TECHNICAL REPORT RD-PS-98-11

DYNAMIC MODELING OF THE POLARIS SPORTSMAN 500 ATV USING DYNAMIC ANALYSIS AND DESIGN SYSTEM (DADS)

19981014 032

Bradley J. Huhlein
Propulsion and Structures Directorate
Missile Research, Development, and Engineering Center

September 1998

U.S. ARMY AVIATION AND MISSILE COMMAND
Redstone Arsenal, Alabama 35898-5000

Approved for public release; distribution is unlimited.

DESTRUCTION NOTICE

FOR CLASSIFIED DOCUMENTS, FOLLOW THE PROCEDURES IN DoD 5200.22-M, INDUSTRIAL SECURITY MANUAL, SECTION II-19 OR DoD 5200.1-R, INFORMATION SECURITY PROGRAM REGULATION, CHAPTER IX. FOR UNCLASSIFIED, LIMITED DOCUMENTS, DESTROY BY ANY METHOD THAT WILL PREVENT DISCLOSURE OF CONTENTS OR RECONSTRUCTION OF THE DOCUMENT.

DISCLAIMER

TRADE NAMES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1998	Final Report August 1998

4. TITLE AND SUBTITLE

Dynamic Modeling of the Polaris Sportsman 500 ATV Using Dynamic Analysis and Design System (DADS)

5. FUNDING NUMBERS

6. AUTHOR(S)

Bradley J. Huhlein

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Commander, U.S. Army Aviation and Missile Command
Missile Research, Development, and Engineering Center
ATTN: AMSAM-RD-PS
Redstone Arsenal, AL 35898

8. PERFORMING ORGANIZATION

TR-RD-PS-98-11

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT *(Maximum 200 Words)*

A dynamic model of the Polaris Sportsman 500 All-Terrain Vehicle (ATV) was built using Dynamic Analysis and Design System (DADS) version 8.5. Aspects of the model included the front MacPherson struts and rear independent suspension. The model also allowed control over the path and speed of the vehicle using the DADS control elements.

The modeling methods discussed here are general in nature and may be applied to other DADS vehicle models of similar systems. This report also provides a useful reference source to those using this model.

14. SUBJECT Polaris Sportsman 500 All-Terrain Vechile (ATV), Tactical Unmanned Vehicle (TUV), Dynamic Analysis and Design System (DADS), Continuously Variable Transmission (CVT)

15. NUMBER OF PAGES 24

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

The U. S. Army Aviation and Missile Command (USAAMCOM), Missile Research, Development, and Engineering Center (MRDEC), in cooperation with Polaris Industries Inc., developed a dynamic model of the Polaris Sportsman 500 All-Terrain Vehicle (ATV) using the Dynamic Analysis and Design System (DADS) software package. This modeling was performed as a part of a study for the Tactical Unmanned Vehicle (TUV) program. The discussion in this report is limited to the overall modeling approach due to proprietary nature of the subject being examined.

II. POLARIS SPORTSMAN 500 ATV

The Polaris Sportsman 500 is a 500 cc, four valve, four stroke, liquid-cooled, ATV (Fig. 1). Special features of the Sportsman 500 are the front MacPherson struts and independent rear suspension with antiroll bar (torsion bar) (Fig. 2). The transmission is a Polaris version of an automatic Continuously Variable Transmission (CVT) called a Polaris Variable Transmission (PVT) with three gears: high, low, and reverse. Ground clearance is given at nearly 11 inches. The tires used on the Sportsman 500 are Goodyear Tracker P ATV tires. Other features of the Sportsman 500 are given in Appendix A.

Figure 1. The Polaris Sportsman 500 ATV

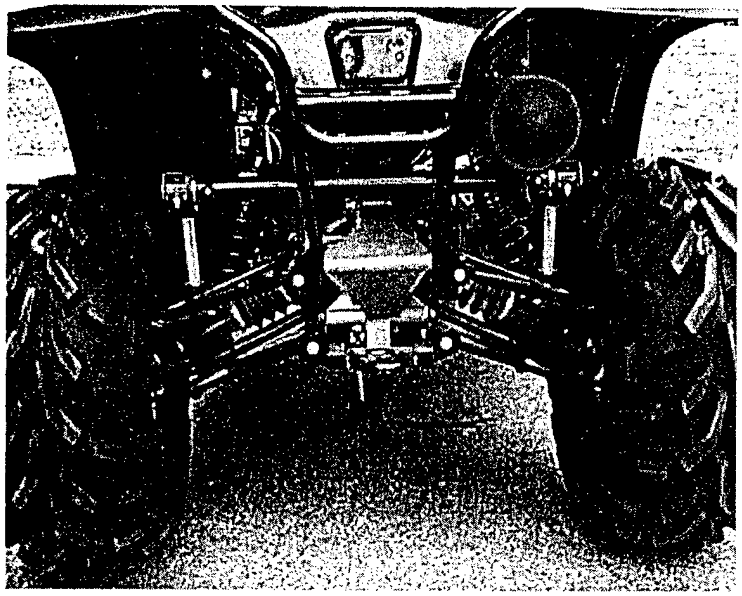


Figure 2. Rear Suspension of the Polaris Sportsman 500 ATV

III. MODELING

The dynamic modeling was performed using DADS version 8.5. The DADS model of the Sportsman 500 ATV consists of 20 bodies and 15 Degree-of-Freedom (DOF). A topology diagram of the model is shown in Figure 3.

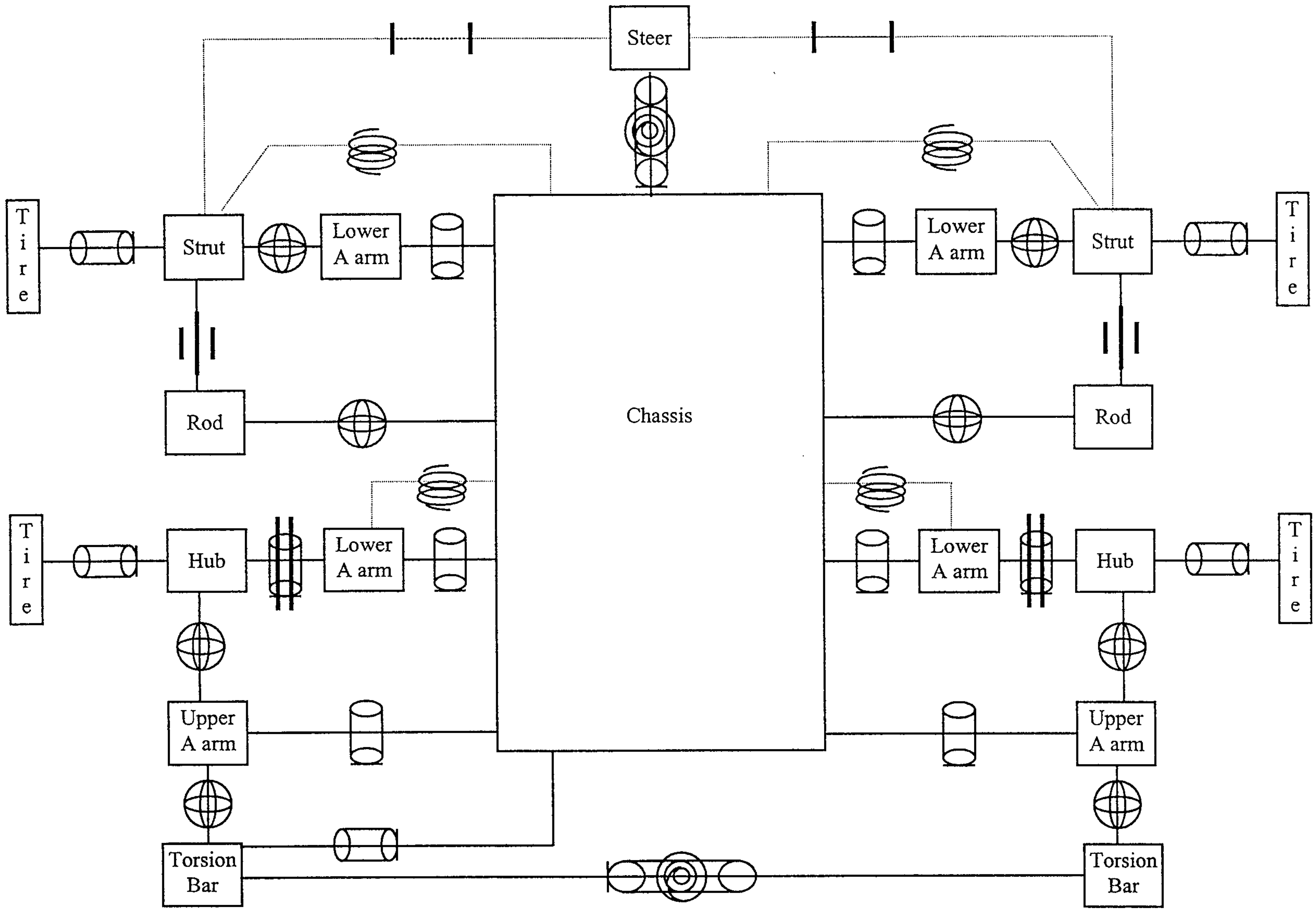


Figure 3. Topology of the Polaris Sportsman 500 ATV Modeled in DADS

A. Coordinate System

The global coordinate system used was positive X forward, positive Y roadside, and positive Z up. A vehicle reference Coordinate System (CSYS) was established using the CSYS element, located at (0, 0, 19). This is the same reference frame Polaris used to develop the Pro-Engineer (Pro-E) model of the chassis. All of the vehicle body's origins are children to this reference. Other Pro-E models supplied by Polaris were the front strut, the rear, upper, and lower A arms, and the rear hubs. These Pro-E files were rendered and brought into DADS using .slp files for most of the model's geometry, (Fig. 4).

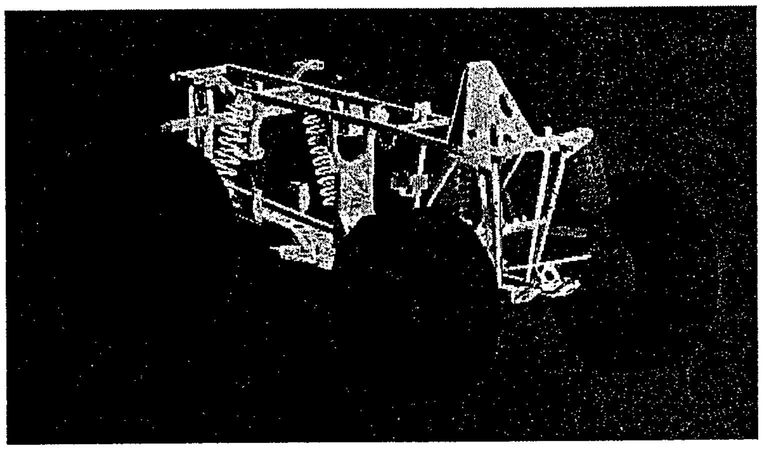


Figure 4. Graphical Display of DADS Model of the Polaris Sportsman 500 ATV

B. Mass Properties

Most of the model's bodies have negligible mass moments of inertia as compared to the mass moments of inertia of the chassis and engine. These smaller bodies mass moments do not greatly affect the overall dynamics of the vehicle. Therefore, the chassis was given the mass moments of inertia for the entire vehicle, and most of the other bodies were given very small mass moments of inertia. However, the tires were given reasonable mass moments because of the requirements for the tire element chosen for this model.

C. Suspensions

The front MacPherson suspension was modeled using three bodies per side. The lower A arm is connected to the chassis with a revolute joint. The strut body is connected to the lower A arm with a spherical joint. A strut rod, added to allow translation, is attached to the chassis with a spherical joint. A translation joint is used between the strut and the strut rod. The tire is connected to the strut with a revolute joint. The stiffness and damping of the strut are modeled using a Translational Spring-Damper-Actuator (TSDA) force element between the chassis and the strut body.

The rear suspension is made up of eight bodies. On both sides, the lower A arm is attached to the chassis using a revolute joint. The hub has a cylindrical joint connecting it to the lower A arm and a spherical joint attaching it to the upper A arm. The upper A arm is connected to the chassis with a revolute joint. This four-bar linkage was modeled in such a way as to avoid redundancy in constraints. The tires were attached to the hub using a revolute joint. The shocks were modeled using TSDAs. The torsion bar was modeled using two bodies with a revolute joint and Rotational Spring-Damper-Actuator (RSDA) between them. One of the bodies was connected to the chassis with a revolute joint. A distance constraint was placed between each side of the torsion bar and its corresponding upper A arm.

D. Steering

The body, called steer, is used to represent the turning mechanism of the vehicle by using distance constraints between it and the strut bodies. The steer body is attached to the chassis using a revolute joint. At the revolute joint, a RSDA force element was placed to provide control over the torque applied at the joint by the control elements.

E. Path and Speed Control

Controller elements were used for governing the path and speed of the vehicle. Generic block diagrams were obtained from Computer Aided Design Systems Inc. (CADSI), the distributor of DADS, for these controllers. The block diagram for the Sportsman 500 ATV model controlling the path is shown in Figure 5. Two one-body input elements are used as the input to the user algebraic element, one input element for the x-direction and one for the y-direction. Each input uses a triad called carrot, located on the chassis body, which is used as the guiding point. This controller utilizes the applications of the user algebraic controller element. For this application of the user algebraic element, the NDADS3D executable must be set up to run. NDADS3D allows special user defined subroutines to be used. In this case, a subroutine called fr3512.f was used to define the functional performance of the user algebraic element. The user algebraic element, in this case, is comparing the desired path with the path of the carrot triad. This subroutine was obtained from CADSI. Other inputs into the user algebraic element are the curves defining the x and y position of the desired path. These curves were created using the spline curve element. Data points for the curves are given in terms of the x (or y) position versus path length. These curves are defined in the user algebraic element for IVALUE.1 and IVALUE.2. The value placed in the IVALUE.1 form-fill is corresponding to the x-path curve (e.g. if there are six spline curves, defined in DADS, and the fourth one is the x-path curve, then the number four is placed here). In the form-fill, IVALUE.2, the curve number for the y-path was placed. Appendix B has a brief explanation from CADSI on this path-following control element. From the user algebraic, the path error is sent to the amplifier element where the gain was set at 100. Finally, a torque is applied to the revolute joint between the chassis and the steer body though the output joint element.

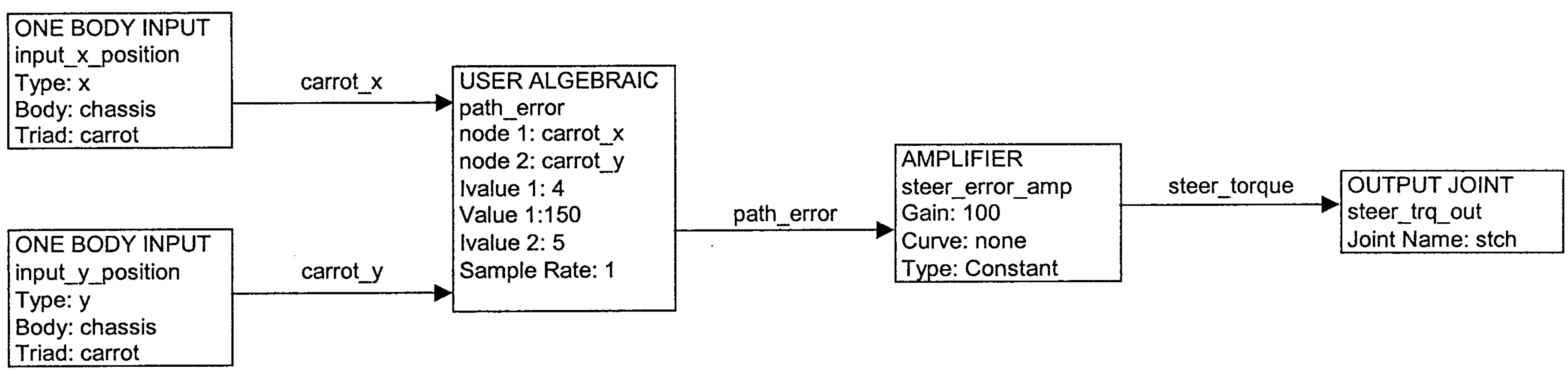


Figure 5. Block Diagram of the Path Controller

The block diagram, for the speed control of the vehicle, is shown in Figure 6. There are two inputs, an input one-body element and an input curve element. The input one-body element was used to measure the local velocity of the vehicle by defining a triad on the chassis. It was important to define the type as a local velocity (local.trans.vel), and not the velocity in the global x-direction (xd). Errors may be caused by using the global velocity in the x-direction if the path defined varies from a straight line in the x-direction. The input curve defines the desired speed. This curve is set to ramp up to a constant speed in five seconds. This speed may be changed by changing the parameter "target_speed" (entered in miles per hour (mph)). Varying speeds may be used by replacing the curve in this element with a varying speed curve. The speed desired is subtracted for the speed actual in the summer element. This is then fed into an amplifier which has a gain of -1000. From there, the error is broken into two amplifiers, one for the front wheels, and one for the rear wheels. The front wheel amplifier has a gain of 0.3 while the rear wheel amplifier has a gain of 0.7. From these amplifiers, the error is applied to the output joint elements which provides the torque to the tires.

A. Tire Elements

The tires were modeled using the generic tire element with the type set to full and the numbers of divisions at 100. The use of the full type tire requires that the tires have reasonable mass moments of inertia. Therefore, estimations of the wheel and tire mass inertia were used for the tire bodies. The variables needed for this type of tire model were: radius, vertical stiffness, number of divisions, damping constant, rolling resistance, friction coefficient, and cornering stiffness. The surface type was left on the simple option. The simple surface type uses the longitudinal friction coefficient as a function of the rolling slip and uses the nominal rolling resistance coefficient.

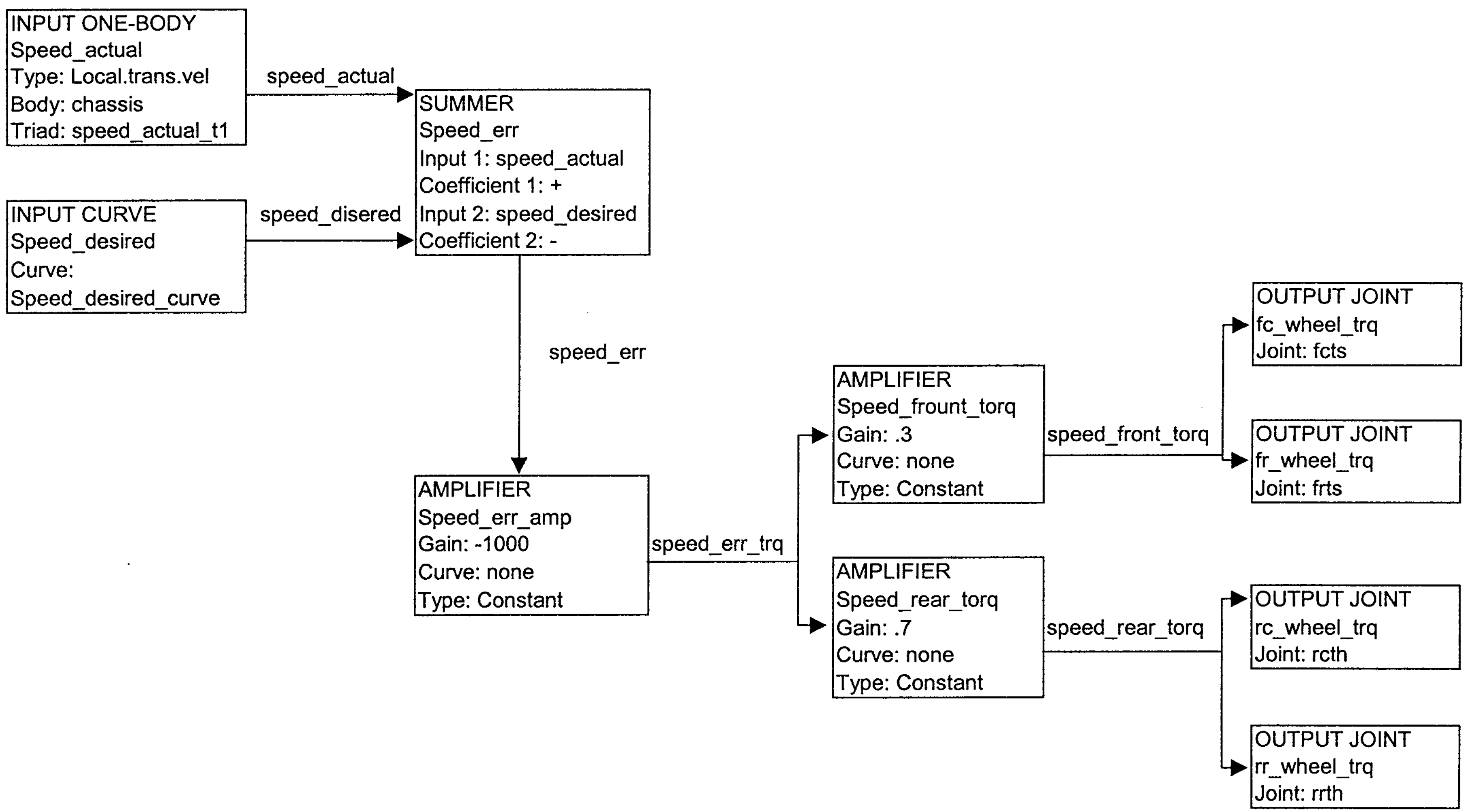


Figure 6. Block Diagram of the Speed Controller

IV. CONCLUSION AND RECOMMENDATIONS

A DADS model of the Polaris Sportsman 500 ATV was completed for the purpose of examining the dynamic performance of the vehicle. This model includes the suspension components and the ability to control the path and speed of the vehicle. This model can be used to explore the best configuration for equipping the Sportsman 500 ATV as a part of the TUV project and can help Polaris study the strengths and weaknesses of new designs. Both of these tasks can be performed before producing hardware and thus adding value and cost savings.

An experimental evaluation of the Sportsman 500 ATV should be conducted for the purpose of comparing real data to the model's results. This can be accomplished by instrumenting the vehicle and performing specific operations, such as running one side over a defined bump, and comparing the results to that of the DADS model results for the same scenario.

A more complete model could be made with the addition of a power train model. This model would have to be built in one of the software packages integrated with DADS works with such as MATLAB Simulink or X-Math Systembuild.

A cosmetic improvement to the model could be made by having the skins of the Sportsman 500 ATV imported into the DADS model. An effort was made with an IGES file obtained from Polaris, but the translation to Pro-E or DADS could not be completed.

BIBLIOGRAPHY

1. Boland, Doug; "Computer Aided Design Systems Inc.", Consulting work: 3 December 1997, 19 February 1998.

2. Dynamic Analysis and Design System Reference Manual, Computer Aided Design Systems Inc., Coralville, IA, Revision 8.5, Volume 1.

3. Gillespie, Thomas D., Fundamentals of Vehicle Dynamics, Society of Automotive Engineers, Inc., Warrendale, PA, 1992.

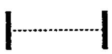
4. Polaris Industries Homepage, at *http://www.polarisindustries.com.*

5. Welcome to the ATV Connection Homepage, at *http:/www.atving.com.*

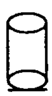
LIST OF SYMBOLS

Body

Cylindrical joint



Distance constraint



Revolute joint

Rotational Spring-Damper-Actuator (RSDA)

Spherical joint

Translational joint

Transitional Spring-Damper-Actuator (TSDA)

APPENDIX A
FEATURES OF THE POLARIS SPORTSMAN 500 ATV

APPENDIX A
FEATURES OF THE POLARIS SPORTSMAN 500 ATV

	Sportsman 500	Sportsman 400L	Xplorer 500	Xplorer 400L
Engine	499cc liquid-cooled four-valve four-stroke	378cc liquid-cooled two-stroke	499cc liquid-cooled four-valve four-stroke	378cc liquid-cooled two-stroke
Lubrication	Dry Sump	Oil Injection	Dry Sump	Oil Injection
Fuel Capacity U.S. Gallons/ Liters	5.25 / 19.87	4 / 15.12	5.25 / 19.87	4 / 15.12
Oil Capacity U.S. Quarts/Liters	2 / 1.89	2 / 1.89	2 / 1.89	2 / 1.89
Coolant Capacity U.S. Quarts/ Liters	2.25 / 2.13	2.25 / 2.13	2.25 / 2.13	2.25 / 2.13
Carburetion	34mm Mikuni	34mm Mikuni	34mm Mikuni	34mm Mikuni
Starting	Electric with recoil backup	Electric with recoil backup	Electric with recoil backup	Electric with recoil backup
Alternator	200 watts	200 watts	200 watts	200 watts
Transmission	Automatic PVT (Polaris Variable Transmission) with E-Z shift high/low and reverse	Automatic PVT (Polaris Variable Transmission) with E-Z shift high/low and reverse	Automatic PVT (Polaris Variable Transmission) with E-Z shift high/low and reverse	Automatic PVT (Polaris Variable Transmission) with E-Z shift high/low and reverse
Drive	Push button engage four-wheel shaft drive	Push button engage four-wheel drive	Push button engage four-wheel shaft drive	Push button engage four-wheel drive
Wheelbase	50.5	49.75	50.5	49.75
Turning Radius	65 in.	65 in.	65 in.	65 in.
Dry Weight	649 lbs./ 295 kgs.	585 lbs./ 265.4 kgs	649 lbs./ 295 kgs.	585 lbs./ 265.4 kgs
Length/ Width/ Height	81 in./ 46 in./ 47 in. 205.7 cm/ 116.8 cm/ 119.4 cm	77 in./ 46 in./ 46 in. 195.6 cm/ 116.8 cm/ 116.8 cm	81 in./ 46 in./ 47 in. 205.7 cm/ 116.8 cm/ 119.4 cm	81 in./ 46 in./ 47 in. 205.7 cm/ 116.8 cm/ 119.4 cm
Front Suspension	MacPherson strut with 6.25 in./ 15.9 cm of travel	MacPherson strut with 6.25 in./ 15.9 cm of travel	MacPherson strut with 6.25 in./ 15.9 cm of travel	MacPherson strut with 6.25 in./ 15.9 cm of travel
Rear Suspension	Progressive rate fully independent with anti-roll bar- 9.5 in./ 24.1 cm of travel, two 1 in. gas shocks	Progressive rate swing arm- 8.5 in./ 21.6 in. of travel, 1 1/4 gas shocks	Progressive rate fully independent with anti-roll bar- 9.5 in./ 24.1 cm of travel, two 1 in. gas shocks	Progressive rate swing arm- 8.5 in./ 21.6 in. of travel, 1 1/4 gas shocks
Front/ Rear Brakes	Single-lever hydraulic disc with mechanical auxiliary foot brake	Single-lever hydraulic disc with mechanical auxiliary foot brake	Single-lever hydraulic disc with mechanical auxiliary foot brake	Single-lever hydraulic disc with mechanical auxiliary foot brake
Front Tires Rear Tires	25 x 8 x 12 (5 psi) 25 x 12 x 10 (5 psi)	25 x 8 x 12 (4 psi) 25 x 12 x 10 (3 psi)	25 x 8 x 12 (5 psi) 25 x 12 x 10 (5 psi)	25 x 8 x 12 (4 psi) 25 x 12 x 10 (3 psi)

Load Capacity Front* **Load Capacity Back***	90 lbs./ 40.8 kgs* 180 lbs./ 81.6 kgs*	90 lbs./ 40.8 kgs* 180 lbs./ 81.6 kgs*	90 lbs./ 40.8 kgs* 180 lbs./ 81.6 kgs*	90 lbs./ 40.8 kgs* 180 lbs./ 81.6 kgs*
Hitch Capacity	30 lbs./ 13.6 kgs tongue capacity	30 lbs./ 13.6 kgs tongue capacity	30 lbs./ 13.6 kgs tongue capacity	30 lbs./ 13.6 kgs tongue capacity
Headlights	1 handlebar single beam hi 60 watt qtz. hal. 2 grill single beam lo- 35 watt qtz.	1 hood single beam hi- 60 watt 2 grill single beam lo- 35 watt qtz. hal.	2 grill dual beam hi/lo 35/35 watt qtz. hal.	1 handlebar single beam hi 60 watt qtz. hal. 2 grill single beam lo- 35 watt qtz
Speedometer Odometer/ Tripmeter	Standard	Standard	Accessory	Standard
DC Outlet	Front receptacle Rear plug-in	Front receptacle Rear plug-in	Rear plug-in	Rear plug-in
Brake Light	Standard	Standard	Standard	Standard
ATVs	**Sportsman 500**	Sportsman 400L	**Xplorer 500**	Xplorer 400L

*Check owner's manual for rack loading requirement and restrictions. Polaris reserves the right to change specifications at any time without incurring obligation.

APPENDIX B
DESCRIPTION OF PATH-FOLLOWING CONTROL

APPENDIX B
DESCRIPTION OF PATH-FOLLOWING CONTROL

Path-Following Control Element (fr3512.f): Description

The user-algebraic element has been programmed to determine the degree to which a point on a body is tracking a path in the global X-Y (horizontal) plane (Figure 2). To use this capability, the user must create control input elements which measure the X and Y coordinates of a given point on a given body. The user must also create two curves which describe the target path X and Y values as functions of the arc length along the path (L). The output from the element is the perpendicular distance (D) or velocity from the reference path, with a positive value being to the right of the path, and a negative value being to the left (when moving in the +L direction).

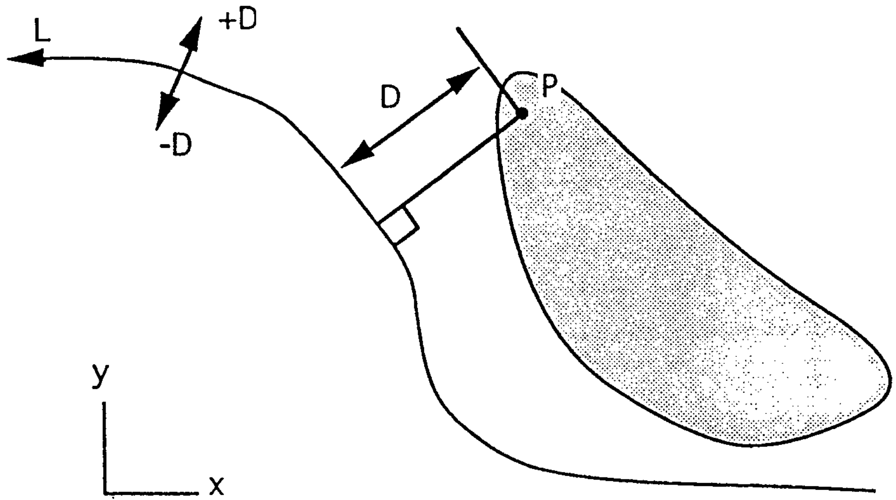


Figure 2. Path Follower Implementation.

Path-Following Control Element: Usage

The following variables must be entered in the user-algebraic element to use the path-follower:

INPUT.NODE.1	The name of the input control node representing the global X position of the point of interest on the body.
INPUT.NODE.2	The name of the input control node representing the global Y position of the point of interest on the body.
OUTPUT.NODE	The name of the output control node representing distance or velocity of the point of interest with respect to the path.
IVALUE.1	The number of the curve representing the global X of the path vs L. This is the order of the curve in the '.def' file.
IVALUE.2	The number of the curve representing the global Y of the path vs L. This is the order of the curve in the '.def' file.
IVALUE.3	If this value is 0 or 1, the distance is returned; if it is 2, the velocity is returned.
VALUE.1	The initial guess for the variable L. The user-algebraic element searches on L to find the point on the path closest to the point of interest on the body.
VALUE.2	A scaling factor. The reported distance or velocity is divided by this value. A value of zero results in no scaling.

INITIAL DISTRIBUTION LIST

	Copies
IIT Research Institute ATTN: GACIAC 10 W. 35th Street Chicago, IL 60616	1
AMSAM-RD, Ellen Mahathey	1
AMSAM-RD-OB-R	15
AMSAM-RD-TI (Tech Info)	1
AMSAM-AR-EF, Mr. Bradley Huhlein	3
AMSAM-L-G-I, Mr. Fred Bush	1