Modeling & Simulation for Tank R&D including Vehicle-Ground Interaction

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GROUND SYSTEMS RESEARCH CENTER,
TECHNICAL RESEARCH & DEVELOPMENT INSTITUTE,
MINISTRY OF DEFENSE, JAPAN
CONTENTS OF THE PRESENTATION

1 PHASE 1 & PHASE 2
(1) Simulation of Combat Vehicle Mobility
(2) Vehicle-Ground Interaction for Tank R&D

2 PHASE 3
(1) Simulation of Tank Turret Motion
(2) Hardware-in-the-Loop Simulation for Tanks
(3) Simulation of Active Suspension for Tanks
(4) Hybrid Electric Propulsion system for Combat Vehicles
1 PHASE 1 & PHASE 2
(1) Simulation of Combat Vehicle Mobility
BACKGROUND

VIRTUAL PROTOTYPING BY SIMULATION

TEST & EVALUATION BY SIMULATION
REAL-TIME SIMULATOR INCLUDING HUMAN OPERATION IS REQUIRED.

BACKGROUND

MAN IN THE LOOP SIMULATION

TO EVALUATE VEHICLE MOBILITY INCLUDING HUMAN OPERATION

VEHICLES

- VEHICLE MOBILITY EVALUATION
- STEERING-ABILITY EVALUATION

HUMAN

- DRIVER'S FIELD OF VISION
- ACCELERATION
- BRAKING
- STEERING

OPERATION INPUT
BACKGROUND

TO NEED TO VEHICLE MOBILITY ON VARIOUS TERRAINS

PHASE 1

PAVED ROAD

PHASE 2

ROUGH TERRAIN

SOFT TERRAIN
DEVELOPED SIMULATOR FOR COMBAT VEHICLE CONCEPT & EVALUATION

CREW SEATS & DRIVER’S VIEW SCREEN

CONTROL CONSOLE

DRIVER’S SEAT

GUNNER’S SEAT

COMMANDER’S SEAT

SIMULATOR CONTROL UNIT
A MOTION BASE CONNECTED THE SIMULATOR

THE MOTION BASE FOR THE SIMULATOR
DEMONSTRATION OF THE SIMULATION BY THE COMBAT SIMULATOR

TO EVALUATE VEHICLE MOBILITY, GUN STABILITY, AND FUTURE HYBRID ELECTRIC PROPULTION AND FORWARD LOOKING ACTIVE SUSPENSION
<table>
<thead>
<tr>
<th>COMPONENTS</th>
<th>PHASE 1</th>
<th>PHASE 2</th>
<th>PHASE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENGINE, SUSPENSION</td>
<td>32</td>
<td>153</td>
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<tr>
<td>TRACKED RUNNING GEAR</td>
<td>46</td>
<td>584</td>
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<td>HULL, DRIVING SYSTEM</td>
<td>11</td>
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<td>TERRAIN PROGRAM</td>
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<td>GUNNER PERISCOPE</td>
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<tr>
<td>COMMANDER PERISCOPE</td>
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<td>BALLISTICS</td>
<td>4</td>
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<tr>
<td>TURRET</td>
<td>2</td>
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<tr>
<td>SHELL</td>
<td>3</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>TOTAL</td>
<td>106</td>
<td>886</td>
<td>1154</td>
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<tr>
<td>MAIN FUNCTION</td>
<td>PHASE 1 &amp; 2</td>
<td>PHASE 3</td>
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<td>• PREDICTIVE FUNCTION OF THE VEHICLE MOBILITY BY A DETAILED MATHEMATICS MODEL</td>
<td>SGI CORP. : Onyx3400</td>
<td>CPU : MIPS Technologies, Inc. : R14000, 20UNITS × 600 MHz</td>
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<td>• PREDICTIVE FUNCTION OF A FUTURE ADVANCED VEHICLE</td>
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<td>MEMORY : 10GB</td>
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<td>• REAL-TIME PROCESSING FUNCTION OF THE DATA INPUT AND OUTPUT</td>
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<td>• PREDICTIVE FUNCTION OF THE TURRET PERFORMANCE BY A DETAILED MATHEMATICS MODEL</td>
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<td>SGI CORP. : Onyx4</td>
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<td></td>
<td></td>
<td>CPU:</td>
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<td></td>
<td></td>
<td>MIPSTechnologies, Inc. : R16000</td>
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<td></td>
<td></td>
<td>• 40 UNITS × 700MHz</td>
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<td></td>
<td></td>
<td>• MEMORY: 15 GB</td>
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PROGRESS OF ENGINE MODEL

- CONSIDERING EXHAUST TURBO-CHARGER INDEPENDENTLY
- INCLUDING THE ENGINE GAS EQUATION

**PHASE 1**

- STEADY STATE TORQUE CURVE
- $1$st ORDER DELAY (TURBO LAG)

**PHASE 2**

- TORQUE
- $\frac{1}{T_s+1}$
- ACCELERATION
- PRESS. TEMP.
- INTERCOOLER
- COMPRESSOR
- TURBINE
- EXHAUST TURBO-COMPRESSOR

**ENGINE SPEED**

**CRANK SHAFT**

**TORQUE**

**GOVERNOR**
TANK ACCELERATION TEST

PHASE 1 SIMULATOR

PHASE 2 SIMULATOR

ENGINE SPEED / rpm

EXPERIMENTAL DATA

TIME / s
ACCELERATION TEST FOR WHEELED ARMORED PERSONNEL CARRIER

PHASE 1 SIMULATOR

PHASE 2 SIMULATOR

ENGINE SPEED/ rpm

EXPERIMENTAL DATA

TIME / s
PROGRESS OF SUSPENSION MODEL

PHASE 1
SPRING & DAMPER MODEL

PHASE 2
SEAL GAS, ADIABATIC COMPRESSION OF OIL, VALVE MECH. COIL VS VISCOUS FORCE

VALVE MECHANISM

SIMPLE DISPLACEMENT (LINEAR)

TRACKED WHEEL

SEAL GAS

OIL

PISTON

WHEEL ARM

SUSPENSION MECHANISM DISPLACEMENT (NON LINEAR)
（2）VEHICLE-GROUND INTERACTION FOR TANK R&D
### VEHICLE TRACKS AND SOFT SOIL INTERACTION MECHANISM

<table>
<thead>
<tr>
<th>SINKAGE</th>
<th>SLIPPING</th>
<th>EVACUATION OF SOIL</th>
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<tbody>
<tr>
<td><img src="image1" alt="Sinkage Illustration" /></td>
<td><img src="image2" alt="Slipping Illustration" /></td>
<td><img src="image3" alt="Evacuation Illustration" /></td>
</tr>
</tbody>
</table>

- **Compression Force of Soil**
- **Shear Force of Soil**
- **Slip**

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17
TRACKS-SOFT SOIL INTERACTION

VERTICAL DIRECTION FORCE

SOFT SOIL

FRICTION OF HULL BASE

TERRAIN REACTION FORCE (RESISTANCE)

TERRAIN REACTION FORCE (SUPPORT FORCE)

TERRAIN REACTION FORCE (PROPULSION)

HORIZONTAL DIRECTION FORCE

RESISTANCE OF EVACUATED SOIL

VEHICLE RUNNING DIRECTION

FRICTION OF HULL BASE

SHEAR RESISTANCE
(1) DEFINE THE SOFT SOIL WITH 2D MESH FOR EACH 20cm DISTANCE.
(2) CALCULATE CONTACT PRESSURE AND SINKAGE AT THE CONTACT POINTS.
(3) MEMORIZE THE SINKAGE HISTORY.
TRACK & WHEEL MODEL

DOUBLE PIN CRAWLER
CRAWLER, CONNECTER, ROBBER BUSH, PIN

CRAWLER, CONNECTER, ROBBER BUSH, PIN

SPRING-DAMPER/TORSION SPRING-DAMPER

RUNNING RESISTANCE

FORCE FROM THE CRAWLER

CONTACT POINT

SURFACE OF THE TERRAIN

TERRAIN REACTION FORCE
COMPARISON BETWEEN SIMULATION AND EXAMINATION

EXAMINATION

SIMULATION
COMPARISON BETWEEN SIMULATION AND EXAMINATION

EXAMINATION

SIMULATION
COMPARISON OF SIMULATION AND EXPERIMENTAL DATA

SINKAGE OF GROUND SURFACE

SINKAGE / %

0  1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16

NUMBER OF PASSING VEHICLE

▲ SIMULATION
▲ EXPERIMENTAL DATA
TANK SOFT TERRAIN TURNING TEST

EXPERIMENTAL

SIMULATION

EXPERIMENTAL DATA AND SIMULATION RESULTS

- Actual test
- Simulation

- Inner
- Outer
TANK SOFT TERRAIN MOBILITY TEST

VALIDATED SIMULATION RESULTS BY THE EXPERIMENTAL TEST DATA CONCERNING TURRET STABILITY FOR TANK DURING THE RUNNING ON THE SOFT TERRAIN

EXPERIMENTAL VALIDATION SIMULATION
TANK SOFT TERRAIN MOBILITY TEST

· VEHICLE AVERAGE VELOCITY : 13 km/h
· EQUIVALENT CONE INDEX
SIMULATION OF TANK MOBILITY ON THE SOFT TERRAIN
TERRAIN AND PROVING GROUND MODEL

- THE SIMULATOR HAS THE ACTUAL PROVING GROUND’S 3D SURFACE DATA.

PROVING GROUND

ROUGH TERRAIN
2 PHASE 3
(1) SIMULATION OF TANK TURRET MOTION
SIMULATION OF ARTILLERY & TURRET STABILIZATION AND TRACKING OPERATION (VERTICAL MOTION)

RUNNING DIRECTION

TARGET

EXPERIMENTAL

SIMULATION

VALIDATION
TRACKING SIMULATION BY RUNNING OVER OBSTACLES

VEHICLE SPEED 30 km/h
SIMULATION OF ARTILLERY & TURRET STABILIZATION AND TRACKING OPERATION (VERTICAL MOTION)

RUNNING DIRECTION

TARGET

EXPERIMENTAL

SIMULATION

VALIDATION
TARGET TRACKING SIMULATION BY SLALOM RUNNING

VEHICLE SPEED 40 km/h
（2）HARDWARE-IN-THE-LOOP SIMULATION FOR TANKS
APPLICATION OF SIMULATION TECHNOLOGY FOR NEW TANK DEVELOPMENT
APPLICATION OF SIMULATION TECHNOLOGY FOR NEW TANK DEVELOPMENT

ARTILLERY

TURRET

ENGINE

HULL

TERRAIN SURFACE
HARDWARE IN THE LOOP SIMULATION

- COMPUTER
- SCREEN
- CONSOLE
- DRIVER
- GUNNER
- COMMANDER
- Power Train Simulator
- Rough Terrain Simulator
- Turret Motion Simulator
HARDWARE IN THE LOOP SIMULATION

- Load Signal
- Load Torque
- Operation Signal
- I/F Connection Signal
- Sprocket Rotating Speed
- Vehicle Attitude, Vertical Vibration (test)
- Rough Terrain
- Load Signal
- Load Torque
- Operation Signal
- Vehicle Attitude, Vertical Vibration (test)
- Rough Terrain
- Operation Signal
- Vehicle Attitude, Vertical Vibration (test)
- Cylinder displacement
- Operation Signal
- Vehicle Attitude, Vertical Vibration (test)
- Rough Terrain
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HARDWARE IN THE LOOP SIMULATION

TO EVALUATE HULL MOTION AND HIT PRECISION DURING VEHICLE RUNNING

MOVING TARGET SCREEN

ROUGH ROAD SIMULATOR
HARDWARE IN THE LOOP SIMULATION

MOVING TARGET SCREEN

ROUGH ROAD SIMULATOR
HARDWARE IN THE LOOP SIMULATION

TURRET MOTION

MOVING TARGET SCREEN

TURRET

MOVING TABLE
HARDWARE IN THE LOOP SIMULATION

SIMULATION MODEL  ACTUAL TURRET VIBRATION DATA

FROM FRONT

FROM BACK

ACTUAL ENGINE OUTPUT DATA
PROTOTYPE of NEW TANK
(3) SIMULATION OF ACTIVE SUSPENSION FOR TANKS
EXPERIMENTAL SET-UP OF PREDICTION CONTROL OF AN ACTIVE TYPE SUSPENSION DEVICE

ROAD SURFACE GENERATOR

LASER RANGE FINDER

ACTIVE HYDROPEUMATIC SUSPENSION

VEHICLE OFF-ROAD SIMULATOR

1st 2nd 3rd 4th 5th 6th
EXPERIMENTAL SET-UP OF PREDICTION CONTROL OF AN ACTIVE TYPE SUSPENSION DEVICE
VEHICLE RUNNING SIMULATION WITH PREDICTION CONTROL OF AN ACTIVE TYPE SUSPENSION DEVICE

VEHICLE SPEED 25 km/h

WITH PASSIVE SUSPENSION DEVICE  WITH ACTIVE SUSPENSION DEVICE
VEHICLE RUNNING TEST WITH AN ACTIVE TYPE SUSPENSION DEVICE USING ACTUAL VEHICLE TESTBED
(4) HYBRID ELECTRIC PROPULSION SYSTEM FOR COMBAT VEHICLES
HYBRID ELECTRIC PROPULSION SYSTEM

DIAGRAM OF SERIES HYBRID ELECTRIC PROPULSION SYSTEM

- Engine
- Generator
- Motor
- Battery
- Converter
- Reduction Gear
- Drive Wheel (Right)
- Drive Wheel (Left)
- Inverter
- Controller
- BMU
- DC Bus
- Power Shaft
- Control Signal Line
- Electric Power Line

Charge Discharge Operation

Image of Hybrid Vehicle
HYBRID VEHICLE

START & ACCELERATION TEST (0-200m), VEHICLE MASS 13 t
HYBRID VEHICLE

TURNING TEST, VEHICLE MASS 13 t
HYBRID ELECTRIC PROPULSION VEHICLE PROTOTYPE

RUNNING ONLY WITH BATTERY

SPOT TURN IN HYBRID MODE

FORWARD TRAVELING IN HYBRID MODE

REVERSE TRAVELING IN HYBRID MODE
<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>SUMMARY</strong></td>
<td></td>
</tr>
<tr>
<td><strong>1.</strong></td>
<td>A REAL-TIME SIMULATOR HAS BEEN DEVELOPED FOR VIRTUAL PROTOTYPING AND VIRTUAL-TESTING FOR TRACKED AND WHEELED VEHICLES.</td>
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<td><strong>2.</strong></td>
<td>USING THIS SIMULATOR, THE NEW TANK WAS VIRTUALLY PROTOTYPED AND EVALUATED INCLUDING THE MOBILITY OF THE VEHICLE AND THE INTERACTION WITH THE SOFT GROUND.</td>
</tr>
<tr>
<td><strong>3.</strong></td>
<td>A FUTURE VEHICLES WITH ACTIVE SUSPENSION AND A HYBRID ELECTRIC PROPULSION SYSTEM WAS VIRTUALLY PROTOTYPED AND VIRTUALLY TESTED BY THIS SIMULATOR.</td>
</tr>
<tr>
<td><strong>4.</strong></td>
<td>IN THE NEXT STEP, THIS SIMULATOR WILL BE IMPROVED SO THAT SIMULATION CAN BE ACCOMPLISHED WITH A EASIER PROGRAMMING AND FASTER CALCULATIONS, AND SO IT CAN EVALUATE THE VEHICLES UNDER THE VARIOUS CIRCUMSTANCES.</td>
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THANK YOU
FOR YOUR ATTENTION