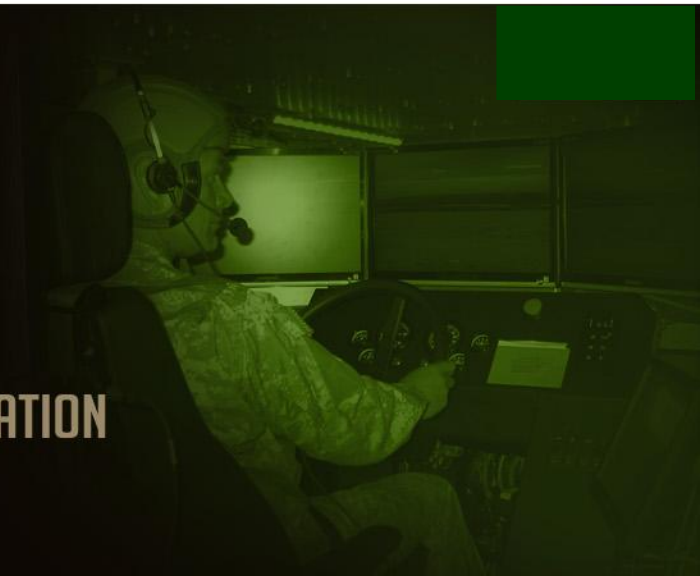




MSTV

MODELING AND SIMULATION, TESTING AND VALIDATION



NEW FINITE ELEMENT / MULTIBODY SYSTEM ALGORITHM FOR MODELING FLEXIBLE TRACKED VEHICLES

Paramsothy Jayakumar, Mike Letherwood

US Army RDECOM TARDEC

Ulysses Contreras, Ashraf M. Hamed, Abdel-Nasser A. Mohamed, Ahmed A. Shabana

University of Illinois at Chicago

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 25 AUG 2011		2. REPORT TYPE Briefing		3. DATES COVERED 25-08-2011 to 25-08-2011	
4. TITLE AND SUBTITLE NEW FINITE ELEMENT / MULTIPBODY SYSTEM ALGORITHM FOR MODELING FLEXIBLE TRACKED VEHICLES				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Paramsothy Jayakumar; Mike Letherwood; Ulysses Contreras; Ashraf Hamed; Ahmed Shabana				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army TARDEC ,6501 E.11 Mile Rd,Warren,MI,48397-5000				8. PERFORMING ORGANIZATION REPORT NUMBER #22193	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army TARDEC, 6501 E.11 Mile Rd, Warren, MI, 48397-5000				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) #22193	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES briefing for Ground Vehicle Systems Engineering and Technology Symposium (GVSET) 2011					
14. ABSTRACT NA					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 16	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

OUTLINE

MSTV

MODELING AND SIMULATION, TESTING AND VALIDATION



- Multibody System (MBS) Simulation
- Tracked Vehicle Models
- Challenges
- Project Objectives
- ANCF Finite Elements
- Integration of FE/MBS Algorithms
- Numerical Example
- Summary
- Future Work



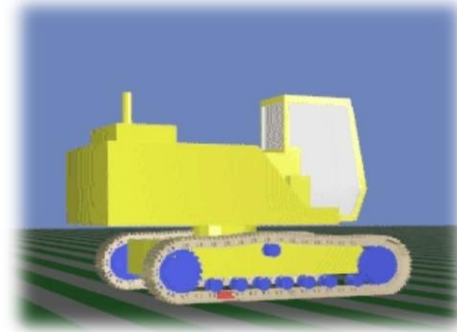
- Implementation of general MBS algorithms started in the mid seventies.
- First generation MBS codes were designed to solve systems that consist of rigid bodies only.
- Second generation MBS codes that allowed for modeling small deformation of flexible bodies with distributed inertia were introduced in the early eighties.
- Existing commercial MBS codes cannot systematically solve large deformation FE problems.
- The objective of this project is to address this important problem in order to develop a new generation of flexible MBS algorithms.
- These new algorithms can be effectively used to solve chain and tracked vehicle problems.

- TARDEC has a history of providing strong support for MBS research.
- This support led to the development of a new generation of MBS codes at the University of Iowa approximately 30 years ago.
- Successful integration of small deformation finite element (FE) and MBS algorithms was accomplished.
- This procedure has been implemented in most commercial MBS computer codes and is currently widely used in industry.
- TARDEC is currently working with the University of Illinois at Chicago on the development of a new generation of MBS codes based on the integration of computational geometry, large displacement FE, and MBS algorithms.

TRACKED VEHICLE MODELS



- Level of details included in tracked vehicle models depends on the available MBS simulation technology.
- First spatial MBS tracked vehicle model with rigid link chains was developed in the mid nineties.
- First MBS tracked vehicle model with rubber track (belt) was developed a few years ago.
- Development of flexible link chain models will require efficient integration of large displacement FE/MBS algorithms.
- This requires the use of new generation of MBS algorithms and computer programs .





- Chains have large number of joints and nonlinear inertia.
- Joints increase the number of nonlinear algebraic equations leading to a more complex algorithm.
- Development of accurate rigid link chains can be challenging.
- Efficient flexible link chain models cannot be developed using the floating frame of reference formulation implemented in most MBS codes.
- The use of new concepts and approaches is necessary.

$$\left. \begin{aligned} \mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}_q^T \boldsymbol{\lambda} &= \mathbf{Q} \\ \mathbf{C}(\mathbf{q}, t) &= \mathbf{0} \end{aligned} \right\}$$



$$\begin{bmatrix} \mathbf{M} & \mathbf{C}_q^T \\ \mathbf{C}_q & \mathbf{0} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{q}} \\ \boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \mathbf{Q}_e + \mathbf{Q}_v \\ \mathbf{Q}_d \end{bmatrix}$$

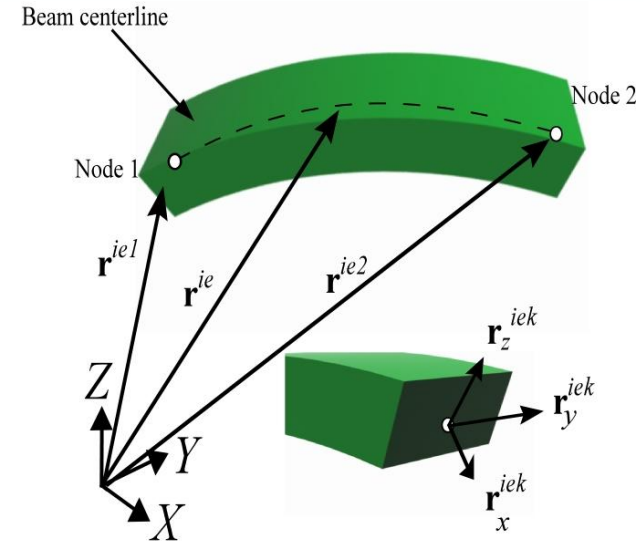
PROJECT OBJECTIVES



- Develop new generation of MBS tracked vehicle models with flexible link chains.
- In order to address the challenges in developing such models, the large displacement FE absolute nodal coordinate formulation (ANCF) is used.
- Use ANCF finite elements to obtain constant inertia leading to an optimum sparse matrix structure and zero Coriolis and centrifugal forces.
- Use ANCF finite elements to formulate chain linear connectivity conditions, leading to the elimination of dependent variables at a preprocessing stage (no chain joints in the MBS code).
- Demonstrate the new concepts and algorithms by implementing in a new tracked vehicle model.



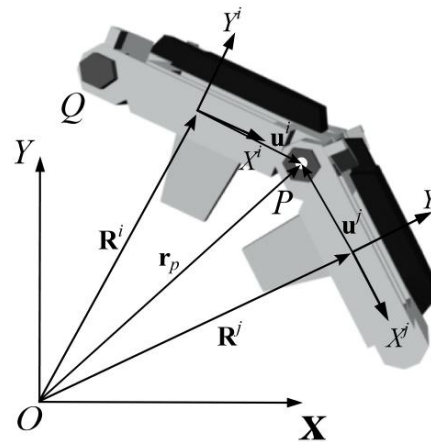
- ANCF finite elements correctly describe rigid body motion.
- The constant inertia matrix leads to optimum sparse matrix structure and zero Coriolis and centrifugal forces.
- General constitutive models can be used in the case of beams and plates.
- ANCF finite elements can be used to obtain linear chain connectivity conditions



$$\mathbf{r}^{ie} = \mathbf{S}^{ie}(x^{ie}, y^{ie}, z^{ie})\mathbf{e}^{ie}$$

$$\mathbf{r}_p^i = \mathbf{r}_p^j$$

$$\left(\frac{\partial \mathbf{r}^i}{\partial \alpha} \right)_p = \left(\frac{\partial \mathbf{r}^j}{\partial \alpha} \right)_p$$



INTEGRATION OF FE/MBS ALGORITHMS



- The new concepts and algorithms are implemented in the MBS code SAMS/2000.
- SAMS/2000 allows modeling systems that consist of rigid, flexible, and very flexible bodies.
- Rigid body formulation, floating frame of reference formulation, and ANCF are implemented.
- ANCF large displacement Cholesky coordinates can be used to obtain an optimum sparse matrix structure for articulated systems.
- Joint constraint equations are satisfied at the position, velocity, and acceleration levels.

$$\left. \begin{aligned} \mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}_q^T \boldsymbol{\lambda} &= \mathbf{Q} \\ \mathbf{C}(\mathbf{q}, t) &= \mathbf{0} \end{aligned} \right\}$$



$$\begin{bmatrix} \mathbf{M}_{rr} & \mathbf{M}_{rf} & \mathbf{0} & \mathbf{0} & \mathbf{C}_{q_r}^T \\ \mathbf{M}_{fr} & \mathbf{M}_{ff} & \mathbf{0} & \mathbf{0} & \mathbf{C}_{q_f}^T \\ \mathbf{0} & \mathbf{0} & \mathbf{M}_{aa} & \mathbf{0} & \mathbf{C}_{q_a}^T \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{C}_s^T \\ \mathbf{C}_{q_r} & \mathbf{C}_{q_f} & \mathbf{C}_{q_a} & \mathbf{C}_s & \mathbf{0} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{q}}_r \\ \ddot{\mathbf{q}}_f \\ \ddot{\mathbf{q}}_a \\ \ddot{\mathbf{s}} \\ \boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \mathbf{Q}_r \\ \mathbf{Q}_f \\ \mathbf{Q}_a \\ \mathbf{0} \\ \mathbf{Q}_c \end{bmatrix}$$



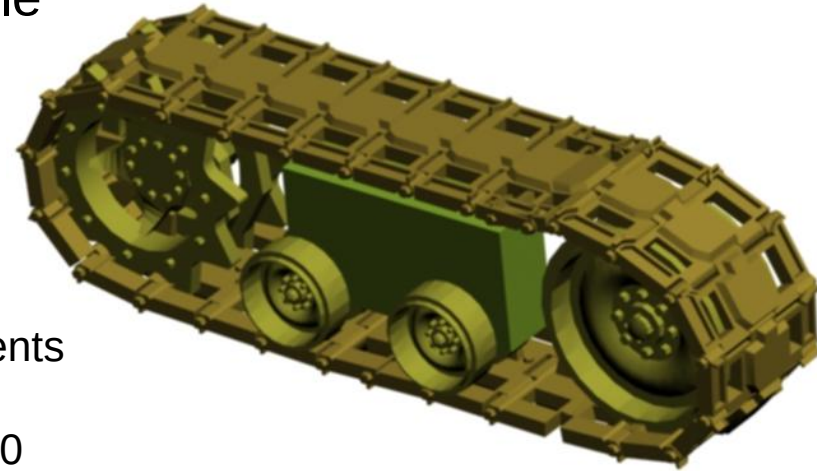
NUMERICAL EXAMPLE

MSTV

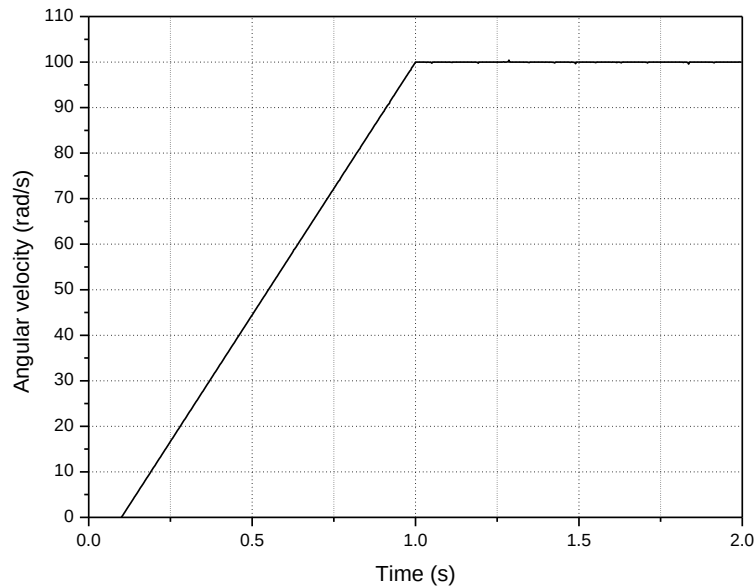
MODELING AND SIMULATION, TESTING AND VALIDATION



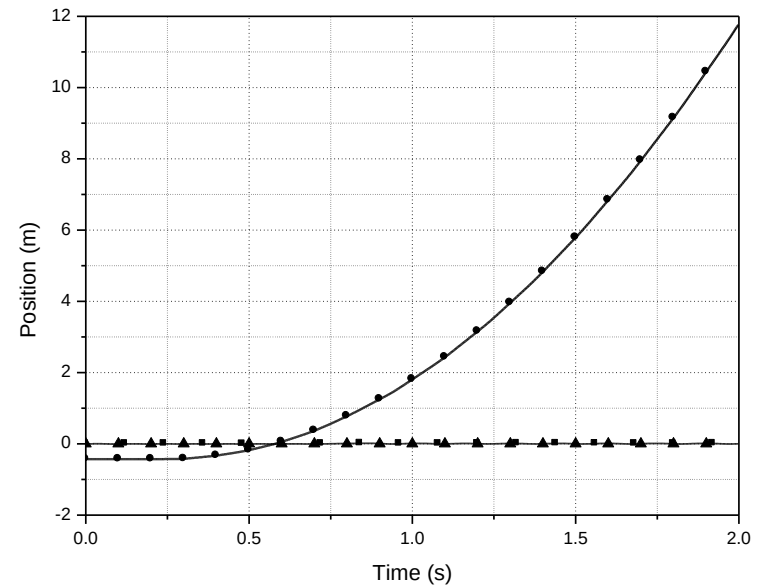
- A simple tracked vehicle model example may be used to illustrate the ideas presented.
- Model details:
 - The chain is modeled using 24 ANCF elements that have a rectangular cross section of dimensions $0.02\text{m} \times 0.4\text{m}$ and density of 2000 kg/m^3
 - The incompressible Neo-Hookean model and non-linear damping model are used to model the internal behavior of the rubber chain



RESULTS



- Sprocket angular velocity



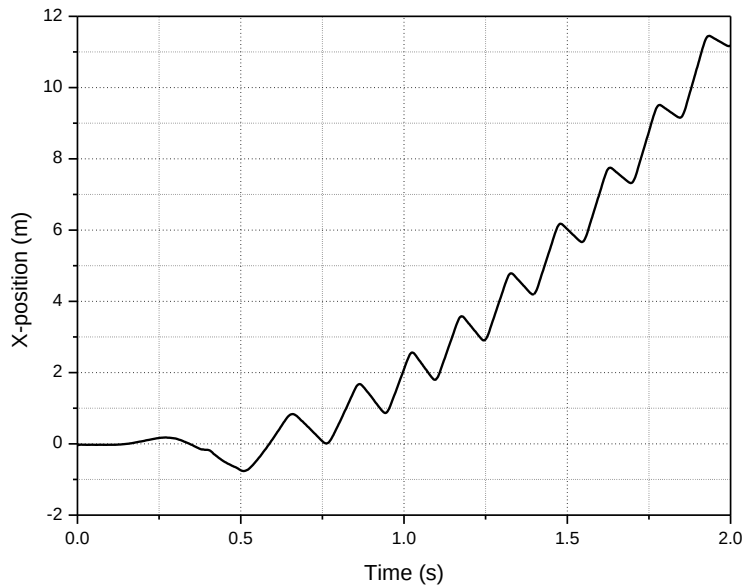
- Position of the center of mass of the chassis

- X coordinate
- ▲ Y coordinate
- Z coordinate

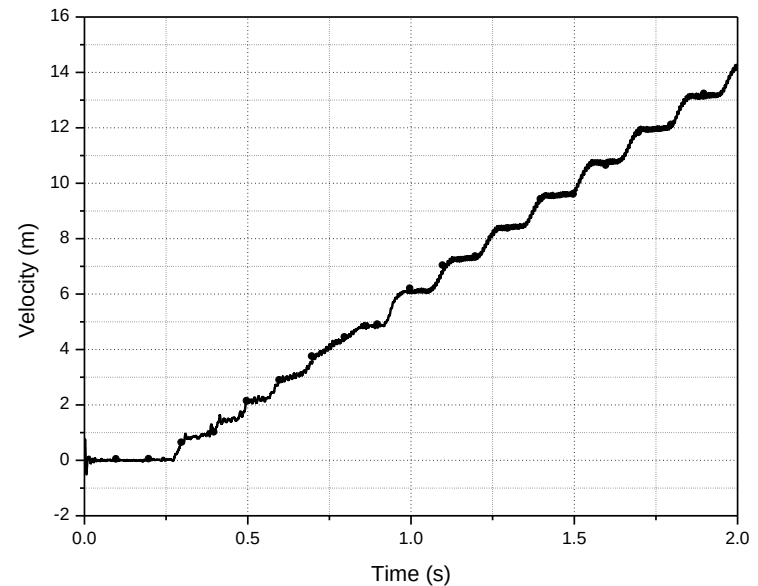
Results

MSTV

MODELING AND SIMULATION, TESTING AND VALIDATION



- X coordinate of the position vector of a point on the rubber chain

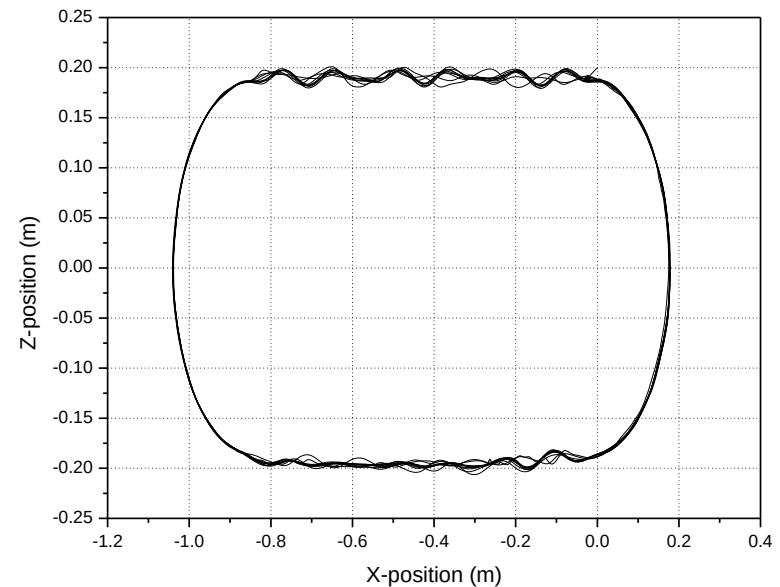
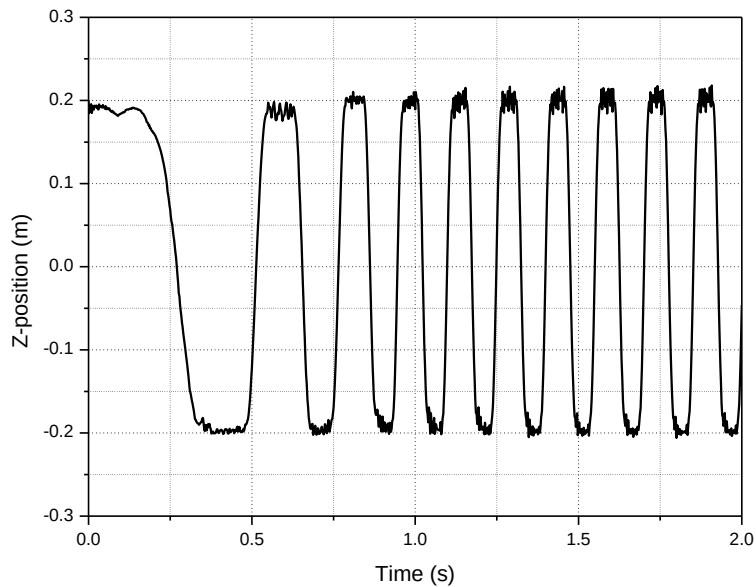


- X-velocity of the center of mass of the chassis

Results

MSTV

MODELING AND SIMULATION, TESTING AND VALIDATION



- Trajectory of a point on the rubber chain

- Z coordinate of the position vector of a point on the rubber chain

- Integration of large displacement FE/MBS algorithms is necessary for the development of efficient and detailed tracked vehicle models.
- ANCF finite elements allow for the development of new FE meshes that have **linear connectivity** and **constant inertia**.
- Dependent variables can be systematically eliminated at a preprocessing stage (no need for joint formulation in the MBS code).
- The constant inertia allows for the development of an **optimum sparse matrix structure** of the equations of motion.
- The new concept was demonstrated using a chain example.



FUTURE WORK



- Develop a detailed tracked vehicle model with flexible link chains.
- The forces determined from the MBS simulation will be used to determine the link stresses.
- High deformation soil models may be included in the MBS environment.
- Comparisons between rigid and stiff track link tracked vehicles may be conducted in order to determine/outline the importance of deformation in tracked vehicle links (thermal stresses may be important).



MSTV

MODELING AND SIMULATION, TESTING AND VALIDATION

Questions?