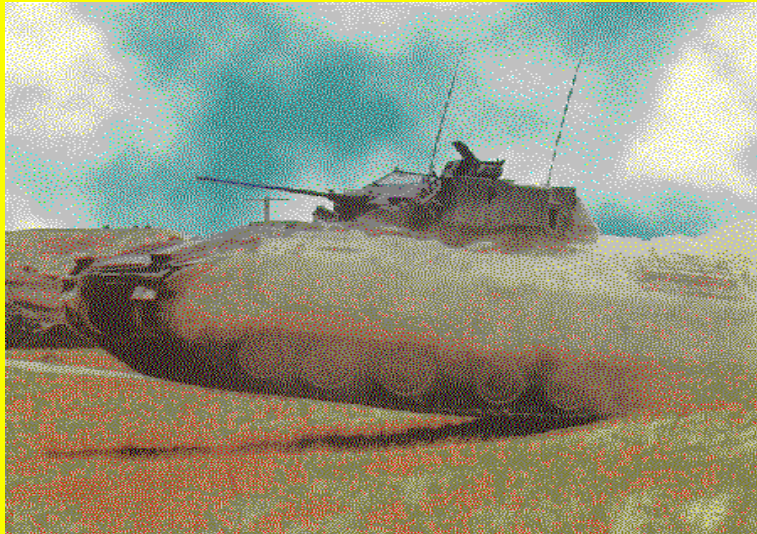


## Case Study II

# Dynamic Analysis and Design of Tracked Vehicles





## Objectives

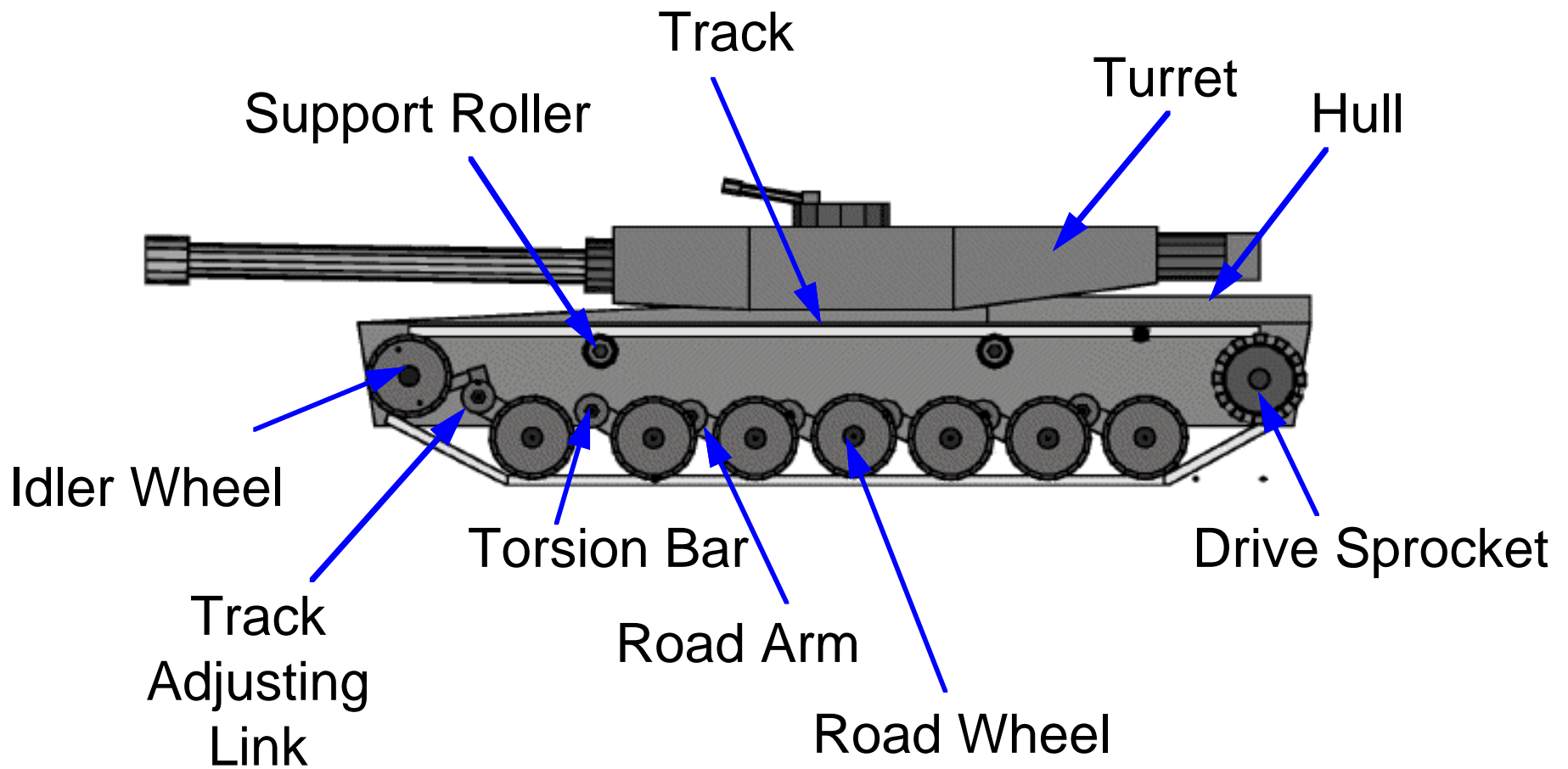
- **Create a flexible simulation environment for the efficient prediction of track vibration, powertrain performance, and vehicle dynamics**
- **Provide an efficient tool for the assessment of designs for tracked vehicles**
- **Develop a distributed, object-oriented environment to perform design optimization**

# M1 Abrams Tank

- Main battle tank
- Weight: approx. 70 tons
- Max. speed: approx. 45 mph

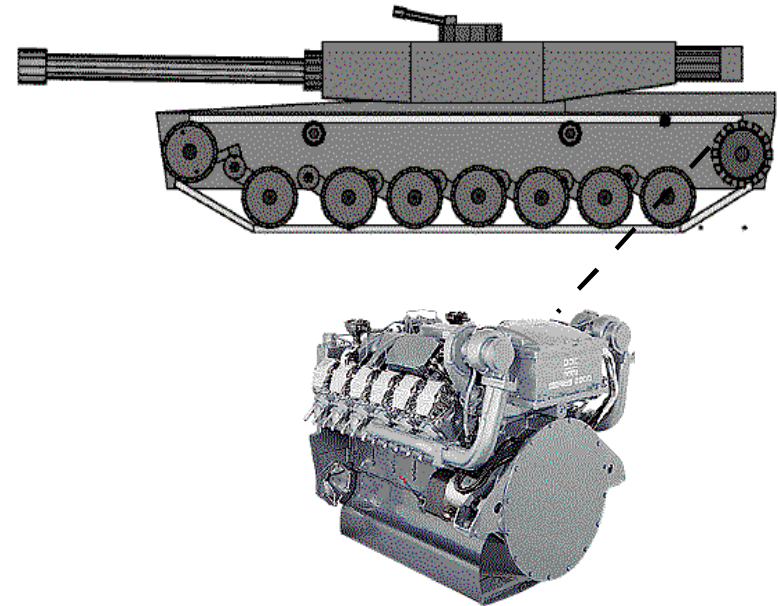


# M1 Abrams Tank



## Outline

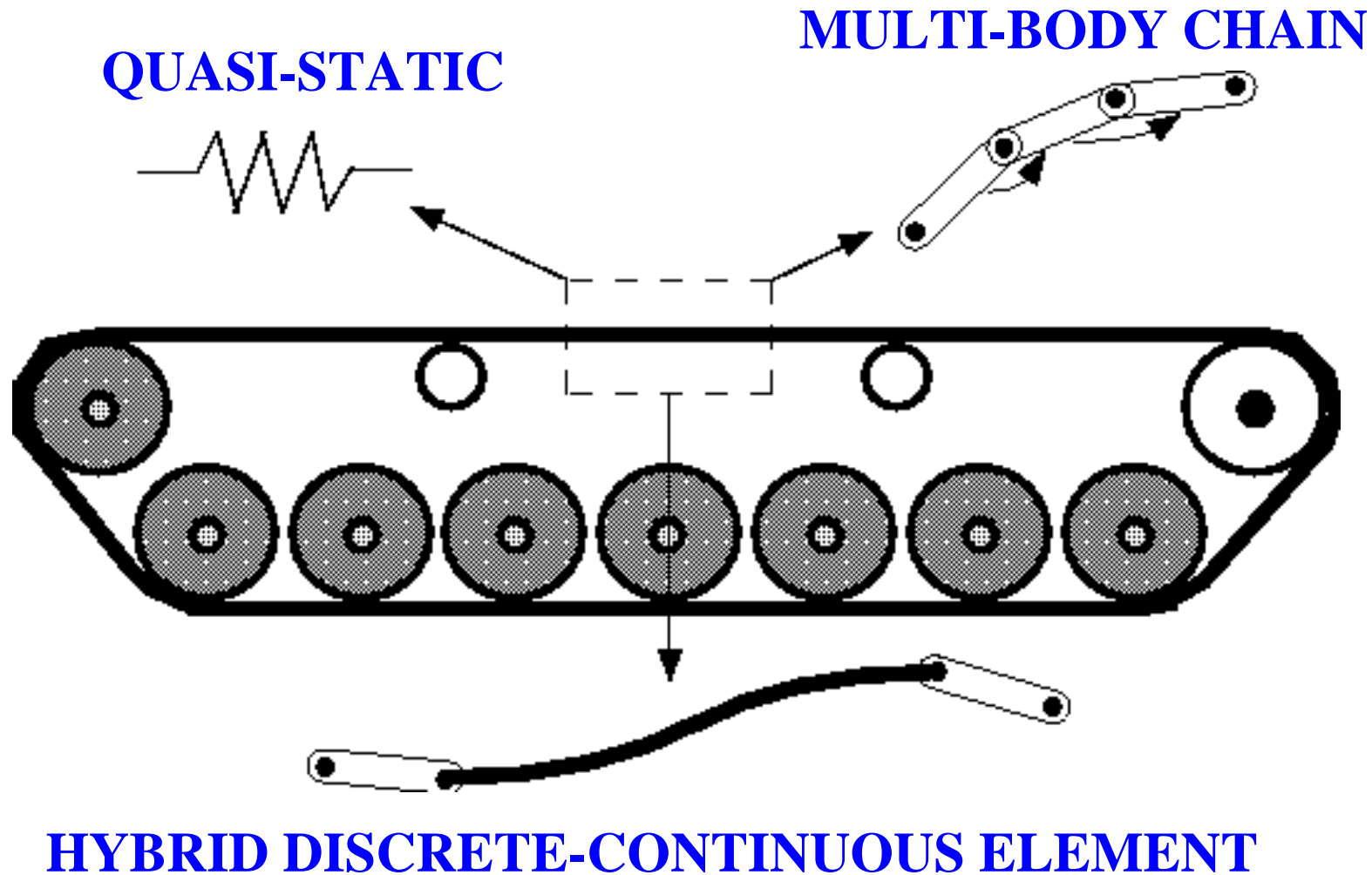
- **Modeling and simulation of tracked vehicles**
  - ◆ **Track vibration models**
  - ◆ **Vehicle multi-body dynamics models**
- **Integration of powertrain and structure models**
- **System integration for track and road arm analysis and design**



# Modeling and Simulating Tracked Vehicles

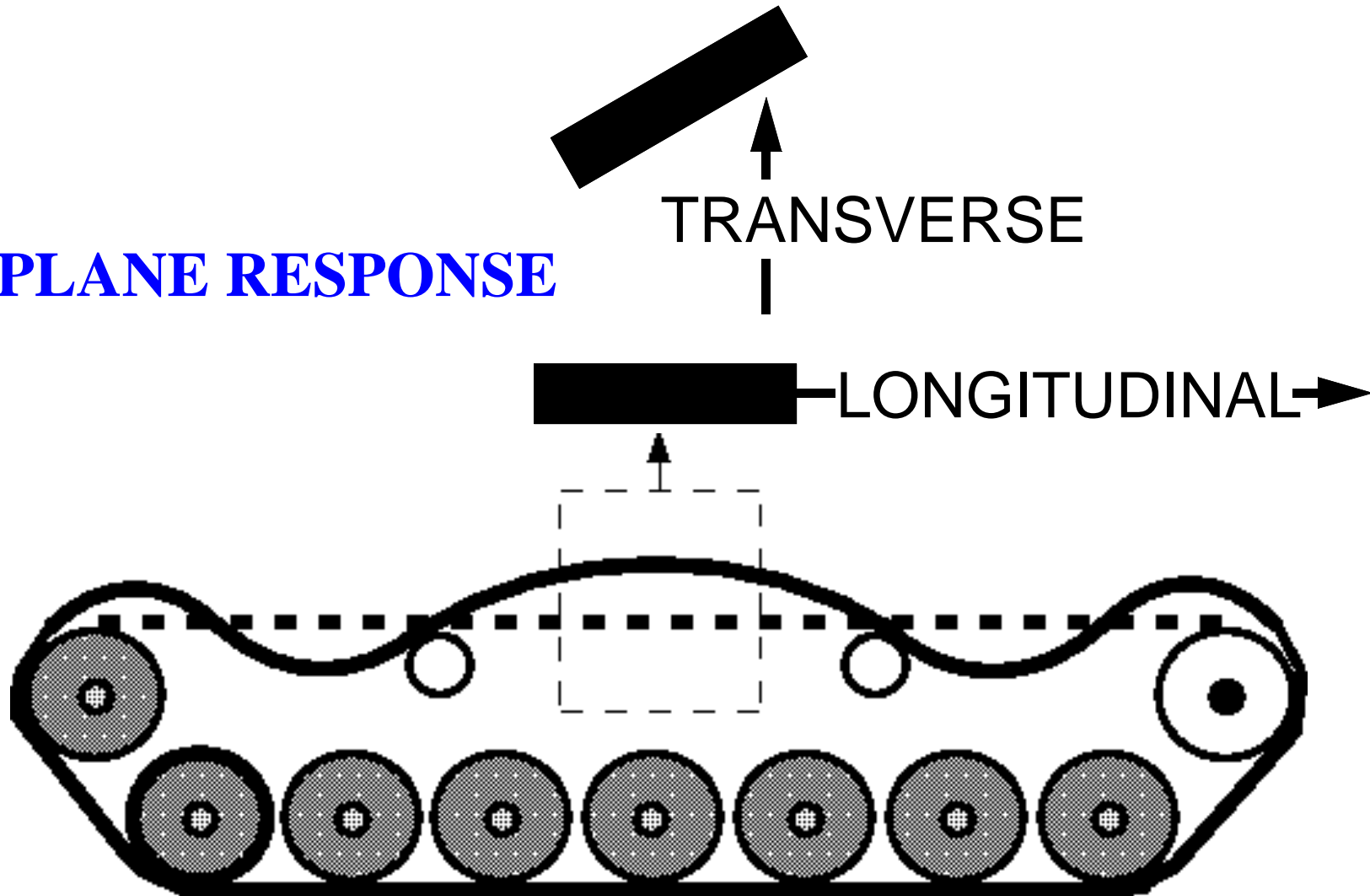


# Track Models



# Dominant Deformation Modes

**IN-PLANE RESPONSE**



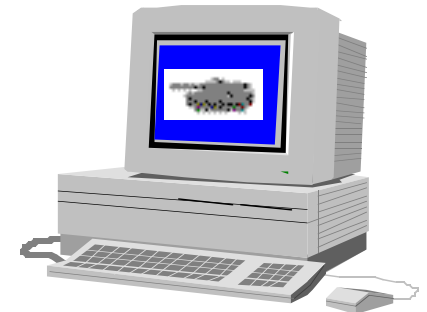
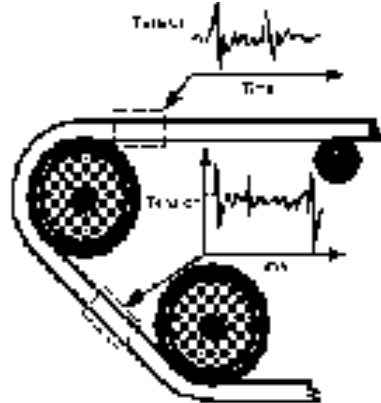
# Research Plan

**Continuous  
Element  
Model**

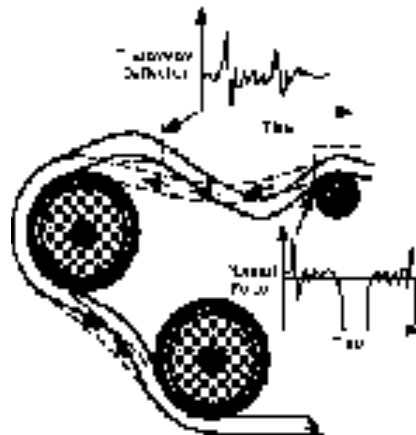
**Experimental  
Validation**

**Implementation into  
DADS vehicle model**

**Longitudinal  
Vibration**

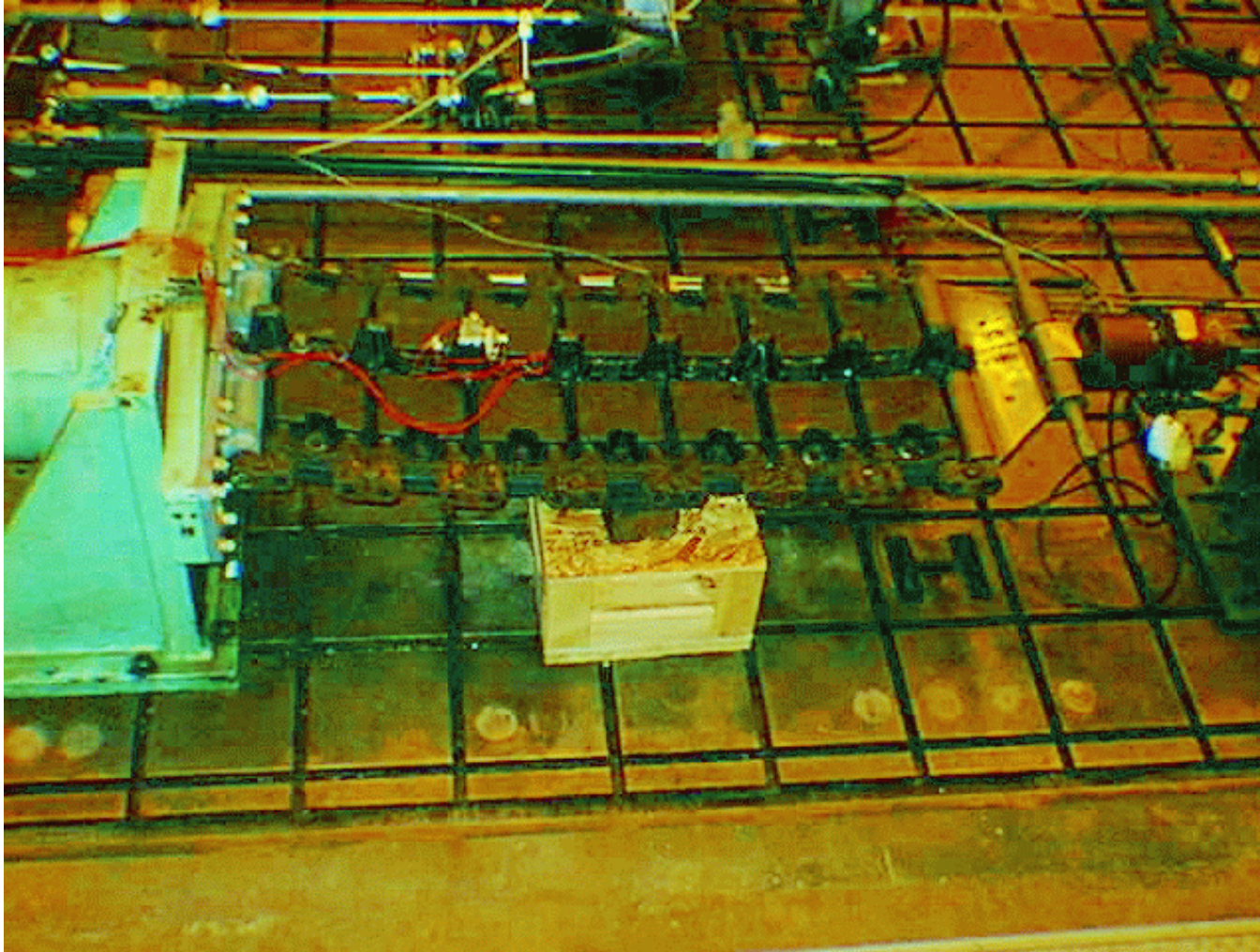


**Coupled  
Longitudinal  
and  
Transverse  
Vibration**

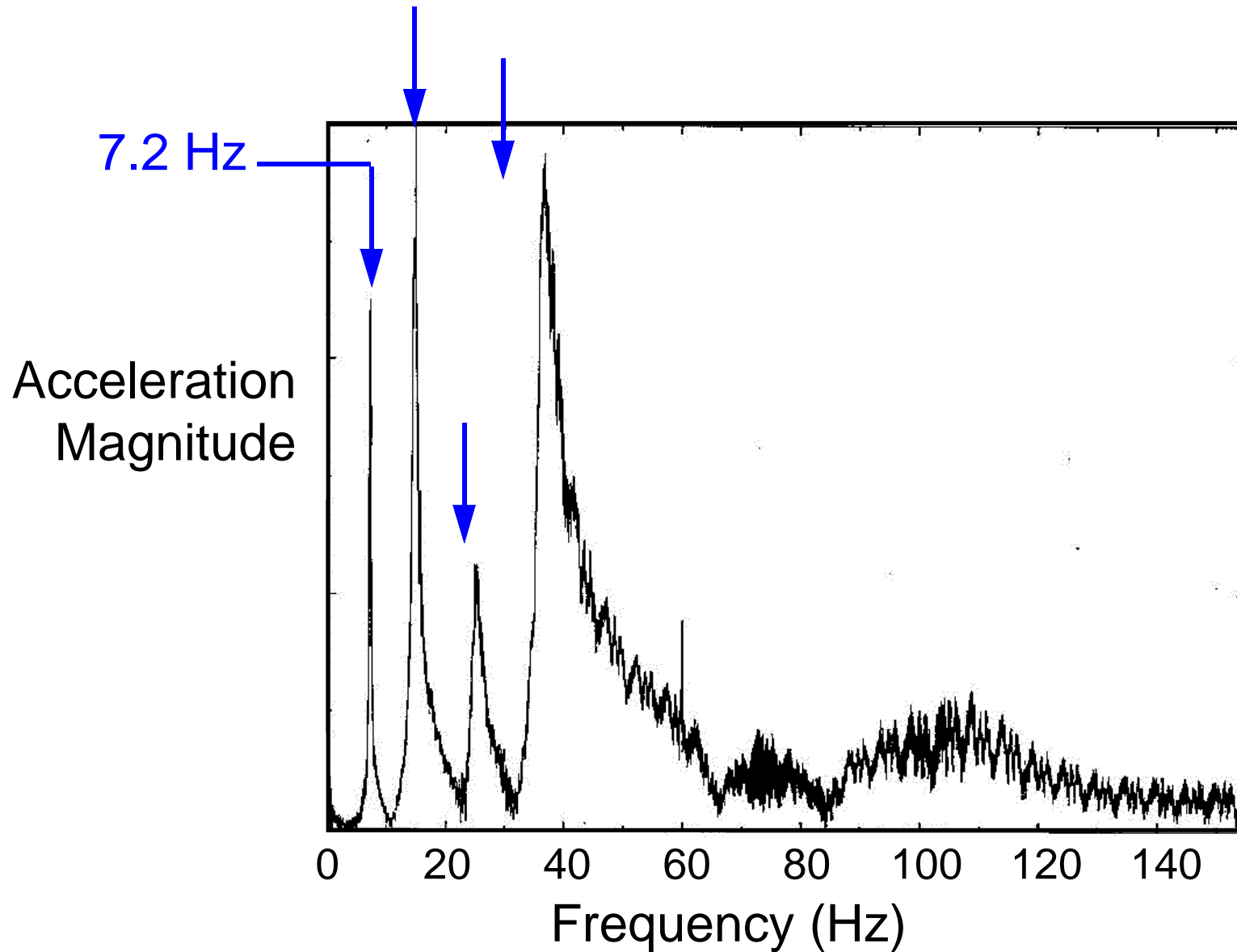




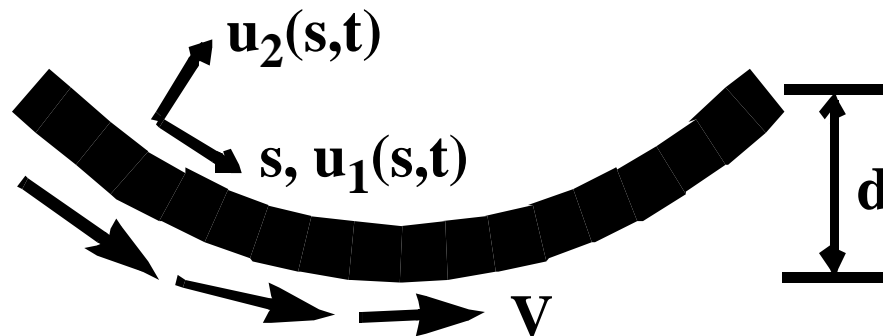
# Experimental Validation



# Vertical Accelerometer



# Transverse Vibration Element Model



**V** - track speed

**d** - static sag

**k** - static curvature

**T** - static tension

**f(t)** - dynamic strain

Longitudinal Response  
(quasi-static)

$$u_1(s, t) = f(t)s + k \int_0^s u_2(\eta, t) d\eta$$

Transverse  
Response

$$m(u_{2,tt} + 2Vu_{2,st} + V^2u_{2,ss}) + kEAf(t) = Tu_{2,ss}$$

$$f(t) = \frac{-k}{L} \int_0^L u_2(\eta, t) d\eta$$

# Vibration Mode Shapes



$f_1 = 3.7 \text{ Hz}$



$f_2 = 5.5 \text{ Hz}$



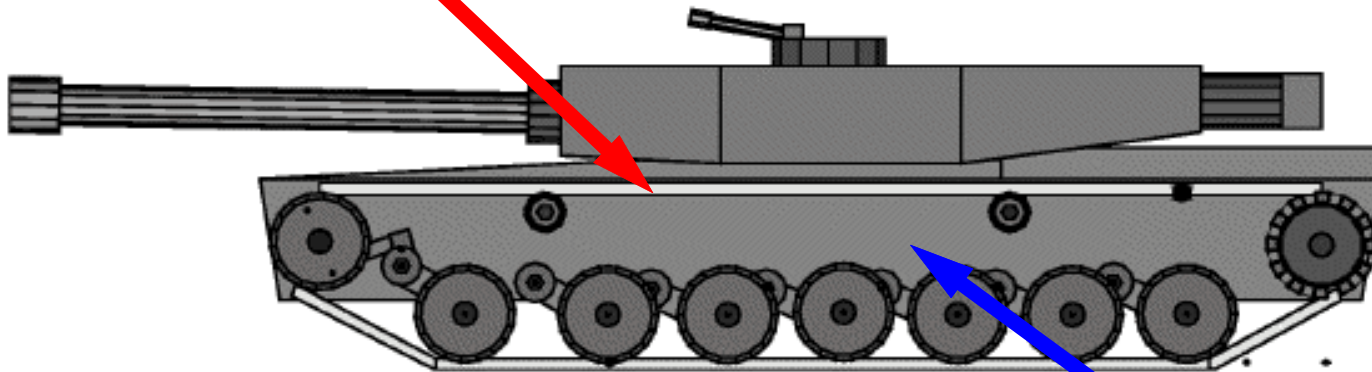
$f_3 = 7.3 \text{ Hz}$



$f_4 = 7.6 \text{ Hz}$

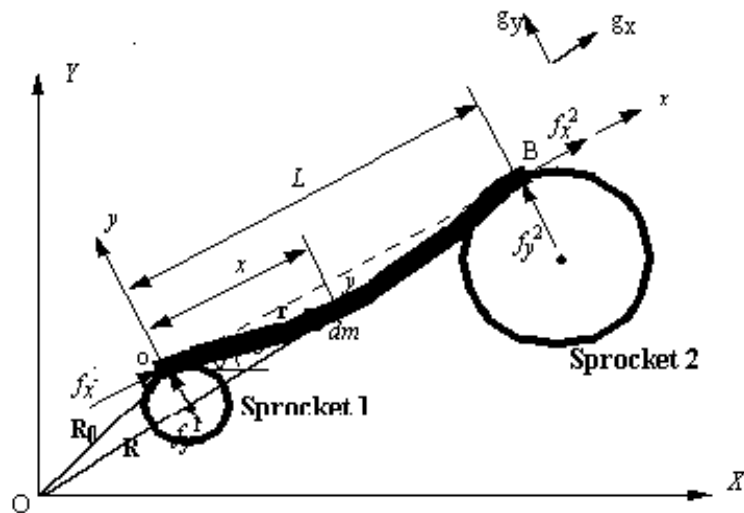
# Mixed Eulerian/Lagrangian Description of Motion

Eulerian Description of Motion



Lagrangian Description of Motion

# Component Mode Synthesis Method for Discretization



- Rigid body mode
- Constraint mode
- Longitudinal vibration modes
- Transverse vibration modes

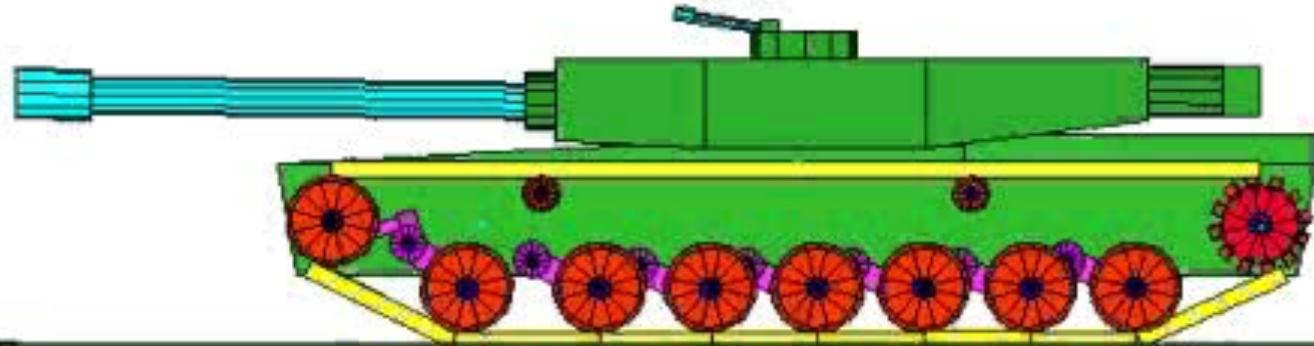


# General Track Element Models Six Variations

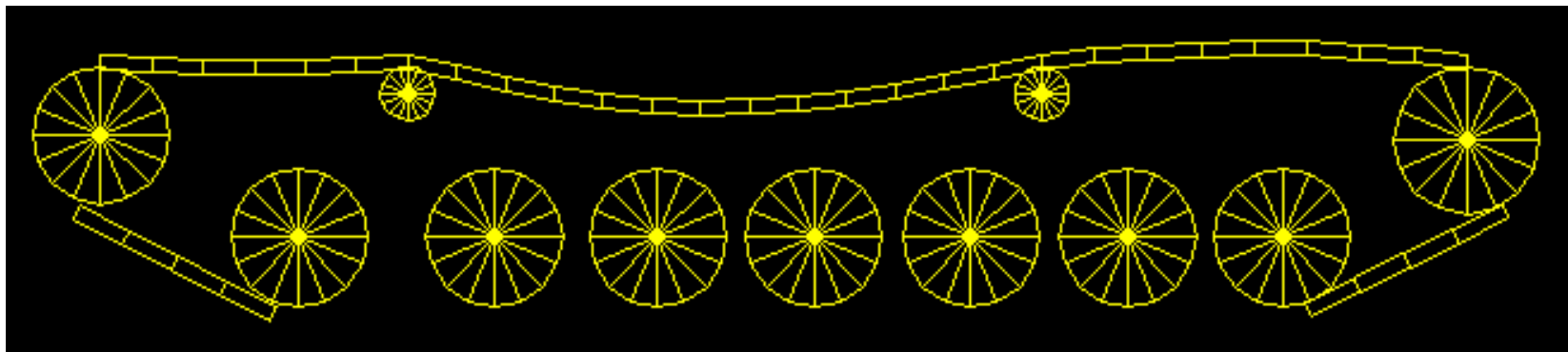
- **Static (spring-damper) model**
- **Lumped mass-spring-damper model**
- **Quasi-static (Guyan reduction) model**
- **Dynamic model with longitudinal vibration**
- **Dynamic model with transverse vibration**
- **Dynamic model with coupled longitudinal and transverse vibration**



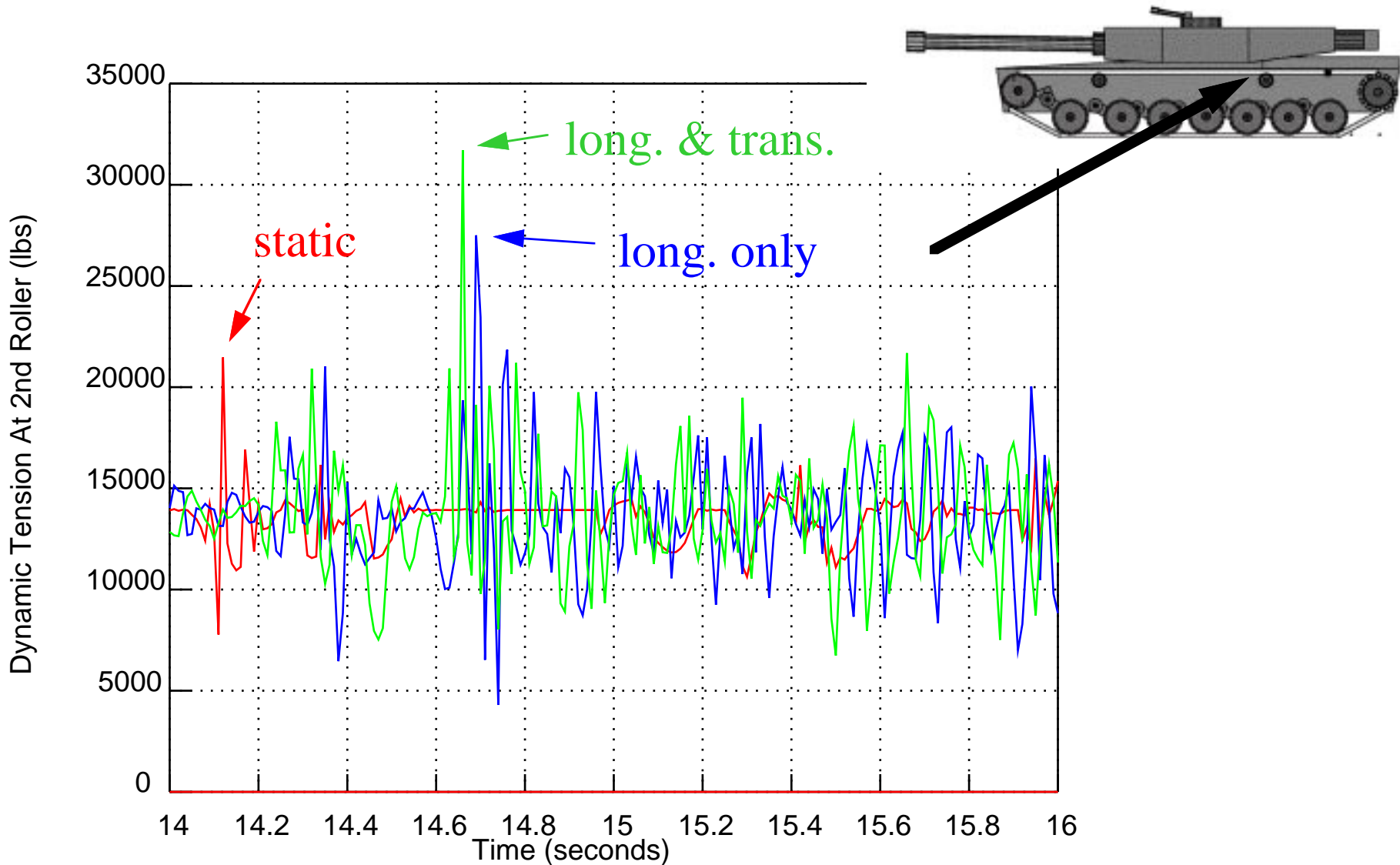
# M1 Tank Traversing Profile 4



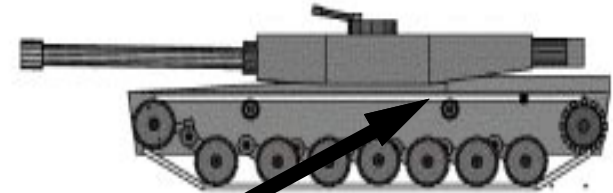
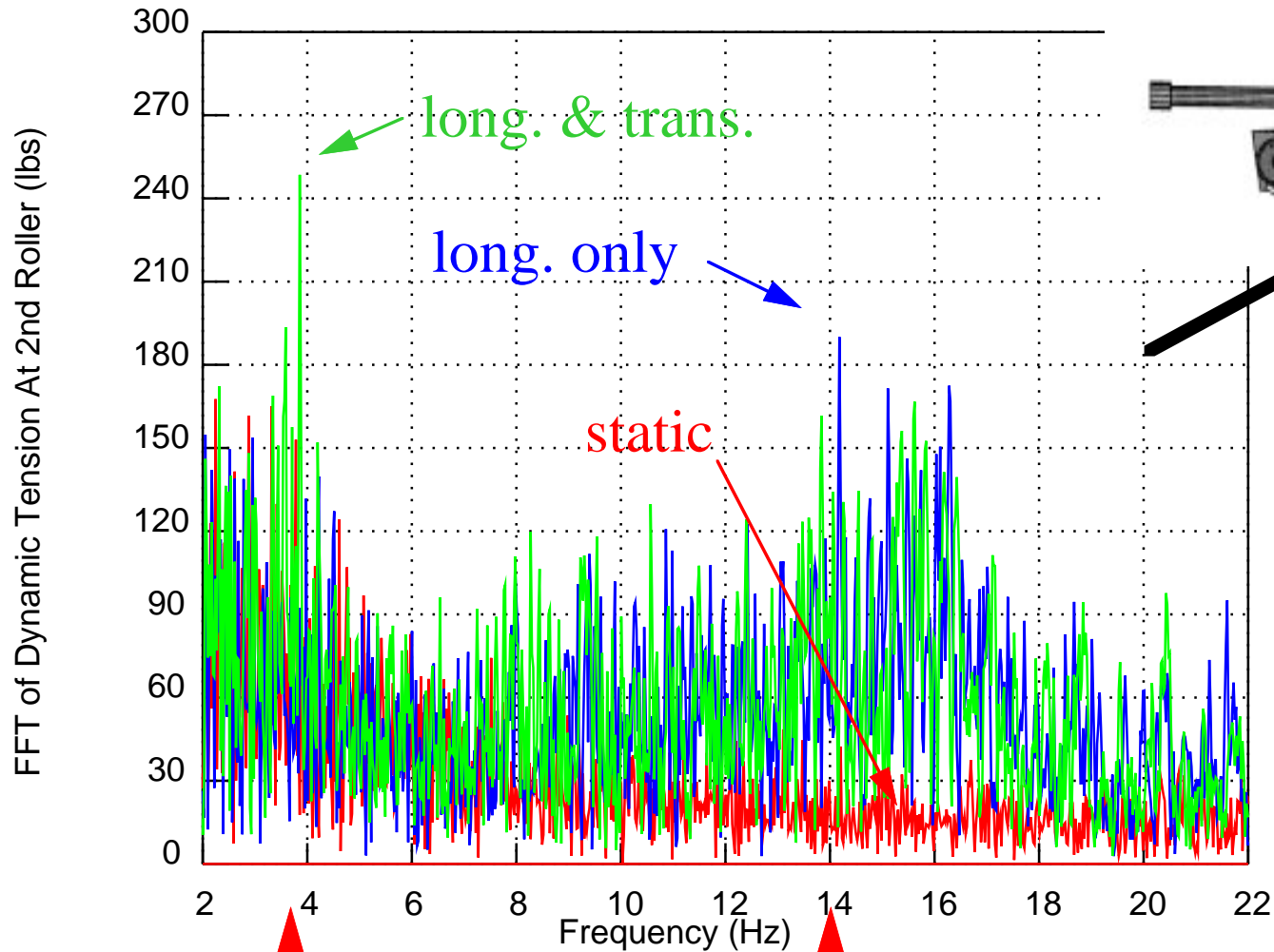
# Track Transverse Vibration



# Dynamic Tension



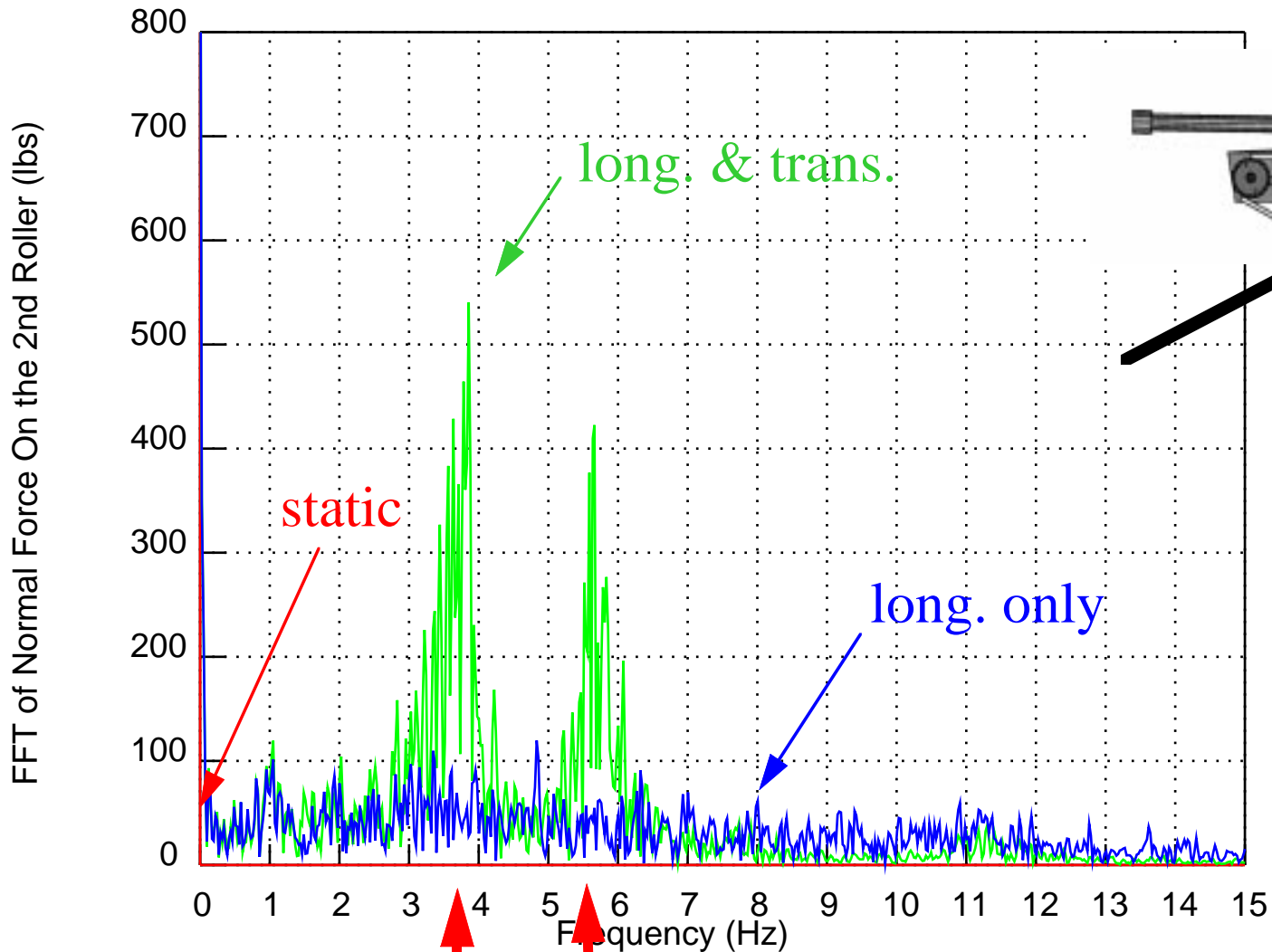
# FFT of the Dynamic Tension



$$f_{1 \text{ trans}} = 3.7 \text{ Hz}$$

$$f_{1 \text{ long}} = 14.0 \text{ Hz}$$

# FFT of Normal Contact Force

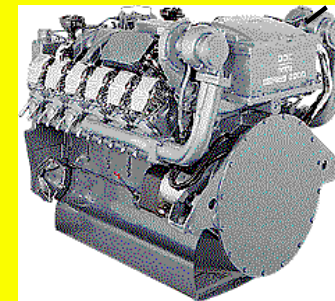
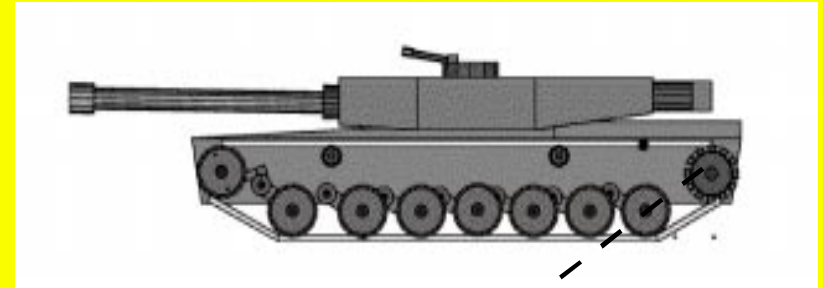


$$f_{1 \text{ trans}} = 3.7\text{Hz}$$

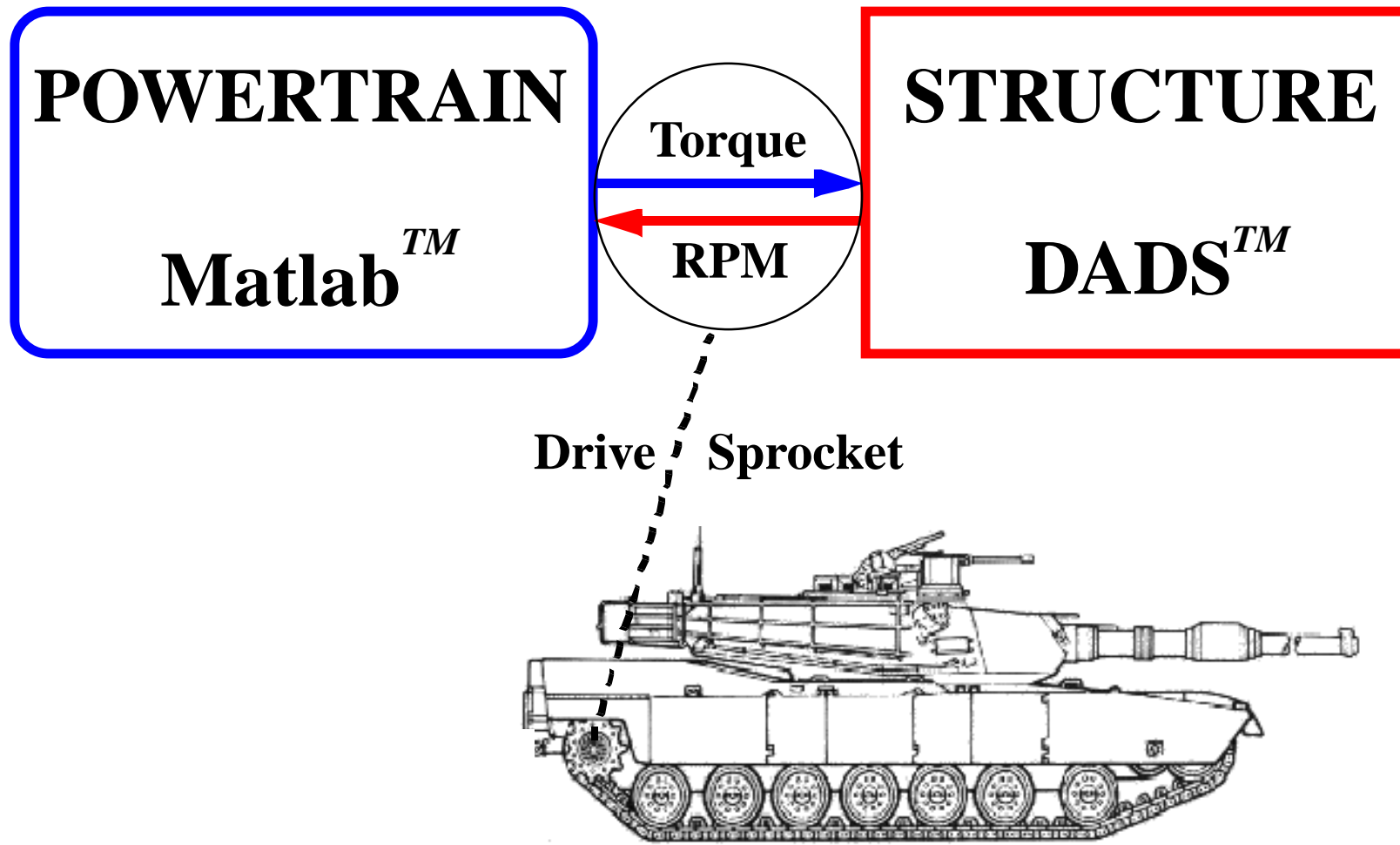
$$f_{2 \text{ trans}} = 5.5\text{Hz}$$

# Integration

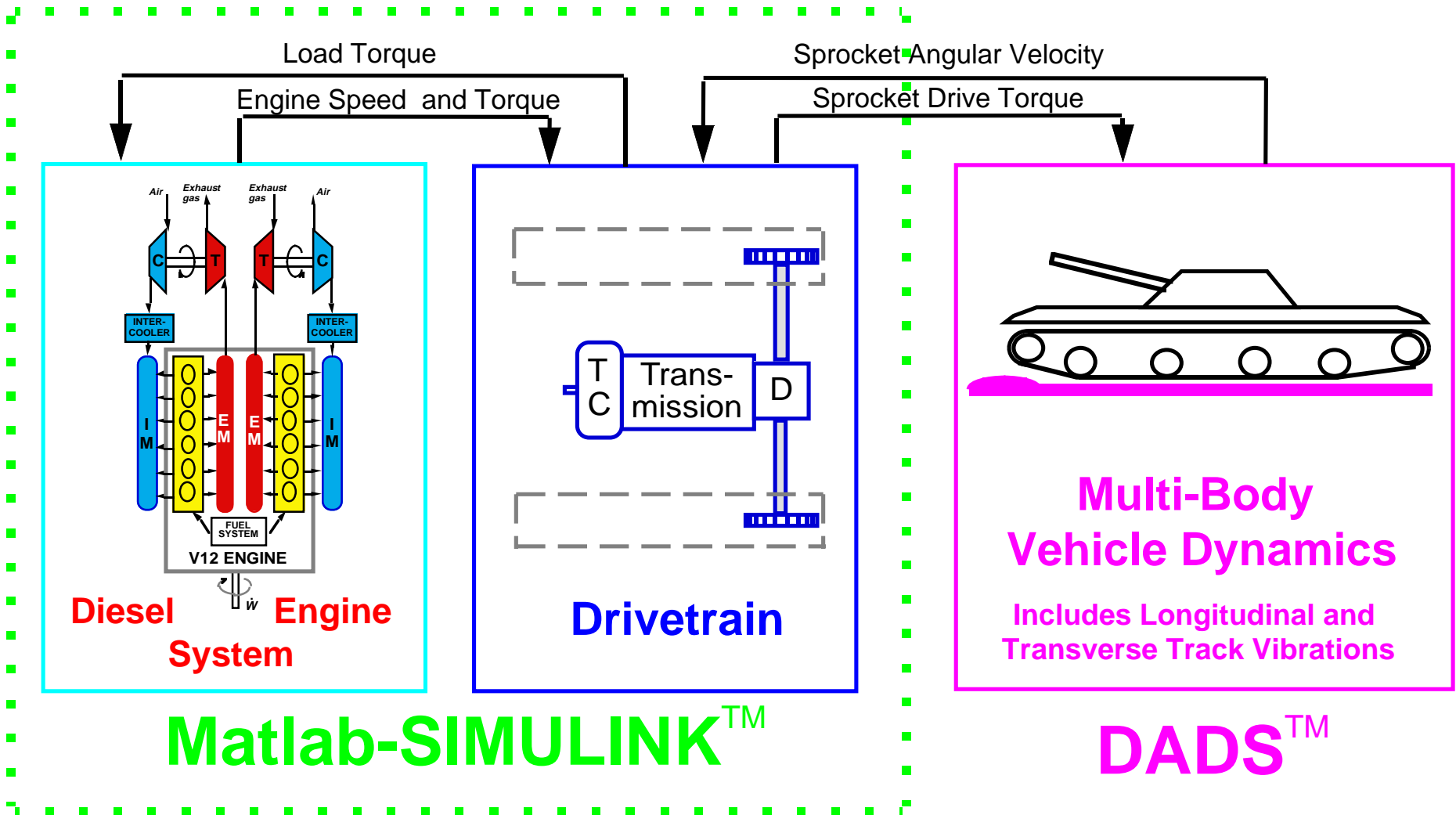
- Integration of powertrain and structure models
- System integration for track and road arm analysis and design



# Integration of Powertrain and Structure Models

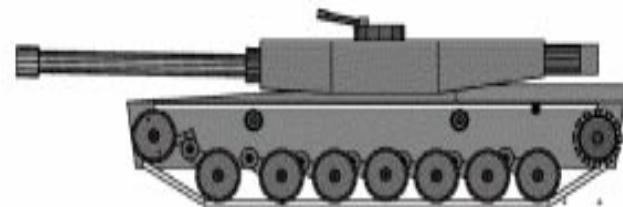


# Tank System Integration in the Distributed Computing Environment

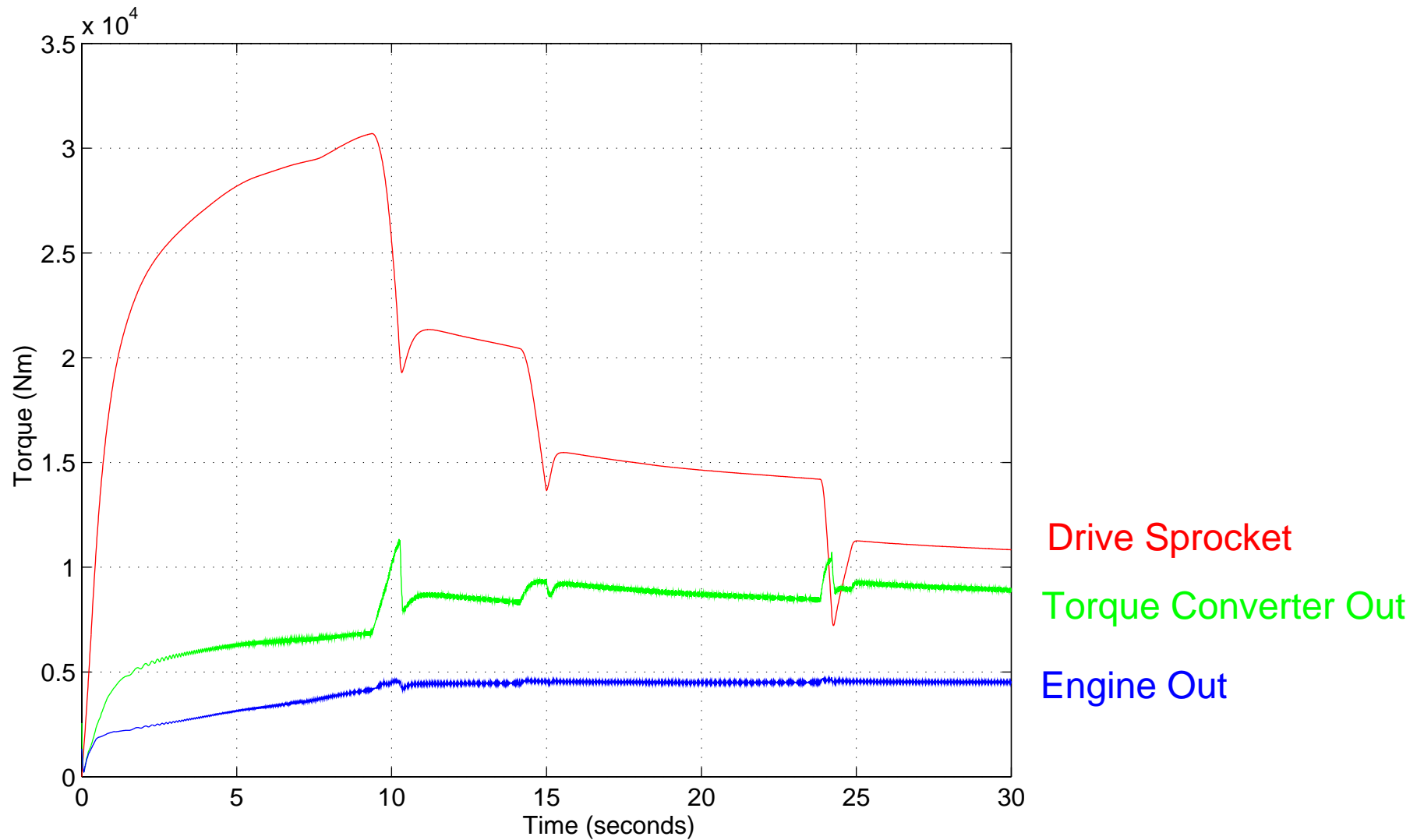


# Integrated Simulation 1 Results

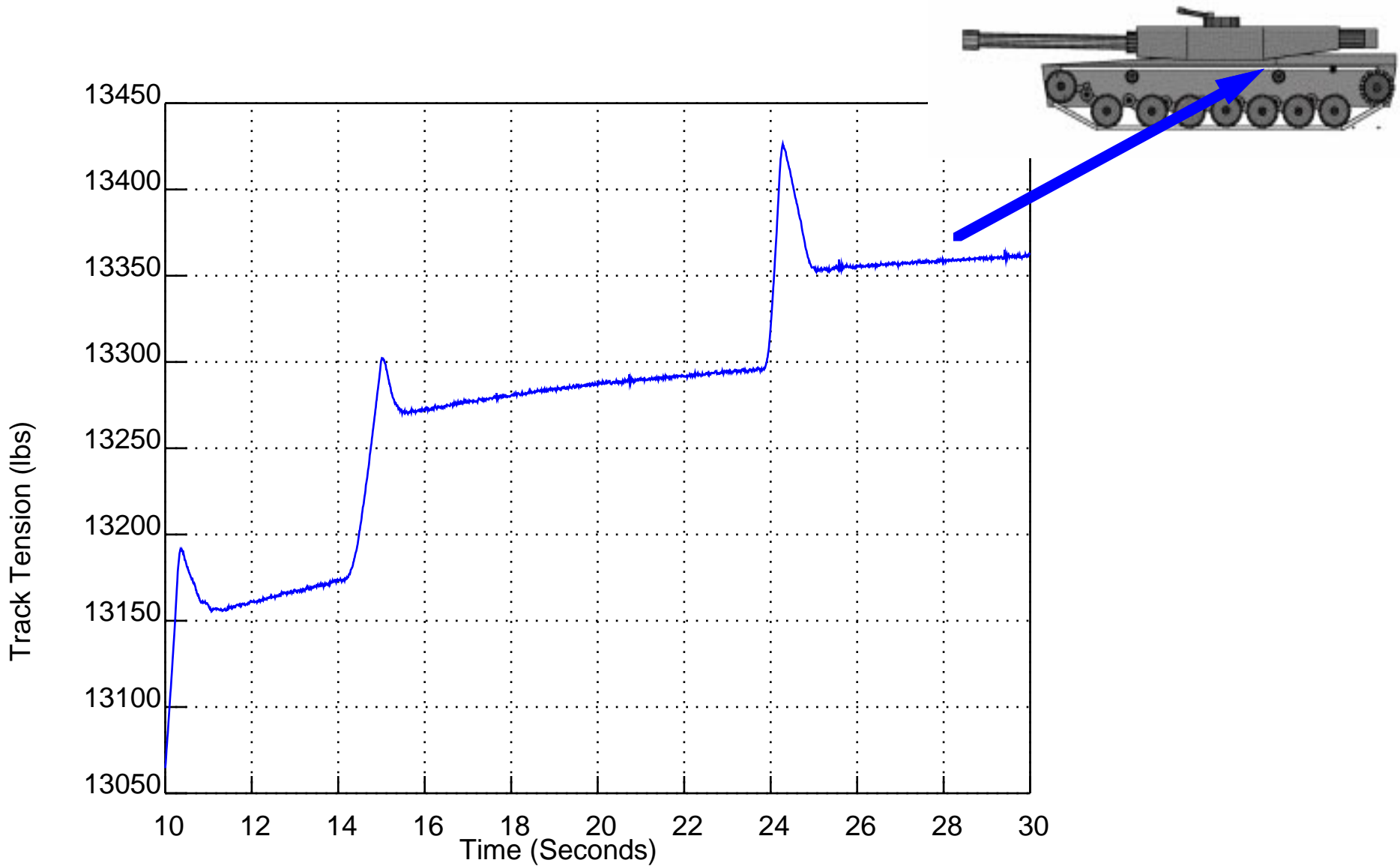
- **Terrain: Flat**
- **Driver Demand: 90%**



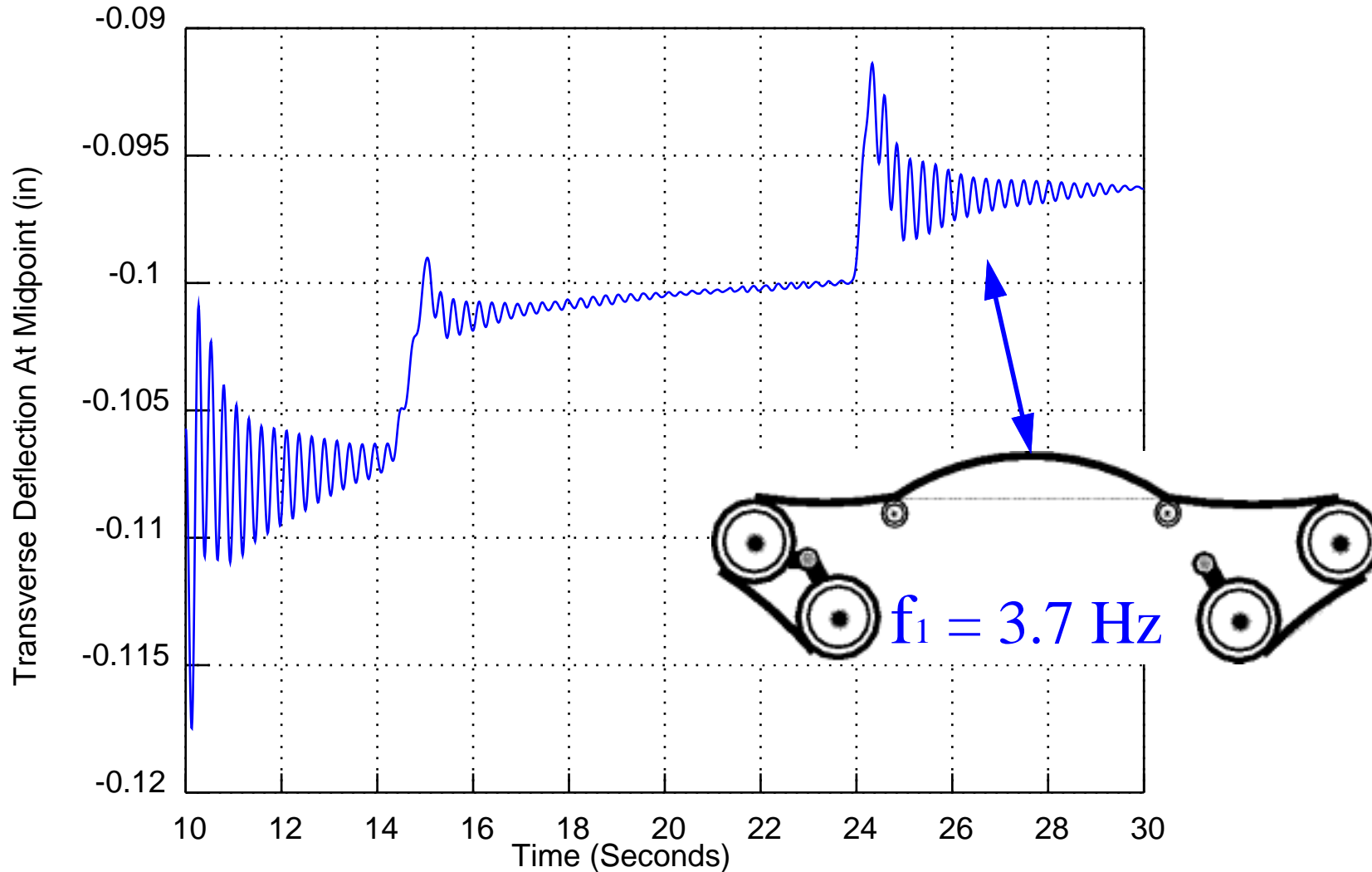
# Integrated Simulation 1: Torque



# Integrated Simulation 1: Track Tension

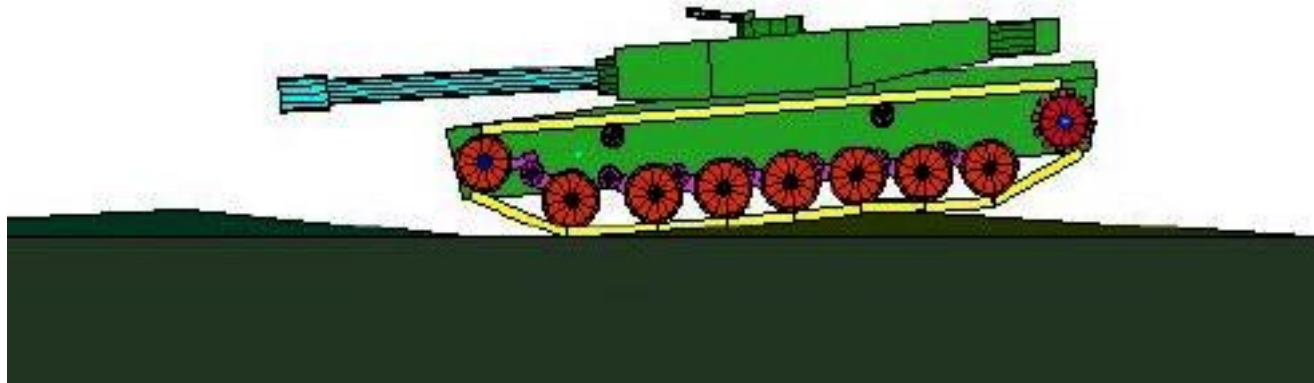


# Integrated Simulation 1: Track Deflection

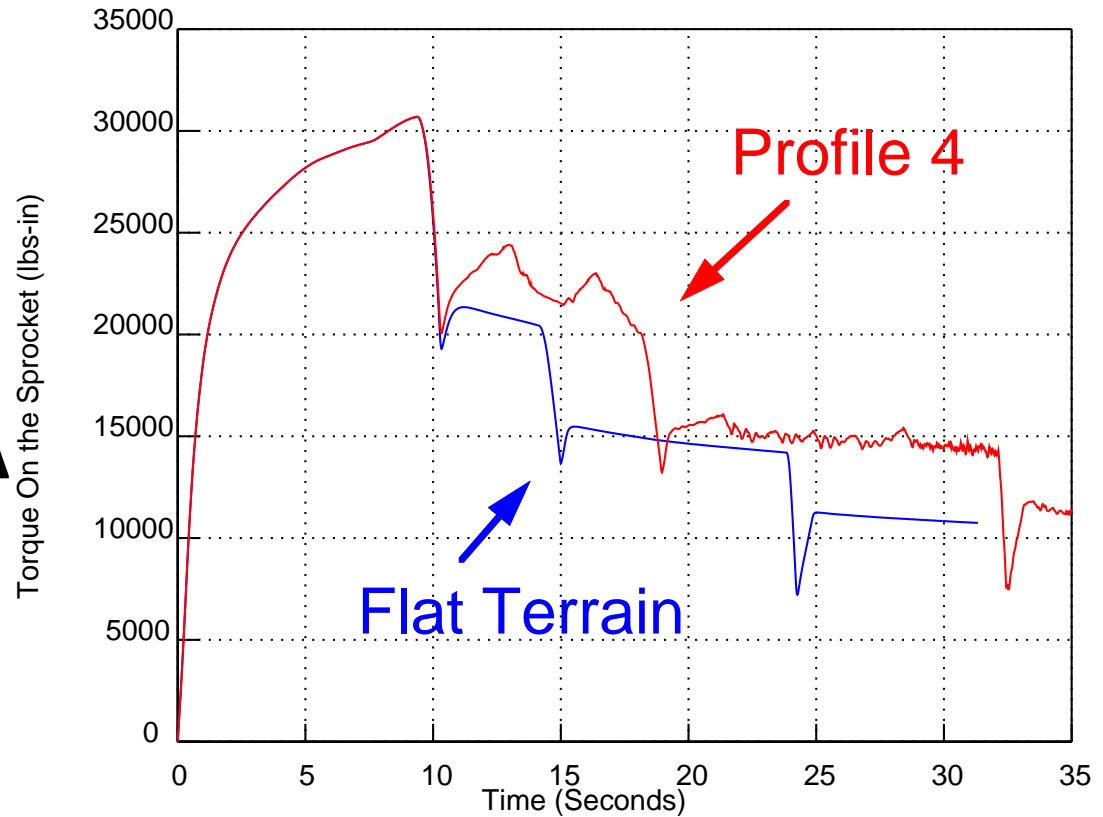


# Integrated Simulation 2 Results

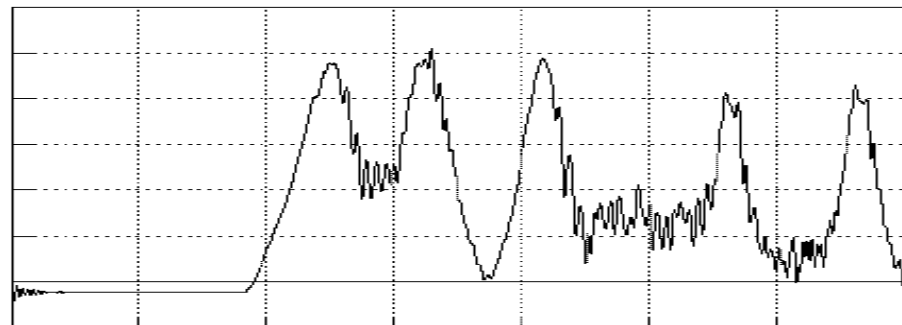
- **Terrain: Profile 4**
- **Driver Demand: 90%**



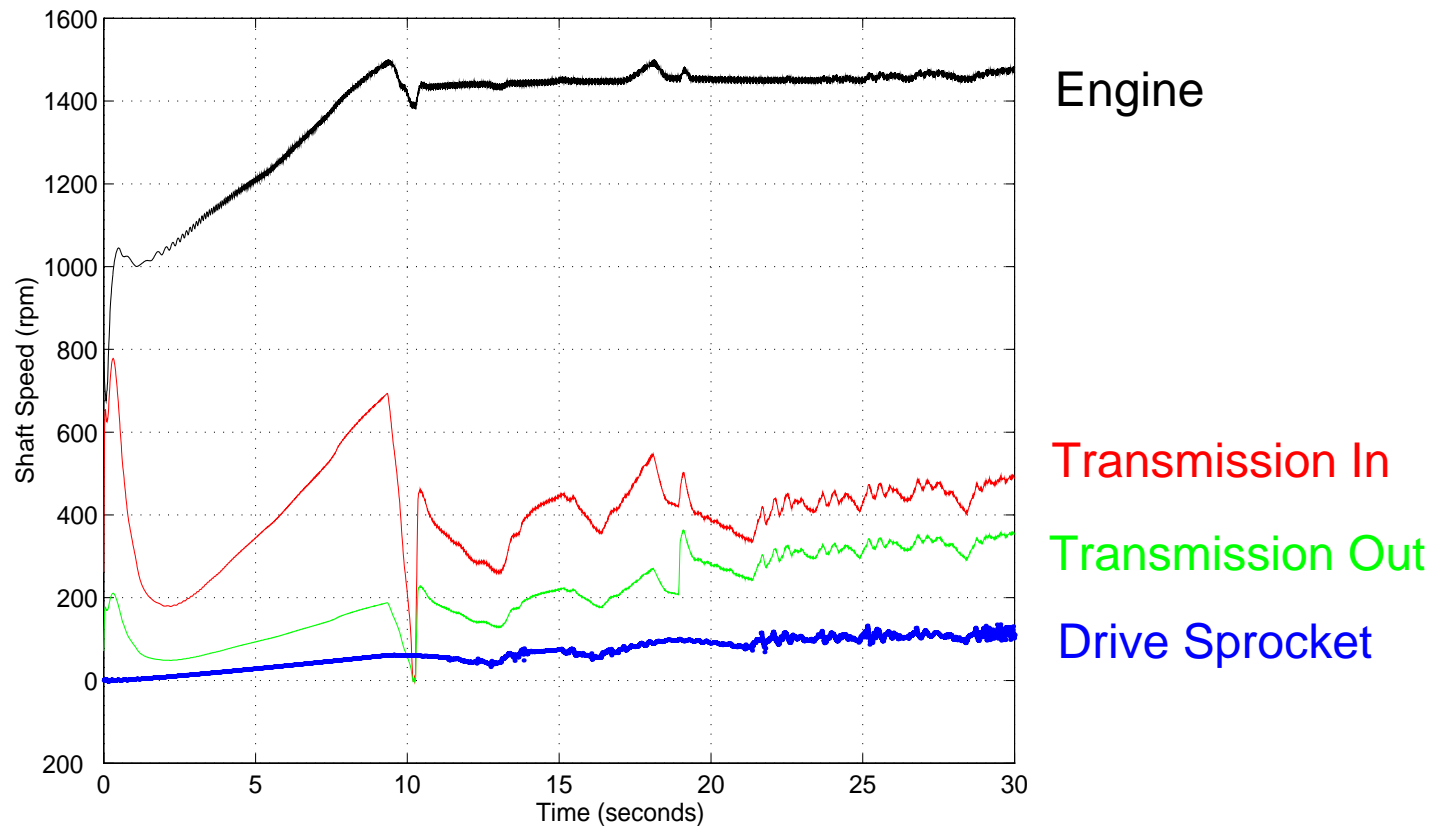
# Integrated Simulation 2: Sprocket Torque



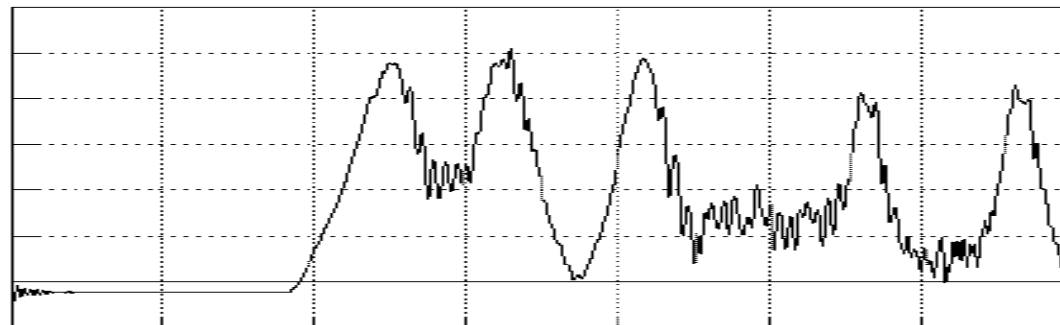
Vertical Displacement of Vehicle CG



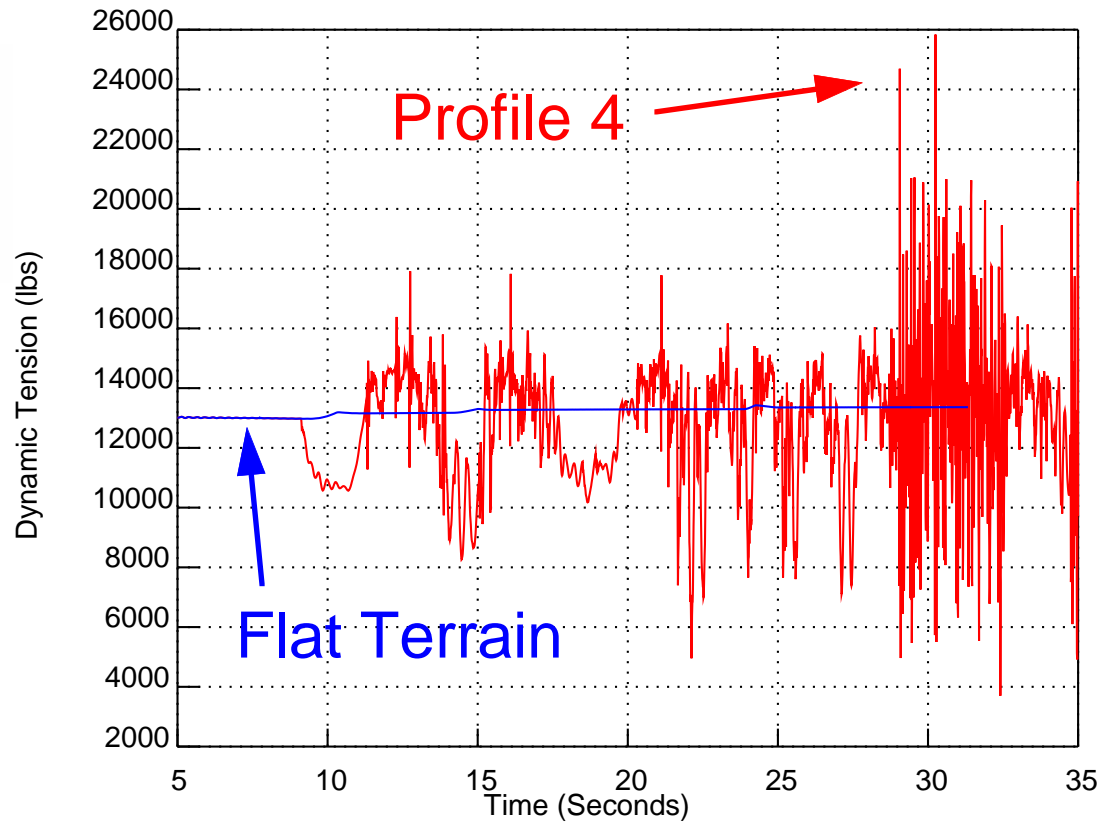
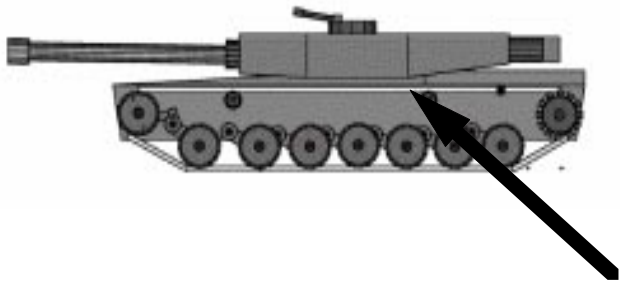
# Integrated Simulation 2: Rotational Speed



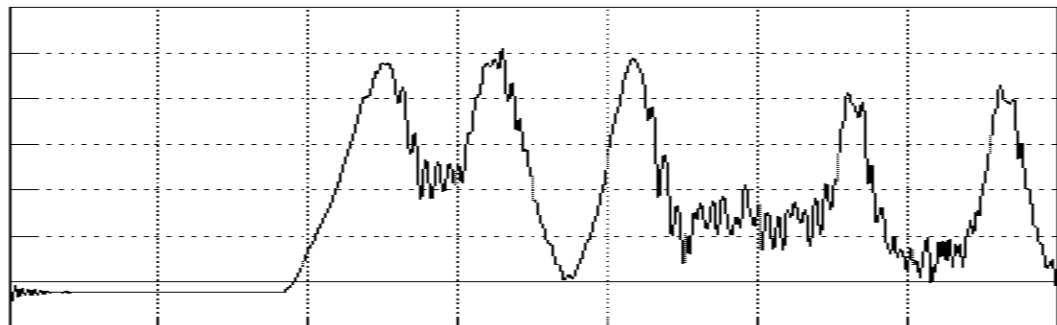
Vertical Displacement of Vehicle CG



# Integrated Simulation 2: Track Tension



Vertical Displacement of Vehicle CG



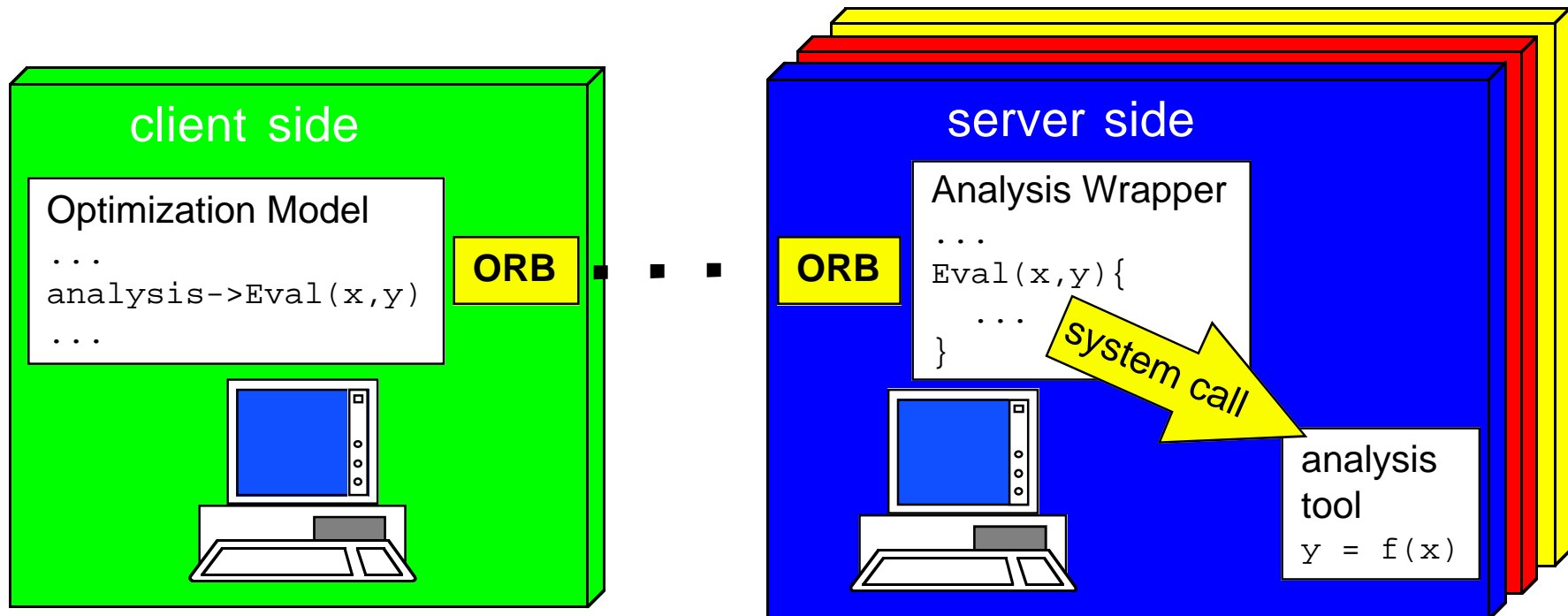


## System Integration for Track and Road Arm Analysis and Design

- **GOAL: Integrate models, analysis and design tools**
  - ◆ developed and located at different locations
  - ◆ for distributed analysis and design optimization
  - ◆ within a CORBA (Common Object Request Broker Architecture) environment
- **VEHICLE: M1 Abrams tank**
- **PARTICIPANTS:**
  - ◆ **University of Michigan (UM):**  
DADS vehicle and track dynamics models
  - ◆ **University of Iowa (UI):**  
Road arm life prediction/optimization (DRAW & DSO tools)

## Model and Tool Integration with CORBA

- Architecture for distributed object communication
- Platform and language independent
- Allows interchangeable components

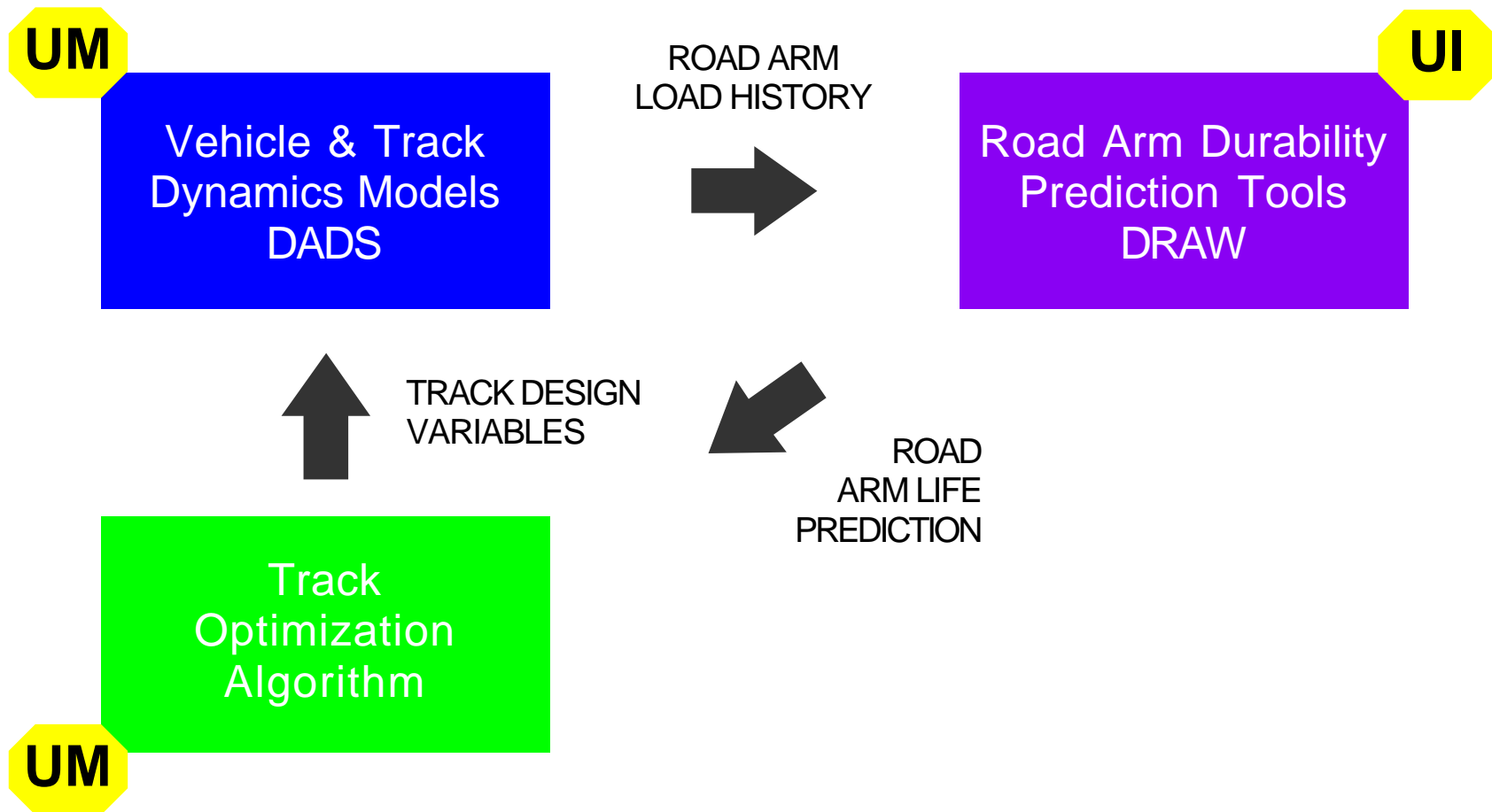




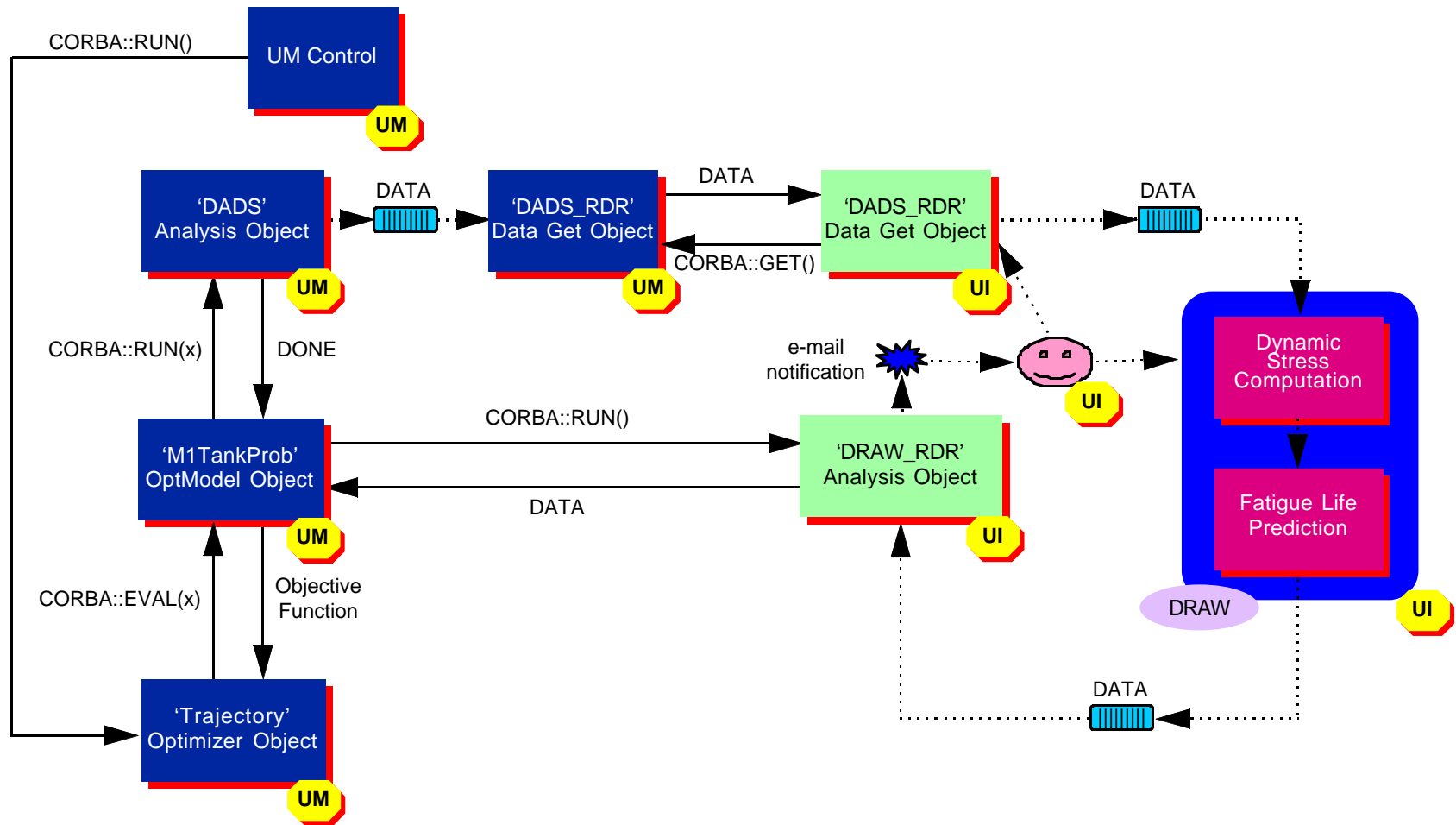
# Track Optimization

- **DESIGN OBJECTIVE:**  
Maximize Road Arm Life Prediction (UI's DRAW tool)
- **DESIGN VARIABLES:**  
Track Parameters (UM's DADS models)
  - ◆ Stiffness
  - ◆ Density
  - ◆ Initial/static tension
- **OPTIMIZATION APPROACHES:**  
Sample design objective on a grid of design points  
Snyman-Fatti multistart trajectory method:
  - ◆ Global
  - ◆ Gradient-based
  - ◆ Noise insensitive

# Integration of Models, Analysis and Design Tools for Track Optimization

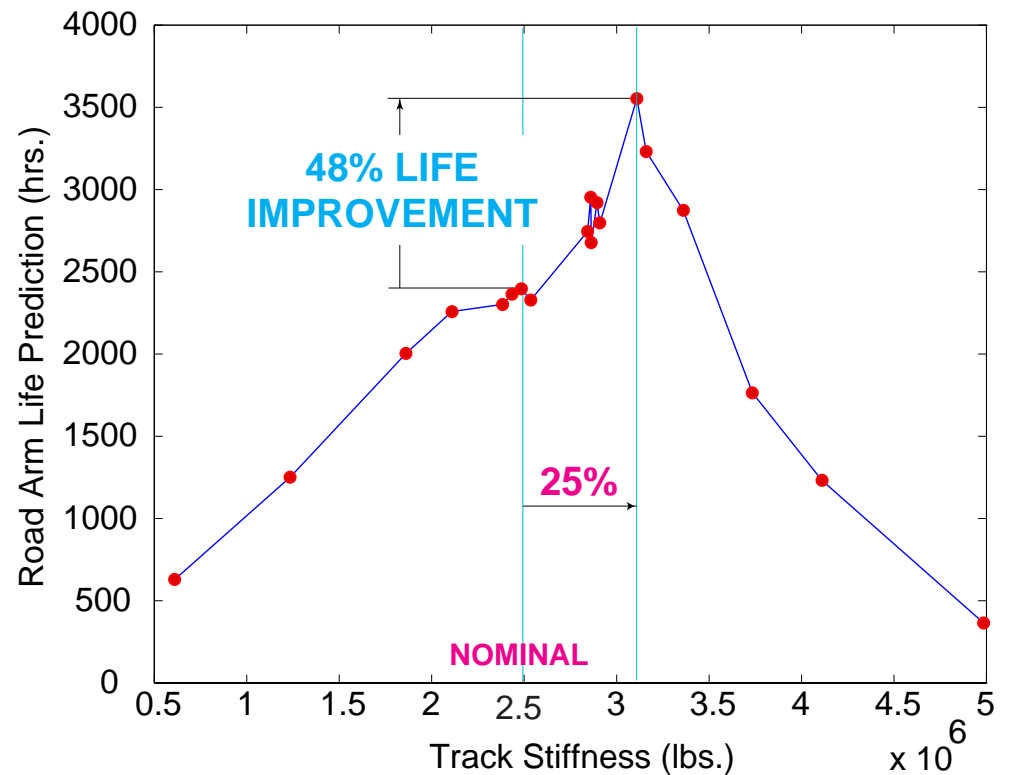


# CORBA Software Integration: Track Optimization

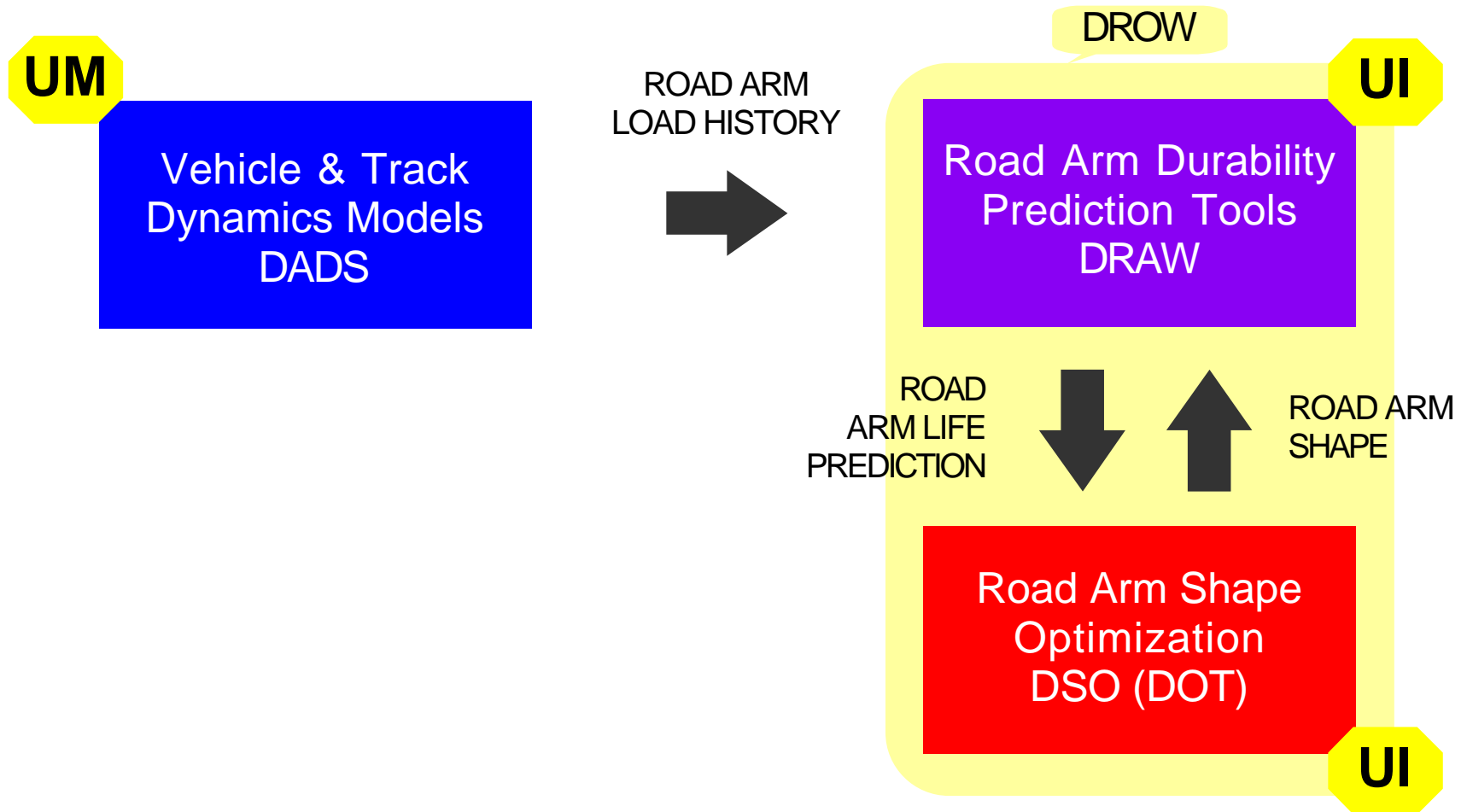


# Track Optimization Results

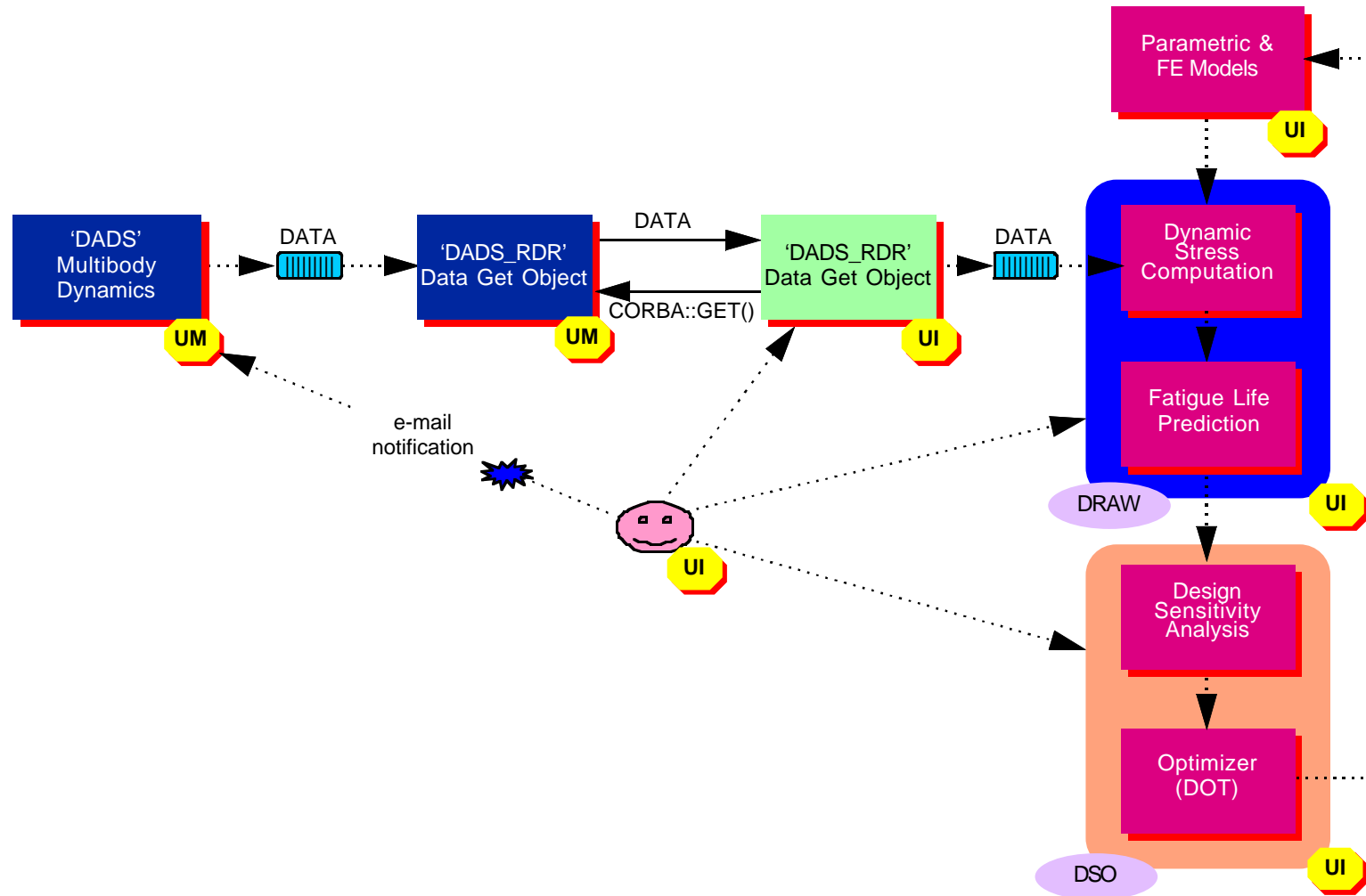
- **TRACK STIFFNESS:**
  - ◆ Nominal: 2.5e6 lbs.
  - ◆ Range: 0.625e6 to 5e6 lbs.
  
- **LIFE IMPROVEMENT:**
  - ◆ 48% for a 25% increase in track stiffness
  
- **COMPUTATIONAL COST:**
  - ◆ Dynamic and life prediction analyses take together about one day



# Integration for Road Arm Shape Optimization

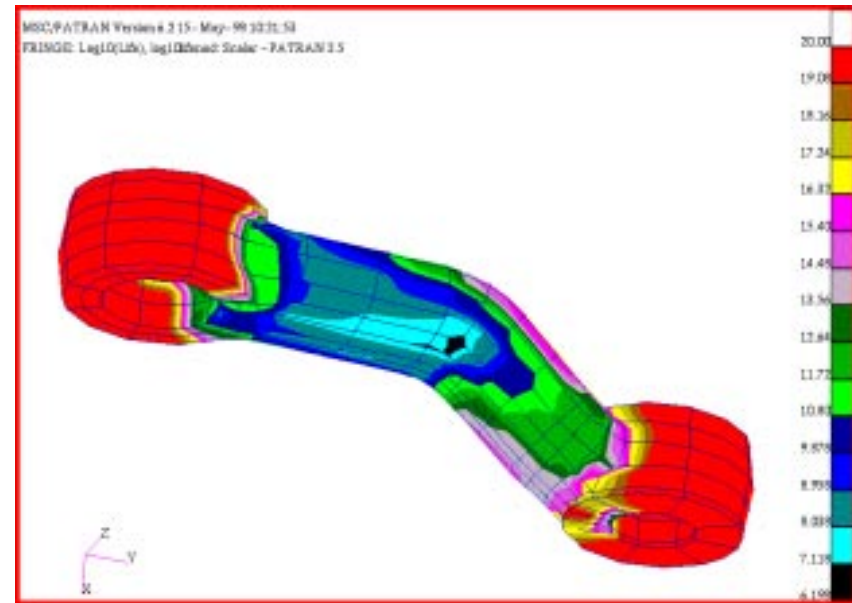


# CORBA Integration: Road Arm Shape Optimization



# Shape Design Problem

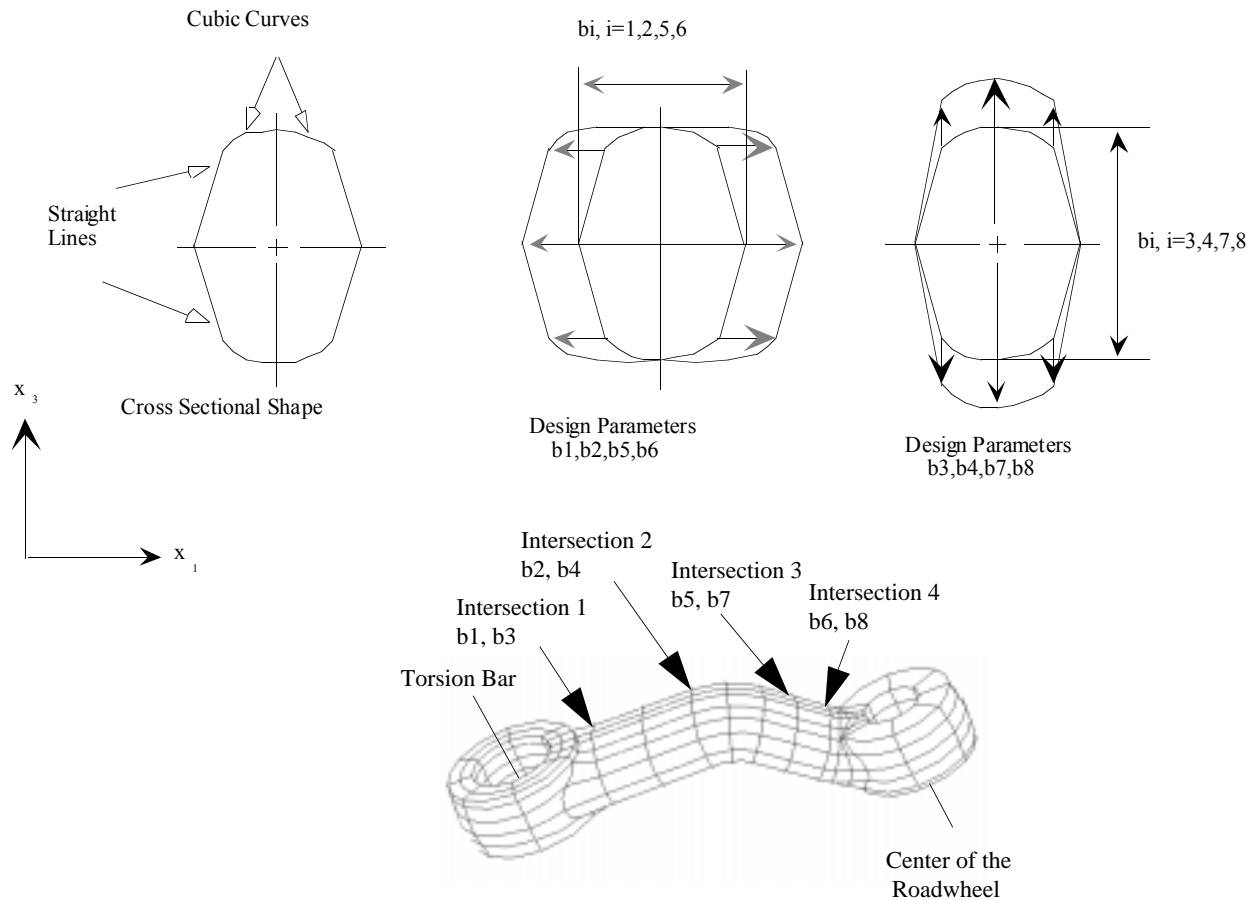
- Objective Function - Minimize Volume
- Fatigue Life is 2189 Hours at the Initial Design
- 56 Constraint Functions - Fatigue Life Longer Than 69444 Hours at 56 Critical Nodes
- 8 Shape Design Parameters
- MFD Algorithm Is Used for Optimization



| DP  | Value(in) | LowerBd | Upper Bd | DP  | Value(in) | LowerBd | Upper Bd |
|-----|-----------|---------|----------|-----|-----------|---------|----------|
| db1 | 1.968     | 1.5     | 2.5      | db5 | 2.635     | 2.2     | 3.1      |
| db2 | 1.968     | 1.5     | 2.5      | db6 | 5.057     | 4.9     | 5.5      |
| db3 | 3.250     | 2.9     | 3.8      | db7 | 3.038     | 2.6     | 3.5      |
| db4 | 3.170     | 2.8     | 3.8      | db8 | 2.909     | 2.7     | 3.5      |

# Shape Design Parameterization

- Section Dimensions (Heights and Widths) Are Selected as Design Parameters



# Design Optimization History

- Optimal Design Is Obtained in 12 Iterations

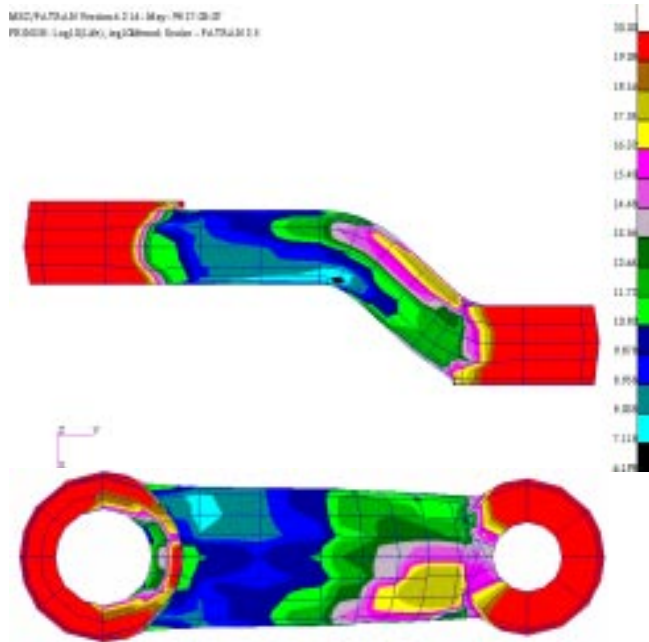


Cost Function History

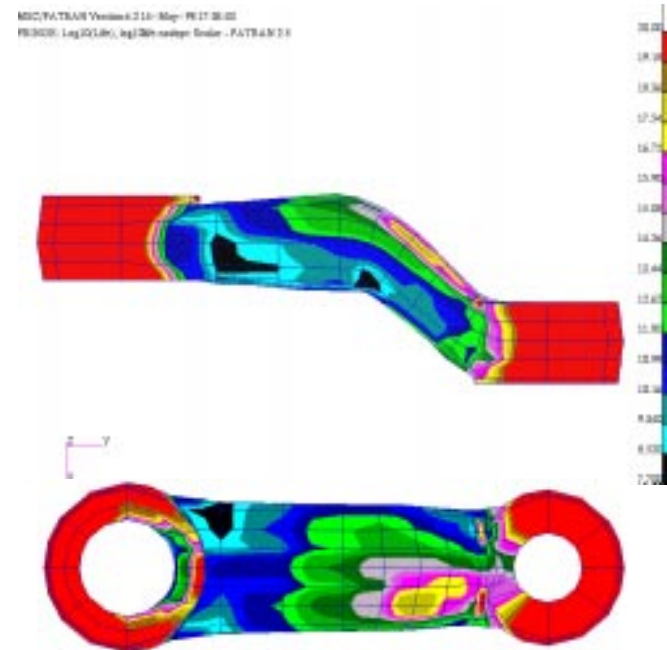


Design Parameter History

# Life Contour at Initial and Optimal Designs



**Initial Design**

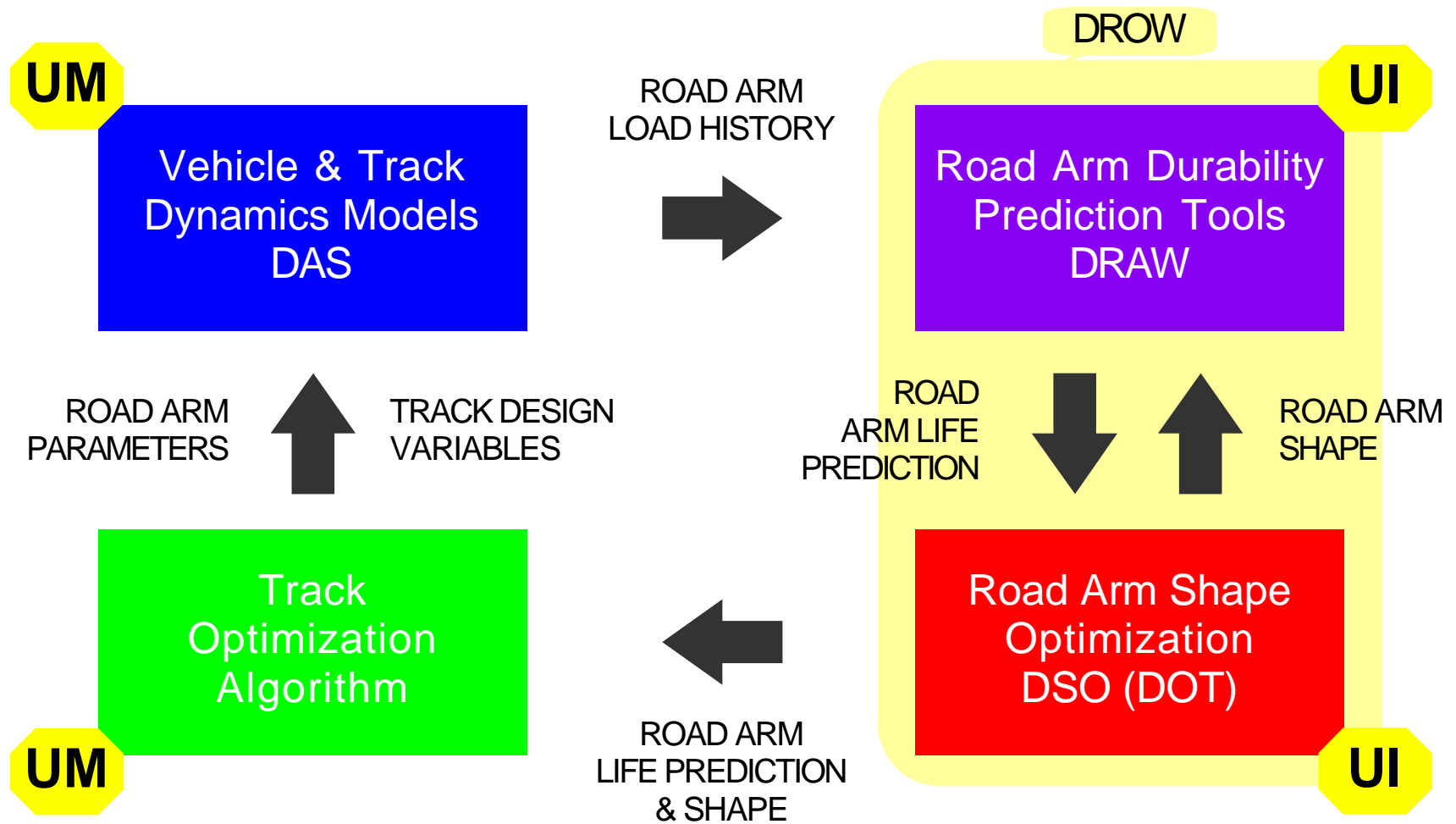


**Optimal Design**

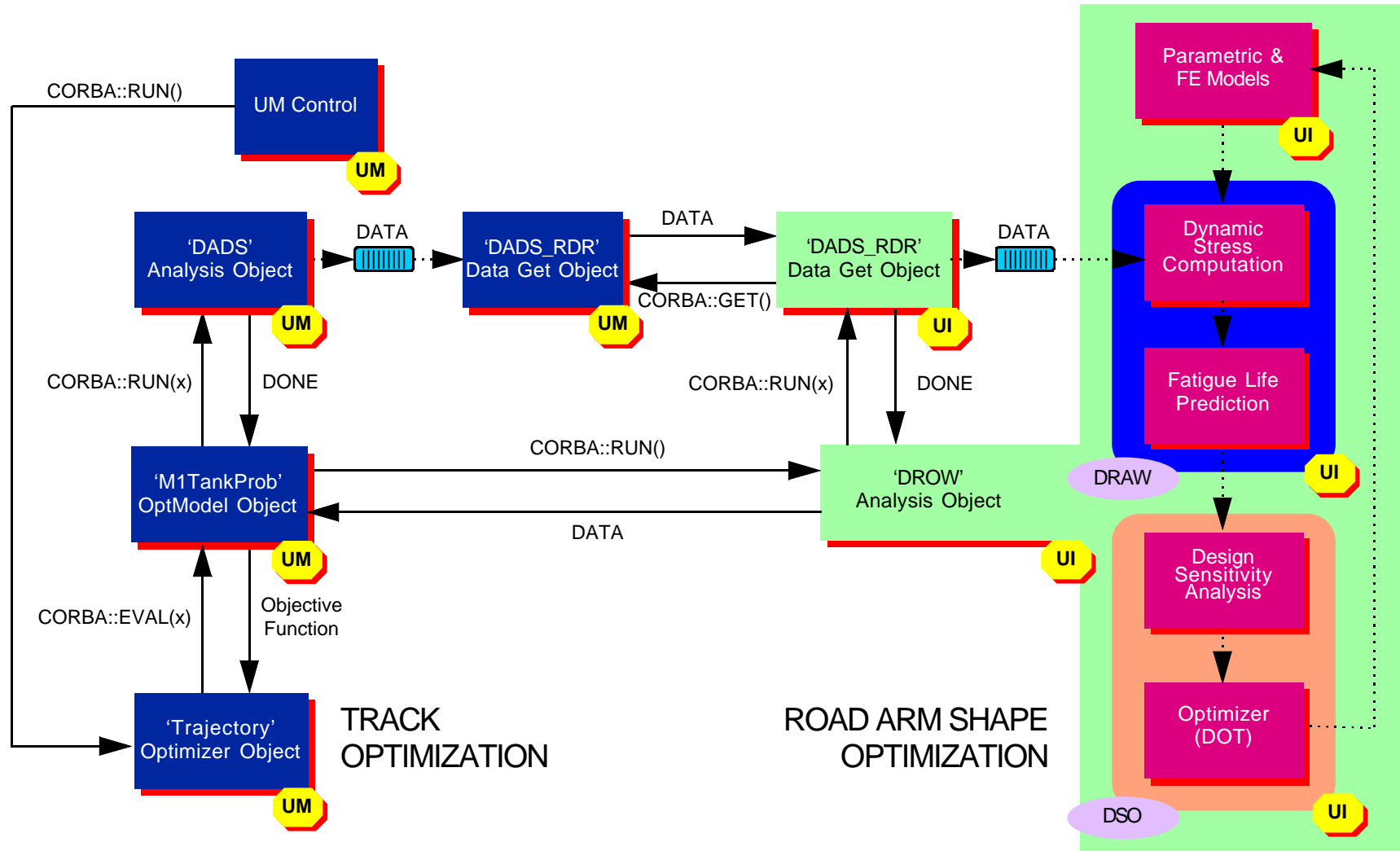
|                           | Initial | Optimal |
|---------------------------|---------|---------|
| Volume (in <sup>3</sup> ) | 515.1   | 522.1   |
| lowest life (hr)          | 2189    | 69623   |

|    | Initial (in) | Optimal |    | Initial (in) | Optimal |
|----|--------------|---------|----|--------------|---------|
| b1 | 1.968        | 2.099   | b5 | 2.635        | 2.718   |
| b2 | 1.968        | 2.488   | b6 | 5.057        | 4.850   |
| b3 | 3.250        | 3.050   | b7 | 3.038        | 2.897   |
| b4 | 3.170        | 2.917   | b8 | 2.909        | 2.701   |

# Future Work: Integration for Track and Road Arm Shape Optimization



# CORBA Integration: Track and Road Arm Shape Optimization





## Contributions of Case Study

- Development of dynamic track model with longitudinal and transverse vibration
- Implementation of new track model in DADS<sup>TM</sup> (with enhancements)
- Development of integrated powertrain/vehicle models
- Integration of vehicle dynamics models, road arm life prediction, and design tools across different platforms and physical locations using CORBA
  - ◆ Track optimization
  - ◆ Road arm shape optimization