Heavy Assault Bridge Simulation

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ABSTRACT

In support of the design effort, analysts are required to develop high resolution system level simulation models. The development of a dynamics simulation model that describes the mechanical behavior of the systems is often not sufficient in the presence of a control system in the design. The reverse is also true. A comprehensive control system model is not sufficient without an adequate representation of the mechanical system dynamics.

GDLS has successfully developed an ADAMS® simulation model of the Heavy Assault Bridge System (HABS) in support of the development effort. Integrating high resolution dynamics and control systems into one simulation model, enabled the Design Engineers to develop and validate a new control system design prior to hardware development and field test, while reducing development time and cost.

HAB SYSTEM DESCRIPTION

The HAB system (Figure 4) is an integrated M1A2 ABRAMS chassis with a bridge mechanism designed by MAN of Germany. The bridge is 80 feet long controlled by a feedback control system that can deploy or retrieve in under 4 minutes. During launch or retrieval the control system drives the bridge through 14 stages of motion by individually commanding four hydraulic actuators and one hydraulic motor (bridge drive).

SIMULATION MODEL OVERVIEW

The simulation model was modeled with ADAMS®. Figure (1) describes the structure of the simulation model and the flow of variables between the main modules.

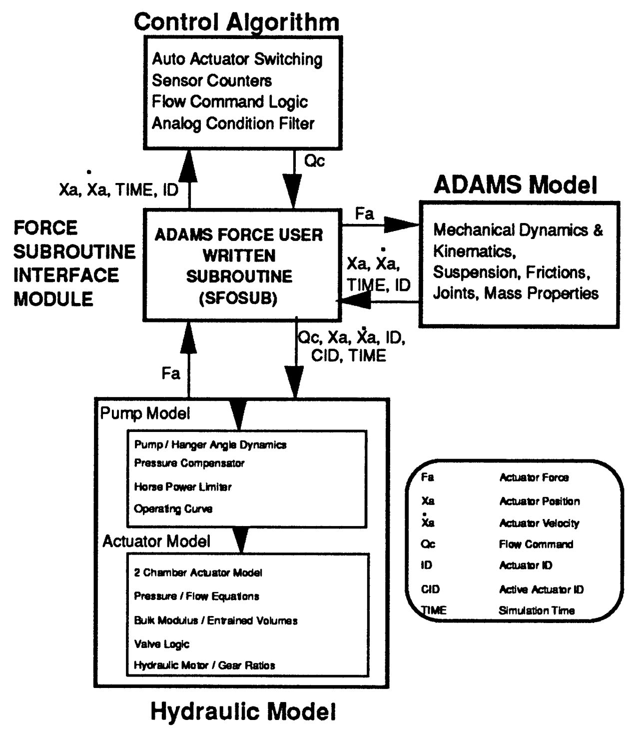


Figure (1): ADAMS® Model Flow Diagram

The dynamics was modeled by ADAMS® and the control system was modeled through user-written subroutines integrated with ADAMS®. The control algorithm commanded a flow rate to the pump. The pump module generated the flows and pressures to the actuators. The actuators generated the force/torque to drive the dynamics model.

Following is a description of each of the main modules and their interfaces as simulated in ADAMS®:

ADAMS® Force Interface Module

The Force Interface Module is a FORTRAN based subroutine that interfaces ADAMS® to the force routines. This routine is called upon by ADAMS® to obtain the current actuator forces. The routine calls the Control Algorithm, Pump Model and then in turn the Actuator Model to receive the applied actuator force to the system. The module is used for interfacing with other force subroutines used for suspension and track force computations.

Control System Algorithm Module

The Control System Algorithm subroutine describes the entire control operation of the HAB system. It contains automatic actuator switching which will cycle the sequence of stages for either the laying or retrieval of the bridge. When one stage is complete the module will automatically activate the next stage of operation.

The sensors on the HAB provide position data for each actuator. The position data was obtained by calling ADAMS® subroutines for the current actuator positions. The positions were then converted to equivalent sensor counts. The original HAB control algorithms were emulated by table look-up techniques duplicated from the original HAB on-board software inherited from the MAN design. For a given position sensor count, a desired flow command was obtained. The table look-up method was then expanded by the addition of a rate feedback control loop to improve the performance and reliability of the HAB system. The control system diagram of the old and improved design is described in Figure (2).

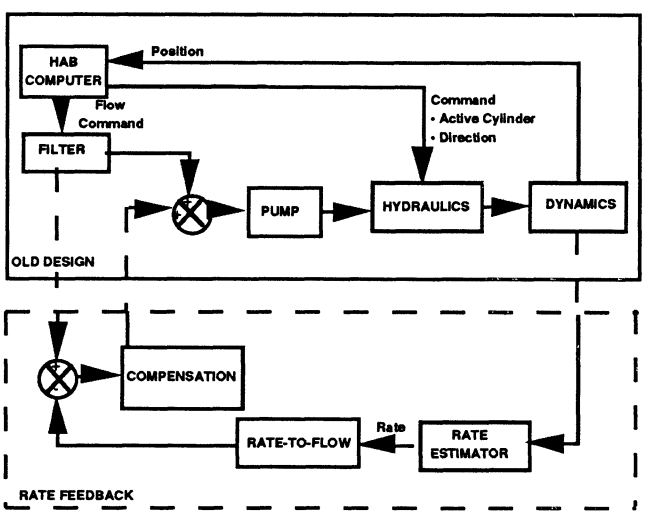


Figure (2): Control System Block Diagram

Additionally a direction is commanded to the logic in the actuator model to represent the directional valve. An analog filter used on the HAB system was also included in the model. This was accomplished by incorporating the equations describing the filter into the model. The flow command generated is passed through a D/A to signal form, then passed to the filter. The output of the filter is then passed to the pump for a flow command. The integration method used to solve the equations for the filter were performed by calling ADAMS® integration subroutines. ADAMS® integration subroutines were favored over user written routine for compatibility with the dynamics integration.

Hydraulic Pump Module

The hydraulic pump subroutine contained equations describing the hydraulic pump used on the HAB system. The hydraulic pump supplies pressure to the actuators and hydraulic motor. Figure (3) describes the flow between the pump and one actuator.

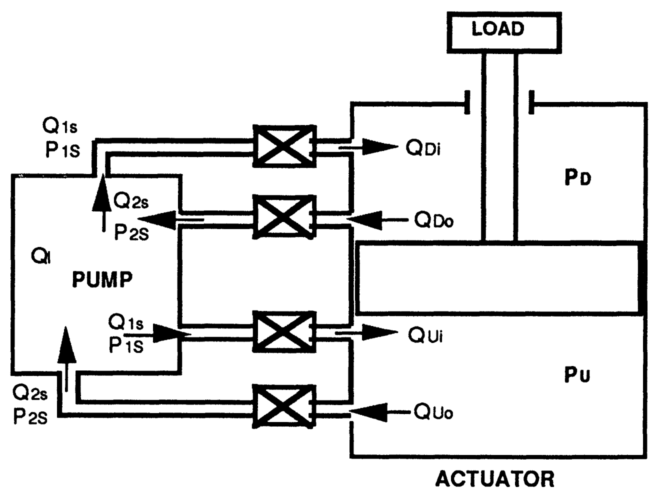


Figure (3): Pump and Actuator Flow Diagram

The pump supply pressure is computed as follows:

$$\frac{dP_{1S}}{dt} = \frac{\beta}{V_{1S}}(Q_{1S} - Q_{Ui} - Q_l) \quad (1)$$

$$\frac{dP_{2S}}{dt} = \frac{\beta}{V_{2S}}(Q_{DO} - Q_{2S} + Q_l) \quad (2)$$

Where;

$Q$ = Flow Rate

$\beta$ = Bulk Modulus

$V$ = Entrained Volume

$$\frac{dP_s}{dt} = \frac{dP_{1s}}{dt} - \frac{dP_{2s}}{dt} \quad \text{.........................................} (3)$$

Integrating $\frac{dP_s}{dt}$ we obtain the Supply Pressure $P_s$

The flow rate is determined from the following equation:

$$Q_{Ui} = C_U\sqrt{P_s - P_U} \quad \text{.................................} (4)$$

$$Q_{DO} = C_D\sqrt{P_D - P_r} \quad \text{................................} (5)$$

Where;

$C_U$ = Flow Coefficient Up Chamber

$C_D$ = Flow Coefficient Down Chamber

$P_U$ = Pressure Up Chamber

$P_D$ = Pressure Down Chamber

$P_r = P_{2S}$ = Return Pressure

To add detail to the transient characteristics of the pump, the hanger angle (swash plate) dynamics and a pressure compensator based on the pump specifications characteristics were added. The horsepower limiter and an operating curve was also incorporated. The operating curve assured that the pump model had the same limit characteristics as the real pump especially at the low flow commands. The pump model produced the supply pressure and flow being applied to the actuator chambers based on an input flow command received from the Control Algorithm Module.

Hydraulic Actuator Module

The actuator model contains the dynamics for both the upper and lower chamber of the actuator. This detail was needed so that the effective areas of the actuator piston are accurately described. The equations describing the compressible fluid dynamics for both chambers' pressures, flows and entrained volumes were included.

Additional logic was added to make the two chamber model work properly. Some of the logic describes the characteristics of the internal valving used in the actuator system. Additional dynamics was added to describe the relief valve characteristics used on the HAB system based on hydraulic schematic diagrams.

All the actuators of the system are continuously modeled even when they are not the ones currently being controlled. This detail was included so that the pressures of all the chambers can be monitored for the entire operation of the HAB. When an actuator is not active it will not receive a flow from the pump, however it still behaves like a hydraulic spring with variations in pressure and force from the dynamic loads.

The force computation was computed from the following equation:

$$F = A_U P_U - A_D P_D - F_r \frac{dL}{dt} \quad \text{..............................} (6)$$

Where;

$A_U$ = Up Chamber Area

$A_D$ = Down Chamber Area

$\frac{dL}{dt}$ = Piston Velocity

$F_r$ = Viscous Friction Coefficient

Hydraulic Motor Module

The bridge drive portion of the model describes the hydraulic motor characteristics. The equations that describe the motor torque, motor displacement and associated pressure and flows were incorporated. The basic torque equation was as follows:

$$T_Q = D_M(\Delta P) - T_r W_M \quad \text{.............................} (7)$$

Where;

$T_Q$ = Motor Torque

$D_M$ = Motor Displacement

$\Delta P$ = Pressure Across the Motor ($P_U - P_D$)

$T_r$ = Viscous Friction Coefficient

$W_M$ = Motor Velocity

The gear ratios of the bridge drive mechanism were also included in this module.

Dynamic System Description

ADAMS® main module describes the mechanical functionality of the chassis and the bridge. The model describes all the main parts and joints of the HAB system and has twenty-four degrees-of-freedom. The chassis model included the mass properties of the hull, road arms, wheels and track, and defined the joint constraints for all the suspension/hull attachments. The suspension forces were described as user-written force subroutines that computed the suspension spring and damping forces and torques for each road wheel station. The bridge assembly was modeled by describing the mass properties of each component. Frictional forces were incorporated between sliding surfaces of the bridge and at all joint elements. Coefficient of friction's were obtained from previous vehicle testing. Actuator forces driving the mechanism were obtained from the force interface module at each integration step.

## RESULTS

The model was first used to duplicate the performance of the original control system design developed by MAN of Germany. The control system design was not adaptive to environmental changes such as, temperature and its effects on joint friction, gravitational effects while operating on inclines/slopes, and changes in bridge weight and mass properties due to heavy mud and/or snow loads. Results from the model correlated well with test results and showed that the system failed under certain operating conditions. The failures were due to insufficient flows/pressures generated to drive the bridge parts to the desired positions. This is primarily due to the fixed flow rate commands at fixed actuator positions provided by the data table embeded in the controller.

The model was used in the second phase to improve the control system design by introducing a rate and position feedback loop. The additional computations can be accommodated, since the old processor was to be replaced by a more powerful processor. The operating scenarios were re-run using the new design. Results showed that the new control system design adapted to all operating conditions. By adding the position feedback, the performance was further enhanced by reducing the roughness of the system. In addition, the launch and retrieval time were minimized by optimizing the control system parameters.

Figures (4&5) are frame sequences from the HAB simulation. The frames represent intermediate stages of the HAB system during launch. The frames were captured from the animation post processor developed on a Silicon Graphics workstation.

## CONCLUSIONS

This simulation effort demonstrated the effectiveness of using a comprehensive simulation model in support of the design effort, by reducing the development time and cost and assuring high reliability and performance of the HAB system. To accomplish the results of this effort without such a tool, the development effort will have had to be done on the field during the test and validation phase, adding delays and cost. An additional advantage to this model was the ease of simulating a wide range of operating scenarios as compared to the physical field testing. The model is intended to be used after the development phase and into the production phase. Additional validation and model tuning will be performed after test data is obtained.

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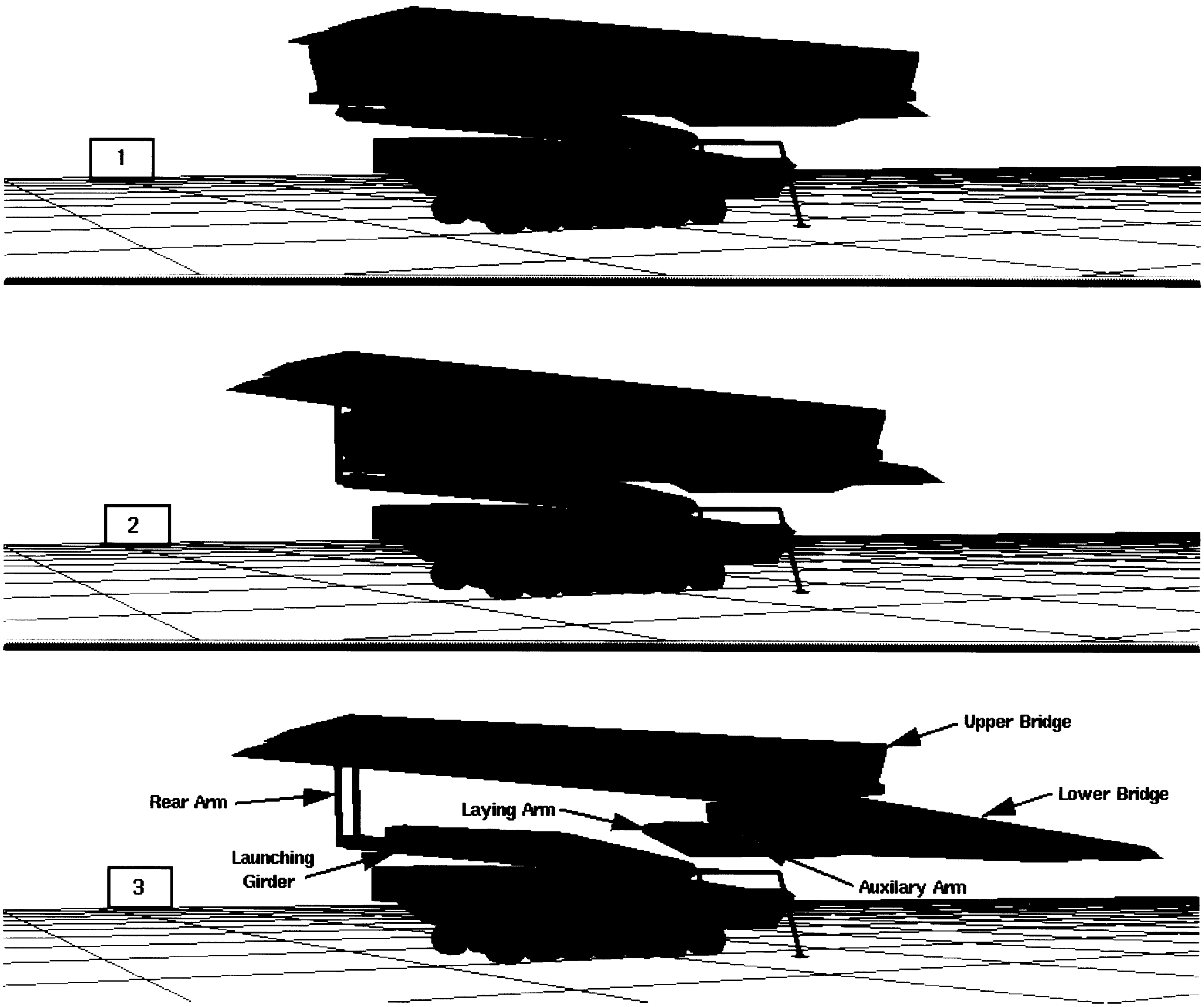


**Figure (4)**

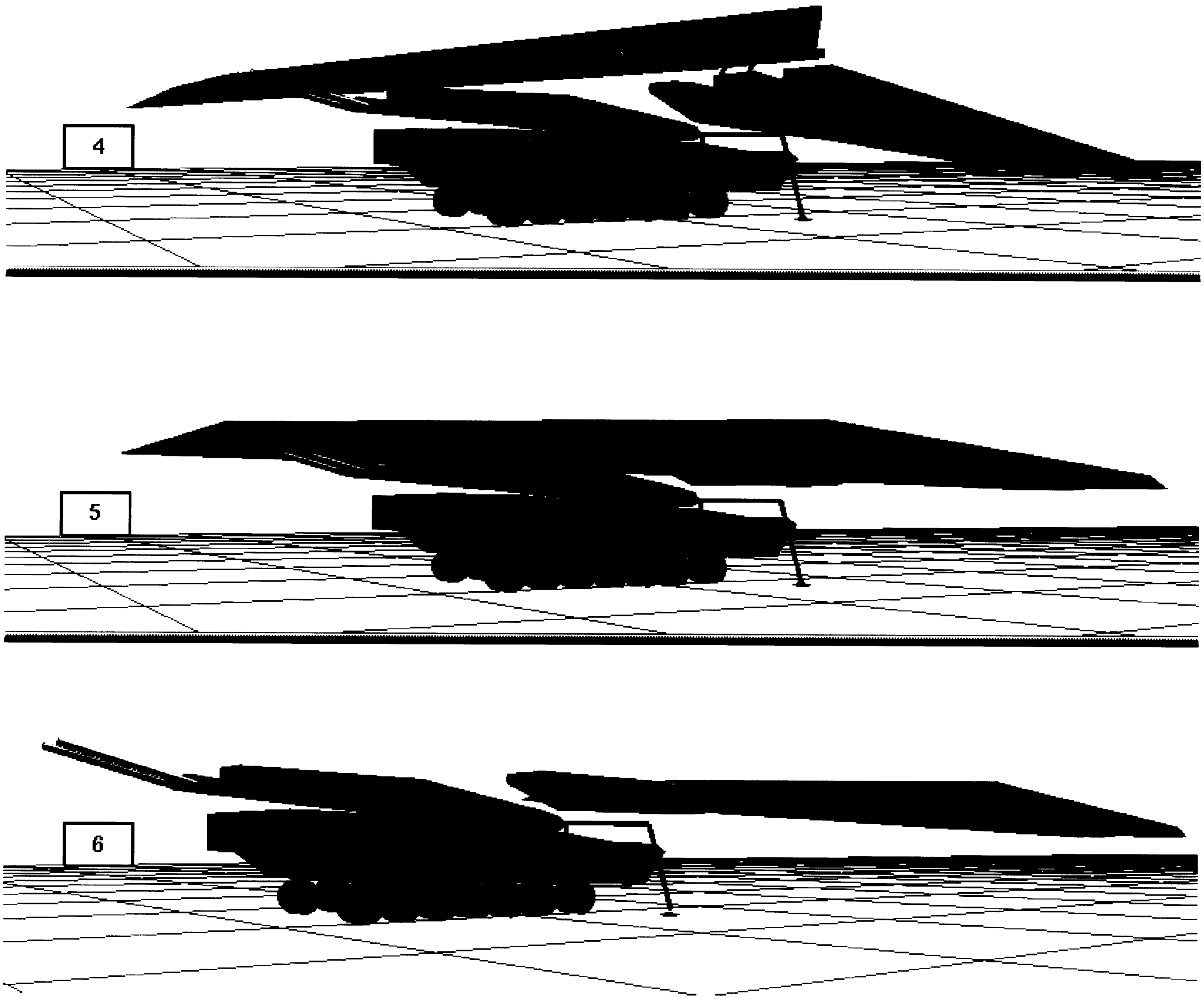


Figure (5)

HEAVY ASSAULT BRIDGE

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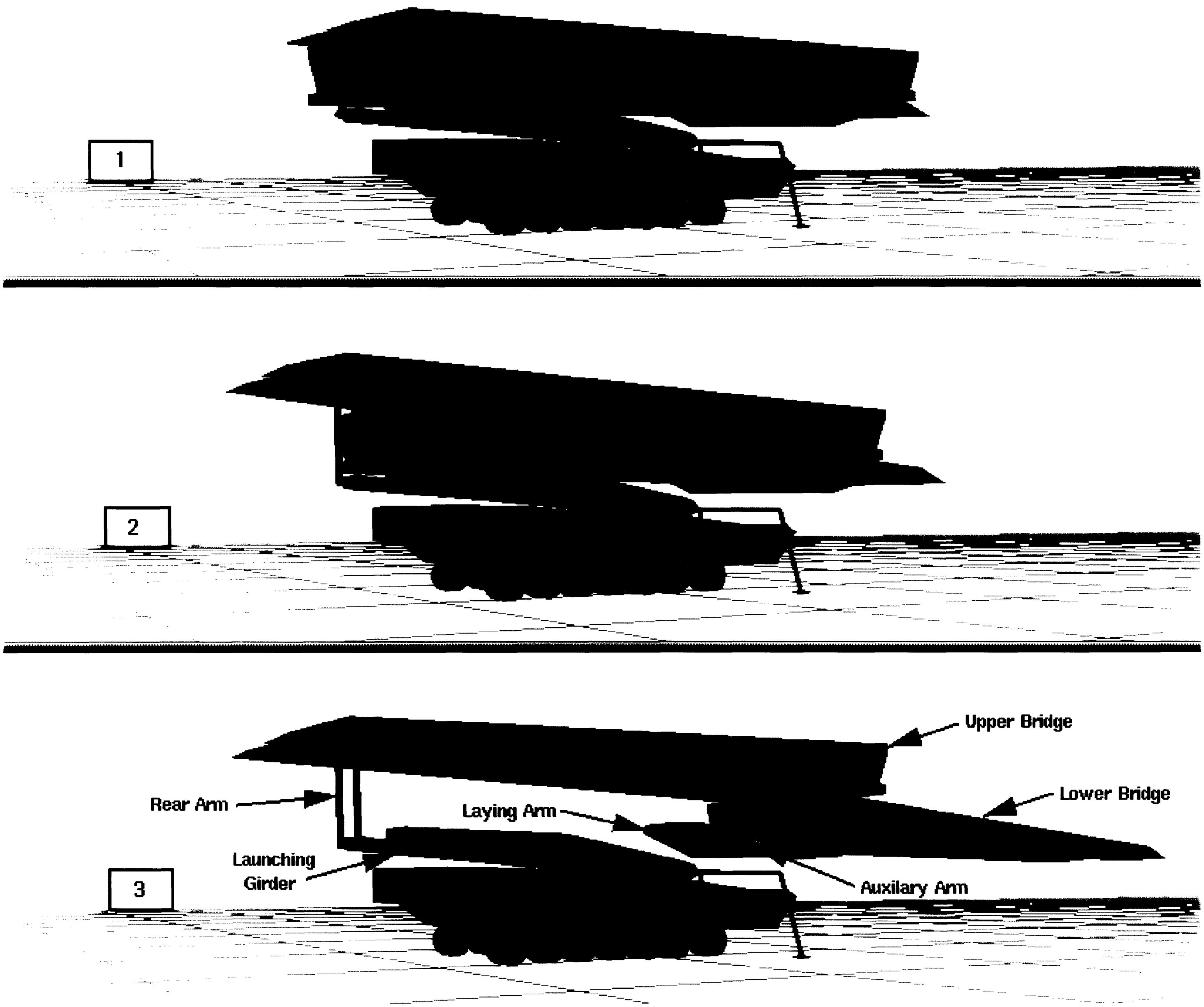


Figure (4)

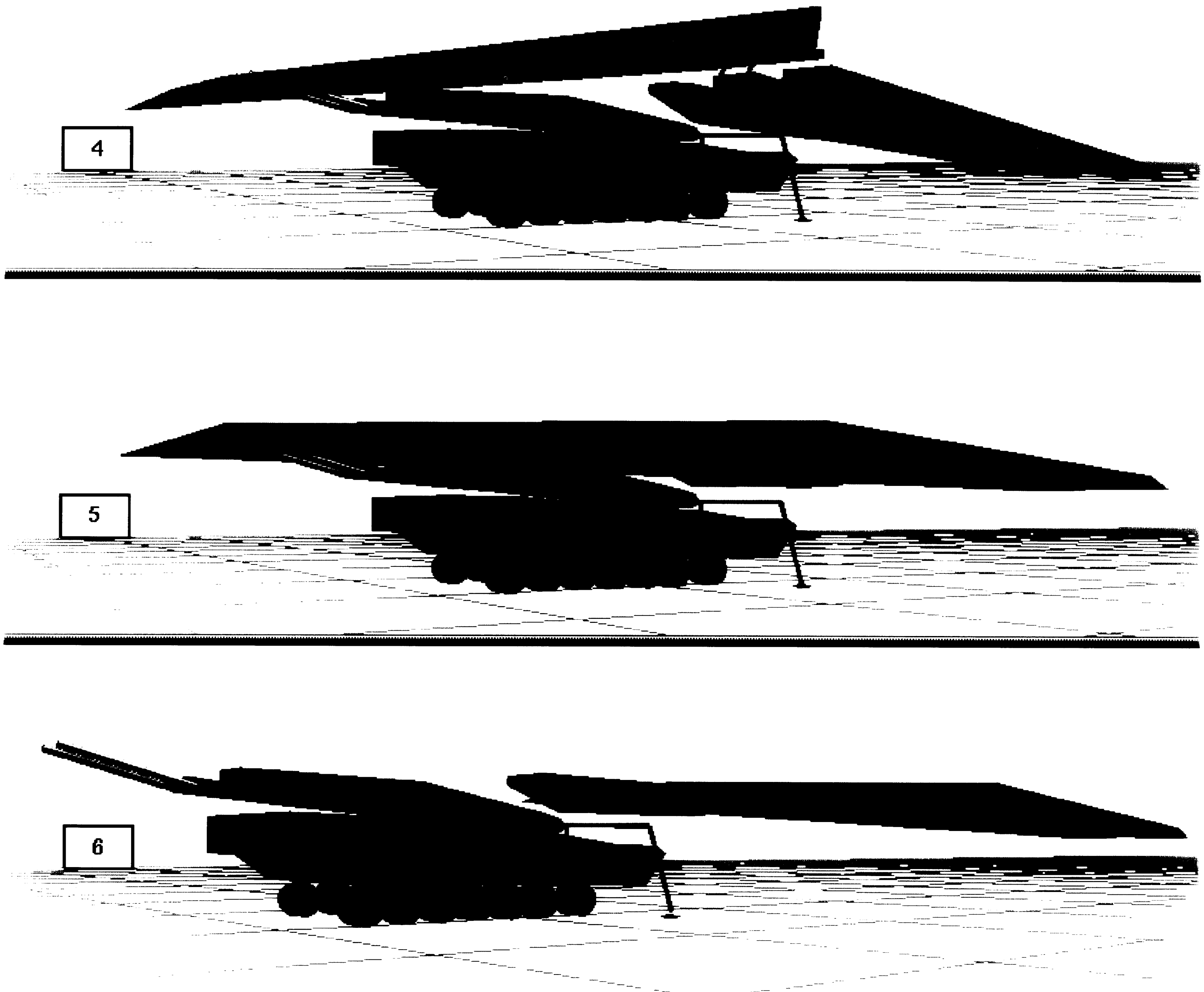


Figure (5)