Rocket
- Weapon system/subsystem design, optimization and analysis
  - Howitzer
  - Tank
  - Mortar
- Firing and fligt tests

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Thank you

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